Habitat and estimated density of *Magicicada septendecula* (Hemiptera: Cicadidae), a 17-year periodical cicada newly discovered in Connecticut, United States of America

Chris T. Maier[1]

Abstract—Periodical cicadas in the genus *Magicicada* Davis (Hemiptera: Cicadidae) of brood II emerged in the eastern United States of America in 2013. In Connecticut, only *Magicicada septendecim* (Linnaeus) had been recorded until this emergence when *Magicicada septendecula* Alexander and Moore was found on Totoket Mountain in North Branford, Connecticut, United States of America. This discovery represented the northeastern-most record of this species. In two 0.25-ha plots where *M. septendecula* and *M. septendecim* emerged and chorused, species of *Carya* Nuttall (Juglandaceae) comprised 59.9–63.7% of the total basal area, with *Carya glabra* (Miller) Sweet, accounting for 43.9–60.0%. In one plot, 31.6% of the total basal area was *Fraxinus americana* Linnaeus (Oleaceae). By using the proportion of exuviae of *M. septendecula* (hind tibial length < 6.3 mm) and *M. septendecim* (length $\geqslant$ 6.3 mm) near trees and the mean number of emergence holes per 0.25-m^2 quadrat (1.88), it was estimated that 1487 *M. septendecula* and 17 313 *M. septendecim* emerged in one 0.25-ha plot. Mean tibial length of *M. septendecula* was significantly smaller in males (5.53 mm) than females (5.99 mm), and the sex ratio did not depart significantly from 1:1. *Magicicada septendecula* may be threatened by the decline of *F. americana* and *Juglans cinerea* Linnaeus (Juglandaceae), the first a known host and the second a suspected host.

Introduction

Periodical cicadas in the genus *Magicicada* Davis (Hemiptera: Cicadidae) are fascinating insects because they have lengthy life cycles, synchronised mass emergences, and large aggregations of chorusing males. Emergences of 17-year periodical cicadas in the northeastern United States of America are composed of *Magicicada cassinii* (Fisher), *Magicicada septendecim* (Linnaeus), and *Magicicada septendecula* Alexander and Moore or of some combination of these species. Marlatt (1907), Williams and Simon (1995), and others have summarised the remarkable life history of *Magicicada* species. *Magicicada septendecim* is the most widespread and often the most abundant of the three, whereas *M. septendecula* usually is the rarest (Alexander and Moore 1962; Dybas and Lloyd 1974). Lloyd and White (1983) have proposed that the rarity of *M. septendecula* at sites with crowding may be related to its tendency to delay its emergence by one year, which greatly decreases its survival.

Alexander and Moore (1962), Dybas and Lloyd (1974), Lloyd and White (1976), and others have described the habitat or host preferences of *Magicicada* species. They have concluded that *M. septendecula* tends to use forest-edge or open areas, especially ones with hickories, *Carya* Nuttall species (Juglandaceae), black walnut, *Juglans nigra* Linnaeus (Juglandaceae), or both, for reproductive activities and development. In an analysis of ovipositional preferences, White (1980) has suggested that *M. septendecula* has a broader host range in disturbed forests than in mature ones. Typically, *M. septendecula* shows a greater tendency to oviposit in *Carya* species than do *M. cassinii* and *M. septendecim* (Lloyd and White 1976).

Based upon museum specimens, 17-year periodical cicadas have been collected in Connecticut,

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C.T. Maier,[1] Department of Entomology, Connecticut Agricultural Experiment Station, 123 Huntington Street, P.O. Box 1106, New Haven, Connecticut 06504-1106, United States of America

[1] Corresponding author (e-mail: chris.maier@ct.gov).

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United States of America, since at least 1843 (C.T.M., unpublished data). Connecticut specimens belong to brood II or XI, although the latter brood is now extinct (Manter 1974). From 1843 to 2012, *M. septendecim* was the lone species known from the state (Leonard 1964; Manter 1974; Maier 1980, 1982a, 1982b, 1985, unpublished data). However, during my survey of brood II in 2013, I found *M. septendecula* on Totoket Mountain in North Branford, Connecticut. The objectives of this paper are to document the discovery, to characterise the forest in the centre of two chorusing areas, and to estimate the nymphal density at one site.

Materials and methods

Discovery of *Magicicada septendecula* in Connecticut

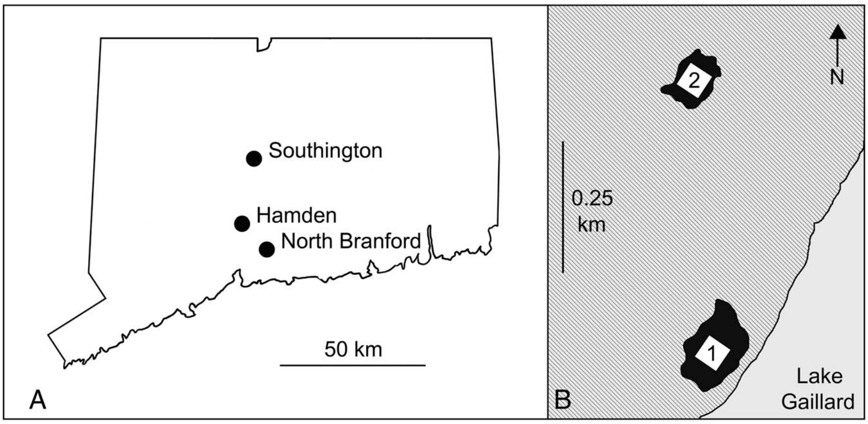
The presence of *M. septendecula* was confirmed by collecting specimens, by hearing the calling song of males, or both. To rule out a possible earlier discovery of *M. septendecula* in Connecticut, I searched for specimens of brood II and XI in 12 insect collections, which are identified in the Acknowledgements. I also examined New York, United States of America, specimens of *M. septendecula* from all broods to find nearby locations with this species.

Both adults and exuviae of *M. septendecula* and *M. septendecim* from Connecticut in 2013 are deposited in the insect collection in the Department of Entomology, Connecticut Agricultural Experiment Station, New Haven, Connecticut.

Characteristics of chorusing centres

The basal area of trees in two emergence and chorusing areas of *M. septendecula* in North Branford (Fig. 1) was calculated after measuring the diameter of trees at breast height (dbh) or 1.4 m above ground during July 2013. All of the live trees ⩾ 10 cm in diameter were measured in one 50 × 50-m plot (0.25 ha) near the centre of each area (Fig. 1B). Hereafter, these forested plots will be called plot 1 (41.3513°N, 72.7858°W; elevation 86 m) and plot 2 (41.3560°N, 72.7861°W; elevation 112 m). These plots were located on the east-facing slope of the basalt ridge known as Totoket Mountain, which is located mainly in North Branford, New Haven County, Connecticut. Trunks that split into two or more boles were treated as separate trees if the split was < 1.4m above ground. To estimate stand composition about five years earlier (~2008) and to reveal recent change in plots 1 and 2, dead standing or fallen trees with bark also were identified. Basal area was the principal measure used to assess dominance in the plots. Plots 1 and 2 were thinned between 1990 and 2001, but the identity and size of the removed trees are unknown. Species diversity of trees in plots was calculated with the Shannon and Weaver (1963) index (*H*′).

Fig. 1. Areas sampled for *Magicicada* species in Connecticut, United States of America, in 2013. (A) Forested areas where exuviae were collected and measured. (B) Two chorusing centres of *Magicicada septendecula* with associated 0.25-ha plots on Totoket Mountain in North Branford. Square white plots 1 and 2 are located near the middle of the otherwise black chorusing centres.



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The longitude, latitude, and elevation in the centre of plots 1 and 2 were recorded with a hand-held Garmin GPS 72H (Garmin International, Incorporated, Olathe, Kansas, United States of America). Boundaries of chorusing areas (Fig. 1B) were estimated by walking from the centre to points where only a single male was singing. The size of the chorusing areas around plots 1 and 2 was estimated on 8 June and 15 June, respectively, when it was sunny and > 21 °C.

Soil samples were collected at a depth of 10–15 cm, and then analysed for texture, nutrient content, and pH at the Connecticut Agricultural Experiment Station, New Haven, Connecticut, by using mainly the Morgan soil testing method (Lunt *et al.* 1950). Samples were collected at three locations within each plot, and then combined before analysis.

Estimating density

The density of cicadas was estimated by counting nymphal emergence holes of *Magicicada* species in 100 quadrats (0.5×0.5 m, or 0.25 m^2) that were randomly selected in the 0.25-ha plot 1 (Fig. 1B). To find each quadrat, a grid of string lines spaced 5 m apart was installed in a northeast-southwest and a northwest-southeast direction. A tape measure and a metrestick were used to pinpoint individual quadrats as accurately as possible. The sampling procedure was not altered even if a tree trunk was in one of the quadrats; thus, the entire soil surface was considered to be potentially available for emergence. Sampling was conducted during the first 10 days of July after the emergence of *Magicicada* species had ended and before that of species of *Tibicen* Latreille (Hemiptera: Cicadidae) had peaked. In North Branford, the first *Tibicen* species sang on 8 July.

To estimate the proportion of nymphal emergence holes that belonged to each of the two *Magicicada* species in plot 1, exuviae were collected within 1 m of trunks of 69 trees that were ≥ 10 cm in diameter and within 25 m of the centre of the plot. The length of the right hind tibia (left one, if the right was missing) of exuviae was measured as indicated by Dybas and Lloyd (1962). All tibiae in this study were measured to the nearest 0.067 mm (the length of one unit of the micrometer) with an ocular micrometer in the eyepiece of an Olympus SZ40 zoom stereomicroscope (Olympus Optical Company Limited, Hatagaya, Shibuya-ku, Tokyo, Japan).

Dybas and Lloyd (1962, 1974) determined that in Virginia, United States of America, the hind tibial length could be used to identify most exuviae of *Magicicada* species. For example, with the method of Dybas and Lloyd (1974), exuviae from Connecticut with a tibial length ⩾ 6.0 mm would be assigned to *M. septendecim,* and those with shorter ones would be *M. septendecula.* I took a slightly different approach to assign species because I found one adult female of *M. septendecula* next to her exuviae that had a hind tibial length of 6.16 mm. Dybas and Lloyd (1974) either underestimated the upper range for the tibial length of *M. septendecula*, or this species can be larger in Connecticut.

To determine the size range of hind tibiae of *Magicicada* species, I measured the length of 100 tibiae of exuviae of each sex at Southington, Hartford County (41.6390°N, 72.8413°W) and at Hamden, New Haven County, Connecticut (41.4432°N, 72.9008°W) (Fig. 1A). These sites had exclusively *M. septendecim* in 2013. Southington was dominated by sugar maple, *Acer saccharum* Marshall (Sapindaceae), and Hamden was dominated by red oak, *Quercus rubra* Linnaeus (Fagaceae). In Southington, the tibial length of *M. septendecim* was 5.83–7.10 mm (mean 6.71 mm) for males and 6.30–7.57 mm (mean 7.03 mm) for females. Only one male had a tibia as short as 5.83 mm; the other 99 had lengths between 6.30 and 7.10 mm. In Hamden, the male length was 6.30–7.30 mm (mean 6.80 mm), and the female length was 6.43–7.71 mm (mean 7.06 mm). Therefore, at North Branford, exuviae with a tibial length < 6.3 mm were considered to be *M. septendecula*, whereas those with a length ⩾ 6.3 were *M. septendecim.* If the North Branford population of *M. septendecim* were similar to the Southington one, then one out of 100 males might be assigned incorrectly. In plot 1 at North Branford (Fig. 1B), tibial lengths were analysed for only *M. septendecula.* The tibial length of < 6.3 mm also was used to identify exuviae of *M. septendecula* in plot 2 and near a butternut, *Juglans cinerea* Linnaeus, in the chorusing area with plot 1 (Fig. 1B).

Sexual differences in tibial length of exuviae of *Magicicada* species were analysed with a *t*-test of means (Systat Software, Incorporated 2002). For *M. septendecula*, the sex ratio was tested with a χ^2 analysis.

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Results and discussion

Discovery of *Magicicada septendecula* in Connecticut

The first adults of *M. septendecula* (*n* = 2♂♂) were collected on the foliage of understorey trees in plot 1 (Fig. 1B) at 1300 hours Eastern Standard Time (EST) on 6 June 2013. No males of *M. septendecula* were singing on this date even though it was sunny and 21–22°C. I collected additional adults on understorey foliage in plot 1 on 8 June (*n* = 1♀, with exuviae) and 9 June (*n* = 1♀). On these days, as well as during visits to plot 1 on 12, 15, and 18 June, males of *M. septendecula* were singing sporadically or chorusing mainly in tops of trees of pignut hickory, *Carya glabra* (Miller) Sweet, and white ash, *Fraxinus americana* Linnaeus (Oleaceae), in plot 1. Males sang between 1200 and 1500 hours EST when it was mostly sunny and between 21 °C and 28 °C. The chorusing area that included plot 1 was ~1.3 ha (Fig. 1B). Males of *M. septendecula* sang in the area that included plot 1 on at least five different days, which was more than the one to two days reported by Williams and Smith (1991) for *Magicicada tredecula* Alexander and Moore.

On 15 June, I found a second chorusing area with *M. septendecula* (plot 2 at centre) on the forested basalt ridge ~0.5 km to the north of plot 1 (Fig. 1B). In this 0.6-ha area where exuviae (*n* = 1♂, 1♀) of *M. septendecula* were collected, males chorused in tops of trees of especially *Carya* species and *F. americana*. Additional areas with *M. septendecula* are likely to be found along this ridge system because it extends 11–12 km through terrain that largely is undeveloped and unsurveyed.

Along most of the ridge with plots 1 and 2 (Fig. 1B), *M. septendecim* chorused so loudly in mid-June that individual songs of males and discrete chorusing centres of this species could not be distinguished. However, in the two chorusing centres with *M. septendecula*, the intensity of chorusing by *M. septendecim* was less than in surrounding areas, and songs of individual males of *M. septendecim* could be heard.

Based upon examination of *Magicicada* specimens in museum collections, my discovery of *M. septendecula* is the first record from Connecticut and the northeastern-most one for this species. The nearest extant populations of *M. septendecula* of brood II are in the lower and mid-Hudson Valley of New York (White *et al.* 1982; C.T.M., unpublished data) > 100 km from the ones in Connecticut. *Magicicada septendecula* of brood II also is present on Staten Island, New York (> 140 km from the North Branford chorusing centres), where its singing was heard in 1979 (Simon 1979), 1996, and 2013 (C.T.M., unpublished data).

Historically, *M. septendecula* of brood XIV may have occurred at Wyandanch (Town of Babylon) and Dix Hills (Town of Huntington) (Alexander and Moore 1962), which are in Suffolk County, New York, on Long Island ~75–85 km to the west southwest of the new sites in Connecticut. The identification of museum specimens of *M. septendecula* from Wyandanch in 1923 and from Dix Hills in 1940, however, probably should be considered tentative because *M. cassinii* occasionally can have orange abdominal banding that resembles the pattern on *M. septendecula.* Davis' (1924) casual description of singing certainly documented the presence of *M. septendecim* and another *Magicicada* species at Wyandanch. Alexander and Moore (1962) considered the 1923 specimens collected by Davis and others to represent all three northern species of *Magicicada.* Since 1940, there have been no additional reports of *M. septendecula* on Long Island (Simon and Lloyd 1982).

The presence of *M. septendecula* in Connecticut and the mid-Hudson Valley of New York (White *et al.* 1982; C.T.M., unpublished data) appears to contradict the hypothesis that this species is absent from the northern edge of the range of *Magicicada* species (Alexander and Moore 1962; Dybas and Lloyd 1974; Lloyd and White 1983). The hypothesis proposed by these researchers, however, was derived mainly from direct observations in the upper Midwest and before thorough searches of the Hudson Valley.

Characteristics of chorusing centres

The characteristics of the forest in plots 1 and 2 where *M. septendecula* emerged and chorused are summarised in Tables 1 and 2. In 2013, the majority of the trees in plots 1 and 2 were *Carya* species (Table 1). In plot 1, the dominant species was *C. glabra* in both ~2008 and 2013. In the recent past, *J. cinerea* also occurred in plot 1.

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Table 1. Species composition of trees in plots with *Magicicada septendecula* at North Branford, Connecticut, United States of America, in ~2008 and 2013.

	% Total trees			
	Plot 1		Plot 2	
Tree species and family	~2008	2013	~2008	2013
Acer saccharum Marshall (Sapindaceae)	15.9	16.2	4.8	5.6
Betula lenta Linnaeus (Betulaceae)	10.3	10.1		
Carya glabra (Miller) Sweet (Juglandaceae)	51.4	55.6	30.2	36.0
Carya ovata (Miller) Koch (Juglandaceae)	5.6	6.1	12.3	14.6
Fraxinus americana Linnaeus (Oleaceae)	1.9	1.0	48.1	38.2
Juglans cinerea Linnaeus (Juglandaceae)	1.9			
Juniperus virginiana Linnaeus (Cupressaceae)			3.8	4.5
Ostrya virginiana (Miller) Koch (Betulaceae)	3.7	4.0		
Quercus alba Linnaeus (Fagaceae)	3.7	3.0	0.9	1.1
Quercus rubra Linnaeus (Fagaceae)	2.8	2.0		
Quercus velutina Lamarck (Fagaceae)	2.8	2.0		
Total trees	107	99	106	89

The ~2008 sample included trees that were dead in 2013 but probably alive in ~2008. Percentages were rounded to the nearest 0.1; thus, columns may not total exactly 100.

Table 2. Diameter at breast height (dbh), basal area, and percentage of total basal area of trees in plots with *Magicicada septendecula* at North Branford, Connecticut, United States of America, in 2013.

	Dbh (cm)		Basal area $(m^2) \times 10^3$		% Total basal area	
Tree species	Plot 1	Plot 2	Plot 1	Plot 2	Plot 1	Plot 2
Acer saccharum	14.5 ± 4.3	18.5 ± 7.3	18.0 ± 12.1	30.2 ± 20.3	7.5	4.4
Betula lenta	20.7 ± 5.7		35.9 ± 19.1		9.4	
Carya glabra	21.7 ± 7.7	23.2 ± 7.7	41.6 ± 27.2	46.6 ± 26.3	60.0	43.9
Carya ovata	16.9 ± 4.4	22.7 ± 4.4	23.7 ± 12.0	41.8 ± 15.4	3.7	16.0
Fraxinus americana	30.8	19.4 ± 5.1	74.5	31.6 ± 15.9	2.0	31.6
Juniperus virginiana		19.2 ± 2.3		29.4 ± 8.6		3.5
Ostrya virginiana	12.6 ± 2.0		12.8 ± 3.9		1.3	
Quercus alba	34.0 ± 2.5	17.0	90.9 ± 13.0	22.7	7.1	0.7
Quercus rubra	35.9 ± 4.0		101.6 ± 22.7		5.3	
Quercus velutina	29.0 ± 7.5		68.3 ± 34.1		3.6	
Total basal area (m^2)					3.8	3.4

Dbh and basal area are given as mean ± SD. Percentages of total basal area are rounded to the nearest 0.1; thus, columns may not total exactly 100.

The last tree of *J. cinerea* in the plot was toppled during a snow storm in October 2011 (C.T.M., unpublished data). In plot 1, ~40% of the soil surface was covered with the remains of nuts of *J. cinerea*, providing further evidence that this species was more prevalent in the past and available as a host for *M. septendecula*. In plot 2, *F. americana* was the most numerous tree species even though it had decreased in relative abundance over approximately five years.

Species diversity (H') decreased with time from 1.63 to 1.46 in plot 1, whereas it increased slightly in plot 2 from 1.28 to 1.31. These diversity values are the same or higher than the mean of 1.28 that Maier (1980) calculated for 17 Connecticut forests with populations of *M. septendecim*.

Mean diameter and basal area of trees varied between plots (Table 2). The relatively high standard deviations for diameter and basal area of several species provide evidence that plots had

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trees of mixed ages. When tree importance is based on the percentage of total basal area comprised by each species, *Carya* species collectively dominated in both plot 1 (63.7%) and plot 2 (59.9%), with *C. glabra* being the most important hickory in both plots. *Fraxinus americana* was the second most important species in plot 2, whereas it was relatively insignificant in plot 1.

Trees in the two plots grew on sandy loam, with the soil nutrients being higher in plot 1 than plot 2. The nitrate nitrogen was ~5 parts per million (ppm) in plot 1 and 3 ppm in plot 2; the ammonium nitrogen was 24 and 12 ppm; phosphorus was 19 ppm and 12 ppm; potassium was 90 and 60 ppm; calcium was 700 and 500 ppm; and, magnesium was 25 and 18 ppm. The pHs of 5.6 and 5.0 in these respective plots were higher than was the mean pH recorded for 17 Connecticut forests with *M. septendecim* (Maier 1980) and for Kentucky, United States of America, forests with *M. septendecula* and other *Magicicada* species (Kalisz 1994). In a soil survey of New Haven County, Reynolds (1979) assigned the soil in plot 1 to the Holyoke–Cheshire complex, and that in plot 2 to the Holyoke–Rock outcrop complex. Holyoke soils tend to be shallow and well drained, occurring on ridges with bedrock-controlled glacial till.

Forested plots in Connecticut (Tables 1, 2; Fig. 1B) had some of the same features that Alexander and Moore (1962) and Dybas and Lloyd (1974) reported for forests or scattered trees with *M. septendecula* or its southern equivalent, *M. tredecula.* For example, trees in the Juglandaceae, notably *Carya* species, dominated in plots 1 and 2 (Tables 1, 2), and could have been more important in the past when *J. cinerea* was present (Table 1). Second, canopies of trees in the plots had good solar exposure, much like the preferred, isolated *Carya* species mentioned by Alexander and Moore (1962) and Dybas and Lloyd (1974). The sloping landscape (10–20% grade) in plots 1 and 2 contributed to increased solar exposure especially on the eastern and southern sides of trees. Furthermore, trees in plot 1 were near the edge of the forest, being bordered by a lake to the east (Fig. 1B). Finally, canopies of *F. americana* in plot 2 were increasingly exposed to the sun because of thinning caused by steady decline from larval infestations of the emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae).

The future of *M. septendecula* in the emergence and chorusing areas in Connecticut is uncertain. Two threats to its survival probably are the decline of *F. americana* from larval boring by *A. planipennis* and of *J. cinerea* from fungal diseases and succession (*e.g.*, Graves 1923; Anderson and LaMadeleine 1978; Ward *et al.* 1999). The first threat is most apparent in plot 2 where *A. planipennis* already is causing tree decline. Trees of *F. americana* in the two plots probably will die within six years (Knight *et al.* 2013). The second threat is evident in the chorusing area with plot 1, where only one live tree of *J. cinerea* (dbh 32 cm) remains and where dead ones are on the ground (Table 1). The one live tree apparently supported nymphal development because it had eight exuviae of *M. septendecula* at the base of its trunk, which was separated from other trunks by at least 5 m. If *F. americana* and *J. cinerea* are important species for *M. septendecula* in Connecticut, then this cicada truly is in peril. Certainly, Dybas and Lloyd (1974), Lloyd and White (1976), White and Lloyd (1979), and Williams and Smith (1991) have shown that *M. septendecula* and *M. tredecula* use *Fraxinus* species for development, reproductive activities, or both.

Estimating density

The mean density of emergence holes in plot 1 was 1.88 ± 1.69 (SD)/0.25 m^2. With extrapolation from this mean, density in the plot was 7.52 nymphs/m^2 or 18 800 nymphs/0.25 ha. This estimated density per m^2 was near the upper end of the range (2.2–8.0 nymphs/m^2) that Maier (1982b) found in three Connecticut forests with *M. septendecim* and in the upper one-third of the range (3.7–9.3 adults/m^2) that Kalisz (1994) reported for Kentucky forests with *M. septendecula* and at least one other *Magicicada* species. By contrast, density in plot 1 fell within the lower one-third of the range (1.1–26.3 adults/m^2) for *M. septendecim* in the mid-Hudson Valley of New York (Karban 1984).

Based upon the tibial length of 1315 exuviae collected near 69 trunks in plot 1, 7.91% of exuviae were *M. septendecula* and 92.09% were *M. septendecim*. Thus, of the estimated 18 800 cicadas within the plot, 1487 were *M. septendecula* and 17 313 were *M. septendecim.* On a ha-basis, the population size would be 5948

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M. septendecula and 69 252 *M. septendecim*. Now, if a 1% error in assigning abnormally small males of *M. septendecim* to *M. septendecula* were considered, a correction is needed. First, the sex ratio of the exuviae presumed to be *M. septendecula* was 51♂♂:53♀♀, which did not depart significantly from a 1:1 ($\chi^2 = 0.04$, df = 1, $P > 0.05$). If 51/104 (49%) of exuviae were male, then by extrapolation 729 of the 1487 exuviae of *M. septendecula* can be considered males, with about seven potentially assigned incorrectly. With this subtraction, the number of *M. septendecula* in plot 1 would become 1480.

The mean tibial length of exuviae considered to be *M. septendecula* was 5.53 ± 0.02 mm (SD) (range 5.16–5.90 mm) for males and 5.99 ± 0.02 mm (range 5.70–6.16 mm) for females. The size was significantly smaller in males than females ($t = 16.9$, df = 102, $P < 0.0001$). The mean tibial length of male exuviae of *M. septendecim* was 6.71 ± 0.22 mm at Southington and 6.80 ± 0.18 mm at Hamden, whereas for females it was 7.03 ± 0.25 mm and 7.06 ± 0.26 mm, respectively. As with *M. septendecula*, the length was significantly shorter in males than females at both Southington ($t = 9.4$, df = 198, $P < 0.0001$) and Hamden ($t = 8.3$, df = 198, $P < 0.0001$).

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