CEPAEA NEMORALIS IN BURLINGTON, NEW JERSEY, USA: ITS POSSIBLE ORIGIN AND STATE 157 YEARS AFTER ITS INTRODUCTION

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Abstract *The European land snail* Cepaea nemoralis *was introduced into Burlington, New Jersey, USA by William G. Binney in 1857 with specimens from near Sheffield, England. First in 1869 and later in 1878, Binney noted that the species had become widespread throughout the city. Between 1908 and 1933, Henry A. Pilsbry collected a large number of* C. nemoralis *shells in Burlington and noted that the species was still abundant in the early 1930s. A survey done in Burlington in 2013 and 2014 that included some of Pilsbry's localities found only six live snails and six empty shells. The only live snails were found near where Binney's house was in the nineteenth century. Our results show that both the range and the population of* C. nemoralis *in the city have declined drastically since the 1930s. The Burlington colony of* C. nemoralis *is characterized by high frequencies of unbanded or one-banded morphs. This suggests that Binney's founding lot may have originated from the White Peak district of Derbyshire near Sheffield, England.*

Key words *William G. Binney, alien species, population decline, Helicidae*

INTRODUCTION

The second edition of Augustus A. Gould's (1805–1866) *Report on the Invertebrata of Massachusetts* was published posthumously in 1870. Its editor William G. Binney included this first-person narrative under the entry for the European land snail *Helix nemoralis* Linnaeus 1758 (now *Cepaea nemoralis*): "In 1857 I imported some hundred specimens from near Sheffield, England, and freed them in my garden at Burlington, New Jersey. They have thriven well and increased with great rapidity, so that now (1869) the whole town is full of them." (Gould & Binney, 1870). In the fifth volume of *The Terrestrial Air-breathing Mollusks*, Binney (1878) repeated this statement with a new parenthetical date of 1878.

This is the earliest recorded introduction of *C. nemoralis* into North America. Although there have been other intentional and unintentional introductions from Europe and transfers from established colonies to other locations within North America (Reed, 1964; Dundee, 1974; Örstan, 2010), probably for only one other colony is the exact starting date known (Örstan *et al*., 2011). Although *C. nemoralis* does not appear to be a nuisance species, information on the longevity and dispersal of its established colonies could help assess the potential threat of its new colonies and even the colonies of other introduced land snails that may be more invasive and destructive. *Cepaea nemoralis* has been the subject of many studies on the geographical distributions of its well-known polymorphic shell colours and banding as well as the influences of various environmental factors on polymorphism. Thus, the establishment of the possible provenance of Binney's founding population may be possible from an examination of the distributions of various morphs in current and historical collections done in Burlington. This sort of information may in turn be useful in studies of polymorphic shell traits that may have changed in introduced colonies of the species, including the one in Burlington. As a contribution to these research fields, we report here the results of our survey for *C. nemoralis* in Burlington, New Jersey, USA and the results of our analyses of shell polymorphism in the Burlington colony.

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MATERIALS AND METHODS

The first author searched for *C. nemoralis* at the following localities in Burlington (Fig. 1) on 27 July 2013 (stations 1–6) and 16 August 2014 (stations 1 and 7–12):

1. Railroad crossing at intersection of Jones and East Pearl Streets (40.0818 N, 74.8435 W).

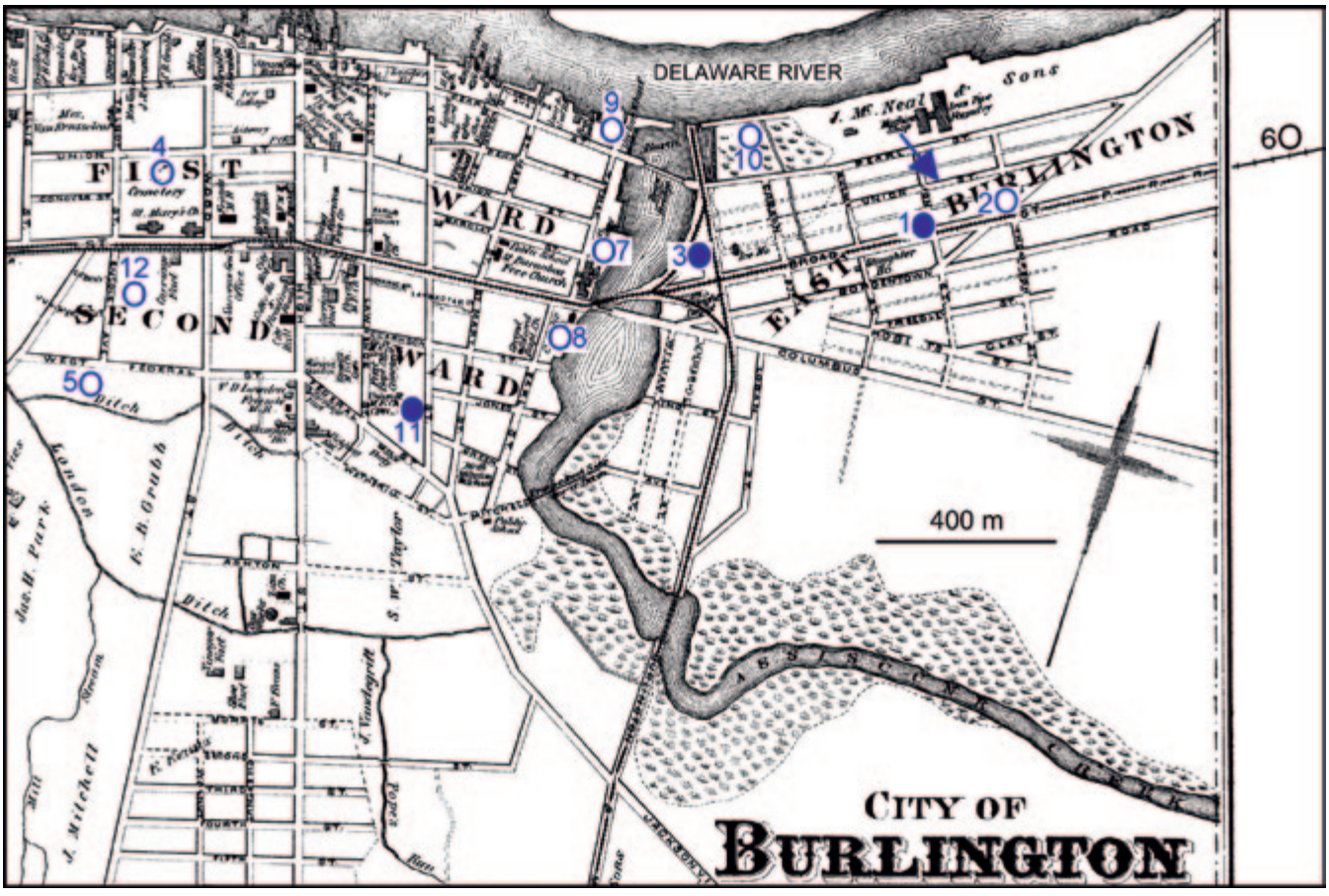

Figure 1 The 1876 map of Burlington with the locations of the present survey stations marked by closed circles (*Cepaea nemoralis* present) or open circles (absent). The arrow marks the approximate location of William G. Binney's house (the point of introduction of the species) on East Union Street.

2. Small grove of trees and shrubs near railroad, 160m northeast of station 1 (40.0826 N, 74.8419 W).
3. Junkyard along grove of trees above Assiscunk Creek (40.0805 N, 74.8489 W).
4. Cemetery of St. Mary's Church, West Broad Street (40.0777 N, 74.8620 W).
5. Park, north shore of J. F. Kennedy Lake (40.0735 N, 74.8606 W).
6. Grove of trees and shrubs near railroad, East Pearl Street (40.0857 N, 74.8359 W).
7. Empty lots with overgrown plants along Tatham Street, above Assiscunk Creek (40.0800 N, 74.8509 W).
8. Cemetery of Knights of Columbus above Assiscunk Creek (40.0780 N, 74.8510 W).
9. Playground and boat landing at Delaware River north of intersection of Tatham and Pearl Streets (40.0818 N, 74.8514 W).
10. Grounds of restaurant at marina, mouth of Assiscunk Creek (40.0824 N, 74.8485 W).
11. Parking lot of Methodist and Baptist cemeteries, York Street (40.0754 N, 74.8544 W).
12. Derelict playground with overgrown plants, Engle Street (40.0759 N, 74.8620 W).

Binney's house, the point of introduction of *C. nemoralis*, was at "222 East Union St., Burlington, N.J." as given in the announcement of his death (Anonymous, 1909). There is no East Union Street in present day Burlington, but an 1876 map of the city (Scott, 1876) shows the continuation of Union Street, from the west of the Assiscunk Creek into the part of town labeled "East Burlington" just north of the present day East Pearl Street (Fig. 1). Binney's house must have been somewhere on Union Street east of the creek. Most of this area is now occupied by a water treatment plant, a police station and an industrial facility, none of which provided public access to their grounds. The locations of stations 1, 2, 3, 6 and 10, all east of the Assiscunk Creek, were selected to be as close to the approximate location of Binney's

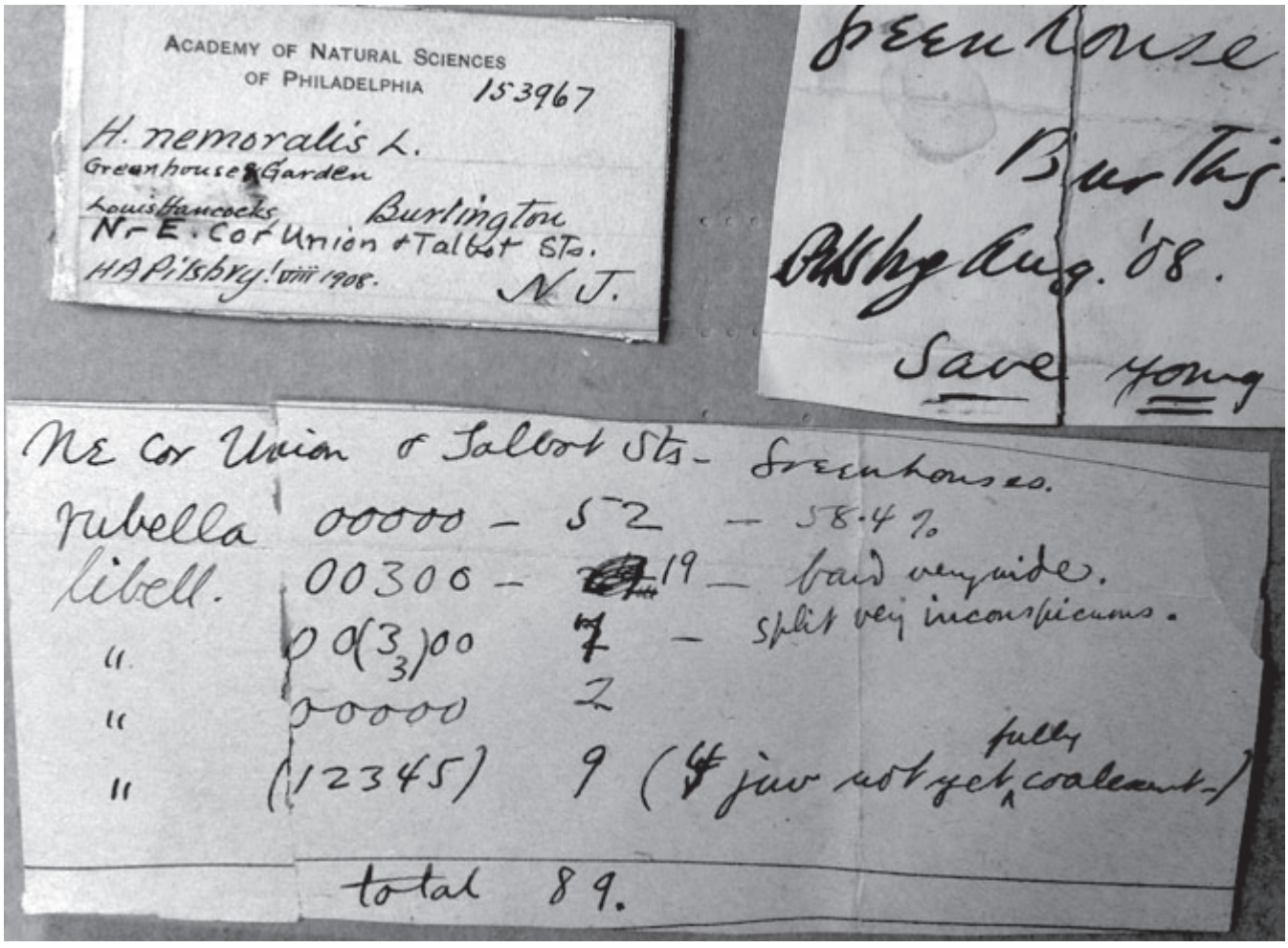

Figure 2 H. A. Pilsbry's score sheet for his 1908 collection of *Cepaea nemoralis* (ANSP 153967).

house as possible. The railroad habitats of stations 1, 2 and 6 were also considered suitable, because *C. nemoralis* was found in similar habitats in Montreal, Canada (Örstan, 2010). Stations 4, 7, 8, 9, 11 and 12 were picked, because they were either the same as or close to the localities where H. A. Pilsbry collected *C. nemoralis* between 1908 and 1933 (Fig. 1). Brief descriptions of Pilsbry's collection stations were available in the online catalog of the Academy of Natural Sciences of Drexel University, Philadelphia, Pennsylvania, USA (Malacology Collection, 2014). Moreover, the cemeteries at stations 4, 8 and 11 and the park at station 5 were all on the 1876 map of Burlington (Fig. 1). Thus, they provided relatively undisturbed snail habitats in continuous existence since Binney's time.

The live snails seen during the survey were left behind and only the empty shells were taken. Two lots have been deposited with the Carnegie Museum of Natural History, Pittsburgh, PA (CM139521 and CM139522).

We scored both the empty shells and the shells of the live snails from Burlington for their bands and colors. The scoring of bands followed Ożgo (2012). We also scored for bands eight lots of *C. nemoralis* from Burlington in the collections of the Academy of Natural Sciences of Drexel University. Two of these lots did not have collection dates, so we associated them with their cataloguing dates of 1893 and 1897, respectively. The remaining lots were collected by H. A. Pilsbry between 1908 and 1933. We did not score the lot from 1908 (ANSP 153967) and instead used Pilsbry's original score sheet that was with the lot itself (Fig. 2). Also, for one lot from 1933 (ANSP 161255) we added to our scores of 117 shells, the data for 59 shells Pilsbry scored and subsequently sent away (the score sheet for these shells was also with the lot).

Figure 3 The live four adults and one juvenile *Cepaea nemoralis* found at station 1 in July 2013.

Results

The only live *C. nemoralis* seen during the survey were at station 1 and consisted of four adults and one juvenile in 2013 and one subadult in 2014 (Fig. 3). In addition, in 2013 one empty adult shell and one empty juvenile shell were found at stations 1 and 3, respectively, and in 2014 one empty juvenile shell and three empty adult shells were found at stations 1 and 11, respectively. No *C. nemoralis* was found at any of the other stations.

Of the total of 12 shells from Burlington (six alive, six empty), six were yellow midbanded (00300), one was pink midbanded and four were pink unbanded (00000). The only five-banded shell was bleached white. The midbanded and the unbanded morph types were also predominant in the old collections of shells from the city (Table 1). Unfortunately, the colours of all of the shells in the old collections had become faded yellow.

Table 1 Distribution of banding morphs of *Cepaea nemoralis* in Burlington. For each year the total number of shells scored (N) and the number of shells for each morph are given. The scoring for 1908 was done by H. A. Pilsbry. The category 12345 also includes the 17 shells in the subcategories (12)345, 123(45) and (12345) for 1908–1933.

Year	N	00000	00300	12345
1893, 1897	6	2	4	–
1908	89	54	26	9
1909	175	134	38	3
1931	133	80	42	11
1933	176	103	44	29
2013, 2014	12	4	7	1

The only shell color data we could use was from Pilsbry's score sheet for his 1908 collection (Fig. 2). According to this, of the 54 unbanded shells, 52 were pink (var. *rubella*), while only two out of 37 yellow shells (var. *libellula*) lacked bands. There were no pink banded shells.

Discussion

Our survey demonstrated that *C. nemoralis* introduced into Burlington in 1857 was still in existence in 2013 and 2014, but the range of the species in the city had shrunk since the 1930s. The population of the species at the time of the survey, as judged from the few live snails encountered, appeared to be very small. We have found only two published brief accounts of the presence of this species in Burlington after Binney (1878). Parker's (1902) account, who wrote that *C. nemoralis* "multiplied and in twenty years they abounded in that town, but afterwards decreased," is suggestive of a population peak, reached perhaps towards the end of the nineteenth century, followed by a decline. The second account was by Pilsbry (1939) who summarized his findings as follows: "At the present time, after eighty years, these snails are still confined to the town, where they are abundant in some gardens and in several urban cemeteries and churchyards. I have not found them in surrounding country." This implies that the species, despite being abundant at some locations in the town, had failed to expand its range. The lack of *C. nemoralis* at our stations 4 and 8 (cemeteries where Pilsbry had found the species) was especially revealing, because not only did both cemeteries have seemingly suitable snail habitat, but they also had long fences bordering the backyards of private residences. Had the snails been present in any of the private gardens as abundantly during our survey as they had been during Pilsbry's surveys, a few would have been expected to have strayed into the cemetery grounds.

With only 12 shells recorded during our survey from more than one locality, we cannot draw any general conclusions about the shell colour and banding polymorphism of the current *C. nemoralis* population in Burlington. However, the shells are unusual in that the commonest form in most natural populations, shells with five bands, is rare. Although the numbers are very small, there appears to be a striking

linkage disequilibrium with unbanded shells being exclusively pink.

Binney did not report on the frequencies of the color and banding morphs among the snails he released. Nevertheless, his drawings of two Burlington shells (Gould & Binney, 1870), one (00300) and the other apparently a (123(45)), show that these morphs that were also collected in later years were already present during the early years of the colony. The frequencies of banding morphs of shells collected at later dates from Burlington offer additional insight (Table 1). The slight variation in the relative frequencies of the morphs among samples may reflect differences in location. It is clear, however, that shells with many bands were always a small minority, with the highest frequency (16.5%) being recorded in 1933. In Pilsbry's 1908 collection (Fig. 2), 52 of the 54 unbanded shells were pink, while only two out of 37 yellow shells lacked bands. There were no pink banded shells. This striking disequilibrium appears to have persisted in the present population (Fig. 3).

Binney stated that his snails were collected near Sheffield, England, presumably in 1857, the year he imported them, or perhaps a year earlier. At that time, it is likely that Sheffield itself held very few, if any, populations of *C. nemoralis* (Cameron *et al*., 2009). Those few that might have survived heavy urban pollution would have been predominantly five-banded. The species is, however, abundant in the nearby White Peak district of Derbyshire, where many populations have extreme morph frequencies, often without five-banded shells (Greenwood, 1972). The area is readily accessible from Sheffield. Therefore, we tentatively conclude that at least the majority of Binney's specimens came from that area. The persistence of this rather unusual pattern (the rarity of five-banded shells and the very strong linkage disequilibrium) suggests that the Burlington colony retains traces of its origin despite the possibility of strong selection in a new and climatically distinct home.

The most extensively studied invasive land snail is probably *Achatina fulica* (Férussac 1821). Many introduced colonies of this snail have been observed to go through consecutive stages of growth, steady state and decline (Mead, 1961; Civeyrel & Simberloff, 1996). The causes of population decline are not known, but bacterial infection, predation, lack of genetic diversity and food shortage have been proposed as possible contributing factors (Mead, 1961; Civeyrel & Simberloff, 1996). Population peaks leading to crashes have also been observed in the introduced colonies of at least one freshwater and one marine mollusk (Burnaford *et al*., 2011; Moore *et al*., 2012). In addition, Simberloff & Gibbons (2004) reviewed several cases of spontaneous declines, sometimes taking place over a period of only a few years, observed in populations of several introduced non-molluscan animal species.

The findings of our survey, combined with earlier accounts, imply that the colony of *C. nemoralis* in Burlington has also gone through a population peak followed by a decline, albeit over a seemingly much longer period than seen in colonies of other introduced species. We can't attribute any definite causes to the population decline. The absence of accumulated empty shells at any of our stations suggests that the population crash took place a long time ago and that the empty shells have since decomposed. One would expect to find more empty shells if the present state of *C. nemoralis* in Burlington were a stage in a cyclic process of population fluctuations (the presence of only a few live snails rules out the possibility that most empty shells had been consumed by their conspecifics for calcium). The remaining live snails are probably riding on the long tail of decline towards the possible extirpation of the species in the city.

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