Too big to be noticed: Cryptic invasion of Asian camel crickets in North American houses

Despite the rapid expansion of the built environment, we know little about the biology of species living in human-constructed habitats. Camel crickets (Rhaphidophoridae) are commonly observed in North American houses and include a range of native taxa as well as the Asian *Diestrammena asynamora* (Adelung), a species occasionally reported from houses though considered to be established only in greenhouses. We launched a continental-scale citizen science campaign to better understand the relative distributions and frequency of native and nonnative camel crickets in human homes across North America. Participants contributed survey data about the presence or absence of camel crickets in homes, as well as photographs and specimens of camel crickets allowing us to identify the major genera and/or species in and around houses. Together, these data offer insight into the geographical distribution of camel crickets as a presence in homes, as well as the relative frequency and distribution of native and nonnative camel crickets encountered in houses. In so doing, we show that the exotic *Diestrammena asynamora* not only has become a common presence in eastern houses, but is found in these environments far more frequently than native camel crickets. Supplemental pitfall trapping along transects in 10 urban yards in Raleigh, NC, revealed that *D. asynamora* can be extremely abundant locally around some homes, with as many as 52 individuals collected from pitfalls in a single yard over two days of sampling. The number of *D. asynamora* individuals present in a trap was negatively correlated with the trap's distance from a house, suggesting that these insects may be preferentially associated with houses but also are present outside. In addition, we report the establishment in the northeastern United States of a second exotic species, putatively *Diestrammena japanica* Blatchley, which was previously undocumented in the literature. Our results offer new insight

into the relative frequency and distribution of camel crickets living in human homes, and emphasize the importance of the built environment as habitat for two little-known invading species of Orthoptera.

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10   INTRODUCTION

11   In the United States, 90% of the human population is predicted to live in urban environments by

12   2050 (U.N. 2012). At this time a large geographic area will be urban, peri-urban and suburban

13   (Nowak and Walton 2005), an area greater than that covered by many of North America's

14   primary vegetation types (Stein, Kutner, and Adams 2000). Although the species living in built

15   environments are among the organisms we see most often, they are not necessarily well-

16   documented. We suspect this is particularly true of species that are neither valued aesthetically as

17   are birds and butterflies, nor are important economic pests (such as bed bugs and roaches). Camel

18   crickets (Orthoptera: Rhaphidophoridae) are among the largest of the many insects that live in

19   modern-day houses, and have an especially longstanding history of contact with humans in our

20   homes. These insects have long been noted in basements and cellars, and one remarkable

21   example of cave art from Paleolithic France depicts the cave-dwelling camel cricket *Trogophilus*

22   sp. (Chopard 1928). The relationship between camel crickets and humans is clearly ancient;

23   however, the biology of these insects as residents of our homes is known primarily from a

24   smattering of specimen records in museums rather than from formal study.

25   Camel crickets comprise a moderately diverse family of Orthoptera, represented by ca. 150

26   species (23 genera) across North America (Arnett 2000). Of these, several species in the large

27   genus *Ceuthophilus* Scudder (e.g., *C. brevipes* Scudder, *C. pallescens* Bruner, C. *agassizii*

28   (Scudder), *C. latens* Scudder, *C. maculatus* (Harris), and others) have been reported as common

29   or occasional inhabitants of North American homes, particularly in cellars and basements

30   (Blatchley 1920; Vickery and Kevan 1983). Outside of these habitats, most species of

31   *Ceuthophilus* (including those occurring in our houses) are found under rocks, logs, or surface

32   debris in forested areas, although a few are known from grassland ecosystems (Vickery and

33   Kevan 1983). Other *Ceuthophilus* (e.g., *C. carlsbadensis* Caudell, *C. longipes* Caudell, *C.*

34   *secretus* Scudder, and others) are common residents of caves, where the droppings and carcasses

35   of these crickets are a major source of energy for other organisms. For this reason camel crickets

36   are considered keystone species in many cave ecosystems (Lavoie, Helf, and Poulson 2007;

37   Taylor, Krejca, and Denight 2005). Although cellars and basements share features with caves

38   (e.g., both tend to be damp, dark, and low in nutrients), most camel crickets found in our houses

39   appear to be distinct from species typically collected in caves (Vickery and Kevan 1983).

40   However, in at least one case (a camel cricket endemic to Tuscany, Italy, *Dolichopoda*

41   *schiavazzii* Capra), populations of an otherwise cave-inhabiting species are also known from

42   cellars and other subterranean environments of human origin (Allegrucci, Minasi, and Sbordoni

43   1997).

44   In addition to a rich diversity of native camel cricket species, non-native camel crickets have also

45   become established in North America. The 'greenhouse camel cricket,' *Diestrammena*

46   *asynamora* (Adelung) is a species native either to Japan or the Sichuan region of China (Rehn

47   1944). This species was first recorded in North America in 1898 from a greenhouse in Minnesota

48   (Rehn 1944), and subsequently has been noted in a number of locations across the eastern and

49   central United States and Canada. *D. asynamora* has also been found throughout much of Europe

50   (Rehn 1944). Many authors have considered this species to be associated primarily with

51   greenhouses (e.g. Bue and Munro 1939, Rehn 1944, Vickery and Kevan 1983), although a few

52   early reports document at least an occasional presence in cellars (Blatchley 1920; Rehn 1944).

53   However, little discussion has been made of this species and its status since Rehn's 1944

54   publication. Modern reports of *D. asynamora* show that it is present in some basements, though it

55   is uncertain whether the sightings of this introduced cricket represent isolated cases of localized

56   abundance or a more extensive invasion. Recent anecdotal reports (www.bugguide.net) also

57 suggest the establishment of a second Asian species, *D. japanica* Blatchley (syn. *D. japonica*

58 Karny, *D. naganoensis* Mori), around New York City, NY. Because camel crickets include both

59 introduced species and geographically and locally rare species, it is possible that basements and

60 cellars might be important habitats for the spread of introduced camel crickets and/or the

61 persistence of native camel cricket species.

62 One challenge with studying the biology of species living in homes is that privacy concerns make

63 these areas difficult to sample. However, citizen science may offer an ideal approach for studying

64 home biodiversity; volunteers can participate in scientific research by self-surveying their own

65 homes. Although obtaining accurate identifications of organisms from public survey data can be

66 challenging, many of the characters that distinguish camel crickets at the generic and/or species

67 level (e.g., coloration, tibial armature) may be visible in photographs. For this reason,

68 photographic documentation is an invaluable addition to public survey data, and provides an easy

69 way to confirm the presence and distribution of camel crickets in our homes.

70 In this study, we use citizen-contributed data to offer new insight into the distribution and

71 composition of camel crickets taking shelter in human homes. Initially, in order to understand

72 how common camel crickets are in houses, we surveyed citizens across the United States about

73 the presence of camel crickets living in and around their homes. We conducted this survey in two

74 ways: 1) we asked visitors to our website to report the presence/absence of camel crickets (as

75 well as other natural history observations in and around their home) via an open survey and 2) we

76 directly administered a closed survey that included a question about camel crickets to volunteers

77 wishing to participate in an unrelated citizen science project (about microbial diversity in the

78 home). We then solicited photographs and specimens of camel crickets from citizen scientists to

79 evaluate the occurrence and geographical distribution of native versus nonnative camel cricket

80   species in homes. These survey results were augmented with trapping efforts to compare the

81   composition of camel crickets living in houses to those present in urban yards.

82   METHODS
83   We used two types of citizen science surveys to characterize the geographic distribution and

84   composition of camel crickets in houses across the United States. First, as part of a broader study

85   about the ecology of human homes, we used an open web survey to poll people across the United

86   States about the organisms they find in their homes; this survey included questions about the

87   presence/absence of camel crickets in or around their homes and their geographic location

88   (Appendix A). We recruited participants to the survey through our website (yourwildlife.org),

89   social media and email campaigns, and the survey remained open to public responses from

90   December 2011 through July 2013. This initial survey had the potential to be biased toward

91   individuals who had camel crickets in their homes, as people may be more likely to report a

92   presence than absence (Bonney et al. 2009). As a result, we conducted a second survey by polling

93   a geographically stratified but naïve population of homeowners. We directly administered a

94   closed survey to 7058 households wishing to enroll in the Wild Life of Our Homes project

95   (WLOH, a separate study mapping the indoor microbial biodiversity of homes;

96   homes.yourwildlife.org) over the period October 2012 – April 2013. Volunteers, representing all

97   50 states and the District of Columbia, were required to complete the brief survey (containing a

98   question about the presence/absence of camel crickets in the home, Appendix A) in order to

99   receive a home microbe sampling kit. Thus, participation was not a function of initial interest in

100   camel crickets, but in this other citizen science project, therefore reducing sampling bias.

101   The results of both surveys were used to map the presence of camel crickets in North American

102   homes. Maps were created using ArcGIS software (ESRI 2006) and R (http://www.r-

103   project.org/). Only data from the second, WLOH participant survey were used to estimate the

104   prevalence of the crickets.

105   In order to understand the relative distribution of native versus nonnative camel crickets we next

106   solicited photographs and/or specimens of camel crickets from citizen volunteers who reported

107   these insects in their homes. These volunteers included a subset of participants from the surveys

108   described above, as well as additional individuals responding to an appeal for participation on the

109   Camel Cricket Census website (http://crickets.yourwildlife.org/). Photographs and specimens

110   were identified to genus based on tibial armature and other relevant characters described in

111   Vickery and Kevan (1983). Where possible, photographs and specimens of the nonnative

112   *Diestrammena* were further identified to species using characters such as the number of tibial

113   spines, tibial spur length, and color pattern as described in Sugimoto and Ichikawa (2003),

114   Vickery and Kevan (1983), and following consultation with experts.

115   Finally, to understand whether the Asian camel cricket *D. asynamora* is living only in houses or

116   also present in yard habitats, we sampled camel crickets in a subset of urban yards at increasing

117   distances from homes known to contain camel crickets. In July of 2013, 10 participating

118   households were recruited from central Raleigh, NC, and pitfall traps placed in the yard of each.

119   Study yards were located within a 1.5 mile radius of North Carolina State University's central

120   campus, and were typically a mix of sun and shade habitat with occasional scattered trees and

121   primarily grass as groundcover. We constructed pitfall traps using plastic cups (7 cm across by 10

122   cm deep) and placed three traps per yard at distances of 1 m, 4 m, and 8 m from each house along

123   a haphazardly placed transect. Traps were baited with a 1:1 dilution of molasses and water as per

124   the methods of Hubbell (1936). We placed inverted plastic bowls elevated approximately 3 cm

125   over the mouth of each trap to protect traps from rain and to encourage camel cricket visitation by

126   offering cover. Contents of traps were collected daily and traps were left in place for two days. In

127   some yards small mammals would disturb the traps, in which case we replaced the molasses bait

128   with soapy water in all traps on a transect to be less attractive to mammalian pests. We sorted the

129   contents of each trap in the laboratory and identified all camel crickets to species with the aid of a

130   dissecting microscope. We then used analysis of covariance (ANCOVA) to test for a relationship

131   between the number of *D. asynamora* individuals in a trap and its distance from a house. Yards in

132   which no camel crickets were recovered at any of the three traps were excluded from analysis.

133   Statistical analysis was performed in JMP v. 10.0 (SAS Institute, Cary, NC).

134   RESULTS
135   Individuals from 549 homes responded to our initial open survey question about the presence or

136   absence of camel crickets in or around their houses, offering positive reports of camel crickets for

137   244 homes across the country. An additional 1,719 households responded to the unbiased (with

138   respect to camel cricket presence) WLOH participant questionnaire. Over both surveys,

139   participants from 669 houses reported having observed camel crickets in their homes, including

140   24.4% of households responding to the unbiased WLOH study (Fig. 1). Together, these surveys

141   allowed us to evaluate the potential distribution of camel crickets associated with human houses

142   across the United States. We use the word "detection" to acknowledge that reports of absence in

143   survey data may reflect failures to detect camel crickets, just as presences may represent failures

144   at identification. For example, a large spider might bear a vague resemblance to a camel cricket

145   for a participant wary of arthropods. Participants from 39 states and the District of Columbia

146   reported observing camel crickets in or around their homes (Fig. 2). The proportion of detections

147   of camel crickets in homes was significantly higher in the eastern United States (28% of reports

148   were positive from states east of Colorado) compared to western states (7% positive reports; two-

149   tailed $P<0.0001$ from Fisher's exact test). Based on the proportion of photographs showing

150   insects incorrectly identified as camel crickets by citizen scientists who responded to our call for

151   photographs (see below), we estimated a 4.6% error rate associated with affirmative reports of

152   camel crickets from all survey data, although this error rate may vary geographically. From

153   Colorado westward only five photographs were submitted, of which 40% (2 of 5) were identified

154   incorrectly as Rhaphidophoridae. The most common taxa mistaken for camel crickets were field

155   crickets (Gryllidae) or other Orthoptera.
156
157   Citizen scientists from 163 households submitted identifiable photographs (N = 151) and/or

158   specimens (N = 12) of camel crickets from their houses. Submissions spanned 23 states and the

159   District of Columbia, as well as one Canadian province with an overrepresentation of

160   submissions (37%) from North Carolina. Out of all identifiable camel cricket submissions, 88%

161   of houses submitted evidence of the Asian genus *Diestrammena*. Only 12% of houses reported

162   members of the native *Ceuthophilus* (Table 1, Fig. 3). In three cases, evidence of both native and

163   nonnative genera were contributed from the same home. Of the 143 submissions recognizable as

164   *Diestrammena*, 108 were of sufficient quality to allow identification to species. Of these, 94% of

165   entries were *D. asynamora* (Fig. 4a), while the remainder (seven entries) were identified as

166   putative *D. japanica* (Fig. 4b). Records of *D. japanica* were submitted exclusively from the

167   northeastern United States in Massachusetts, Pennsylvania, and New Jersey (Fig. 5).

168   We recovered 158 camel crickets from pitfall traps in urban yards in Raleigh, NC. Prior to our

169   investigation, eight of the 10 households participating in our trapping study reported previously

170   having seen camel crickets in their home. Camel crickets were found in seven of the yards

171   sampled, and were absent in both of the yards for which camel crickets were not reported in the

172   house. For houses initially reporting camel crickets as present, an average of 20 individual camel

173   crickets were recovered per yard over the two-day sampling period (95% C.I. = 5-34, range = 0-

174   52). All recovered specimens of Rhaphidophoridae were identified as the Asian species *D.*

175   *asynamora*. The number of *D. asynamora* individuals recovered in traps was negatively

176   correlated with a trap's distance from a house ($R^2 = 0.66$, $P = 0.004$ from ANCOVA after ln-

177   transformation of the number of cricket individuals and after accounting for individual yard, as

178   would reflect variation in local abundances of camel crickets; Fig. 6). In fact, for every yard with

179   successful trapping, more crickets were consistently recovered at traps 1 m from the house than

180   were recovered from the two more distant traps combined. However, in 57% of these yards at

181   least one *D. asynamora* individual was recovered from the trap placed farthest from the house (8

182   m).

183   DISCUSSION

184   Although camel crickets have long been a common presence in our homes, little is known about

185   the identity, occupancy and geography of these animals in homes. Using data contributed by

186   citizen scientists, we found that camel crickets are common in houses across much of the

187   continental United States (Fig. 2), and present in as many as a quarter of homes surveyed as part

188   of another citizen science project. Based on our survey results, camel crickets appear to be

189   geographically widespread in homes particularly across the eastern half of the United States, and

190   to a lesser extent in the southwest and west coast (Fig. 1). Camel crickets were not reported in

191   homes throughout much of the mountain west, although responses from this region were sparse

192   relative to more populated parts of the country (Fig. 1, Fig. 2). Hence, there may be large areas in

193   the west where camel crickets are more common than our data indicate. However, the public can

194   still contribute data to this project, such that we hope to add data for the western U.S. in the

195   coming months or years (crickets.yourwildlife.org). Camel crickets appear to be most prevalent

196 in houses in the southeastern United States, with nearly 50% of households surveyed in Virginia,

197 North Carolina, Missouri, Mississippi, Maryland, and Tennessee reporting the presence of camel

198 crickets in their homes (Fig. 1).

199 Although this survey was potentially biased geographically, it was not biased as a function of the

200 presence or absence of camel crickets. If the abundance of camel crickets (of any species) in and

201 around the average home where they are present is comparable to the abundance of these insects

202 recovered in our pitfall traps around homes in Raleigh, North Carolina, there could be as many as

203 seven hundred million camel crickets in and around homes across the eastern United States alone

204 (calculated based on the number of housing units reported in the 2011 U.S. Census for midwest,

205 northeast and south U.S. census regions for which our survey responses were generally high; see

206 Fig. 2; U.S. Census Bureau 2012). If correct, this would amount to more camel crickets than

207 humans. Although clearly a very rough estimate (e.g., we do not account for other factors such as

208 regional geographic variation in abundance), this figure nonetheless offers a rough estimate of the

209 large populations of camel crickets that may have become established in and around built

210 environments. The size of these populations is all the more remarkable when we consider that

211 most of these camel crickets belong to an introduced species previously not known to be

212 especially common; in contrast, native species appear to be comparatively rare in these

213 environments.

214 Citizen scientists' submissions of photographs and specimens of camel crickets found in homes

215 reveal that the Asian camel cricket *D. asynamora* has become a successful and widespread

216 invader throughout the eastern United States (Fig. 3). Across much of this region this species

217 appears to be a much more common occupant of human homes compared to native *Ceuthophilus*

218 spp. (Table 1). For example, in North Carolina, the state for which we have the richest data,

219   *Diestrammena* (representing *D. asynamora* in all identifiable entries) was present in 92% of

220   houses with camel cricket samples submitted (Table 1). Our pitfall trapping in urban yards

221   reveals that this species also can be extremely abundant, with more than 50 individuals found

222   over two days of sampling in a single yard in Raleigh, North Carolina.

223   Although *D. asynamora* is clearly widespread and abundant in the eastern United States, the

224   extent of this species' range outside of the eastern United States is unclear. Rehn (1944) describes

225   reports of the species in greenhouses and cellars from Maine south to Tennessee, and as far west

226   as Colorado. While his reports derive from a small number of museum specimens combined with

227   scattered anecdotes, they already cover a relatively large geographic area. Our study includes

228   reports of the species only as far west as Kansas, though extending further south into Georgia and

229   South Carolina. Other reports suggest an even larger distribution, but lack of specimen data

230   makes comparison to our results difficult (Vickery and Kevan 1983). According to most

231   accounts, established populations of this species were thought to be present in greenhouses only

232   (Blatchley 1920, Vickery and Kevan 1967, Vickery and Kevan 1983). Hence, *D. asynamora*

233   likely may have increased in abundance since 1944, particularly in houses; however, the species

234   does not necessarily appear to have expanded its geographic distribution.

235   Despite the abundance of *D. asynamora* in and around the home, little is known about the

236   cricket's habits and life history. This species is best known in the literature from its occurrence in

237   greenhouses, where it has been blamed for causing occasional minor damage to plants (Vickery

238   and Kevan 1983). Although its feeding preferences are largely unknown, *D. asynamora* appears

239   like most Rhaphidophoridae to be an omnivorous scavenger, and has been reported foraging on

240   living and dead plant matter and dead insects. The habits and dietary preferences of our native

241   *Ceuthophilus* spp. are only somewhat better known than those of *D. asynamora*. Species of

242 *Ceuthophilus* (including taxa sometimes found in houses) have been observed scavenging

243 opportunistically on a range of food sources including other insects, fungi, and fallen fruit

244 (Taylor, Krejca, and Denight 2005). Examination of several cave-associated *Ceuthophilus* species

245 (Northup 1988) revealed a diverse diet that included mammalian carcasses, feces, other insects

246 (including cannibalized *Ceuthophilus* individuals), and human food waste. Like *D. asynamora*,

247 some species of *Ceuthophilus* appear to be occasional predators of other insects (Taylor, Krejca,

248 and Denight 2005, Vickery and Kevan 1983). Although we know little about the life history of

249 *D. asynamora* or *Ceuthophilus* in houses, *D. asynamora* is reported to breed year-round in heated

250 greenhouses. Breeding in *D. asynamora* is thought to occur only in the dark, and eggs are

251 typically laid in the soil (Vickery and Kevan 1983).

252 Although *Ceuthophilus* and *Diestrammena* both appear to be fairly generalized omnivores, we

253 can infer little about the extent to which these insects' habits and life histories are comparable

254 (and hence might lead to direct or indirect competition) in houses. Differences in the natural

255 history of the two taxa potentially could affect the extent to which these crickets would be

256 perceived by our citizen scientist contributors. For example, if the principal species of

257 *Ceuthophilus* in houses were found to be more reclusive than *D. asynamora*, this could in part

258 explain the larger number of *D. asynamora* reports by our contributors. However, the results of

259 our pitfall experiment suggest that for at least some areas the perception of greater numbers of *D.*

260 *asynamora* than *Ceuthophilus* associated with houses is real, especially considering that

261 numerous individuals of various *Ceuthophilus* species (including those sometimes found in

262 houses) have been commonly recovered from molasses-baited pitfall traps in other studies not

263 near houses (Blatchley 1920; Hubbell 1936; Taylor, Krejca, and Denight 2005). Although we

264 might expect larger insects to be noticed more readily by citizen scientists, the principal species

265   of *Ceuthophilus* occurring in houses are in fact slightly larger on average than *D. asynamora*

266   (Blatchley 1920). Hence, the more numerous reports of *D. asynamora* relative to *Ceuthophilus* do

267   not appear to have been biased by body size. Nonetheless, we recommend future study to

268   understand the relative life histories of these species, their interactions with each other and other

269   house-dwelling arthropods, and the ways in which they use our houses as habitat.

270   The appearance of a second introduced species, *Diestrammena japanica,* as an exotic in the

271   United States has never before been recorded in the literature, although its presence has been

272   reported anecdotally in some northeastern states concordant with those found in our study (see

273   www.bugguide.net). Some confusion arises in the erroneous early use of the name *D. japanica* as

274   a synonym for *D. asynamora* (Blatchley 1920), a misapplication subsequently clarified by Rehn

275   (1944). Aside from *D. asynamora* only one other species of *Diestrammena* has been reported in

276   the literature from the United States. This second species, reported by Morse (1904) as *D.*

277   *unicolor*, is known in the United States from only a single specimen collected in a greenhouse in

278   Chicago. This specimen, described as being uniformly piceous in color (Blatchley 1920), is

279   clearly distinct from our records of *D. japanica*, despite any potential nomenclatural

280   incongruities.

281   In our study, the presence of two species of *Diestrammena* in our samples is confirmed by the

282   widely divergent number of tibial spines between *D. asynamora* and *D. japanica* (ca. 60 and 30

283   respectively; Sugimoto and Ichikawa 2003), a character clearly visible in many of the

284   photographs submitted. Although our identification of the species *D. asynamora* was confirmed

285   on the basis of at least 170 specimens as well as by photographs, our records for *D. japanica*

286   were based on photographs only, and we must therefore allow for some uncertainty as to the

287   identity of the second species as the true *D. japanica.* Photographs of the second *Diestrammena*

288   species were identified as *D. japanica* based on a combination of outwardly visible characters

289   such as tibial spur length, tibial spine number, pronotal luster, and coloration (Sugimoto and

290   Ichikawa 2003). In addition, the distinctive pronotal pattern of *D. japanica* (Sugimoto and

291   Ichikawa 2003) was an exact match for our specimens. Although we offer clear evidence for the

292   presence of two introduced species of *Diestrammena* in the United States, we recommend future

293   study of museum specimens and examination of male genitalia (ideally in comparison with type

294   material) to confirm the second species as *D. japanica*.

295   Our collections of camel crickets from pitfall traps in urban yards revealed that *D. asynamora* is

296   not restricted to house environments, but is also a common presence in adjacent yards. Whether

297   these same individuals present in yards are also moving in and out of houses is unclear. The fact

298   that these crickets were significantly more abundant in traps placed within a meter of the house

299   (Fig. 6) suggests that *D. asynamora* may be closely associated with human dwellings even when

300   found in outdoor habitats. However, as we did not account for potential variability in local

301   habitats within a transect (e.g., traps placed 1m from houses could have been more proximate to

302   bushes compared to further traps), such variation may have biased our transect results.

303   Surprisingly, no native camel crickets were recovered from any of these traps. Although

304   behavioral differences (e.g., in activity level) between cricket species could potentially cause one

305   species to appear more readily in pitfalls, pitfall traps baited with molasses have repeatedly been

306   shown in other work to be highly profitable for sampling *Ceuthophilus* spp. (Blatchley 1920;

307   Hubbell 1936; Taylor, Krejca, and Denight 2005). This suggests that in some localities *D.*

308   *asynamora* may be the dominant camel cricket not only in houses but also in urban yards.

309   However, it is yet unclear whether *D. asynamora* has also invaded wilder habitats with less

310   human disturbance, or if in North America the species persists exclusively in habitats associated

311 with anthropogenic structures. The extent to which *D. asynamora* has actually displaced or is

312 actively competing with native populations of *Ceuthophilus* (a genus that includes a number of

313 rare or sensitive species) is also unknown, and further study is needed to determine whether this

314 new invader poses an ecological threat, or is merely a harmless visitor in our houses and yards.

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Figure 1

Percentage of households by state reporting the presence of camel crickets around the home

Responses to the Wild Life of Our Home survey, showing the percentage of households from each state answering 'yes' to the question 'have you seen camel crickets in or around your home?'. Numerals in each state represent the total number of responses (yes or no) for that state.

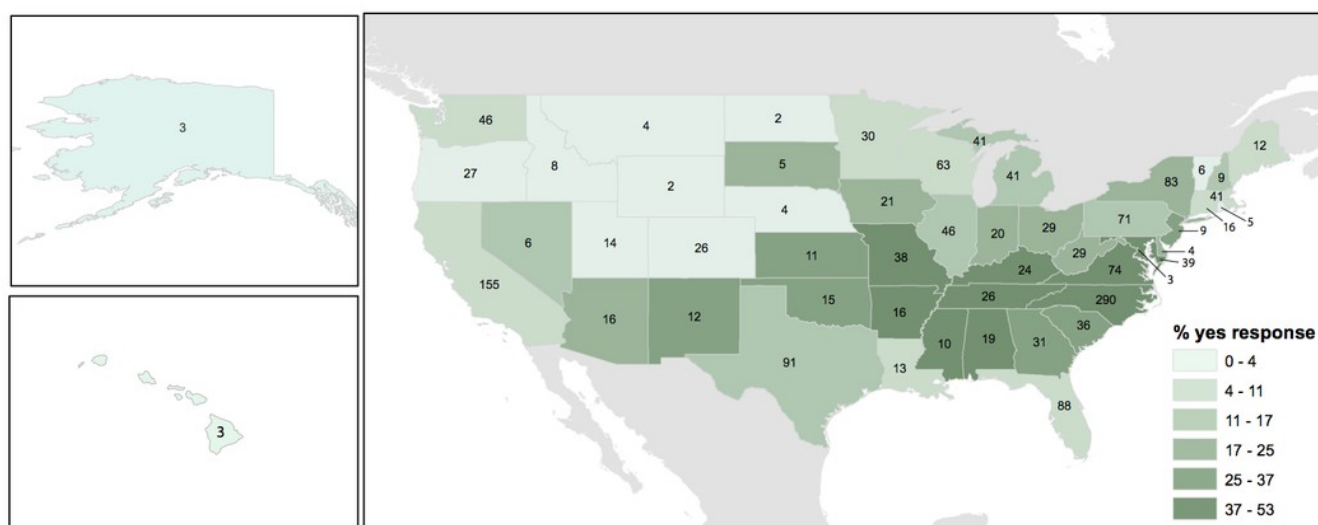



Figure 2

Survey responses showing presence or absence of camel crickets in homes

Map of combined responses to the open survey question and the Wild Life of Our Homes survey question asking citizens if they have observed camel crickets in their houses. Blue points represent positive reports of camel crickets found in homes ($N = 669$), whereas red points indicate households where camel crickets have not been knowingly observed ($N = 1,598$).

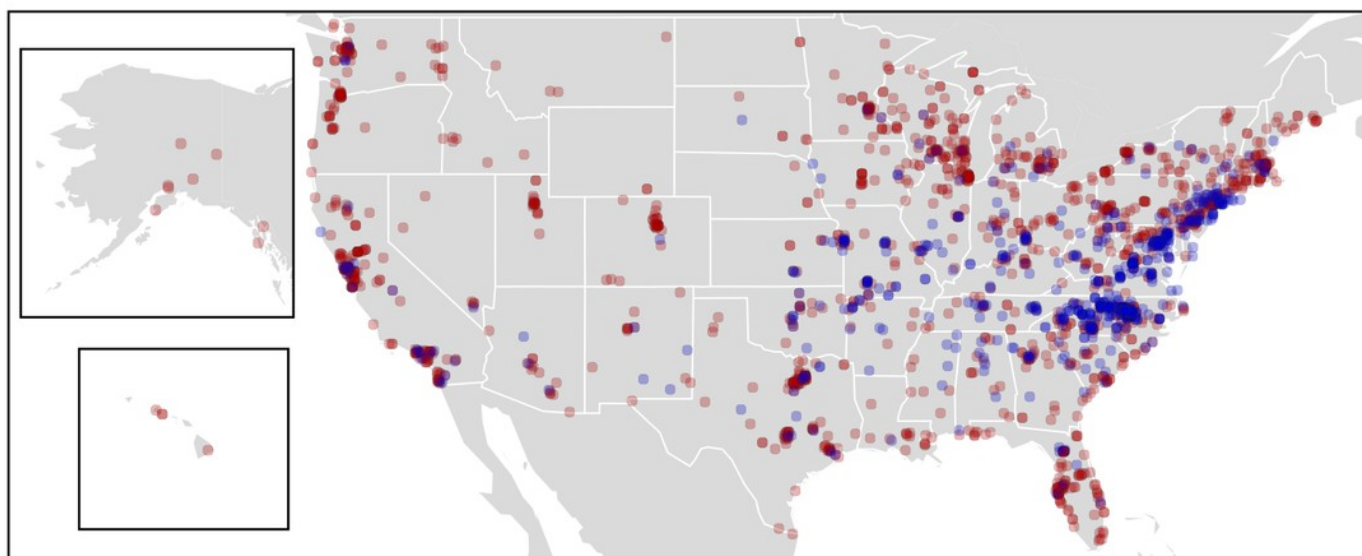



Figure 3

Distribution of *Ceuthophilus* and *Diestrammena* in homes

The distribution of native *Ceuthophilus* spp. (black circles; *N* = 20) versus exotic

Diestrammena spp. camel crickets (white points; *N* = 143) in homes, based on photographic

and specimen submissions contributed by citizen scientists.

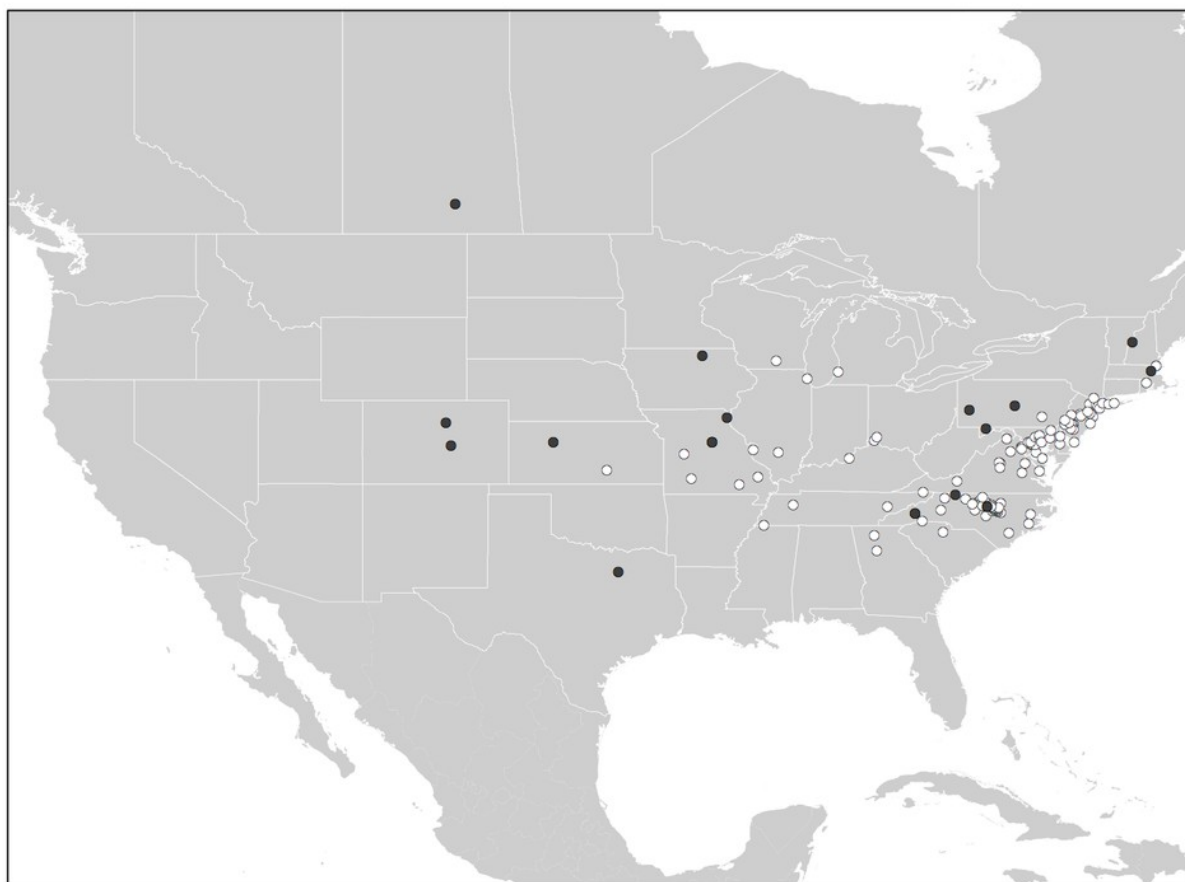



Figure 4

Images of *Diestrammena asynamora* and putative *D. japanica*.

Photographs of the two species of *Diestrammena* submitted by citizen scientists, showing (a) *D. asynamora* (Andrew Blanchard, Creative Commons Attribution License 2014) and (b) putative *D. japanica* (Kathryn Kinney, Creative Commons Attribution License 2014).

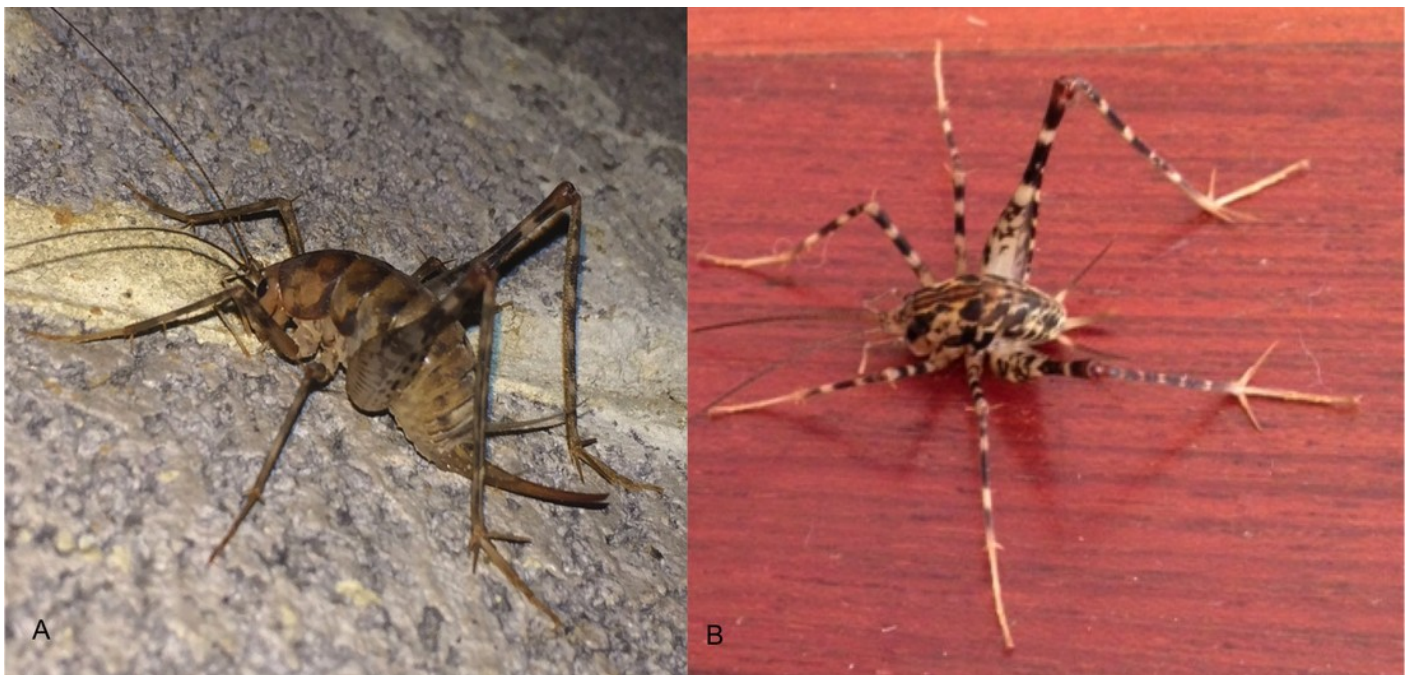



Figure 5

Distribution of *Diestrammena* species in American houses.

The relative distribution of the two *Diestrammena* species reported from houses in the United States, as indicated by photographs and/or specimens from citizen scientists. Records of *D. asynamora* (*N* = 101) are indicated in grey, *D. japanica* (*N* = 7) in white.

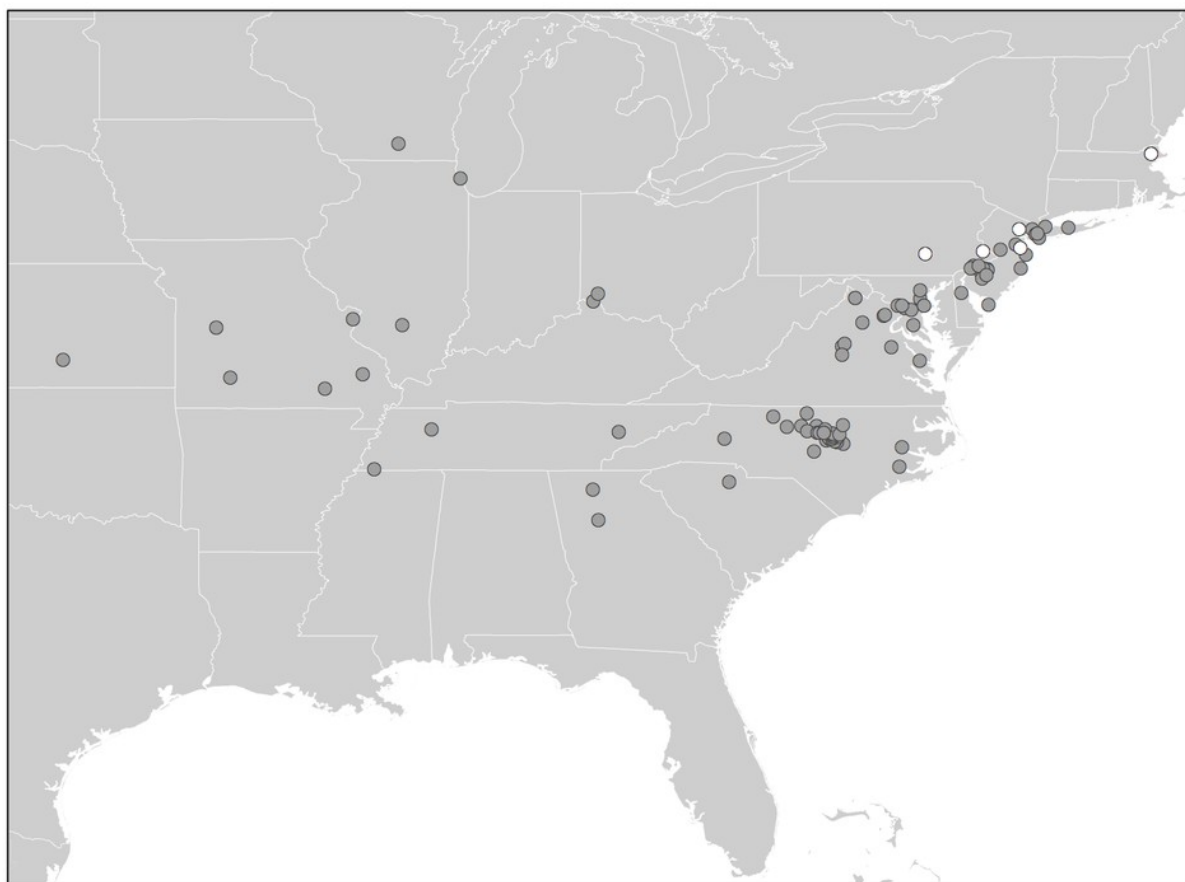
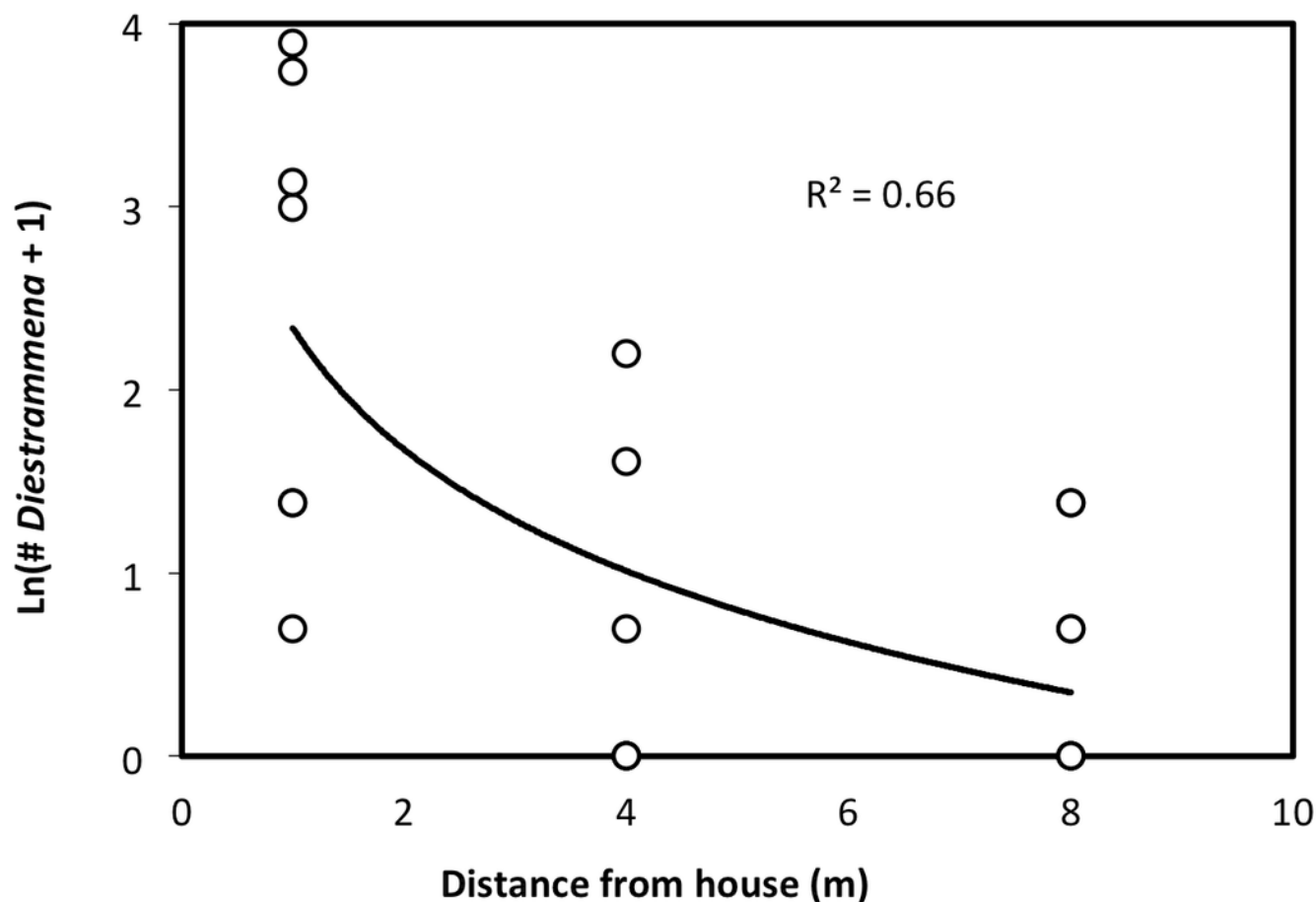



Figure 6

The number of D. asynamora crickets in yard traps as a function of the distance from a house.

The number of *D. asynamora* individuals recovered from a pitfall trap was negatively correlated with the distance of a trap from a house (R^2 = 0.66, *P* = 0.004 from ANCOVA, after accounting for individual yard effect). Each dot represents a single pitfall trap (*N* = 21, with three traps placed in each of seven yards).

Number of houses with camel crickets by state

Results of citizen-contributed photographic or specimen submissions showing the relative number of households with the Asian *Diestrammena* versus native *Ceuthophilus* samples by state or Canadian province. Two houses in North Carolina each contributed specimens of both genera. The subset of households submitting photographs and/or specimens of *Diestrammena* that could be determined to species are further distinguished to show the relative number and distribution of records for *D. asynamora* versus putative *D. japanica*.

State or province	Total responses	# Houses with *Ceuthophilus*	# Houses with *D. asynamora*	# Houses with *D. japanica*	# Houses with *Diestrammena* sp. (unidentified)
Colorado	2	2	0	0	0
Delaware	2	0	1	0	1
Georgia	2	0	2	0	0
Iowa	1	1	0	0	0
Illinois	2	0	2	0	0
Kansas	2	1	1	0	0
Kentucky	1	0	0	0	1
Massachusetts	3	1	0	2	0
Maryland	17	1	10	0	6
Michigan	1	0	0	0	1
Missouri	9	4	5	0	0
North Carolina	60	5	41	0	14
New Hampshire	1	1	0	0	0
New Jersey	16	0	12	2	2
New York	9	0	7	0	2
Ohio	2	0	2	0	0
Pennsylvania	10	2	4	2	2
Saskatchewan	1	1	0	0	0
South Carolina	1	0	1	0	0
Tennessee	3	0	3	0	0
Texas	1	1	0	0	0
Virginia	15	0	10	0	5
Wisconsin	1	0	1	0	0
District of Columbia	1	0	0	0	1
Total records	163	20	102	6	35