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INDOOR ARTHROPOD COMMUNITIES AND DISTRIBUTIONS IN U.S. HOMES

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Abstract By furthering our understanding of biodiversity in urban landscapes, we can advance our understanding of urban pests. We investigated the complete arthropod community of the indoor biome in 50 houses (located in and around Raleigh, North Carolina, USA). We discovered high diversity, with a conservative estimate range of 32 to 211 morphospecies, and 24 to 128 distinct arthropod families per house. However, the majority of these arthropods are not considered urban pests. We found arthropods within homes are both diverse and prevalent, and are a mix of closely synanthropic species and a great diversity of species that enter homes accidentally. Despite being found in the majority of homes, several arthropod groups such as gall midges (Cecidomyiidae) and book lice (Liposcelididae) remain unfamiliar to the general public. The diversity of arthropods was non-random with respect to location within the house; for instance, certain families, such as camel crickets (Rhaphidophoridae) and isopods (Armadillidiidae) were particularly abundant in basements. On a landscape scale, the indoor arthropod community conformed to the "luxury effect," with houses located in higher income neighborhoods having higher arthropod richness, even when accounting for house size and local vegetation. These findings present a new understanding of the diversity, prevalence, and distribution of the arthropods in our daily lives.

Key words Landscape ecology, biodiversity, urban ecology.

INTRODUCTION

Humans have lived with animal associates (both invited and uninvited) for thousands of years. The most diverse group of organisms on Earth is made up of arthropods (insects, arachnids, myriapods, crustaceans, etc.), and while many species are known to live closely with humans (Robinson, 2005), very few studies have assessed the entire community of arthropods that dwell with people, except for a few noteworthy pest species. To better understand the diversity of arthropods found in homes we comprehensively sampled specimens from houses located in and around Raleigh, NC, USA. We identified the types of arthropods and where they were found in homes, using these data to describe what arthropod diversity in houses look like and other aspects of the indoor arthropod community.

MATERIALS AND METHODS

Full methods (including a map of the study area) for this study can be found in Bertone et al. (2016) and Leong et al. (2016). Briefly, 50 free-standing, volunteer homes were randomly selected in and around Raleigh, NC, USA. Trained entomologists visited these homes and hand-collected all arthropods, living and dead, from all visible surfaces of all rooms. Only attics and crawl spaces were sampled less thoroughly, for safety reasons. All specimens were collected into vials of ethanol each labeled according to house, room type and other characteristics (floor type; windows and doors to the outside). Specimens were identified by MAB and KMB as specifically as possible, with arthropod family as the major taxonomic unit. In each group, the number of morphospecies (i.e. those that appeared to be different species) was also documented per room. Some difficult to identify groups (based on current knowledge) and/or specimens (due to physical damage precluding identification) were identified to the most specific taxon possible. We classified rooms into six categories based on their similarities: attics, basements (including finished and unfinished basements, and crawl spaces), bathrooms (including bathrooms and laundry rooms), bedrooms (including bedrooms, offices, and libraries), common rooms (including living rooms, dining rooms, and attached hallways), and kitchens (including kitchens and pantries); rooms not conforming to one of the categories were classified as "other" and were excluded from analysis. We estimated diversity of families based on the complete list of families acquired over each sampled house using the Chao2 Estimator with 1,000 randomization runs in EstimateS (Colwell, 2013). For analyses related to neighborhood income and arthropod diversity, see Leong et al. 2016.

RESULTS AND DISCUSSION

Overall Metrics

Houses in the study ranged from 840 to 4,833 square feet in area (mean = 2,072; median = 1,720) and were from seven to 94 years old (mean = 41.35; median = 30.5). During the course of sampling 554 rooms in the 50 homes, over 10,000 specimens were collected and identified. These specimens represented all four subphyla (Chelicerata, Myriapoda, Crustacea, and Hexapoda), as well as six classes, 34 orders and 304 families of arthropods (for a complete list of taxa see Tables 1 and S1 in Bertone et al. 2016). While we could not determine the exact number of morphospecies, there were at least 579 morphospecies based on our most conservative estimates (calculated by summing the maximum number of morphospecies for each family ever found in a single room).

We collected 24–128 families from each house, resulting in an average of 61.84 (s.d. = 23.24) distinct arthropod families per house and a total gamma diversity (across houses) of 304 families (Figure 1A). One hundred and forty-nine (149) families were rare, collected from fewer than 10% of homes, 66 of which were found in just a single home. The number of families collected in a home was correlated with house size ($r2 = 0.3$, $p = < 0.001$). Conservative species estimates by home ranged from 32 to 211, with an average of 93.14 (s.d. = 42.34) morphospecies per house (Figure 1B). Our conservative species estimate assumes that rooms with the greatest number of morphospecies by family included all species from other rooms (which is almost certainly untrue), thus this number is likely much lower than the true number of species per house.

Taxon Specific Observations

While overall diversity was high, 12 frequently found families were identified in at least 80% of homes (Figure 4 in Bertone et al. 2016). Four families were identified from 100% of houses sampled: cobweb spiders (Theridiidae), carpet beetles (Dermestidae), gall midge flies (Cecidomyiidae) and ants (Formicidae). Book lice (Liposcelididae) and dark-winged fungus gnats (Sciaridae) were found in 98% and 96% of homes, respectively. Nearly half of all families (five of 12) found in over 80% of homes were true flies (Diptera): fungus gnats (Sciaridae); mosquitoes (Culicidae); scuttle flies (Phoridae); non-biting midges (Chironomidae); and gall midges (Cecidomyiidae).

Typical household pests were found in a minority of the homes, such as German cockroaches (*Blattella germanica*: 6% of houses), subterranean termites (Rhinotermitidae: 28% of houses), and fleas (Pulicidae: 10% of houses); bed bugs (*Cimex lectularius*) were not found during the study. Larger cockroaches (Blattidae), such as smoky brown (*Periplaneta fuliginosa*) and American cockroaches (*Periplaneta americana*) were found in the majority of houses (74%). However, the American cockroach (which is the species considered a true pest) was only recovered from three homes; smoky brown cockroaches made up the vast majority of large cockroaches collected. All pest species were less common than other more inconspicuous arthropods such as pillbugs (Armadillidiidae, 78%) and springtails (Entomobryidae, 78%). In addition to those listed above, many of the same pests we recovered were also found in archaeological sites (see discussion in Bertone et al. (2016).

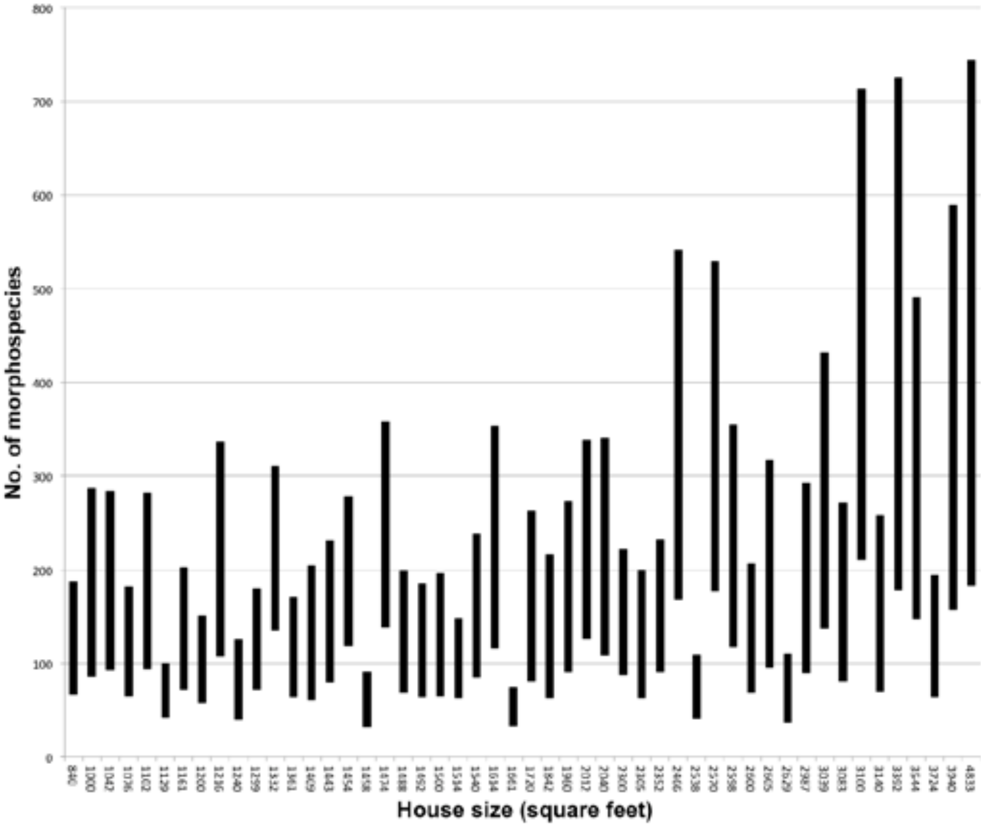

Figure 1 A. Number of morphospecies collected from homes ranked by house size. The bottom limit is the minimum or conservative estimate of morphospecies by house which was calculated by taking the maximum number of morphospecies from the room containing the highest number of morphospecies, for each family, and summing the total The upper limit is the maximum possible of morphospecies within a house, with the assumption that each set of morphospecies within each room were unique from other rooms.

Arthropod Distribution within the Home

Arthropods were found on every level of the home and in all room types. Only 5 rooms (non-attics) had no arthropod specimens collected (four bathrooms, one bedroom). Six arthropod orders dominated houses, comprising 81% of the diversity in an average room: Diptera (true flies, 23%), Coleoptera (beetles, 19%), Araneae (spiders, 16%), Hymenoptera (predominantly ants, 15%), Psocodea (book lice, 4%), and Hemiptera (true bugs, 4%) (Figure 2). Eight additional orders made up another 15% of the diversity (Blattodea, Collembola, Lepidoptera, Isopoda, Zygentoma, Polydesmida, Orthoptera, and Acari), while all remaining orders comprised a total of 4% of the overall diversity (Figure 2). The percentage of rooms in which an arthropod was collected varied among taxa, as did their presence in rooms of different types (Table 1 in Bertone et al., 2016).

We found that although many groups were common throughout a home, some were more restricted to certain room types than others. After ranking the prevalence of different families by room type, many common groups change rank drastically between rooms. Isopods (Armadillidiidae) and camel crickets (Rhaphidophoridae) ranked as commonly found in basements, but did not make it into the top ten (or even top 20 in most cases) for any other room type. This is expected, as these arthropods are typically limited to dark, damp environments not usually found homes except in basements.

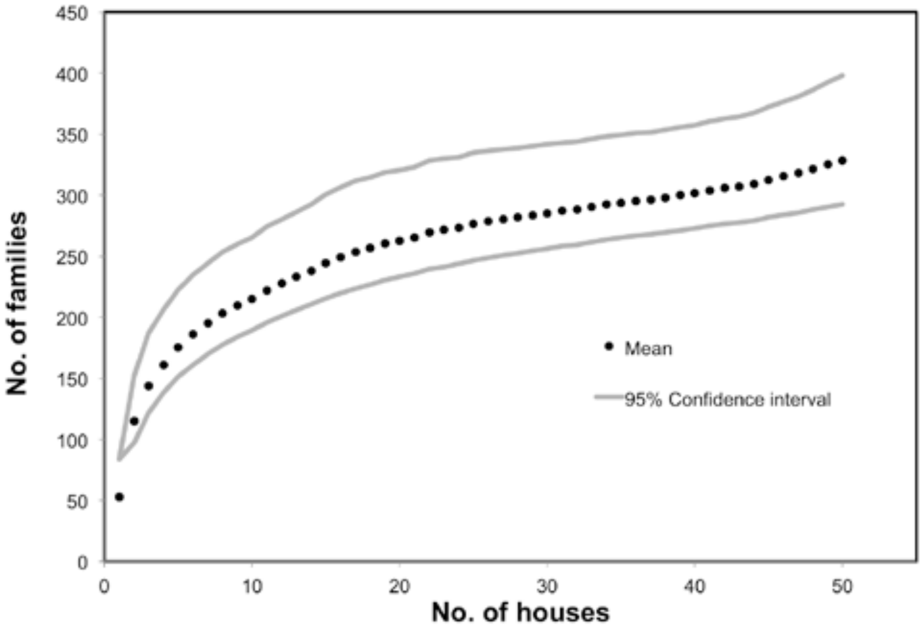

Figure 1B. Estimated diversity of families. The mean, along with 95% lower and upper confidence intervals, was calculated based on the complete list of families acquired over each sampled house using the Chao2 Estimator with 1,000 randomization runs in EstimateS (from Bertone et al., 2016).

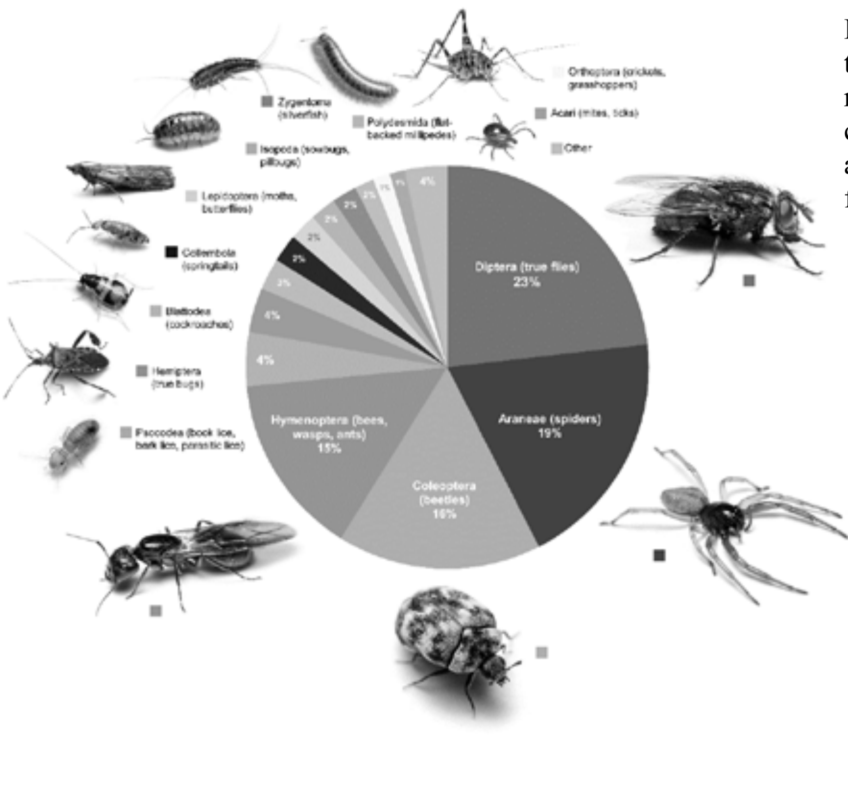

Figure 2. Proportional diversity of arthropod orders across all rooms. Average morphospecies composition calculated across all room types. Photos modified from Bertone et al., 2016.

Arthropods and the Luxury Effect

The "luxury effect," in which wealthier neighborhoods are more biologically diverse, has been observed for both plants and animals including birds (Luck et al., 2013), lizards (Ackley et al., 2015), and bats (Li and Wilkins, 2014). However, where indoor environments are concerned, there is a general perception that homes in poorer neighborhoods harbor more indoor arthropods (Cohn et al., 2016; Wang et al., 2007).

After model testing, we found that indoor arthropod diversity was best predicted by models that take into consideration not only house square footage, local ground vegetation cover and diversity, but also mean neighborhood income. To better understand the impact of vegetation on indoor arthropod diversity, we further explored the interactions between income and our house-level vegetation variables. The interaction term revealed that for houses whose yards have limited ground vegetation cover, being located in a higher income neighborhood had a strong positive effect on indoor arthropod diversity (Figure 3). Yet for houses that have yards with high ground vegetation cover, neighborhood income did not influence indoor arthropod diversity. We suspect that in higher income neighborhoods, enhancements at the neighborhood scale (including higher vegetation overall, as found in Hope et al., 2003; Kinzig et al., 2005; Grove et al., 2006; Clarke et al., 2013) can compensate for limited vegetation in the yard of an individual house. Thus, simply being located in a higher income neighborhood may provide ecological benefits to outdoor and indoor biodiversity. This suggests that vegetation at the scale of neighborhoods can be predictive of indoor arthropod diversity at the scale of individual houses. It matters, in short, not only how much vegetation you have in your yard, but how much is present in the yards and other habitats nearby (Goddard, 2010).

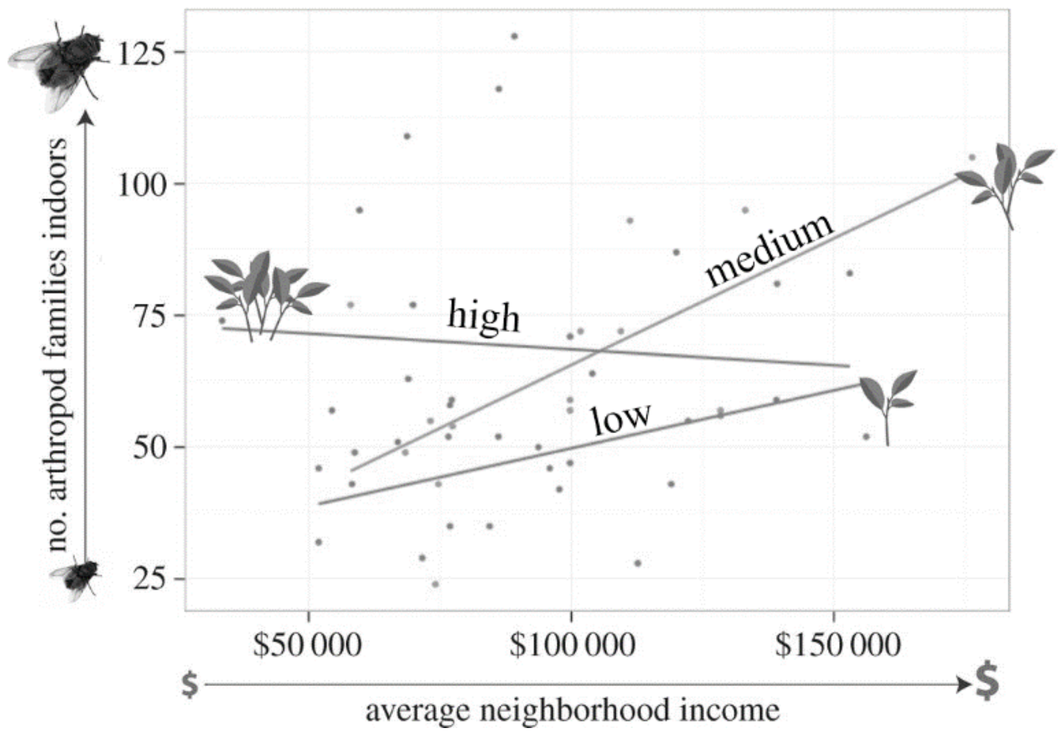

Figure 3. Interaction plot. For houses with low and medium levels of vegetative ground cover, neighbourhood income had a strong influence on number of arthropod families. (modified from Leong et al. 2016)

CONCLUSIONS

Our results show indoor communities of arthropods in the Southeastern U.S. are a mixture of both synanthropic species (i.e. those that rely on human dwellings for shelter and breeding sites) and accidental visitors from the outdoors that become trapped inside. We also found the majority of arthropods in homes are not typical pest species, though pests were collected. Although almost all parts of a home can be occupied by arthropods, some arthropods are associated with certain room types more than others. Lastly, houses in neighborhoods with higher income appear to have more diversity of arthropods entering homes.

REFERENCES CITED

Ackley, J.W., J. Wu, M.J. Angilletta Jr., S.W. Myint, and B. Sullivan. 2015. Rich lizards: How affluence and land cover influence the diversity and abundance of desert reptiles persisting in an urban landscape. Biol. Conserv. 182, 87–92. doi:10.1016/j.biocon.2014.11.009

Bertone, M.A., M. Leong, K.M. Bayless, T.L.F. Malow, R.R. Dunn, and M.D. Trautwein. 2016. Arthropods of the great indoors: characterizing diversity inside urban and suburban homes. PeerJ 4:e1582 https://doi.org/10.7717/peerj.1582

Clarke, L.W., G.D. Jenerette, and A. Davila. 2013. The luxury of vegetation and the legacy of tree biodiversity in Los Angeles, CA. Landsc. Urban Plan. 116, 48–59. doi:10.1016/j.landurbplan.2013.04.006

Cohn, R.D., S.J. Arbes, R. Jaramillo, L.H. Reid, and D.C. Zeldin. 2006. National prevalence and exposure risk for cockroach allergen in U.S. households. Environ. Health Perspect. 114, 522–526.

Colwell, R.K. 2013. EstimateS: statistical estimation of species richness and shares species from samples. Version 9. User's Guide and application. Available at http://purl.oclc.org/estimates

Goddard, M. A., A.J. Dougill, and T.G. Benton. 2010. Scaling up from gardens: biodiversity conservation in urban environments. Trends Ecol. Evol. 25, 90–98. doi:10.1016/j.tree.2009.07.016

Grove, J.M., A.R. Troy, J.P.M. O'Neil-Dunne Jr., W.R. Burch, M.L. Cadenasso, and S.T.A. Pickett. 2006. Characterization of Households and its Implications for the Vegetation of Urban Ecosystems. Ecosystems 9, 578–597. doi:10.1007/s10021-006-0116-z

Hope, D., C. Gries, W.X. Zhu, W.F. Fagan, C.L. Redman, N.B. Grimm, A.L. Nelson, C. Martin, and A. Kinzig. 2003. Socioeconomics drive urban plant diversity. Proc. Natl. Acad. Sci. U. S. A. 100, 8788–8792. doi:10.1073/pnas.1537557100

Kinzig, A.P., P. Warren, C. Martin, D. Hope, and M. Katti. 2005. The effects of human socioeconomic status and cultural characteristics on urban patterns of biodiversity. Ecol. Soc. 10, 23.

Leong, M., M.A. Bertone, K.M. Bayless, R.R. Dunn, and M.D. Trautwein. 2016. Exoskeletons and economics: indoor arthropod diversity increases in affluent neighbourhoods. Biol. Lett. 2016 12 20160322; DOI: 10.1098/rsbl.2016.0322. Published 2 August 2016.

Li, H. and K.T. Wilkins. 2014. Patch or mosaic: bat activity responds to fine-scale urban heterogeneity in a medium-sized city in the United States. Urban Ecosyst. 17, 1013–1031. (doi:10.1007/s11252-014-0369-9)

Luck, G.W., L.T. Smallbone, and K.J. Sheffield. 2013. Environmental and socio-economic factors related to urban bird communities. *Austral Ecol.* 38, 111–120. doi:10.1111/j.1442-9993.2012.02383.x

Robinson, W.H. 2005. Urban insects and arachnids: A handbook of urban entomology. Cambridge: Cambridge University Press.

Wang, C., M.M.A. El-Nour, and G.W. Bennett. 2007. Survey of Pest Infestation, Asthma, and Allergy in Low-income Housing. J. Community Health 33, 31–39. doi:10.1007/s10900-007-9064-6