Zoosymposia 12: 064–068 (2018)
http://www.mapress.com/j/zs/

ISSN 1178-9905 (print edition)
ZOOSYMPOSIA
ISSN 1178-9913 (online edition)

http://dx.doi.org/10.11646/zoosymposia.12.1.7
http://zoobank.org/urn:lsid:zoobank.org:pub:E9BB4BBD-0E89-4995-A293-B74E5A5A3E7F

The Exoskeletons in our Closets: A synthesis of research from the 'Arthropods of our Homes' project in Raleigh, NC.

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INTRODUCTION

The history of people living with insects, spiders and their relatives is long, probably as long as humans have been using fixed domiciles (e.g., caves). Studies of caves inhabited by prehistoric people 26,000 years ago suggest arthropod pests already lived alongside our ancestors in those caves (Araújo *et al.* 2009). Arthropods are also both abundant and diverse in domestic archaeological sites from agricultural civilizations in Egypt, Israel and Europe (Switzerland and Greenland). Arthropods are especially common in association with stored food products and livestock (Panagiotakopulu 2001; Overgaard Nielsen, Mahler, and Rasmussen 2000; Kislev, Hartmann, and Galili 2004).

The nature of the relationship between humans and their domestic arthropod associates is varied. Many arthropods in homes are pests that reduce the quality of life of a home's residents (Robinson 2005). Some eat our food or search for water, including stored product pests, and 'countertop' pests such as ants and cockroaches. Other arthropods feed on our textiles (carpet beetles and clothes moths) or the home structure itself (some beetles and termites). The most concerning are those of medical and veterinary importance, such as allergen producers (cockroaches and dust mites) and blood-feeders (mosquitoes, fleas, bed bugs, mites & ticks, etc.). Other arthropods decrease well-being through their effects on the emotional or psychological status of human inhabitants, an effect obviously heavily contingent on culture (and at odds, one suspects, with the psychological effect of the same arthropods on entomologists). While pests are the household arthropods most often studied, not all species of arthropods found in homes fit this description, and many either go unnoticed or are in fact beneficial to us. Very few, if any, studies have addressed the complete arthropod fauna of modern homes.

We investigated the full diversity of arthropods from a variety of free-standing houses located in the North Carolina Piedmont region, specifically Raleigh and surrounding areas. The goals of this research were aimed at discovering the indoor arthropod community, and explaining the physical house attributes, landscape contexts, and behaviors of residents that most affect the community of arthropods that reside with humans.

STUDY SYSTEM AND METHODS

From May to October 2012, the living and dead indoor arthropod community was sampled in 50 homes in and around Raleigh, NC, USA. All homes included in the study were within a 30-mile radius of Raleigh's center (35.7719° N, 78.6389° W) in order to focus on local variables of interest (such as house design and urban vegetation) while holding large-scale differences in species pools relatively constant. This region, located in the Southeastern United States, is located in the Piedmont of North Carolina and characterized by red clay soils and deciduous/pine forests (with meadows and aquatic/semi-aquatic systems interspersed). We solicited volunteers owning or renting free-standing homes in Raleigh and neighboring areas of North Carolina, USA,

Accepted by Brian Brown: 16 Jan. 2018; published: 26 Mar. 2018

and selected 50 homes to visit to capture the diversity among participants who filled out an online questionnaire about the characteristics of their household and behavior of its residents.

Trained entomologists visited these homes and hand-collected all arthropods, living and dead, from all visible surfaces of all rooms. All specimens were collected room-by-room into vials of 95% ethanol. Data on room type, floor surface type, and numbers of windows and doors leading to the outside were recorded for each sampling event. 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.

Besides these directly collected data within the home, we combined our Raleigh arthropod dataset with several biological, geophysical, and socioeconomic variables at local and landscape scales that we hypothesized could influence indoor arthropod diversity. Further methodology details can be found in the sections below and in (Bertone *et al.* 2016; Leong *et al.* 2016, 2017).

MAJOR FINDINGS

There is high arthropod diversity in homes

In 50 homes, we collected over 10,000 arthropod specimens. Collected specimens represented all four subphyla (Chelicerata, Myriapoda, "Crustacea," and Hexapoda), as well as six classes, 34 orders and 304 families of arthropods (Bertone et al 2016). While we cannot determine the exact number of species that were collected, 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 discovered high diversity, with a conservative estimate range of 32 to 211 morphospecies overall and on average 93 mosphospecies found per house. We found that arthropods within homes are both diverse and prevalent, and are a mix of closely synanthropic species and a great diversity of species that wander indoors rarely. A complete list of all collected taxa can be found in (Bertone *et al.* 2016)

The core arthropod community includes many non-pest groups

Frequently cited indoor arthropod pests, such as bed bugs and termites, were not frequently encountered in most homes. The majority of our collected indoor diversity (73%) was made up of true flies (Diptera), spiders (Araneae), beetles (Coleoptera), and wasps and kin (Hymenoptera, especially ants: Formicidae) (Figure 1). 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 arthropod community differs among rooms in houses

We classified rooms based on their usage—as attics, basements, bathrooms, bedrooms, common rooms, and kitchens; rooms not conforming to one of the categories were classified as "other" and were excluded from analysis. The diversity of arthropods was non-random with respect to location within the house; we tended to collect a higher diversity of arthropods from rooms that are more permeable to the outdoors (common rooms, more numbers of windows and doors leading to the outside, and on the ground floor level) (Leong *et al.* 2017). Carpeted rooms also tended to have more arthropod diversity, perhaps due to both providing more refuge for small organisms and because these rooms allowed for more arthropod bodies to accumulate over time (Leong *et al.* 2017). Basement community composition make-up was the most distinct from the rest of the house (Leong *et al.* 2017).

We could not detect any large effects of human resident behavior on indoor arthropod communities

Using variables of pet ownership, pesticide usage, indoor plant maintenance, and household cleanliness, we were unable to detect any major influences on the indoor arthropod community composition.

The neighborhood and landscape context impacts indoor arthropod diversity

The "luxury effect," in which wealthier neighborhoods are more biologically diverse, has been observed for both plants and animals including birds (Luck, Smallbone, and Sheffield 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.* 2006; Wang, El-Nour, and Bennett 2007).

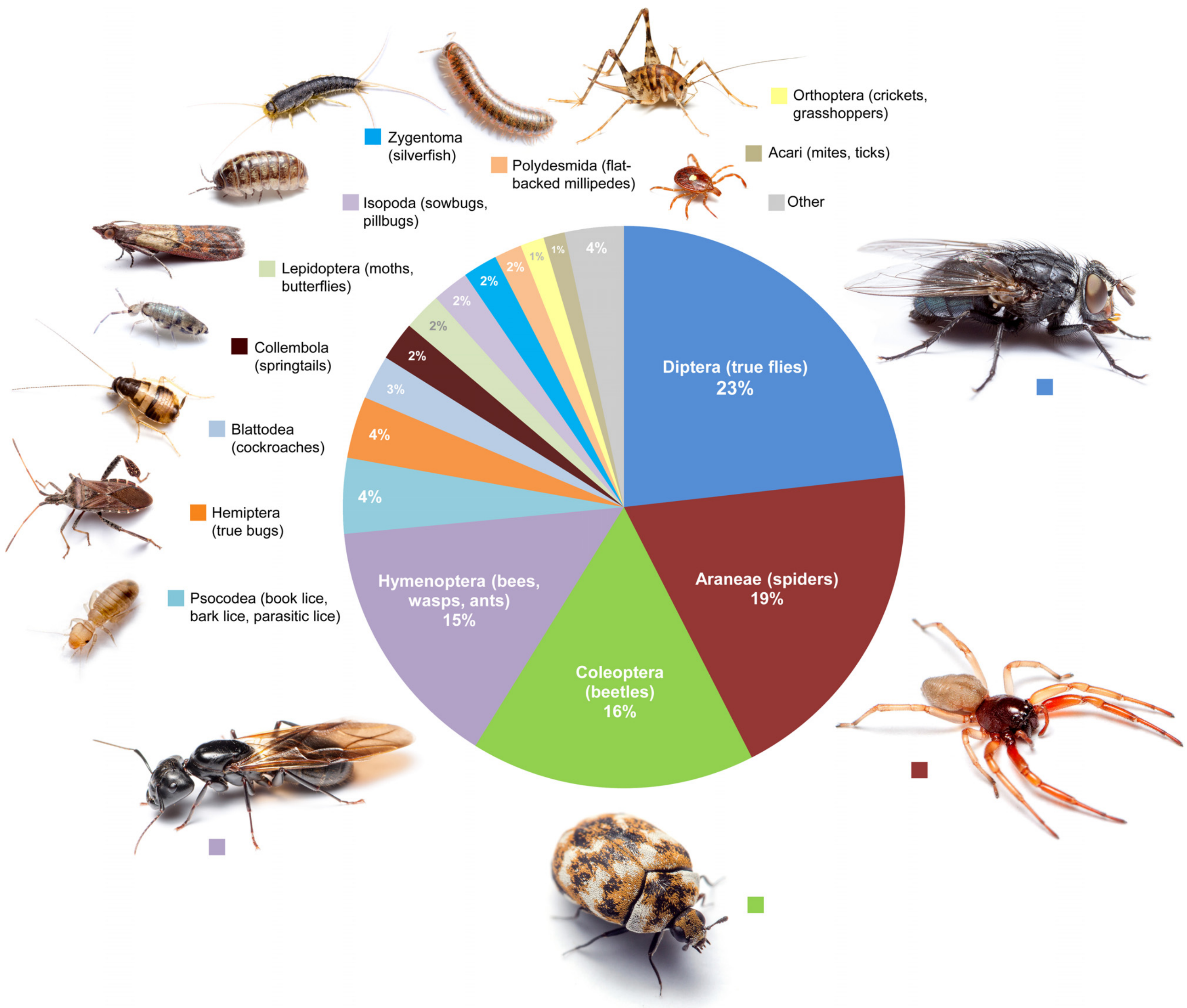

FIGURE 1. Proportional diversity of arthropod orders across all rooms. Average morphospecies composition calculated across all room types. All photos by MAB. (from Bertone *et al.* 2016)

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 (Leong *et al.* 2016). 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 2). 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)) can compensate for limited vegetation in the yard of an individual house.

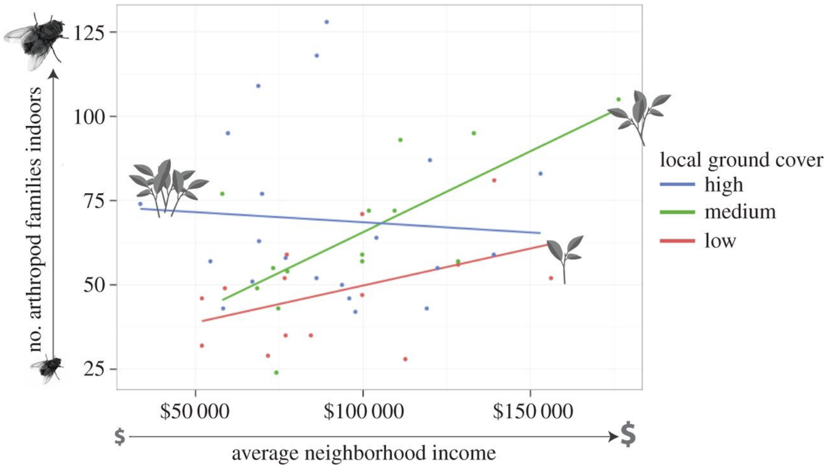

FIGURE 2. Interaction plot. For houses with low and medium levels of vegetative ground cover, neighbourhood income had a strong influence on number of arthropod families. (from Leong *et al.* 2016)

CONCLUSION

For as long as humans have lived in fixed habitations there have been other arthropods that dwell alongside us. While all previous work on indoor arthropods has focused almost exclusively on pests, here we investigated the complete arthropod community of the indoor biome in 50 houses located in and around Raleigh, North Carolina, USA. We discovered not only much higher diversity than expected, but also findings that present a new understanding of the diversity, prevalence, and distribution of the arthropods in our daily lives. Future work could focus more closely on teasing apart specific factors that influence patterns of indoor arthropod community composition, but just as importantly the natural history of the many poorly studies species found inside homes. We aim to expand the geographic range of our home sampling to understand whether the patterns and diversity we observe is consistent across habitats and home types on a global scale.

REFERENCES

Ackley, J.W., Wu, J.G., Michael, J. Angilletta, Jr., Soe, W. M. & Brian, S. (2015) Rich Lizards: How Affluence and Land Cover Influence the Diversity and Abundance of Desert Reptiles Persisting in an Urban Landscape. *Biological Conservation*, 182 (February), 87–92.
https://doi.org/10.1016/j.biocon.2014.11.009

Araújo, A., Ana, M.J., Karl, R. & Luiz, F.F. (2009) Paleoparasitology of Chagas Disease: A Review. *Memórias Do Instituto Oswaldo Cruz*, 104 (July), 9–16.
https://doi.org/10.1590/S0074-02762009000900004

Bertone, M.A., Misha, L., Keith, M.B., Tara, L.F.M., Robert, R.D. & Michelle, D.T. (2016) Arthropods of the Great Indoors: Characterizing Diversity inside Urban and Suburban Homes. *PeerJ*, 4 (January), e1582.
https://doi.org/10.7717/peerj.1582

Cohn, R.D., Samuel, J.A., Renee, J., Reid, L.H. & Zeldin, D.C. (2006) National Prevalence and Exposure Risk for Cockroach Allergen in U.S. Households. *Environmental Health Perspectives*, 114 (4), 522–526.
https://doi.org/10.1289/ehp.8561

Hope, D., Gries, C., Zhu, W.X., Fagan, W.F., Redman, C.L., Grimm, N.B., Nelson, A.L., Martin, C. & Kinzig, A. (2003) Socioeconomics Drive Urban Plant Diversity. *Proceedings of the National Academy of Sciences of the United States of America*, 100 (15), 8788–8792.
https://doi.org/10.1073/pnas.1537557100

Kinzig, A.P., Warren, P., Martin, C., Hope, D. & Katti, M. (2005) The Effects of Human Socioeconomic Status and Cultural Characteristics on Urban Patterns of Biodiversity. *Ecology and Society,* 10 (1), 23.
https://doi.org/10.5751/ES-01264-100123

Kislev, M.E, Hartmann, A. & Galili, E. (2004) Archaeobotanical and Archaeoentomological Evidence from a Well at Atlit-Yam Indicates Colder, More Humid Climate on the Israeli Coast during the PPNC Period. *Journal of Archaeological Science*, 31 (9), 1301–1310.
https://doi.org/10.1016/j.jas.2004.02.010

Han, L. & Wilkins, K.T. (2014) Patch or Mosaic: Bat Activity Responds to Fine-Scale Urban Heterogeneity in a Medium-Sized City in the United States. *Urban Ecosystems*, 17 (4), 1013–1031.
https://doi.org/10.1007/s11252-014-0369-9

Leong, M., Bertone, M.A., Bayless, K.M., Dunn, R.R. & Trautwein, M.D. (2016) Exoskeletons and Economics: Indoor Arthropod Diversity Increases in Affluent Neighbourhoods. *Biology Letters*, 12 (8), 20160322.
https://doi.org/10.1098/rsbl.2016.0322

Leong, M., Bertone, M.A., Savage, A.M., Bayless, K.M., Dunn, R.R. & Trautwein, M.D. (2017) The Habitats Humans Provide: Factors Affecting the Diversity and Composition of Arthropods in Houses. *Scientific Reports,* 7 (1), 15347.
https://doi.org/10.1038/s41598-017-15584-2

Luck, G.W., Smallbone, L.T. & Sheffield, K.J. (2013) Environmental and Socio-Economic Factors Related to Urban Bird Communities." *Austral Ecology*, 38 (1), 111–120.
https://doi.org/10.1111/j.1442-9993.2012.02383.x

Overgaard, N.B., Mahler, V. & Rasmussen, P. (2000) An Arthropod Assemblage and the Ecological Conditions in a Byre at the Neolithic Settlement of Weier, Switzerland. *Journal of Archaeological Science,* 27 (3), 209–218.
https://doi.org/10.1006/jasc.1999.0448

Panagiotakopulu, E. (2001) New Records for Ancient Pests: Archaeoentomology in Egypt. *Journal of Archaeological Science,* 28 (11), 1235–1246.
https://doi.org/10.1006/jasc.2001.0697

Robinson, W.H. (2005) *Urban Insects and Arachnids: A Handbook of Urban Entomology*. Cambridge University Press.
https://doi.org/10.1017/CBO9780511542718

Wang, C.L., El-Nour, M.M.A. & Bennett, G.W. (2007) Survey of Pest Infestation, Asthma, and Allergy in Low-Income Housing. *Journal of Community Health,* 33 (1), 31–39.
https://doi.org/10.1007/s10900-007-9064-6