Available online at www.sciencedirect.com
ScienceDirect
Current Opinion in Insect Science

Democratizing evolutionary biology, lessons from insects

Robert R Dunn[1,2] and DeAnna E Beasley[3]

The engagement of the public in the scientific process is an old practice. Yet with recent advances in technology, the role of the citizen scientist in studying evolutionary processes has increased. Insects provide ideal models for understanding these evolutionary processes at large scales. This review highlights how insect-based citizen science has led to the expansion of specimen collections and reframed research questions in light of new observations and unexpected discoveries. Given the rapid expansion of human-modified (and inhabited) environments, the degree to which the public can participate in insect-based citizen science will allow us to track and monitor evolutionary trends at a global scale.

Addresses
[1] Department of Applied Ecology, North Carolina State University, Raleigh, NC 27695-7617, USA
[2] Center for Macroecology, Evolution and Climate, Natural History Museum of Denmark, University of Copenhagen, DK-2100 Copenhagen, Denmark
[3] Department of Biology, Geology and Environmental Science, University of Tennessee at Chattanooga, Chattanooga, TN, 37403, USA

Corresponding author: Dunn, Robert R (rrdunn@ncsu.edu)

Current Opinion in Insect Science 2016, **18**:89–92

This review comes from a themed issue on **Insect phylogenetics**

Edited by **Gregory W Courtney** and **Brian M Wiegmann**

For a complete overview see the Issue and the Editorial

Available online 18th October 2016

http://dx.doi.org/10.1016/j.cois.2016.10.005

Introduction

In the future citizen science is likely to play a much larger role in evolutionary biology than it does today. It must if we are to accelerate the pace of discovery (relative, of course, to the pace of extinction). It must too if we are to improve the education of the general public about evolution and all of the decisions each person makes with evolutionary consequences.

The idea of engaging the public in the scientific process in general, and evolutionary biology in particular, is ancient. Such efforts are now often described as citizen science (though the use of this term has varied through time as it does today among scientific and regional cultures). Two phenomena related to citizen science are, however, relatively new. One is the extent to which our modern challenges in education and global change increasingly require understanding large-scale phenomena (e.g., shifts in the distribution of a species). A second is the extent to which digital technology is making it easier and easier for the public to collect data and otherwise be part of the scientific process. The phone is now a scientific tool with which billions of people can record aspects of their world. Imagine a world in which just as many people have hand held devices (it could be their phones) with which to sample and study DNA from around where they live. Efforts to leverage these transitions are nascent in evolutionary biology and yet an indication of what the future can hold, particularly with regard to the study of insects.

Insects provide more opportunities for the citizen scientist than perhaps any other group of organisms in as much as insects species are, to varying degrees, large enough to be photographed (when compared to bacteria, in any case), legal to collect (in most cases), vastly understudied relative to their diversity, with most species not yet named, and consequential (insects pollinate flowers, turn over soil, vector deadly pathogens and much else). One approach to incorporating insects into citizen science is to study them in much the way as one might study birds through citizen science projects. One takes non-destructive samples of the insects (e.g., through photography), then, through observation after observation, uses those samples to depict the distribution (or even abundance) of a species (or lineage) of interest and, in many cases, how that distribution is shifting. Such work is hugely important and well-developed in large online community efforts such as BugGuide.net and DiscoverLife.org, in which many of the photographic contributions come from citizen scientists [1, 2]. More specifically, citizen scientists have contributed to our understanding of charismatic species such as fireflies (legacy.mos.org/fireflywatch/about_firefly_watch), monarch butterflies [3], cabbage white butterflies (www.pierisproject.org/about.html), ladybugs [4] and periodical cicadas [5].

What makes insects different from birds is that in addition to mysteries as to their shifting distributions there remain fundamental mysteries as to their evolution, life history, natural history and nearly everything else, even for relatively well-studied groups. As a result, there is great potential for engaging the public in the study of insects in ways that are far more comprehensive than has classically been the case for birds. Such intensive studies are possible because insects can often be observed in captivity (or in the wild) throughout their life history stages, because insect specimens can be collected and because collected insect specimens can be studied in more detail. All of these realities are especially interesting in light of the future of systematics. The literature on the modern use of citizen science data is modest and so rather than a classical review we'll now proceed to walk through several case examples that illustrate our main points.

School of Ants

School of Ants was started in 2011 as a means to engage the public in the study of backyard ants [6]. Its initial goals were to document (much as with studies of birds) the distribution of species. It differed though in as much as the focus was on backyards (which bird studies often eschew, in search of the wild) and it required participants to collect specimens and send those specimens to North Carolina State University (or now, North Carolina State University or the University of Florida). Several years into the project, specimens (which taxon-specific sytematists were paid to ID) are now being used to study the evolution of these common species, first the widespread but poorly studied ant *Tetramorium* sp. *E* (http://schoolofants.org/species/119) and more recently the ant *Tapinoma sessile* and *Prenolepis imparis*. The specimens made available through the project allowed for evolutionary studies that would have been difficult or perhaps even impossible. In this case, citizen scientists collected what was most common, which was, in many cases, poorly known and underrepresented in collections. This study system offers a general model that can be used for the study of backyard insects, particularly ubiquitous taxa such as ants. In fact it has been adopted by related projects on ants in Australia, Italy, and now Germany and Denmark.

The School of Ants example is one in which researchers begin with a large insect group and then solicited collections. The data from collections were initially presence/absence data, but because physical samples existed they could be used in subsequent studies. In as much, the School of Ants approach was akin to the traditional work of a museum collection, except in its emphasis on thousands or even tens of thousands of public collectors rather than a smaller number of highly trained amateurs or professionals. But other more direct approaches to involving the public in evolutionary biology also exist.

Camel Cricket Project

In the Camel Cricket Project, efforts began by asking participants to list what they found living with them in their homes (in the most general sense). Participants were then specifically asked about particular taxa (ants, roaches, camel crickets). The first inquiry was open-ended, akin in some ways to an excursion into the field, where observations are being noted before any real study is designed. The difference is that the geographic area of the observations is, in this case, North America, though one can conceivably envision the entire world. This first foray revealed that people were finding camel crickets in places where historic records and revisions from decades prior suggested they should not occur. This led to a follow up, a request for photographs of the camel crickets (the default of scientists engaging the public often seems to be distrust public observations and treat unusual observations as errors). The photographs quickly revealed the punch line to the study, namely that the camel crickets in homes were not the native species thought to be present in the genus *Ceuthophilus* but instead TWO introduced Asian species (*Diestrammena asynamora*, *Diestrammena japonica Blatchley*) known to be in the U.S. but not understood to be common in homes [7]. This realization prompted additional follow-ups, a call for specimens (now just of the species of interest, which was made easier since the scientists could provide an online guide to identification) for evolutionary study, and a call for questions about camel crickets. In this case, following the observations of the public led to the evolutionary study of a species that was not even of interest initially.

In the Camel Cricket Project, engaging the public led to the reframing of the scientific question, and it led to larger number of samples being collected than would otherwise be possible, but it also led to something else, a new kind of question, a question that the scientists themselves were ignoring. Again and again in citizen science, the public, when asked their thoughts about a project, asks questions. Sometimes these questions are nuanced. In other cases, as with the camel crickets, they are more direct. Participants in the Camel Cricket Project repeatedly asked, 'What good are camel crickets anyway?'

As scientists, we are trained to reject the idea that species need to have any value other than their intrinsic value. They are good because they exist. Yet, let's reframe the question slightly differently. What if what the public is asking in this case is something more along the lines of, 'given that this species occurs right where I live, it seems as though we ought to at least understand if it might have some value to humanity.' That seems like a fair ask. And so the Camel Cricket team began to consider whether the camel crickets in homes might have value to humans. They zeroed in on the possibility that camel crickets, in consuming diets low in nutritional value, and replete with recalcitrant carbon compounds (such as lignocellulose), might host microorganisms able to digest such compounds. This was of interest in as much as the lignin of lignocellulose is a major waste product of the paper industry. If it is degraded, however, the lignin becomes a potential source of energy. The team, in less than 6 months of studying the camel crickets, doubled the number of kinds of bacteria known on Earth to be able to degrade lignin.

Arachnids

The rarest sort of project that involves both evolutionary research and insects seems to be those that, from the very beginning, seek to study the evolution of a particular group of insects. Here, two examples come from arachnids. In one case, citizen volunteers opportunistically collected specimens of tarantulas (*Aphonopelma* spp.) across the southwestern United States, which researchers used for DNA analysis. The result was a broader understanding of the diversity of a charismatic group [8]. In another case, a team of scholars enlisted teachers and students from North Carolina schools to sample the *Demodex* mites living on teachers and, in some cases, students. In the case of the tarantulas, the model was one in which little data was taken by the participants on exactly where the tarantula was, or its life history. In contrast, in the case of the *Demodex* mites, much of the work went in to characterizing the proportion of participants who were habitat for face mites before studying the evolutionary biology of the mites [9].

Global citizen science and the need for discovery

Looking to the future, the examples of evolutionary studies of insects based on or involving citizen science nearly all focus on species that live near (or even on) humans. On some superficial level, this is a limitation of the approach. If we are to study and classify all of the insects of the world, knowing only those that live with us will show science just part of the big story of life (and miss, all the entomologists reading will be quick to viscerally feel, some of the rarest and most interesting species). This perspective, however, misses a key reality of the world. Insect collections are based, largely, on the efforts of collectors going out to 'wild' or 'natural' places in their regions or, nearly as often, traveling to remote sampling sites in other regions. The idea of 'going to the field' is based on the very idea that one must leave to study interesting life. But if we empower kids and adults around the world to work with professional scientists to do science, we will have the ability to collect and study life wherever people live. A quick inspection of the Earth reveals that people live nearly everywhere. If we leverage the people everywhere on Earth to help to study the life in their backyards we will be able to study millions of species. How would one carry out such an effort in practice? Perhaps the most sensible approach is to imagine hubs in countries around the world, hubs where insects that have been sampled in homes and backyards are sorted and provisionally identified. As sequencing gets cheaper, the first step with each specimen could then be to sequence the specimen (based on a leg, e.g.). Unusual samples could then be studied morphologically in more detail. Such a systematic effort may seem far fetched, but versions of it are already underway among diverse projects on ants. If we were to achieve such an effort, we might have the possibility to engage hundreds of millions of people in real science and, in doing so, to teach science as a process while doing science (imagine a Massive Online Course based on data you have collected in which the resolution to the course is the resolution to the study, or the next step anyway).

Achieving such an effort calls for providing the citizen scientist with tools for studying life and sharing observations with the larger community. Farnsworth et al. (2013) highlights a variety of web-based field guides, stand-alone applications, interactive keys and visual recognition software that allow citizen scientists to do just that [10]. In addition, given the large, crowdsourced data available to researchers, data validation protocols are important for ensuring the data collected is of high quality. This step is important not only for researchers but also for the citizen scientist in ensuring that their efforts are of scientific value. Bonter and Cooper (2012) describe an online data validation protocol in a citizen science tracking bird distribution [11].

But for as much as there is an opportunity to achieving such a global effort, there is a cost to failing to do so. As a scientific community we have proven ourselves totally impotent when it comes to conducting large-scale surveys of the life around us. The first effort to find all of the species in a national park, Guanacaste National Park, stalled. Another similar project, in a much less diverse region, the Great Smoky Mountains National Park, continues on the basis of a diligent but largely volunteer staff. As of today, as far as we are aware, no place on Earth has yet been exhaustively sampled. One exception is the Zurqui All-Diptera Biodiversity Inventory project in Costa Rica where researchers collected and identified a number of fly species new to science [12]. The other is a study of fifty houses in Raleigh and Durham, North Carolina. In the study, Michelle Trautwein and colleagues found more than 2000 insects and other arthropod species and considered themselves likely to find more were sampling to continue [13]. In short, we do not even understand what lives in homes. This is intriguing (and motivating) in the abstract, but it is also a major problem. If we pan back to the global scale, what this humbling state of affairs means is that in homes around the world, one can find tens of thousands, perhaps hundreds of thousands of species, not yet named. Some of those species are unnamed pests, even pests that can kill humans, such as unnamed mosquito species that vector pathogens. We need to study evolutionary biology with the public because it can speed up our discovery, because it enables the public to engage science directly and learn and because the species that the public is most likely to encounter are among those most significant to civilization and yet, nonetheless, still very often poorly known.

Acknowledgements

We thank Lauren Nichols for reviewing an initial draft of the manuscript. The authors were supported by NASA Biodiversity grant (ROSES NNX09AK22G) and National Science Foundation grants (0953390 & 551819-0654) to R.R.D.

References

1. Coyle DR, Pickering J, Dyer KA, Lehman FR, Mohan JE, Gandhi KJ: **Dynamics of an unprecedented outbreak of two native moth species, Cissusa spadix and Phoberia atomaris (Lepidoptera: Noctuidae), on oak trees (Quercus spp.) in the Southeastern United States**. *Am Entomol* 2013, **59**:82-94.
2. Buck JH, Marshall JM: **Hitchhiking as a secondary dispersal pathway for adult emerald ash borer, Agrilus planipennis**. *Michigan Entomol Soc* 2009, **197**.
3. Urquhart FA: **Found at last: the monarch's winter home**. *Natl Geogr Mag* 1976, **150**:161-173.
4. Losey JE, Perlman JE, Hoebeke ER: **Citizen scientist rediscovers rare nine-spotted lady beetle, Coccinella novemnotata, in eastern North America**. *J Insect Conserv* 2007, **11**:415-417.
5. Beasley DE, Benson EP, Welch SM, Reid LS, Mousseau TA: **The use of citizen scientists to record and map 13-year Periodical Cicadas (Hemiptera: Cicadidae: Magicicada) in South Carolina**. *Florida Entomol* 2012, **95**:489-491.
6. Lucky A, Savage AM, Nichols LM, Castracani C, Shell L, Grasso DA, Mori A, Dunn RR: **Ecologists, educators, and writers collaborate with the public to assess backyard diversity in The School of Ants Project**. *Ecosphere* 2014, **5**:art78.
7. Epps MJ, Menninger HL, LaSala N, Dunn RR: **Too big to be noticed: cryptic invasion of Asian camel crickets in North American houses**. *PeerJ* 2014, **2**:e523.
8. Hamilton CA, Hendrixson BE, Bond JE: **Taxonomic revision of the tarantula genus Aphonopelma Pocock, 1901 (Araneae, Mygalomorphae, Theraphosidae) within the United States**. *Zookeys* 2016, **560**:1-340.
9. Thoemmes MS, Fergus DJ, Urban J, Trautwein M, Dunn RR, Findley K, Oh J, Yang J, Conlan S, Deming C *et al.*: **Ubiquity and diversity of human-associated Demodex mites**. *PLOS ONE* 2014, **9**:e106265.
10. Farnsworth EJ, Chu M, Kress WJ, Neill AK, Best JH, Pickering J, Stevenson RD, Courtney GW, Van Dyk JK, Ellison AM: **Next-generation field guides**. *Bioscience* 2013, **63**:891-899.
11. Bonter DN, Cooper CB: **Data validation in citizen science: a case study from Project FeederWatch**. *Front Ecol Environ* 2012, **10**:305-307.
12. Hartop E, Brown B: **The tip of the iceberg: a distinctive new spotted-wing Megaselia species (Diptera: Phoridae) from a tropical cloud forest survey and a new, streamlined method for Megaselia descriptions**. *Biodivers Data J* 2014, **2**:e4093.
13. Bertone MA, Leong M, Bayless KM, Malow TLF, Dunn RR, Trautwein MD: **Arthropods of the great indoors: characterizing diversity inside urban and suburban homes**. *PeerJ* 2016, **4**:e1582.