Decline of amateur Lepidoptera collectors threatens the future of specimen-based research

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Abstract

Amateur butterfly and moth collectors in the United States have procured more Lepidoptera specimens than professional scientists. The advent of large government-supported databasing efforts has made a quantitative examination of the impact of amateur collecting of these insects possible. We reviewed trends in Lepidoptera collecting since 1800, utilizing more than 1 million United States lepidopteran specimens that have been publicly databased. Our findings show a steep rise in the collection of specimens after World War II, followed by a short plateau and sharp decline in the late 1990s. In contrast, the rate of observations submitted to databasing groups dramatically increased around 2005. Declining acquisition of Lepidoptera specimens may compromise critically important testing of contemporary and future ecological, conservationist, and evolutionary hypotheses on a grand scale, particularly given documented declines in insect populations. We suggest that increasing collaboration between professional and community-based scientists could alleviate the decline in amateur-collected specimens.

Insects have been housed in natural history collections dating back to Renaissance cabinets of curiosity. Natural history collections, now often held by academic institutions, are invaluable resources that contain troves of information about species across time and space (Polgar et al. 2013). These specimen-based collections and their associated data provide a record of changes in species range, seasonality, and plasticity of morphological traits. In addition, these collections provide data to guide experimental design in taxonomy, ecology, and for the testing of large-scale hypotheses (e.g. identifying patterns of insect responses to global environmental change) (Prather et al. 2004b, Polgar et al. 2013, Brooks et al. 2017, Malaney and Cook 2018).

Many natural history collections trace their origins and growth to the efforts of amateur naturalists or avocational collectors. These amateurs contributed to scientific endeavors through collecting, observing, and communicating with "professionals" (Vetter 2011). However, the line between the "amateur" and "professional" entomologist has often been blurred. For example, the Lepidopterists' Society was founded with the intention of bringing amateurs and professionals together in their study of butterflies and moths (www.lepsoc.org, accessed 15 September 2020). Although some amateurs devote just as much effort to collecting as professionals, we define professionals as holding positions as university professors or as curatorial staff in an institutional natural history collection.

The contributions of amateur scientists continue to be valuable sources of data in many fields of biological science, including entomology (e.g. Hallmann et al. 2017). Unfortunately, the number of amateurs working and publishing in natural history and insect taxonomy is on the decline, despite the need for their help in documenting and identifying insect species (Hopkins and Freckleton 2002). For example, publications by

British amateur entomologists decreased by ~50% within half a century (Hopkins and Freckleton 2002). For this reason, it is important to evaluate the overall impact of amateur collectors on existing specimen collections.

Lepidoptera (butterflies and moths) are charismatic and popular with the public. For this reason, they have been collected extensively in the United States, particularly by amateurs since the early 1800s. As a result, Lepidoptera specimens are well represented in US collections. Approximately 17 million specimens exist in US collections (Seltmann et al. 2017), which could provide the data needed to address large-scale biological and ecological hypotheses such as those addressing the northward movement of species from the southern US in consideration of climate change (Short et al. 2018, Cobb et al. 2019). In 2016, funding from the National Science Foundation supported LepNet, a major effort among 27 US collections (many with long histories of Lepidoptera collecting) to database and georeference 1.7 million specimens, emphasizing moths over butterflies (Seltmann et al. 2017). Specimens in these collections represent all US states and the 86 lepidopteran families occurring in North America. However, details regarding the number of specimens collected during specific time periods and in individual US states have yet to be examined. As observed in other specimen-level datasets, the spatial and temporal distribution is likely uneven (e.g. Malaney and Cook 2018), and this trend has been noted in global inventories and observation records of lepidopteran species (Girardello et al. 2019). Declines in specimen collecting observed across many taxa in part explain contemporary gaps in collection records and specimen distributions (Gardner et al. 2014). Not widely documented are the professions of collectors who contributed specimens to these collections. Although professional entomologists have made a large impact, amateurs made significant contributions to museum collections and insect systematics (e.g. Alfred Russell Wallace) (Vetter 2011, Hallmann et al. 2017). As such, understanding amateurs' role in documenting lepidopteran diversity is important, especially given shifting attitudes that discourage the collecting of natural history specimens (Minteer et al. 2014). Furthermore, declines in collecting coincide with an increasing trend in butterfly watching. For example, iNaturalist has logged >1.3 million research grade observations since 2011 (www.inaturalist.org, accessed 1 April 2020). Using LepNet-databased specimen and observation records, we review patterns in collected specimens and submitted observations of Lepidoptera in the US since 1800—which includes many of the earliest possible records for the US—by amateurs and professionals. We address potential correlations between patterns of collecting, observing, and collector profession in order to explain trends observed in the data.

Evaluation of the lepidopteran specimen and observational data

Data associated with 1,405,997 Lepidoptera specimens housed in 75 US insect collections were downloaded from the Symbiota Collections of Arthropods Network database (SCAN) (www.SCAN-bugs.org, accessed 16 May 2019). Using the 'tidyverse' R package (R version 3.6.1, tidyverse version 1.3.0), collection data were revised to include only lepidopteran specimens that were collected in the United States between 1800 and 2018 (R Core Team 2019, Wickham et al. 2019). The remaining 1,031,401 specimens were used to determine the number of collection events per year and the collection locality at state level. The number and proportion of specimens for all represented lepidopteran families was also evaluated (table S1). The package 'ggplot2' (version 3.2.2) from the 'tidyverse' suite of R packages was used to generate all graphs (Wickham et al. 2019). A rolling decadal average and standard deviations (also on a rolling decadal basis) for annual collecting events were calculated using the 'TTR' package (version 0.23-4) (Ulrich 2018). The data for states with and without a LepNet institution were compared using a Kruskal-Wallis one-way analysis of variance due to non-normality of the data.

Valid specimen records were again revised to include only records with collector information; the remaining records were sorted by collector name and year and tallied to generate a specimen count per year for each collector. Collectors were identified as professional or amateur by reviewing institutional records of associated collectors and using Google searches of names on the Internet. The top 10% of collectors (1,322)—in terms of specimens collected—were then compared using repeated Mann-Whitney-Wilcoxon tests for each decade between 1925 and 2009 on a sliding window basis using the base statistical package in R. We started this analysis in 1925 to capture any differences between amateurs and professionals over more than 20 years prior to the founding of the Lepidopterists' Society (est. 1947). The top 10% of collectors represented 80.89% of the total number of specimen records. Duplication of collectors (e.g. Mo Nielsen, M. C. Nielsen, Mogens C. Nielsen, etc) was minimized by human review, combining obviously similar names and via Google searches.

We limit our analyses of collector data to the years prior to 2009 because of a potential 10-year lag in the curation of specimens due to insufficient resources for processing; this information is based on discussions with attendees at the Entomological Collections Network 2018 meeting. That is, specimens collected in 2009 are likely to be curated, identified, and available for databasing by 2019. We also acknowledge that there undoubtedly are private Lepidoptera collections that are currently inaccessible and known to only a few professional researchers (C. Grinter, personal communication). While dates and locations of these specimens may fill in data gaps, they are mostly unavailable for research and their inclusion is beyond the scope of this study.

Observational data for Lepidoptera were downloaded from SCAN on 17 August 2019 (1,487,931 records). These records were aggregated from the Moth Observations Database, iNaturalist, BugGuide, LepSnap, the Lepidopterists' Society Season Summaries, PollardBase, SCAN's General Research Observations, and a handful of observations provided to SCAN from personal collections. Using the 'tidyverse' R package (Wickham et al. 2019), the observation data were revised to include only submitted observations of Lepidoptera that occurred in the United States between 1800 and 2018 (831,892 observations).

A patchwork of Lepidoptera specimen data across the US and through time

Given their popularity with the public, Lepidoptera are perhaps the most collected insect group. It is likely that more than half of the 17 million US specimens in US collections were accumulated through the efforts of amateur collectors. Collections of butterflies and moths may reflect the best dataset of ecologically important insects available to scientists.

Geographical gaps in collecting are striking (figure 1). Overall, there is a dearth of specimens collected throughout the central United States, especially in the Great Plains. Most states are represented by <0.5 specimens/km^2. This may be an artifact of state size—larger states require more specimens to achieve a similar proportion of specimens as compared to smaller states—and human population density. Although the Kenelm Philip collection of over 83,000 arctic Lepidoptera specimens (Bakker 2014) is included in SCAN, Alaska is still represented by less than 0.05 specimens/km^2. The states with such low numbers of specimens per square kilometer are mostly those without an institution participating in LepNet ($P = 0.005694$). For example, no Texan institute was funded by the LepNet project (Seltmann et al. 2017), and only 360 specimens collected in Texas from Texan institutes exist in the SCAN database. However, the Texas A&M Insect Collection houses the Roy Kendall Lepidoptera collection of approximately 100,000 specimens and associated records from the southwestern United States (Anonymous 2004), which is not available via a public database. Funding to database this collection would have a significant positive impact on documenting the occurrence of southwestern Lepidoptera.

The accumulation of US specimens grew slowly between 1800 and into the 1940s (an average of 0.71% annually between 1800 and 1940), followed by a great increase in the years following World War II (82.44% increase between 1945 and 1960)(figure 2). After the establishment of the GI Bill, the number of years men spent in postsecondary education increased by an estimated 15-20%. Nearly 70% of men who turned 21 between 1940 and 1955 attained a college education for little to no cost (Stanley 2003). Many veterans who made use of the GI Bill studied the sciences (Altschuler and Blumin 2009). This increase in science education coincides with institutional collection growth into the 1970s. Although other factors, such as the rise of the middle class, growth of universities, and the founding of the Lepidopterists' Society likely helped the growth of collections, the GI Bill was a likely catalyst that gave amateur lepidopterists the time and education to generate collections (Altschuler and Blumin 2009).

Lepidoptera collecting increased dramatically until the 1970s, maintained a short plateau, and has plummeted since the late 1990s (down 59.45% between 1998 and 2009) (figure 2). Although more moths occur in the specimen data set (moths: 677,385; butterflies: 353,985, table S1), a general pattern of increase, plateau, and a final decline of specimen numbers were observed for both moths and butterflies when calculated separately (figure 2, inset). Interestingly, the decline in collecting butterflies began in the 1980s, before any decline in moth collecting, which may reflect a bias in databasing priorities or collector preferences—a subject for subsequent study. The number of moth specimens collected increased through the mid-2000s before declining into the 2010s; this is perhaps due to the number of moth species of agricultural interest present in the US, in addition to databasing priorities. Overall, the decline has become more prominent in recent years, decreasing from a rolling decadal mean of 18,324 specimens in 1999 to 10,689 in 2009 (figure 2). Conversely, observational records of Lepidoptera have greatly increased since 1990 and have grown more than 30x as of 2010 (figure 3). Lepidoptera collecting is not alone in its decline; many herbaria have also hit a peak in annual specimen collection events before declining dramatically (Prather et al. 2004a). This trend may be associated with the number of students studying the natural sciences at the undergraduate level. Though the biological sciences tend to retain the interest of undergraduates, this is often a reflection of intentions to enter professional post-graduate study in medicine, not interest in biology and the life sciences (Green 1989, Stolzenberg et al. 2019). The decision to choose careers away from natural history continues today at undergraduate and graduate levels and likely impacts the growth of natural history collections (Tewksbury et al. 2014, Stolzenberg et al. 2019).

Interestingly, the increasing trend in participation in butterfly and moth observation activities (figure 3) suggests that interest in natural history is prevalent in society (Yoon 2009). Perhaps the smart phone has rekindled latent curiosity regarding nature. The ubiquity of camera-enabled cell phones (Bhatti et al. 2010), the promotion of citizen science into the mid-2010s (Gura 2013), and the proliferation of online resources dedicated to identifying insects have facilitated relatively simple reporting of natural observations and participation in scientific studies (Follett and Strezov 2015). Community-based scientists have generated millions of documented Lepidoptera observations and participated in at least 61 scientific studies on Lepidoptera (Wang Wei et al. 2016).

The importance of amateur Lepidoptera collectors

Amateur lepidopterists collected significantly more specimens than professional collectors (487,152 vs 346,740; $P = 0.01111$) (figure 4). There was a significant difference between the number of specimens collected by amateur and professional collectors for most of World War II; this difference lasted into the 1950s (table S2). There was also a significant difference between types of collectors between the years of 1971-1986 and 1997-2009 (table S2).

Historically, amateur entomologists played an important role as data producers who helped amass specimen-based collections (Hopkins and Freckleton 2002). Many organized groups of amateur collectors arose from their shared enthusiasm for insects, especially in the nineteenth and twentieth centuries, even amidst a growing emphasis on professionalism in the biological sciences (Hunter and Jaros-Su 1997, Lonsdale 2012). Some of these amateur entomological groups are still active, such as the Lepidopterists'

Society, the Michigan Entomological Society (MES), and others throughout the United States, Europe, and Japan (Kawahara and Pyle 2012, Lonsdale 2012). These societies act as catalysts for citizen participation in biodiversity science and support amateur collecting, along with helping to engage the next generation in entomological study (box 1). For example, members of the MES have organized group collecting trips—including the foundation of a formal annual spring collecting trip (Michigan Entomological Society 1965)—which likely contributed to spikes in collecting activity in Michigan. In addition, members of the Wisconsin Entomological Society have donated over 14,000 Lepidoptera specimens to the Milwaukee Public Museum over the last 20 years (JMZ, personal observation). The accumulated collections of insects and data from amateur entomological societies contribute to, and likely enable, professional entomological research.

Continued collection of biological specimens is critical for a greater understanding of biodiversity and environmental change (Prather et al. 2004b). Through the efforts of amateur and professional entomologists, historical specimen collections provide data to track changes in patterns of biodiversity that predate observational records (Hill et al. 2012, Short et al. 2018, Cobb et al. 2019, Heberling et al. 2019). For example, a local society of skilled German amateurs were the first to quantify a continuing decline in insect biomass based on decades of saved samples from traps (Hallmann et al. 2017), and various scientific institutions in Europe are also making use of amateur entomologists to attempt further study into steep rates of insect decline.

The impact of a decline in Lepidoptera collecting

The quality and quantity of research-grade specimen-based data provided by amateurs have been increasingly recognized, despite a decades-long decline in amateur and professional collecting activity (Tewksbury et al. 2014, Heberling et al. 2019). In some cases, the decline has been linked to a lack of funding for natural history research and a simultaneous decline in the teaching of skills needed for natural history in university settings (Tewksbury et al. 2014, Hiller et al. 2017). This coincides with the need for increased maintenance, growth, and accessibility of natural history collections; for example, only 5% of institutionally-held insect specimens have been databased (Cobb et al. 2019). In the United States, there is limited funding to support natural history collections, despite the demonstrable need for curatorial staff, digitization of specimen records, and space (Prather et al. 2004b, Snow 2005). In addition, the dramatic increase of observational records of Lepidoptera within the last two decades suggests that amateurs are vouchering their observations with photos instead of specimens, which is expected given the wide availability of camera-enabled cell phones. The dearth of funding and decline in amateur specimen collecting will likely impact many areas of biological research that rely on specimen-based data (Snow 2005). The continued acquisition of specimens has many implications for the biological sciences; there are many areas of research that will depend on specimens into the future, such as the identification of economically-important species, the study of global climate change, and other uses for these data that we cannot predict or foresee (Heberling et al. 2019).

The continued need for amateur collectors and observers

Engaging new collectors is necessary for entomological collections to continue to grow and document trends in insect diversity. The existing networks of amateur collectors have encouraged new participation through reduced membership dues, increased social media presence, and occasional free nets for students (e.g. Lepidopterists' Society, MES). In addition, amateur entomological societies conduct public outreach and promote the participation of new, young collectors (e.g. Lonsdale 2012). Other opportunities for creating a future core of amateur collectors exist in K-12 schools (5-18 year old children) and at universities. For example, the Entomological Society of America offers the "Chrysalis Fund" for funding insect-based education at the K-12 level (www.entsoc.org/chrysalis-fund, accessed 28 April 2020). General entomology and insect taxonomy courses are available at many US state universities. Thus, much of the necessary "infrastructure" is in place to grow and nurture amateur collectors, but the "metamorphosis" of these amateurs into lifelong collectors is the challenge. It is unknown how effectively the "infrastructure" will inspire a future of lifelong collecting especially when faced with societal values that discourage collecting specimens (Minteer et al. 2014).

Given the increasing number of Lepidoptera observations submitted to SCAN and its constituent collections, it appears that entomological societies and K-12 activities are maintaining and promoting laypersons' latent curiosity in the natural world (Yoon 2009). The ease of capturing an image of an interesting butterfly and electronic submission of the image to taxonomic databases (such as iNaturalist) has promoted the causal observer to a community-based scientist. Indeed, these data have been used for research ranging from behavior to biogeography and to conservation (Bergerot et al. 2010, Wang Wei et al. 2016).

The activities of amateur collectors and observers are complementary to each other in terms of the information they provide to researchers. While the curation, identification, and databasing of specimens can be a relatively time consuming process—delaying research scientists' access to data—observations are available for research relatively quick given little need to curate images, the availability of crowd-sourced identifications, and automated databasing. However, specimens provide data concerning the whole organism from spatial-temporal to morphological to DNA data, and physical specimens have been the standard for vouchering scientific studies for decades. Observational data or field images are mostly two-dimensional, providing the time and place of a species' occurrence. Only limited data concerning morphology, systematics, physiology, ecology, and biology may be gleaned from images. For example, identification of many insects requires views of the body that may not be visible in photographs unless taken from highly specific angles and with magnification. Amateur collecting of specimens may be limited to areas and taxa not regulated by international, national, and local laws. In addition, regulations and ethical concerns can limit the number of individual specimens collected, especially of endangered species (Minteer et al. 2014). There appears to be few limits as to where, what, and how many Lepidoptera can be photographed, which can help to fill gaps in species occurrence data.

It seems prudent to encourage these community-based observers to also collect specimens (when lawful) in order to enable other scientific endeavors. We know of cases where professionals collaborate with amateurs to obtain specimens of specific taxa for research. For example, William Taft, Jr., an amateur expert on clearwing moths, often asks iNaturalist observers to collect specimens based on their posted images. These specimens supply Cognato and Taft with the data needed for taxonomic and molecular phylogenetic research, and voucher specimens are deposited in the A.J. Cook Arthropod Research Collection at Michigan State University (ARC). Concerted efforts by professionals to engage amateur observers in targeted specimen collecting could result in greater general participation in specimen collection by the community.

Concluding remarks

Amateurs have collected more total specimens than professionals, but this activity has declined since the 1990s. Perhaps a new cohort of nature watchers will offset this decline in specimen data acquisition though the documentation of Lepidoptera observations. However, recorded observations will only provide data for some scientific studies. Photographs cannot fully replace physical specimens, which provide "tangible" data such as DNA, internal anatomy, and biotic associations (e.g. pollen). In order to preserve these data, increased collecting, especially in threatened habitats, is urgent given the world's current accelerated rate of biodiversity loss (Pimm et al. 2014). Without an increase in the number of active amateur collectors and specimen acquisition to pre-1990 levels, investigations into many areas of critical concern to the biological sciences will remain largely stalled. New collaborations between nature observers and scientists could potentially reverse the decline in specimen collecting and provide specimen-based data to future researchers.

Box 1. Mogens "Mo" C. Nielsen: a profile of an amateur Lepidoptera collector and his impact on the A. J. Cook Arthropod Research Collection.

Of the many amateur collectors who contributed to the A.J. Cook Arthropod Research Collection at Michigan State University (ARC) over the last century, Mo Nielsen was a particularly dedicated benefactor to Michigan lepidopterology and to the development of the ARC. After his service in World War II, Nielsen enrolled in Forest Management at Michigan State University (MSU) were he developed a passion for Lepidoptera. Upon graduating from MSU, he worked for the Michigan Department of Natural Resources and continued to develop a lifelong interest in butterflies and moths (Michigan Entomological Society 2014). He was a founding and lifelong member of the Michigan Entomological Society (est. 1954) and a mentor to young lepidopterists. Nielsen had a cabin (the "hut") (A) located in rural Otsego County, MI. Over a time period spanning more than half a century, Nielsen and many other members of the MES extensively collected Lepidoptera while at the "hut" (Michigan Entomological Society 2014) and amassed >5,000 specimens from Otsego County. In total, Nielsen added >23,000 MI specimens to the ARC, which represents ~15% of the collection's North American specimens. This is just one example of the positive impact a few amateur collectors can make towards collection growth.

NOTE: Include a picture of the HUT (A) in box 1.

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Figure legends.

Figure 1. Distribution of Lepidoptera specimens held in collections across the US normalized by state area in square kilometers. States marked with a star have at least one institution participating in LepNet. LepNet is an effort to database 1.7 million North American Lepidoptera specimens held in 27 US institutional insect collections.

Figure 2. Lepidoptera specimens collected per year since 1800 based on specimens in institutional collections across the United States. In the main figure, the black line represents Lepidoptera specimens collected annually, the blue (middle) line indicates a rolling decadal average, and the grey (flanking) lines represent a single standard deviation from this average on a rolling decadal basis. Inset: annual specimens collected for moths (dark blue) and butterflies (light blue).

Figure 3. Lepidoptera observations per year since 1990. Inset: Lepidoptera specimens collected since 1990. For both graphs, the black line represents the number of events annually, the blue (middle) line indicates a rolling decadal average, and the grey (flanking) lines represent a single standard deviation from this average on a rolling decadal basis.

Figure 4. Amateur (purple) and vocational (light blue) Lepidoptera specimen collection events, 1925-2009.