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Preserving a Legacy: Ensuring the Access and Conservation of the Harold (Harry) G. Fowler (1950–2018) Ant Collection and Data

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Abstract

Biological collections are important repositories of biodiversity, as they include various types of data potentially useful to different areas of science and can contribute to the establishment of biodiversity conservation policies. For a long time, scientific collections were considered only as physical databases; in this context Harold G. Fowler (1950–2018) built an ant collection at the Universidade Estadual Paulista, campus Rio Claro (São Paulo state, Brazil), over the course of a 34-year career, comprising around 20,000 ant specimens. Most specimens came from the Brazilian Atlantic Forest, but many others came from distinct locations in Brazil and abroad. After his death, the collection was left without the necessary curatorial care for a period of time, which required a project to be conceived for its recovery and conservation, with the goal of incorporating it to the Zoology Museum of the University of São Paulo (MZSP). In addition to applying modern technical curation protocols, other activities such as checking, material identification and digitization of the information contained on the sample labels were carried out, forming an accurate database. This process enabled the identification of new distribution records and the discovery of possible undescribed species and unpublished natural history data. After validating this information, we counted 524 valid species and 201 morphospecies belonging to 105 genera and 10 subfamilies. In addition, we integrated technical curation activities with scientific outreach to draw the general public's attention to the importance of biological collections, thus fostering interest in science, biodiversity and nature conservation. Our work highlights the importance of preserving the areas sampled by Fowler's research group. The preservation of vouchers using curatorial practices reinforces the role of scientific collections as important tools for the study, understanding and preservation of biodiversity.

Key words: Myrmecological Collections, Myrmecofauna, Preservation Vouchers, Labels Digitalization, Atlantic Forest

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Resumo

As coleções biológicas são importantes repositórios da biodiversidade, contendo diferentes tipos de dados que podem ser utilizados em diversas áreas da ciência, além de poder contribuir para a formulação de políticas para conservação da biodiversidade. Durante muito tempo, as coleções científicas eram consideradas como bancos de dados físicos, e foi neste contexto que Harold G. Fowler (1950–2018), ao longo de 34 anos de carreira, construiu sua coleção de formigas na Universidade Estadual Paulista—Campus Rio Claro (São Paulo, Brasil), onde manteve um expressivo acervo com cerca de 20 mil espécimes de formigas, principalmente oriundo da Floresta Atlântica brasileira, mas também de outras localidades do Brasil e do exterior. Após seu falecimento, a coleção ficou por um período sem os cuidados curatoriais necessários, o que exigiu a elaboração de um projeto para a recuperação e conservação do acervo com a meta de incorporá-la à coleção de Hymenoptera do Museu de Zoologia da Universidade de São Paulo (MZSP). Além da aplicação de protocolos modernos de curadoria técnica foi realizada a conferência, identificação do material e digitalização das informações contidas nos rótulos das amostras, formando um banco de dados acurado. Este processo possibilitou a identificação de novos registros de distribuição, o encontro de possíveis espécies não descritas e dados de história natural não publicados. Após a validação destas informações, contabilizamos 524 espécies válidas e 201 morfoespécies pertencentes a 105 gêneros e 10 subfamílias. Além disso, integramos as atividades de curadoria técnica com a divulgação científica para chamar a atenção do público sobre a importância das coleções biológicas, fomentando, assim, o interesse pela ciência, biodiversidade e conservação da natureza. Nosso trabalho ressalta a importância da preservação das áreas amostradas pelo grupo de pesquisa do Fowler. A preservação de *vouchers* usando práticas curatoriais, reforça o papel das coleções científicas como uma importante ferramenta de estudo para a compreensão e conservação da biodiversidade.

Palavras-chave: Coleções Mirmecológicas, Mirmecofauna, Vouchers de Preservação, Digitalização de Etiquetas, Mata Atlântica

Introduction

Biological collections gather specimens from ecosystems and constitute historical documentation of their changes over time (NPS 1999). They represent an indispensable tool for taxonomists and systematists (Peixoto *et al*. 2006; Marinoni & Peixoto 2010; Oliveira *et al*. 2011), for researchers studying morphology, natural history, biogeography and ecology (Peixoto *et al*. 2006; França & Callisto 2007), as well as those assessing and/or seeking to mitigate anthropogenic effects on the environment (Meineke *et al*. 2019).

The preservation of specimens in collections supports national and international scientific research programs. It also documents results of projects of all kinds, keeping evidence that enables the replication of observations, which is imperative to good scientific practice (Brandão *et al*. 2021). It also helps to ensure the biological memory of sites that have undergone often irreversible changes, usually due to the intense process of fragmentation of natural vegetation (De Vivo *et al*. 2014), as is the case for most Brazilian biomes (Souza Jr *et al*. 2020). Another important aspect of biological collections is that some threatened species (and some possibly extinct lineages) are only known by their type specimen (ICMBio/MMA 2018), which are mostly kept in those collections. In addition, they have significant educational value, as they support activities in basic and secondary education (non-formal education and science fairs), undergraduate and graduate courses, and underpin environmental education programs, helping to raise public awareness on biodiversity preservation and issues such as the biodiversity crisis and the climate emergency (Sousa & Barbosa 2020).

Besides being fundamental for biodiversity studies (McNelley 2002), the maintenance of collections requires technical and scientific curatorial knowledge. This means that the attention of highly specialized staff is essential, both in terms of conservation and administration techniques, as well as the ability to scientifically interpret and understand the importance of specimens deposited in a collection. In this sense, tested technical curation practices are necessary to maintain them as long-standing entities that expand through the continuous addition of new specimens (Lattke 2003). These practices are related to a set of activities inherent to the administration, organization and maintenance of a collection. Furthermore, it is also important to incorporate new technologies to collections (e.g., programming, bioinformatics, imaging, computerization and databasing) to minimize the time needed by any given researcher to obtain primary data and other information, such as species distribution maps (Konstantinov & Namyatova 2019).

The zoological collections form the basis of research on animal diversity and are crucial to recognize and map this diversity (Taddei *et al*. 1999; Mello 2015). In Brazil, the *Museu de Zoologia da Universidade de São Paulo* (MZSP), the *Museu Emílio Goeldi do Pará* (MPEG), the *Coleção Entomológica Padre Jesus Santiago Moure* (DZUP), and the

Instituto Nacional de Pesquisas da Amazônia (INPA) hold important zoological collections encompassing material from various sources (e.g., regular scientific projects and faunal inventories). These collections enable specimens from collecting expeditions to be permanently deposited and available for public consultation. The protection of this material needs to be ensured to prevent the subsequent need of further physical and financial efforts to maintain or restore the collections, as recent disastrous events have unfortunately shown. We can cite as an example the *Museu Nacional* (MNRJ—where a major fire that occurred in 2017 caused significant losses of collections, including insects). All deposited material should be seen as a common heritage of humanity, as collections are the most obvious testimony of biological diversity (De Vivo *et al*. 2014).

Individual efforts made by scientists often generate research results as well as reference collections. The latter are more restricted in their nature than museum collections and are usually the product of specific research projects. They give the researcher in charge and his or her research group quick and in-depth access to the species of a particular place or region (see Souza-Campana *et al*. 2020), and can be formed by different types of material. Local collections store information on the communities inhabiting a particular region, with its diverse landscapes and floristic formations. This makes them important for researchers interested in identifying organisms collected at specific localities that are represented in these collections (Brandão *et al.* 2021). Species richness patterns are clarified when there is a large volume of data from different locations, gathered employing different collection techniques (Longino *et al*. 2002). Research-based and reference biological collections, as well as regional and local collections, represent an important tool for understanding, for example, the influence of certain factors (biotic, abiotic and local) on species distributions (Córdoba & Pérez 2021). Thus, the curatorial processes involved in building these collections are crucial to the study of biogeographical patterns of species diversity and distribution (Gotelli 2004). Regional collections are broader and gather information on particular ecosystems and their specificities, such as ecotones and isolated sites within other formations (Feitosa 2017). In general, these collections are invaluable sources of taxonomic novelties because they often contain representatives of species that are rarely or not at all represented in larger collections. Monographic collections, i.e. those assembled by a particular researcher, also enable others to understand the concepts adopted by that specialist and thus contribute to the epistemology of the disciplines related to the field of research covered by the collection. This is the case of the collection gathered by Dr. Harold Gordon Fowler (1950–2018), whose research was dedicated to ant ecology. After his death, his collection did not receive proper necessary curatorial care until now; its specimens were stored in 40 wood drawers that had been incorporated to the assets of the *Instituto de Biociências da Universidade Estadual Paulista* (UNESP, campus Rio Claro). Thus, the primary objectives of the present study were: i) present an overview of the material that comprise the "Harold G. Fowler's ant collection"; ii) assess its importance from new scientific and curatorial perspectives; iii) account for new species distribution discoveries; and iv) provide a guide to curatorial best practices for ant collections in general. At the same time, we briefly discuss the importance of scientific dissemination practices for a wide audience to highlight both the relevance of biological collections and scientific research, and Fowler's historical legacy as a researcher.

Methods

Documentary research

To enrich the discussion about the research carried out by Fowler, a descriptive and qualitative approach was used for two purposes: obtain information on his biography and contributions, and provide an overview of "Harold G. Fowler's ant collection." For that, we carried out documentary research, looking for information in his Lattes CV (a Brazilian national database for researchers CV's: http://lattes.cnpq.br/7251053552637553), as well as other relevant sources (e.g., the collection of the *Departamento de Biodiversidade da UNESP*—Rio Claro, Fowler's logbooks, and reports from researchers who were close to him).

Technical curation of the collection

Cleaning—The material was first transferred from the Rio Claro, UNESP campus (Supplementary Material S1) to the University of Mogi das Cruzes (UMC, São Paulo, SP, Brazil), where the technical curation stages were carried out. All drawers were kept in a freezer at -20° C for a week to start the decontamination process. Afterward, we inspected all specimens under a stereoscopic microscope to remove fungal hyphae using entomological forceps (Supplementary Material S2) when necessary, and organized them in new wooden entomological unit pinning trays in entomological drawers (Supplementary Material S3). At this stage, each specimen was further cleaned using a brush and 70% ethanol. After that, those that were still contaminated with fungi were subjected to the protocol developed by Moleiro *et al.* (2023).

Confirmation, identification and validation of specimens—These steps were carried out by five of the authors of this work: CTW, FSM, LPP, OGMS and VHN. They were conducted through the direct observation of specimens under a stereoscopic microscope and comparison with specimens deposited at the MZSP. Some species were identified using published identification keys for genera, as follows: *Acromyrmex* Mayr, 1865 (Forti *et* al. 2006; Forti *et al*. 2022); *Amoimyrmex* Cristiano, Cardoso & Sandoval-Gómez, 2020 (Cristiano *et al*. 2020); *Apterostigma* Mayr, 1865 (Lattke 1997); *Atta* Fabricius, 1804 (Gonçalves 1942); *Azteca* Forel, 1878 (Longino 2007); *Brachymyrmex* Mayr, 1868 (Ortiz-Sepulveda *et al*. 2019); *Cephalotes* Latreille, 1802 (Oliveira *et al*. 2021); *Crematogaster* Lund, 1831 (Longino 2003); *Dinoponera* Roger, 1861 (Dias & Lattke 2021); *Dorymyrmex* Mayr, 1866 (Cuezzo *et al*. 2011); *Gnamptogenys* Roger, 1863 and *Holcoponera* Cameron, 1891 (Camacho *et al*. 2022); *Hylomyrma* Forel, 1912 (Ulysséa & Brandão 2021); *Linepithema* Mayr, 1866 (Wild 2007); *Neoponera* Emery, 1901 (Fernandes *et al*. 2014; Troya & Lattke 2022); *Nylanderia* Emery, 1906 (Kallal & Lapolla 2012); *Odontomachus* Latreille, 1804 (França 2021); *Oxyepoecus* Santschi, 1926b (Albuquerque & Brandão 2004); *Pheidole* group *dilligens* Westwood, 1839 (Casadei-Ferreira *et al*. 2020); *Pheidole* groups *biconstricta*, *fallax*, *flavens*, *punctatissima* and *tristis* (Wilson 2003); *Pogonomyrmex* Mayr, 1868 (Johnson 2015); *Solenopsis* Westwood, 1840 (Trager 1991; Pacheco & Mackay 2013; Pitts *et al*. 2018); and *Wasmannia* Forel, 1893 (Cuezzo *et al*. 2015). The classification of urban ants was based on Loeck & Silva (1999), Campos-Farinha *et al*. (2002) and Zarzuela *et al*. (2002). We assigned a morphospecies number to specimens that could not be identified to species-level, following Suguituru *et al*. (2015) and Souza-Campana *et al*. (2020). The species names were validated based on Bolton (2023). After curation, approximately 4,990 specimens with unique records of collecting expeditions will be deposited at the Hymenoptera Collection at MZSP, following the policies adopted by the collection. Duplicate representatives of the cleaned material will be deposited in the institution of origin collection at UNESP, Rio Claro campus.

Database—We created an occurrence database for the specimens of "Harold G. Fowler's ant collection" and then we copied the original information contained on specimens' labels and when there was incorrect or missing information, we consulted Fowler's logbooks. In the case of ant records that did not have coordinates on labels, we used Google Earth *software* (https://earth.google.com) or the dataset available in Silva *et al*. (2022) to search for the sampling site using information on the specimen's label or in logbooks. The assigned information was then entered into the database, which will receive a unique identifier from the database already in use at MZSP. The material that will be deposited in the MZSP Hymenoptera Collection will be duly incorporated into Specify 6 software (developed by the Biodiversity Research Center, University of Kansas), thus enabling an efficient management and making the data available for consultation.

Results

An overview of Fowler's Collection

A total of 19,895 specimens were found in Fowler's collection, sampled between 1949 and 2004 (Figure 1). Some of these specimens bore no label or associated information (n = 2,152), although they were in excellent condition. Another portion of the material (n = 616) consisted of disarticulated specimens, with only scarce body parts present, and could not be assigned to any taxa. In addition, the opposite situation was also found, i.e. there were labels attached to entomological pins with no specimens associated (n = 530), and these were discarded. At the end of this process, we worked with a set of 16,597 specimens to be submitted to technical curatorial procedures (Supplementary Materials S4 and S5).

Distribution of ant specimens

The Fowler's collection consists of specimens collected in 19 countries, with Brazil being the most sampled, with

14,467 records (87% of the 16,597 specimens), followed by Guinea-Bissau (796), Paraguay (454) and the United States (224) (Figure 1). In Brazil, records were made in 19 out of 26 states and 219 municipalities (Figure 2A), and were most frequent in the state of São Paulo, mostly in Rio Claro and Cananéia. Ilhéus and Canavieiras municipalities, on Bahia state's coast, represent the third and fourth locations with the most collection records (Figure 2A). In general, most of the sampling was made in the Atlantic Forest, especially in areas of Dense Ombrophilous Forest and Semideciduous Forest, but the collection also contains samples from five Brazilian biomes (the Pampa being the only one not represented) (Figure 2B). The results also indicate the presence of invasive species from other countries, such as *Paratrechina longicornis* (Latreille, 1802), native to India (Supplementary Material S6 Table 1).

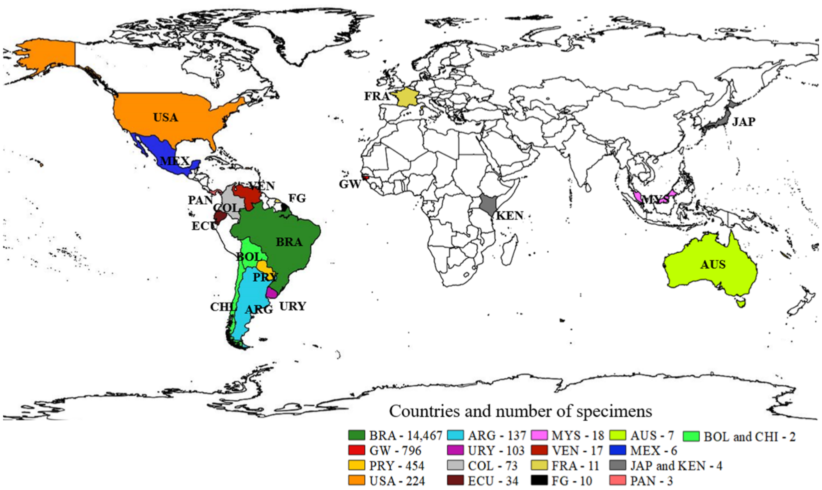

FIGURE 1. Political map of the world, showing the number of specimens recorded in Harold G. Fowler's ant collection for each sampled country. Colors show the different countries; legend shows the number of specimens collected in each country; country codes follow: Argentina (ARG), Australia (AUS), Bolivia (BOL), Brazil (BRA), Chile (CHI), Colombia (COL), Ecuador (ECU), France (FRA), French Guiana (FG), Guinea-Bissau (GW), Japan (JAP), Kenya (KEN), Malaysia (MYS), Mexico (MEX), Panama (PAN), Paraguay (PRY), United States of America (USA), Uruguay (URY) and Venezuela (VEN).

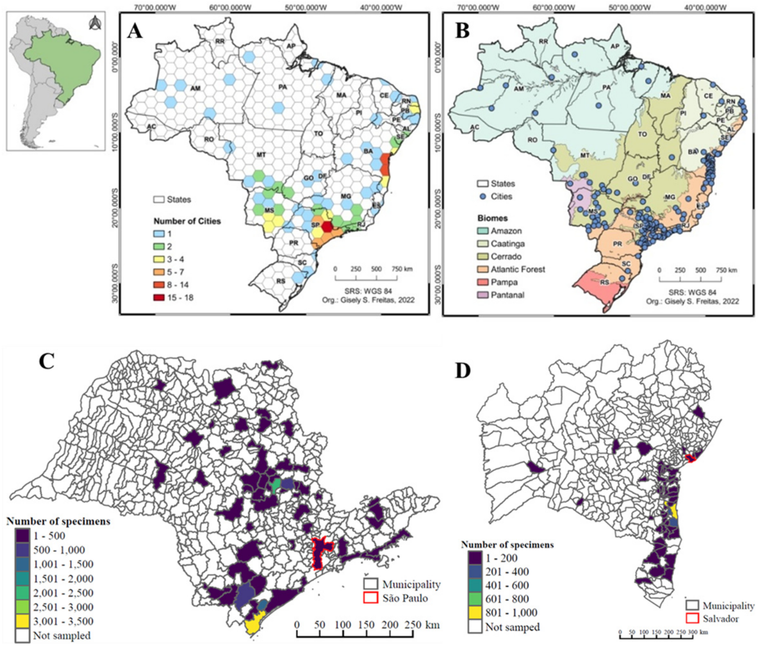

FIGURE 2. Political maps of Brazilian states and municipalities, showing: A. the number of cities sampled and recorded in Harold G. Fowler's ant collection within a hexagonal; B. locality of cities sampled and recorded in Harold G. Fowler's ant collection in relation to the Brazilian Biomes limits; C. number of specimens collected in each of the municipalities of the state of São Paulo (São Paulo highlighted in red); D. number of specimens collected in each of the municipalities of Bahia state (Salvador highlighted in red). Scales are shown for each map.

Taxonomic diversity

The 16,597 specimens that could be submitted to technical curatorial procedures were identified to species-level and are distributed in ten subfamilies, 105 genera and 524 species (Figure 3A). Most are workers (95.93%), but queens (2.36%) and males (1.71%) are also present. The subfamilies with the highest number of species in descending order are Myrmicinae, Formicinae and Ponerinae. Some specimens could not be identified to specific level, namely belonging to Dolichoderinae (13 morphospecies), Dorylinae (3), Ectatomminae (2), Formicinae (26), Myrmicinae (144), Ponerinae (13) and Pseudomyrmecinae (3) (Figure 3B). The total of 77.33% of the specimen labels or records in the logbook do not provide any information on sampling methods. However, this information was recorded in 22.67% of the cases, showing that several techniques were employed by Fowler (Figure 3C).

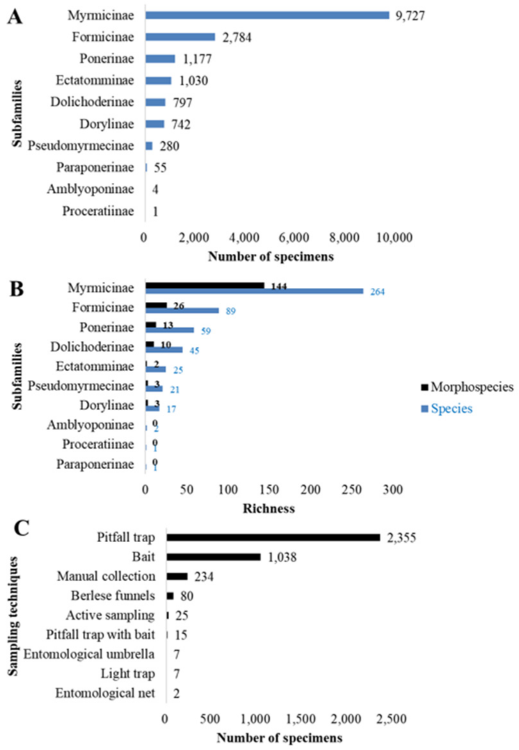

FIGURE 3. Bar plots showing: A. Number of specimens per Formicidae subfamily in Harold G. Fowler's ant collection. B. Species and morphospecies richness by subfamily. C. Number of specimens recorded according to each collection technique.

The oldest record in Fowler's ant collection was *Azteca paraensis bondari* Borgmeier, 1937 (n = 3 specimens) from the Cocoa Research Center, located in the municipality of Itabuna, Bahia, collected December 1949, collected by Maria Alice de Medeiros. The last entry was *Apterostigma* gr. *pilosum* (n = 1), collected at Fazenda São José (semi-deciduous Atlantic Forest), located in the city of Araras, São Paulo, on December 14th, 2004.

Fowler recorded 16 species classified as urban: *Forelius brasiliensis* (Forel, 1908) (0.03% of the total number of individuals), *Pheidole aberrans* Mayr, 1868 (0.04%), *Monomorium floricola* (Jerdon, 1851) (0.09%), *Tapinoma melanocephalum* (Fabricius, 1793) (0.09%), *Paratrechina longicornis* (Latreille, 1802) (0.11%), *Camponotus sexguttatus* (Fabricius, 1793) (0.15%), *Tetramorium bicarinatum* (Nylander, 1846) (0.19%), *Monomorium pharaonis* (Linnaeus, 1758) (0.25%), *Linepithema humile* (Mayr, 1868) (0.46%), *Crematogaster quadriformis* Roger, 1863 (0.66%), *Wasmannia auropunctata* (Roger, 1863) (0.75%), *Pheidole triconstricta* Forel, 1886 (0.86%), *Nylanderia fulva* (Mayr, 1862) (0.97%), *Camponotus rufipes* (Fabricius, 1775) (2.60%), *Solenopsis saevissima* (Smith, 1855) (3.04%) and *Pheidole megacephala* (Fabricius, 1793) (4.15%).

Harold G. Fowler's ant collection includes representatives of species listed in the Red Book of Threatened Brazilian Fauna (ICMBio/MMA 2018): *Atta robusta* Borgmeier, 1939 (n = 7 specimens, classification: vulnerable), *Dinoponera lucida* Emery, 1901 (n = 1, classification: endangered), *Oxyepoecus bruchi* Santschi, 1926 (n = 4, classification: vulnerable—D2). In addition to *O. bruchi,* other species are on the IUCN Red List: *Formica* *polyctena* Foerster, 1850, sampled in France (n = 2, classification: low risk/almost threatened) (IUCN 2023). The genera *Pheidole*, *Crematogaster*, *Tetramorium* Mayr, 1855, *Lepisiota* Santschi, 1926a, *Brachyponera*, and the species *Camponotus sericeus* (Fabricius, 1798), represent new records for Guinea-Bissau; the records come from collections made by Bucar Indjai on Orangozinho Island using attractive baits.

In the Brazilian territory, we reported 107 species as new occurrences for various states, 12 of which were recorded for the first time in the country. Among the new records for Brazil, we highlight *Myrmicocrypta spinosa* Weber, 1937, *Forelius pruinosus* (Roger, 1863) and eight species of *Pheidole* (*P. bergi* Mayr, 1887, *P. dione* Forel, 1913, *P. gigaflavens* Wilson, 2003, *P. mosenopsis* Wilson, 2003, *P. nitidicollis* Emery, 1896, P. *rugiceps* Wilson, 2003, *P. simplex* Wheeler, 1925 and *P. veletis* Wilson, 2003). Moreover, some important findings derived from the collection are i) genus records for new localities, for example, *Syscia* Roger, 1861 (Dorylinae) in the state of São Paulo and *Brachyponera* Emery, 1900 (Ponerinae) in Guinea-Bissau; ii) a possible undescribed species, such as *Syscia* sp. collected in Araras (São Paulo) and *Odontomachus* sp. collected in Rio Claro (São Paulo); and iii) a historical record of *Solenopsis invicta* Buren, 1972 in Rio Claro, São Paulo, being the first record for the species in the state, collected in March, 1984.

Discussion

Harold G. Fowler biography overview

Harold Gordon Fowler was born in 1950 in the United States. He completed his academic training in his home country, graduating at the State University of New York and getting his master's and doctorate degrees at The State University of New Jersey. He then worked as a postdoctoral fellow at the University of Florida until 1984. Throughout his career, Fowler worked at various institutions, but settled at the Universidade Estadual de São Paulo, campus Rio Claro, Brazil, where he worked as a professor and researcher at the Biosciences Institute for 34 years. With extensive experience in the field of Ecology, with an emphasis on Applied Ecology, Fowler concentrated his ecological, behavioral and biological control studies using ants as a model of his study. His efforts resulted in the publication of approximately 300 scientific articles and 40 book chapters. He also advised dozens of students. Moreover, he worked on commissions dedicated to preserving the environment, especially in inland regions of the state of São Paulo. During his professional career, Fowler organized his reference collection of ants, where he deposited specimens of species he studied, samples from localities he visited and collected, and material received as donations. This collection houses specimens of ants collected mainly in fragments of semi-deciduous Atlantic Forests, especially in the region of Rio Claro, state of São Paulo, Brazil. With the aim of connecting the fragments of semi-deciduous forest near the municipality of Rio Claro, Fowler began the discussion on ecological corridors (see Lapola & Fowler 2008).

In recognition to his contributions to the field of myrmecology, two species of ants were named after him: *Pheidole fowleri*, described by Wilson in 2003, and the workerless social parasite *Acromyrmex fowleri*, described by Rabeling, Messer, Lacau & Delabie in 2019. Fowler had already registered aspects of the biology of the latter and discussed it in works published 27 years before the species' formal description. Also, due to his observations on phorids parasitizing ants, especially fire ants (Fowler *et al.* 1995a; Pesquero *et al*. 1995; Porter *et al.* 1995a, 1995b, 1995c; Pesquero *et al*. 1996) he was again honored with the description of a fly *Pseudacteon fowleri* Pesquero, 2000.

Despite the fact that his main work focus was on the ecology, behavior and biological control of ants, Fowler, encouraged by Friar Walter W. Kempf, also dedicated some of his efforts to studying the fauna of Paraguay, describing a species of ant in 1982, *Trachymyrmex kempfi* (valid name *Mycetomoellerius kempfi*). It was an homage to Kempf for his friendship, contributions to the field, help with identifications and premature death (see Fowler 1982). Recognized for his academic excellence, contributions to education and the defense of the environment, Fowler received numerous awards throughout his career. During the development of the project that gave rise to this article, a video about the history and legacy of Fowler was prepared and made available online (see https://www.youtube.com/watch?v=t8GdAkr_91U).

Technical curation of Harold G. Fowler's ant collection

As a way of ensuring the safeguard of "Harold G. Fowler's ant collection", a comprehensive project was drawn up, which included the application of curatorial techniques and making its material available for consultation. This plan culminated in a project entitled "Harold G. Fowler's ant collection (1950–2018): recovery, incorporation and availability of a collection", funded by the Fundação de Amparo à Pesquisa de São Paulo (FAPESP, process 2021/01919-4 in name of Dr. Maria Santina de Castro Morini). This project involved eight researchers and five technical fellows (co-authors of this publication), as well as the allocation of resources for the recovery of the collection. Hence, the collection was restored by the research group at the University of Mogi das Cruzes and its information was checked and validated (see methodology).

The main stages in the process of recovering the collection included decontaminating the material, reassembling of specimens and their parts (when the specimen was broken), adding new labels, when necessary (in addition to the original labels), with all the relevant data, and identifying/updating the identifications previously made. Currently, with the use of collections to answer different questions such as large-scale assessments of ant diversity and to reveal disruptions of native ant assemblages by introduced species (e.g., Andrade-Silva *et al*. 2023; Booher *et al*. 2023), the interest in developing curation protocols and making information available has increased in Brazil. These topics have gained prominence in research projects, graduate programs, and publications (see, for example, Suguituru *et al*. 2015 and the website Formigas do Brasil: https://formigasdobrasil.com/). This curation is essential for specimens taken from the wild are to receive the necessary care to endure the passage of time inside a collection. In the case of Fowler's specimens, 16% of them could not be curated and deposited at MZSP or IB-UNESP as they were unlabeled, badly damaged or lost, without ever allowing a taxonomic assignment.

It is also important to highlight the effort that was made to identify species from hyperdiverse or taxonomically challenging groups, such as *Pheidole,* represented in the collection by 71 species and 47 morphospecies; *Solenopsis,* with 15 species and 26 morphospecies; *Camponotus,* with 57 species and 8 morphospecies; and in the standardization of morphospecies codes or "recognizable taxonomic units" (Oliver & Beattie 1993). The separation and standardized numbering of specimens not identified to species is of vital importance so that they can serve as a basis for comparison between different studies, at least from the same research group (Delabie *et al*. 2012). However, because these concerns are quite recent, there was no such standardization in Harold G. Fowler's ant collection. Similarly, a large part of his material is not accompanied by information on the collection technique used. The lack of this type of information prevents the reproduction and evaluation of the efforts made (Brandão 2015).

Profile of Harold G. Fowler's ant collection

From the specimens that do contain label information on the collection technique used, we can state that Fowler and his collaborators used pitfall traps (e.g., Lapola & Fowler 2008), attractive baits (e.g., Rossi & Fowler 2004) and manual collection techniques (e.g., Fowler & Delabie 1995) (Figure 3C). The mini-Winkler extractor, which revolutionized knowledge on the diversity of edaphic and leaf litter ants from the 1990s onwards (Agosti *et al*. 2000, Delabie *et al*. 2015), was not used by them. However, the Berlese funnel, which uses a similar process to obtain leaf litter ant species, was the fourth most used technique in the collection (Delabie & Fowler 1995).

Species such as *Labidus praedator* (Smith, 1858) (cited in Fowler 1979) and *Pheidole oxyops* Forel, 1908 (Fowler 1980), both collected in Paraguay; *Camponotus pennsylvanicus* (De Geer, 1773) and *C. castaneus* (Latreille, 1802), collected in the United States (Fowler 1986); and *Atta bisphaerica* Forel, 1908, collected in Brazil and Panama (Fowler 1987) represent voucher specimens for published articles, that will now be broadly available for consultation. In addition, one of the important milestones retrieved from the collection's data are the studies on fire ants (Fowler *et al*. 1990), which demonstrated the potential use of this species for pest control in sugarcane plantations (see Rossi & Fowler 2004). Fowler's collection also contains several ants collected in urban environments in Brazil from 1980 onwards (e.g., Fowler *et al*. 1993a, 1993b, 1993c, 1993d; Bueno & Fowler 1994; Fowler *et al*. 1995b, 1995c; Bueno *et al*. 1994; Fowler & Bueno 1996, 1998; Fonseca et *al*. 1997). In particular, Fowler & Bueno (1998) showed that species richness in homes is related to the level of conservation of the building. From these studies by Fowler, in partnership with researcher Dr. Odair Correa Bueno (*Instituto de Biociências da Universidade Estadual Paulista*, campus Rio Claro, São Paulo), it was possible to identify 18 species of urban ants, and consolidate research on ants in urban environments in Brazil.

The history of the collection also reveals Fowler's intense partnership with the researcher Dr. Jacques Hubert Charles Delabie (*Comissão Executiva do Plano da Lavoura Cacaueira, Centro de Pesquisa do Cacau*, Myrmecology Laboratory—Bahia, Brazil). An example is the first specimen from the collection, dated from 1949, and the vast majority of the specimens from the state of Bahia, which were donated to Fowler by Delabie. The collection also harbors vouchers for pioneering studies on exotic ants (the first studies on *Monomorium pharaonis* in Brazil (Fowler *et al*. 1993b, 1993c, 1993d) and ants in hospital environments (Fowler *et al*. 1993c, 1995b, 1995c). The first discussions about the possibility of bacteria being carried by these insects in Brazilian hospitals occurred in 1989 (see reports in Bueno & Campos 2017). Fowler was probably a pioneer also in comparing the foraging of the exotic species *Monomorium pharaonis* and *Tapinoma melanocephalum* in Brazil (Fowler *et al*. 1992). In addition to these species, *Tetramorium bicarinatum*, recorded in the states of São Paulo and Bahia, and *Cardiocondyla emeryi* Forel, 1881, in Bahia and Goiás, both exotic, stand out. However, there are also records of native species, such as *Brachymyrmex admotus* Mayr, 1887 and *Neoponera crenata* (Roger, 1861). Based on these studies, research on urban ants was carried out in various parts of Brazil to understand their diversity, biology and ecology (Bueno *et al*. 2017), and methods suggested to control these insects in urban (Campos-Farinha & Bueno 2004) and hospital environments (Cintra-Socolowski & Bueno 2017). Important records of species [e.g., *Labidus praedator* and *Odontomachus chelifer* (Latreille, 1802)] collected in areas of Semideciduous Atlantic Forest that no longer exist in the municipality of Araras (São Paulo) or species of leaf-cutting ants [e.g., *Atta sexdens* (Linnaeus, 1758)] are also part of the collection. Fowler's studies on leafcutter ants provide important information on the biogeographic patterns and nutritional ecology of these insects (Fowler 1983, 1991). In addition to his aforementioned accomplishments, we can cite his contributions to the taxonomy of the subgenus *Acromyrmex (Moellerius*) Forel, 1893 (Fowler 1988) that he dedicated to the memory of Dr. Cincinnato Rory Gonçalves.

Through the efforts undertaken in the present work, the countless contributions of scientific studies carried out by Fowler will be ensured with vouchers for these works preserved in the long term and available for consultation, which is essential to guarantee the replicability of research carried out in the past.

Discoveries from the collection

Harold G. Fowler's ant collection has a historical record of *Solenopsis invicta* in the state of São Paulo (in Rio Claro), the first record of this species in the state, dated from March 1984. Fowler *et al*. (1990) discussed this subject at length. *Solenopsis invicta* is native to South America and is largely distributed in the Pantanal region, at the headwaters of the Paraguay River, an area composed of savannas and seasonally flooded wetlands; its distribution ranges from Porto Velho (Rondônia, north Brazil) to the extreme south of the country (Pitts *et al*. 2018). But its occurrence has been extending to regions of the Brazilian coast into areas of the Atlantic Domain through introductions by anthropogenic means, with the expansion being discussed as a result of a bottleneck effect (Nagatani *et al*. 2022; Ramalho *et al*. 2023). The species has gained worldwide recognition for its remarkable success as an invasive ant in southern United States, Asia and even Europe, earning its place among the top 100 most harmful invasive species globally, according to the IUCN/SSC Invasive Species Specialist Group.

Among all species deposited in Dr. Fowler's collection, we identified three that are considered threatened in Brazil *(Atta robusta*, *Dinoponera lucida* and *Oxyepoecus bruchi*) (ICMBio/MMA 2018), and another one that is on the IUCN Red List of Threatened Species (*Formica polyctena*) (IUCN 2023). The threats to these species are mainly due to the loss and degradation of their natural habitats and intense deforestation, which puts the fauna of these invertebrates at risk of extinction (Waichert *et al*. 2019). For example, *A. robusta* is endemic to restinga areas in the states of Rio de Janeiro and Espírito Santo. This species has a vulnerable *status* mainly because it occurs in a single habitat (restinga) and due to the intense urban occupation of the coastal strip (Teixeira *et al*. 2003).

Comparing its data with that available on Antmaps.org (Janicki *et al*. 2016), we identified 28 species recorded for the first time in six countries (Ecuador, United States of America, Guinea-Bissau, Panama, Paraguay and Uruguay), and thirteen species recorded for the first time in Brazil (Supplementary Material S5). Guinea-Bissau is one of the countries on the African continent with a large gap in ant sampling, with only seven genera and fifteen species recorded (AntWeb 2023). Regarding the states of Brazil, new records are most abundant for São Paulo (37 species), Paraíba (13 species) and Amazonas (7 species). For São Paulo, there is an important record of a probably undescribed species of *Syscia* (determined by Paloma Andrade and Otávio G.M. da Silva), a genus already known in Brazil, but only in the state of Rondônia. For the state of Paraíba, we found an important record dated September 23, 2002, the first occurrence of *Ectatomma muticum* Mayr, 1870. This species was previously known in all states in the Brazilian Northeast region, except Paraíba. Its occurrence was already predictable since it is found in extrafloral nectaries of *Turnera subulata* from the Caatinga, a predominant native plant in Paraíba (Antweb 2023; Passos & Leal 2019).

Deposit of Fowler's collection at the MZSP Hymenoptera collection

Recovering and depositing Harold (Harry) G. Fowler's (1950–2018) ant collection at MZSP holds immense significance for the scientific community. The impact of this endeavor extends beyond merely safeguarding a collection; it ensures the preservation of a valuable resource for the long term. The existence of these meticulously curated specimens, along with associated data, is a testament to Fowler's scientific contributions. Furthermore, it demonstrates the importance of knowing specimens that represent the existence of a genus or species in a specific place and time, which may now be considered rare or threatened with extinction. By preserving this collection, adding specimens with historical importance and scientific study vouchers, it not only honors his legacy but also paves the way for the future of entomological research.

Moreover, depositing the collection in a faithful depository of biological heritage, such as the MZSP, promotes the principles of replicability in science, a fundamental tenet of the scientific method as proposed by Popper. Researchers from all over the world can now access and verify Fowler's work by consulting the data available online, enabling the validation and replication of his studies. This contributes to the robustness and reliability of scientific knowledge in the field of entomology. It fosters inclusion and diversity in science by eliminating geographical barriers that might have hindered access to such a resource. This not only enriches the body of knowledge in the field but also demonstrates a commitment to making science more accessible and collaborative. In essence, the recovery and preservation of this collection and its deposit at MZSP through an integrative and interinstitutional project stand as a testament to the principles of scientific integrity, inclusivity, and the protection of invaluable scientific resources.

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Supplementary Materials. The following supporting information can be downloaded at the DOI landing page of this paper, or downloaded directly from de link: https://github.com/Lamat-lab/Preserving-a-Legacy-Ensuring-the-Access-and-Conservation-of-the-Harold-Harry-G.-Fowler-1950-2018-.../tree/main/Supplementary%20Materials

Supplementary Material S1. Entomological drawer from "Harold G. Fowler's ant collection." A. Unidentified material deposited in an entomological drawer. B. Ant specimens visibly infested by fungi.

Supplementary Material S2. Ant specimens before (A) and after (B) cleaning with tweezers and 90% ethanol. *Note that, after cleaning, specimen B still has hyphae on the integument.

Supplementary Material S3. Entomological drawer from "Harold G. Fowler's ant collection." A. Unidentified material deposited in an entomological drawer before the cleaning and organization process. B. After the cleaning and organizing process.

Supplementary Material S4. Number and percentage of specimens of the subfamilies in "Harold G. Fowler's ant collection." before and after cleaning, organizing and confirming/identifying the specimens. NA—impossible to identify.

Supplementary Material S5. Taxonomic list of "Harold G. Fowler's ant collection." *new records.

Supplementary Material S6. Exotic species registered in Brazil that are found in the "Harold G. Fowler Ant Collection", and their respective places of origin.