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Thematic Review

Natural history museums and zoological collections of São Paulo State

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Abstract: Scientific collections constitute a valuable source for contributions to scientific research and the training of human resources in systematics, but also other areas of biological knowledge. In this contribution, we intend to discuss these advancements in collections and the role played by FAPESP in sponsoring them, as well as a general overview of the zoological collections in São Paulo state. We also aim to stress the importance of zoological collections and the need for continuous logistic and financial support from institutions and research agencies to maintain and develop these unique repositories of biodiversity. From 1980 to the present, FAPESP supported 118 research projects focused on several areas of zoology that are directly or indirectly associated with collections. There is a constant growth in the number of projects, and the financial support provided by FAPESP through the Biota Program was paramount for the advancement of our knowledge of biodiversity in Brazil. Parallel to the scientific advances, but not less important, this support allowed curators to increase the number of specimens, and to organize, maintain and digitize them in these valuable and irreplaceable collections. Regarding the lack of new taxonomists, it is essential that FAPESP and universities in São Paulo encourage the formation of new academics in zoological groups where specialists are rare. Considering the investment provided by FAPESP, it is quite important that the institutions that benefited from these resources took greater responsibility to safeguard these collections, and they should consider including resources on their budgets to obtain safety certificates, ensuring their permanence for many generations to come. Zoological collections are a heritage of humanity and are essential not only for the improvement of our knowledge of biodiversity but also with direct applications, among other services provided by these biological resources. It is important that research and teaching institutions in São Paulo that house specimens under their care start to value more this important patrimony and this heritage, as these collections represent the most valuable testimony of our impressive biodiversity, records of our past, and windows to our future, essential to our academic, scientific, cultural and social sovereignty.

Keywords: *FAPESP; Invertebrates; Vertebrates; Terrestrial; Freshwater.*

Museus de história natural e coleções zoológicas do Estado de São Paulo

Resumo: As coleções científicas constituem uma fonte valiosa para contribuições à pesquisa científica e para a formação de recursos humanos em sistemática, mas também em outras áreas do conhecimento biológico. Nesta contribuição, pretendemos discutir esses avanços nas coleções e o papel desempenhado pela FAPESP no seu patrocínio, bem como um panorama geral das coleções zoológicas do estado de São Paulo. Também pretendemos enfatizar a importância das coleções zoológicas e a necessidade de apoio logístico e financeiro contínuo de instituições e agências de pesquisa para manter e desenvolver esses repositórios únicos de biodiversidade. Ao longo de 1980 até os dias atuais, a FAPESP apoiou 118 projetos de pesquisa focados em diversas áreas da zoologia, direta ou indiretamente associados a coleções. Há um crescimento constante no número de projetos, e o apoio financeiro da FAPESP por meio do Programa Biota foi fundamental para o avanço do nosso conhecimento sobre a biodiversidade no Brasil. Paralelamente aos avanços científicos, mas não menos importante, este apoio permitiu aos curadores aumentar o número de exemplares, e organizá-los, mantê-los e digitalizá-los nestas valiosas e insubstituíveis coleções. Em relação à falta de novos taxonomistas, é fundamental que a FAPESP e as universidades paulistas estimulem a formação de novos acadêmicos em grupos zoológicos onde os especialistas são raros. Considerando o investimento realizado pela FAPESP, é de suma importância que as instituições beneficiadas com esses recursos tenham maior responsabilidade na salvaguarda desses acervos, devendo considerar a inclusão de recursos em seus orçamentos para obtenção de certificados de segurança, garantindo sua permanência por muitas gerações. As coleções zoológicas são patrimônio da humanidade, e são essenciais não apenas para o aprimoramento do nosso conhecimento sobre a biodiversidade, mas também com aplicações diretas, entre outros serviços prestados por esses recursos biológicos. É importante que as instituições de pesquisa e ensino paulistas que abrigam exemplares sob seus cuidados passem a valorizar mais esse importante patrimônio e essa herança, pois essas coleções representam o testemunho mais valioso de nossa impressionante biodiversidade, registros do nosso passado e janelas para o nosso futuro, essenciais à nossa soberania acadêmica, científica, cultural e social.
Palavras-chave: *FAPESP; Invertebrados; Vertebrados; Terrestres; Água doce.*

Introduction

In the last decade of the XIX century, the state of São Paulo took the first steps toward a position of relevance and leadership in zoological studies in Brazil and even in Latin America, which culminated with the Zoology courses at Universidade de São Paulo being considered the best of the world (https://cwur.org/2017/subjects.php#Zoology). At the end of the 1800s, a series of events converged to the establishment of the Section of Zoology of "Museu Paulista" (the São Paulo state museum): i) the acquisition of the Museu Sertório (a cabinet of curiosities assembled by Coronel J. Sertório, a politician and natural history enthusiast), by the Counselor Francisco de Paula Mayrink (a banker and also a politician); ii) the foundation of "Museu do Estado", later named Museu Paulista, formed by the Museu Sertório and the collections of the "Comissão Geográfica and Geológica de São Paulo", a commission created by the São Paulo state government to study geography, geology, hydrography, climate and natural history (fauna and flora) of the interior of São Paulo, an area at that time largely unknown; iii) the invitation of Hermann von Ihering, a German naturalist and physician to be the director of this newly established museum, which formally started its activities in 1895. Afterward, the Zoological collections were transferred to the Secretaria de Agricultura do Estado de São Paulo (Agriculture Secretary) and then, more than 70 years later, to the Universidade de São Paulo, where it belongs until today, known as Museu de Zoologia da Universidade de São Paulo (MZUSP). MZUSP collections are housed in the only edification in Brazil originally built (in 1938/1939) to be a zoological museum and to receive collections of specimens (Menezes et al., 1997; Landim, 2011).

Nearly 130 years later, the legacy of these forefathers is impressive: this institution harbors about 13 million specimens of several animal groups, as the largest and most representative collection of Neotropical fishes, the largest and most representative collections of Brazilian fishes, amphibians, reptiles, birds, and mammals of the world, and the most complete library of zoology in the country. More importantly, hundreds of zoologists working with the smallest insects to the largest mammals were nurtured and formed within these walls, leading scientists that are i) promoting a substantive increase in the knowledge of our impressive biological diversity and ii) forming new collections throughout the state of São Paulo and Brazil, and even in other countries.

In the last decades, scientific collections installed in universities initially assembled by the initiative of some researchers were being organized, agglutinated, and institutionally intertwined, currently constituting a valuable source for contributions to scientific research and the training of human resources (Bockmann et al., 2011). In the case of Brazil, in the last five decades, large zoological collections have been installed in several universities of São Paulo state, including an important fossil collection encompassing mostly arthropods, but also fishes and other vertebrates, and plants (Guilherme C. Ribeiro, pers. obs.).

More than 20 years ago, in an effort established by the creation of the Biota Program by FAPESP, Taddei et al. (1999) presented a detailed history of the São Paulo zoological collections, with an impressive list of these repositories. Since then, some of these collections were discontinued by the retirements or deaths of specialists (e.g., the collection of annelids of Gilberto Righi, of the Instituto de Biociências da Universidade de São Paulo; the collection of spiders of the Universidade Estadual Paulista, in Botucatu, established by Isabela

Rinaldi; the collection of grasshoppers and crickets of the Universidade Estadual Paulista, in Rio Claro, established by Alejo Mesa; the collection of bats of the Universidade Estadual Paulista, in São José do Rio Preto, established by Valdir A. Taddei, all now housed at MZUSP), but several other collections had continuous growth, with tenths of thousands of specimens incorporated. More importantly, new collections were formed in universities and research institutes, as a consequence of the consolidation of graduate programs and scientific research in Brazil, when the economy was stable and strong, and research agencies, such as FAPESP and CNPq, supported important projects on biodiversity studies. Additionally, during those wealthy years, Brazil massively expanded its road and highway network, electric energy production (with hydroelectric power plants and wind farms), and oil and gas prospecting, and, by law, these activities demanded environmental impact and monitoring analysis to be licensed. These studies were responsible for the collection of important voucher series of specimens, housed in traditional and new collections that were testimonies of natural areas that are partially/completely altered or totally vanished.

Other types of collections flourished in these years, namely collections of wildlife recorded sounds (vocalization of birds, frogs, and some mammals), photographs and videos from camera traps (mostly for mammals), and tissue samples, the last being one of the most important and more frequently accessed by the scientific community. Tissue samples, consisting predominantly of liver and muscle fragments preserved in absolute ethanol or liquid Nitrogen, are the main source of DNA and the main source of information for molecular analyses. With the popularization of phylogenetic, phylogeographic, and evolutionary studies based on gene sequencing, both in SANGER and Next Generation sequencing methods, these tissue collections proliferated in several institutions, even those that do not harbor zoological specimens traditionally preserved.

In this contribution, we intend to discuss these advancements in collections and the role played by FAPESP in sponsoring them, as well as a general overview of the zoological collections in São Paulo state. It is beyond our objectives to present a detailed analysis of all collections and taxonomic groups, especially when there are important initiatives in Brazil currently being conducted by scientific societies (see Chiquito et al., 2021; the Sociedade Brasileira de Zoologia, along with the Fórum de Sociedades Brasileiras de Zoologia, is also working on a large-scale inventory of collections; see https://www.youtube.com/watch?v=LPCIGi59gi8), for thorough and precise information on these collections, in order to establish a national program for collection support on curatorial practices. We also aim to stress the importance of zoological collections and their role in the understanding of the evolutionary processes that shaped such species richness, but also the need for continuous logistic and financial support from institutions and research agencies to maintain and develop these unique repositories of biodiversity.

FAPESP: Support Sampling and Curatorial Procedures

Shortly after its inception, in 1962, FAPESP began to propel biological surveys, such as the "Amazonas Project – Faunistic, Ecological, and Economic Survey of Fisheries Resources in the Amazon" (Projeto Amazonas – Levantamento Faunístico, Ecológico e Econômico dos Recursos Pesqueiros do Amazonas), which started in 1966, under the leadership of the zoologist Paulo Emílio Vanzolini, from MZUSP. Vanzolini was also one of the founders of FAPESP and its advisor for more than three decades (https://bv.fapesp.br/linha-do-tempo/pagina/paulo-emilio-vanzolini/). In the same year, FAPESP also supported biological surveys along the southeast coast, coordinated by Vanzolini and the biologist and oceanographer Marta Vannucci, from the Oceanographic Institute at USP. Probably the most audacious investment by FAPESP for zoology in this period was to support the project "Permanent Expedition to the Amazon" (Expedição Permanente à Amazônia – EPA), also headed by Vanzolini, through which two boats were built to explore the Amazon fauna. The EPA, which began in 1967, lasted two decades, ending activities in 1987, after having brought thousands of fishes (it is estimated that ca. 172,000 fish specimens were collected), reptiles, and terrestrial and freshwater invertebrates to MZUSP (Menezes et al., 1997; Tavares et al., 2015; Marinho et al., 2019; https://bv.fapesp.br/linha-do-tempo/2210/expeditions-pioneers-amazonia/).

Throughout these last four decades, from 1980 to the present, FAPESP supported 118 research projects focused on several areas of zoology, such as taxonomy, systematics, evolution, and biogeography, that are directly or indirectly associated with collections. The cumulative curve of grants (Fig. 1) shows a constant growth in the number of projects, with a short plateau ranging from 2003 to 2010, a steep increase from 2010 to 2011, and a lower growth rate from then to 2021. The creation of the Biota FAPESP Program in 1999 (Fig. 1) was responsible for constant growth in support of research involving collections (either its maintenance or new collecting efforts in the field); in fact, to the present day, about 41% of all research projects supported by FAPESP were associated to this program.

Regarding all modalities granted by FAPESP in Zoology, regular research projects were the most commonly awarded, representing 55% of all grants (Fig. 2); if we consider regular projects associated with Biota Program (22 projects), these represent 68% of research projects. Interestingly, within Biota Program there is a more homogeneous distribution of research projects between the three main modalities, namely Regular (46%), Thematic (35%), and Young Researcher (19%); conversely, 93% of all projects submitted to FAPESP outside Biota were regular projects.

Twenty research institutions in São Paulo (mostly public universities) benefited from support from FAPESP (Fig. 3), 7 of which from the metropolitan area of São Paulo (IBUSP, IB, UFABC, MZUSP, IOUSP, EACH USP, FSPUSP): these institutions received 62 grants from FAPESP (ca. 52% of all projects), and among those, MZUSP was awarded 38 research projects. The campus of UNESP at Rio Claro (17 projects) and USP at Ribeirão Preto (14 projects) were institutions also receiving important and substantive grants from FAPESP, and these institutions obtained nearly 80% of all projects destined for collections in the state in the last 40 years.

Specialists in invertebrates and vertebrates were similarly granted financial resources from FAPESP, with approximately 53.3% and 45% of projects (Fig. 4). Among invertebrates, insects (several orders), were contemplated with 46 research projects, representing approximately 73% of all projects; while in vertebrates, "fishes" obtained 18 projects (34%), followed by birds, amphibians, and reptiles (9, 8 and 8 projects, respectively; all these groups representing 82% of projects with vertebrates).

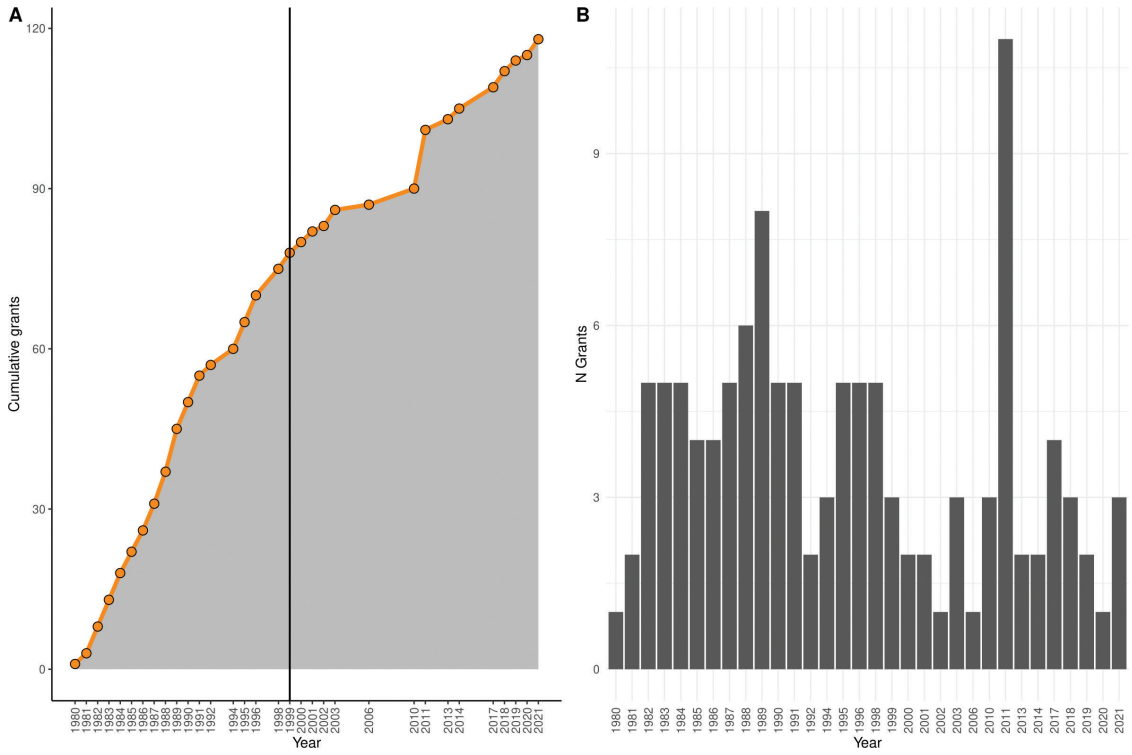

Figure 1. A. Cumulative curve of the number of projects granted by FAPESP to researchers of the state of São Paulo in the area of zoology, associated with collections. B. Histogram with the number of projects granted by FAPESP to researchers of the state of São Paulo in the area of zoology, per year, from 1980 to 2021.

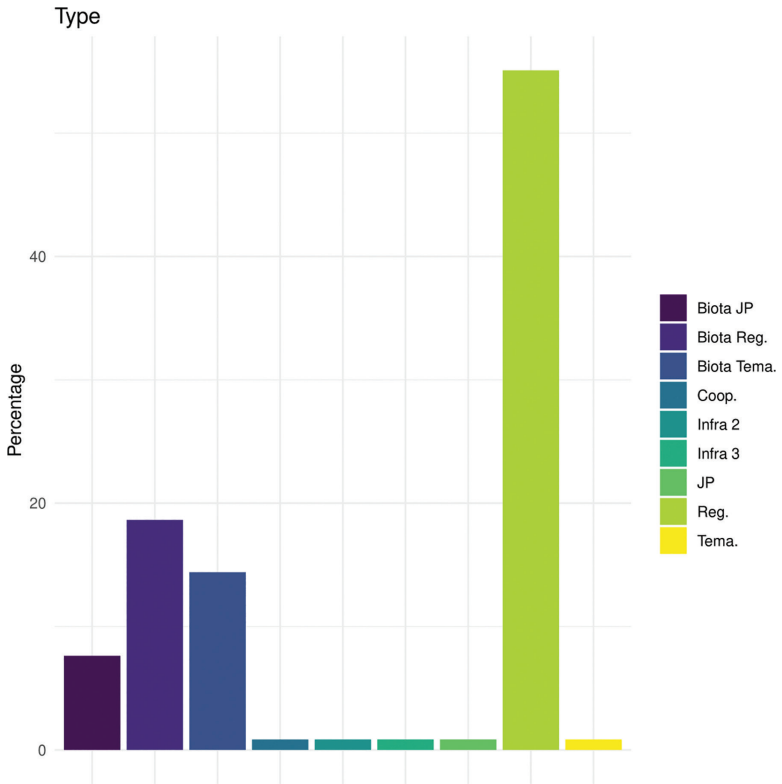

Figure 2. Frequency of projects granted by FAPESP to researchers of the state of São Paulo, from 1980 to 2021, on the area of zoology, associated to collections, according to the different types of projects: BIOTA JP: Young researcher grant associated to BIOTA Program; BIOTA Reg: Regular research grant associated to BIOTA Program; BIOTA Tema: Thematic project associated to BIOTA Program; Coop: Cooperative grant project with other agencies; Infra 2 and 3: Infrastructure Projects for collections; JP: Young Researcher project (not associated to BIOTA Program); Reg: Regular research grant (not associated to BIOTA Program); Tema: Thematic project (not associated to BIOTA Program).

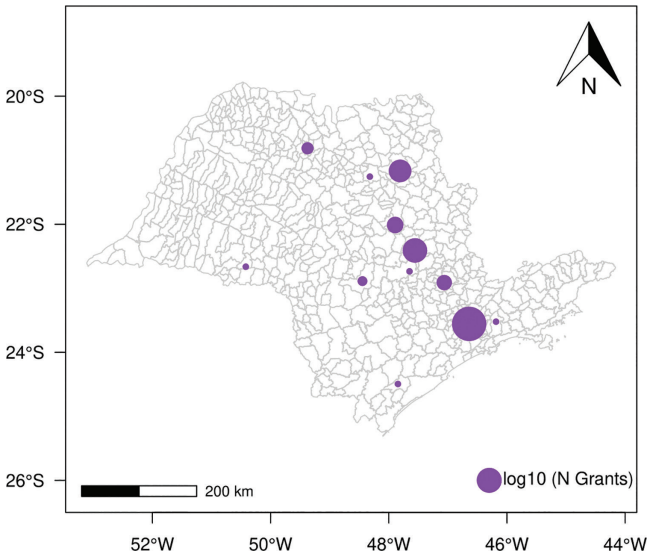

Figure 3. Location of the research institutes and number of projects awarded by FAPESP, from 1980 to 2021.

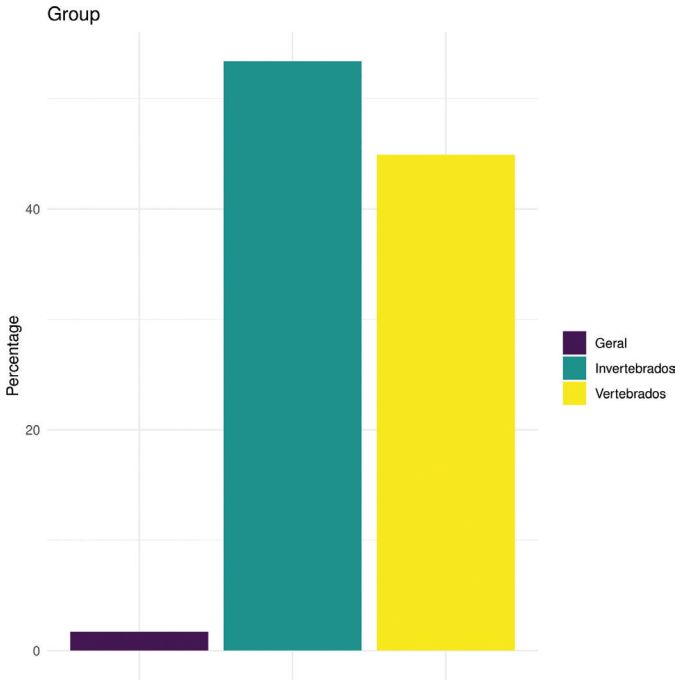

Figure 4. Frequency of projects awarded by FAPESP, from 1980 to 2021, to researchers working with invertebrates, vertebrates and for zoology in General (Geral).

Among all projects, 14 (ca. 12%) were directly involved with zoological collections, either for the acquisition (5 projects) of private collections to be incorporated into MZUSP holdings, and also for curatorial purposes (9 projects), involving traditional collections (8), but also bioacoustics collections (1). Those projects were awarded by FAPESP from 1982 to 1999, with no projects directly associated with the maintenance of scientific collections afterward. We are not certain of the reasons for such interruption, but most likely FAPESP suspended this kind of support for collections, focusing on projects with applied scope or recommended that Technical Reserve (this additional resource started to be included in approved projects in 1998) associated with the research project should be employed to cover some of the curatorial costs.

Although rare and intermittent, FAPESP has opened important calls for proposals dealing specifically with scientific collections. This rarity is surprising, as very impressive results were achieved when such support was provided. It is noteworthy that FAPESP's Call for Proposals #16/2009, entitled "Support for Research Infrastructure to Depository Centers for Information, Documents and/or Biological Collections" (https://fapesp.br/index.php/5417/apoio-the-research-infrastructure), which targeted the improvement of physical and research infrastructure associated with collections, including the availability of the data on the internet. This financing, launched in October 2009, provided a total amount of R$20 million, approximately US$9.85 million at the time This amount equipped São Paulo biological collections at least from MZUSP, Department of Biology of FFCLRP/USP, and IBILCE, UNESP, São José do Rio Preto, providing important infrastructure for housing collections and building security, such as specific furniture, especially compact storage systems, electrical system renovation, cooling appliances, in addition to equipment for research, such as stereomicroscopes, optical microscopes, professional photographic equipment, and a digital X-ray system, as well as IT infrastructure for collection organization and managing. In addition, in 2015 FAPESP partnered with CNPq and launched the PROTAX - Taxonomy Training Program, a highly successful initiative created in 2006 with the purpose of establishing, through a program of formation of taxonomists, the species diversity in Brazil and their phylogenetic relationships and to train highly qualified human resources in taxonomy (Alves et al., 2018).

The financial support provided by FAPESP through the Biota Program was paramount for the advancement (as will be demonstrated below) of our knowledge of the three levels of biodiversity in Brazil (Gaston, 2010), from populations to ecosystems. Parallel to the scientific advances, but not less important, this support allowed curators to increase the number of specimens, and to organize, maintain and digitize them in these valuable and irreplaceable collections.

An important branch of the Biota-FAPESP Program was to promote the digitization of data from the biological collections of the state of São Paulo and their availability on the internet, a pioneering enterprise at the state level, by supporting the development of speciesLink (https://specieslink.net/), a major biodiversity e-infrastructure conceived in 2001 and maintained by the Centro de Referência em Informação Ambiental (CRIA) (Canhos et al., 2015; Nelson & Ellis, 2019). Initially, the initiative addressed only the biodiversity of the state of São Paulo but was soon after it expanded to the entire country and even to other countries (Canhos et al., 2015). Presently, speciesLink provides free and open access to an impressive ~16.1 million data records from 551 collections around the world. Regarding animals, speciesLink gathered 261 collections, 58 of which from the State of São Paulo and hosting 775,870 biological records (mostly lots or unitary specimens) as of January 2, 2023.

Zoological Collections in São Paulo: A Brief Diagnostic

Taddei et al. (1999: p.63, Table 1) listed the existence of 47 collections (nine of them housed at MZUSP) in the state, representing

24 groups. These collections held 6,259,401 specimens and 119,705 lots, with the collection of insects of MZUSP being responsible for more than 75% (4,700,000) of these specimens; regarding the number of lots, the collection of fishes of MZUSP exhibited the largest number, with 75,000 lots, more than 62% of the total.

Presently, parallel diagnostics of several Brazilian collections are underway (an initiative of the Sociedade Brasileira de Zoologia, as mentioned above) and the presentation of such diagnostic data here will diminish the impact of this massive investment of time and effort. We aim, therefore, to present here the impressive growth in the number of collections and number of specimens, as well as the scientific information generated as a consequence of this improvement, of some selected groups of vertebrates and invertebrates.

For mammals, there were three collections in São Paulo in 1999; the centennial and traditional collection of Museu de Zoologia in São Paulo (29,000 specimens), and the new collections of UNESP in São José do Rio Preto (9,600 specimens) and of UNICAMP, formerly ZUEC and presently MDBio, in Campinas (2,200 individuals). Since then, the UNESP collection was discontinued as a consequence of the death of the curator, the late Valdir A. Taddei, but two new collections were created in the early 2000's, at ESALQ USP (with nearly 2,000 specimens) and UNESP Jaboticabal (1,000 individuals), totaling four active collections in the state. Fortunately, the important collection of UNESP, which currently amasses 15,000 specimens of bats, was recently donated to MZUSP, and presently harbors 65,000 individuals, being the second largest collection of mammals in the country (see also Chiquito et al., 2021). There was an increase in the number of specimens at UNICAMP (2,365 exemplars), and today there are approximately 70,365 specimens (in comparison to the 40,800 specimens in 1999) of mammals in the collections of the São Paulo state, and amazing growth with about 1,340 specimens being incorporated annually to these institutions.

At the end of the XX century, Fonseca et al. (1996) listed 483 terrestrial and 41 marine mammal species. In 2021, the taxonomy committee of the Sociedade Brasileira de Mastozoologia (Abreu et al., 2021) listed 725 terrestrial and 45 marine mammal species. On a local scale, considering the diversity of mammals in São Paulo, Vivo et al. (2011) listed 230 species, while today (Galleti et al., this volume) we were able to record 271 species. These represent increases of 246 and 41 species, respectively, an impressive growth in the knowledge on the diversity of a group that is considered well-known when compared to other zoological lineages. This is a result of several factors, from the number of mammalogists working in Brazil and new methods and concepts currently employed by systematists but is obviously correlated to the number of specimens available in our collections. Considering the mammals, a Thematic Project of the Biota Program by the former curator of MZUSP was responsible for several expeditions to the Atlantic Forest and Cerrado, and the inclusion of more than 3,000 specimens in this collection; a Young Researcher grant to the senior author of this contribution, was essential to the nucleation of the new collection of mammals at ESALQ and the collecting of more than 1,200 specimens in several rivers of the western portion Amazon basin, a largely unknown and unsampled area.

For birds, the collections housed at MZUSP (including bird skins, complete specimens preserved in ethanol, skeletons, tissue samples, eggs, nests, and vocalizations) are the largest in the world, out of the global collections housed in the museums of North America and Europa. The collection is also the most complete and comprehensive about Brazilian species and localities on the planet. The number of specimens housed at MZUSP is over 120,000, consisting mostly of bird skins, skeletons and fluid preserved specimens; the collection also includes other types of preserved material, as eggshells and nests, and the total number of voucher specimens in the Birds section is over 140,000 items. The collection suffered for some decades in relative stasis as a consequence of the absence of a curator, but after the support from FAPESP and CNPq, from 2003 to date the collections had a steep increase in number of specimens, from about 74,000 to the ~140,000 items nowadays. The collection is still growing at a rate of ~3,000 to ~4,000 specimens a year, benefiting from at least 3 large field expeditions every year to all Brazilian biomes. The support of FAPESP led to the discovery of more than 10 new species of birds, the publication of about 150 papers in leading journals and 5 books since 2003. The second largest bird collection in the state is housed at Museu de História Natural de Taubaté Doutor Herculano Alvarenga, run by a non-profit Foundation, which houses about 10,000 bird skins and more than 10,000 skeletons of birds, one of the most complete skeleton collections in South America but with a small increase of specimens in recent years. Another important collection is housed at the Núcleo de Doenças de Transmissão Vetorial (NDTV), at the Instituto Adolfo Lutz, which is relevant for some localities in São Paulo state. This collection is not active at the moment. The most important collection of birds' sounds from South America is housed at UNICAMP (Arquivo Sonoro Jacques Vielliard), which also harbors a significant collection of sounds of other animals. The zoological collections at UNICAMP also possess a small scientific collection, which receives a handful of specimens yearly. Finally, the Genetics and Evolution Department at the Instituto de Biociências da USP has an important collection of bird tissues, which started in the late 1990s, with more than 20.000 samples and still receiving a significant number of samples every year, vouchered and unvouchered. Many universities in São Paulo state have small bird collections, composed mainly of domestic, captive-bred, or birds found dead, serving mostly for teaching and educational purposes.

Concerning fishes, Castro (1999) listed six collections based in the state of São Paulo, supported by the following institutions (collections acronyms in parentheses): 1) Museu de Zoologia da Universidade de São Paulo (MZUSP); 2) Museu de História Natural da Universidade de Campinas, Campinas; 3) Laboratório de Ictiologia do Departamento de Biologia da FFCLRP-Universidade de São Paulo (currently Laboratório de Ictiologia Ribeirão Preto, LIRP), Ribeirão Preto; 4) Laboratório de Ictiologia Sistemática da Fundação Universidade Federal de São Carlos (currently Laboratório de Ictiologia Sistemática do Departamento de Ecologia e Biologia Evolutiva da Universidade Federal de São Carlos, LISDEBE), São Carlos; 5) Departamento de Zoologia do IBILCE da Universidade do Estado de São Paulo (DZSJRP), São José do Rio Preto; 6) Base de Pesquisa do Litoral Norte - Instituto de Pesca, Ubatuba. The Sociedade Brasileira de Ictiologia bulletin dedicated its 2019 edition to the ichthyological collections of relevance to the Neotropical region, as a result of the II Symposium on Phylogeny and Classification of Neotropical Fishes, held in Londrina, Brazil, in October 2017. Among the articles included, 22 concerned collections in Brazilian and 17 collections in other countries, but from the State of São Paulo only the collections of DZSJRP, LISDEBE, and MZUSP presented contributions (Langeani et al., 2019; Marinho et al., 2019; Oliveira et al., 2019). The growth of these collections in terms of specimen/lot numbers in just

over two decades (1999-2020) was outstanding: DZSJRP, from 19,419 specimens in 2,884 lots to 286,206 specimens in 22,971 lots; LIRP, from about 23,500 specimens in 2,600 lots to 176,515 specimens in 17,500 lots; LISDEBE, from nearly 500 lots to 62,848 specimens in 7,306 lots; MZUSP, from ca. 750,000 specimens in 75,000 lots to 1,545,642 specimens in 123,114 lots; and ZUEC-PIS, from 11,199 specimens in 4,910 lots to 162,601 specimens in 17,505 lots. We do not have updated data from the Instituto de Pesca collection. In the meantime, other three ichthyological collections were created: the collection of the Laboratório de Biologia e Genética de Peixes (LBP), Departamento de Morfologia do Instituto de Biociências da UNESP, campus Botucatu, increasing from 645 specimens and 5,128 lots at the time of its foundation in 1999, to 186,111 specimens in 24,935 lots in 2020; the Acervo Zoológico da Universidade Santa Cecília (AZUSC), Santos, a collection housed in a private university created by Matheus M. Rotundo and Luis Alberto Zavala-Camin in 1998 that presently contains 25,532 specimens in 6,921 lots (Matheus M. Rotundo, pers. comm.); and the collection of the Laboratório de Ictiologia de Sorocaba (LISO), Departamento de Biologia, Universidade Federal de São Carlos, campus Sorocaba, under the care of George M. T. Mattox and Mauricio Cetra, counting on nearly 2,000 lots, of which 500 so far registered (George M. T. Mattox, pers. comm.). It is relevant to say that almost all of these collections expanded not only in terms of volume of material but also in terms of coverage, expanding it way beyond the national borders. Although the data are grossly underestimated, the increase of the ichthyological collections in volume in slightly more than 20 years is quite impressive, with the collections of DZSJRP, LBP, LIRP, LISDEBE, MZUSP, and ZUEC-PIS, increasing from approximately 804,000 specimens in 95,000 lots in 1999 to over 2,419,000 specimens in over 213,000 lots in 2020, a threefold increase.

In the last 25 years, fish collections in São Paulo state were markedly boosted by funding provided by FAPESP for broad-spectrum projects that included collections, such as the Thematic Projects "Diversidade e Evolução de Gymnotiformes (Teleostei, Ostariophysi)" and "Inventory of the Characiformes (Teleostei, Ostariophysi) fauna from South America", both coordinated by Naércio A. Menezes (MZUSP), and "Diversity of Fish from Streams and Headwaters of the Upper Paraná River Basin in the State de São Paulo, Brazil", led by Ricardo M. C. Castro (LIRP), the last two of which being linked to the Biota/FAPESP Program. In addition, the ichthyological collections have greatly benefited from numerous FAPESP funding for individual projects, including grants for undergraduate and graduate projects. Such an exponential increase was largely due to the intense collection activities promoted by large projects led by curators and by graduate students' projects. Furthermore, many of the shelves in the collections were filled with fish collected in environmental impact assessments, which, by law, must deposit the captured specimens in zoological collections belonging to recognized research and teaching institutions, as was markedly the case of MZUSP and LIRP in the last two decades.

In 1999, there were two collections of Arachnida at São Paulo state, at the MZUSP, and at the campus of Botucatu, UNESP: both collections housed approximately 16,000 lots and 300 specimens, respectively. Those lots were represented mainly by Araneae (13,000 lots), Opiliones (2,500), and Scorpiones (500). Currently, there are 3 collections in São Paulo, at MZUSP, Instituto Butantan (a secular collection, that started in 1900, but was not accessed during the 1999 survey), and at Universidade Federal de São Carlos (established in 2009). These collections assemble, respectively, 76,784, 439,800, and 15,200 lots of all orders of Arachnida, including abundant type material.

An additional Arachnida group meriting attention refers to the mites (Acari). One of the major mite collections in Brazil is housed at Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo, Piracicaba, State of São Paulo (ESALQ/USP). It presently holds nearly 820 mite species of 153 families. Almost 460 of these are holotype specimens, 324 of which were collected in Brazil and 133 in other countries. Altogether, approximately 27,000 specimens are held, approximately 68% of which were collected in Brazil, and the remaining in countries of different continents. Although it contains specimens collected since the 1950s, over 80% of the specimens were collected after the 1990s, especially as a result of the financial support provided by FAPESP. In 1997, two projects were approved for the upgrade of the collection's infrastructure, followed by the approval of three BIOTA/FAPESP projects on the diversity of mites of agricultural importance. As a result, until now, 89 new and more than 200 known species were incorporated into the collection, in addition to a large number of other species waiting to be identified. Additionally, a "Regular Grant" contributed to a significant increase in the number of mites from the Mato Grosso state in the collection. The financial support of FAPESP also significantly enhanced the number of specimens in the reference collection of Departamento de Ciências Biológicas of UNESP (Universidade Estadual Paulista), São José do Rio Preto, São Paulo state. This collection was established in 1985, housing today more than 21,000 specimens of over 300 species of agricultural importance, including 81 holotypes of Brazilian species. Approximately 65% of all specimens were deposited after 2000, mostly with the conduction of two BIOTA/FAPESP projects, representing 22 new and 160 known species, besides a large number of specimens waiting to be identified. The current curator of the collection, A.C. Lofego, was also supported by a "Young Investigator" grant (grant number: 2006/57868-9), for the study of mites of agricultural importance.

Two collections of mites of medical and veterinary importance have mostly benefited from FAPESP grants. The largest of these, Instituto Butantan, São Paulo state, was initiated in 1931 by the renowned mite taxonomist F. da Fonseca. It currently houses 70 tick species and 170 species of other mite groups, associated with mammals (54%), reptiles (12%), amphibians (12%), birds (5%), and insects (2%), as well as free-living mites (15%). In 2011, Darci M. Barros-Battesti coordinated a "Research Infrastructure Program - Biological specimen collections" grant, to upgrade the collection´s infrastructure and to provide digitized images of the specimens deposited. The support provided by FAPESP was fundamental for the improvement of the collection. As a result of the works conducted in a BIOTA/FAPESP project, a considerable number of new tick and other parasitic mite specimens were incorporated into the collection, allowing the complementary description of poorly described species. FAPESP's support allowed the cataloging of the deposited feather mite species. Additional support helped in the establishment, in 2013, of a laboratory (Special Laboratory of Zoological Collections) to replace the former infrastructure, damaged by a fire in 2010. A second important collection is the Feather Mite Collection of Universidade Federal de Santa Catarina, which currently houses 310 species belonging to 200 genera of 26 mite families. Although presently housed outside the state of São Paulo, this prosperous collection was initiated as part of a BIOTA/FAPESP project, coordinated by its present curator, Fabio

A. Hernandes, resulting in the deposit of 76 new and approximately 250 known feather mite species.

Similar to the Arachnida, the Subphylum Myriapoda presented a growth in the number of collections and specimens preserved, as available information assembled by Taddei et al. (1999) the sole collection of São Paulo, at the MZUSP, housed approximately 8,000 lots. Present data lists three collections in the state, at MZUSP, Instituto Butantan, and at Universidade Federal de São Carlos; these institutions house 26,711 lots (1,277, 24,204, and 1,230 lots, respectively), including type specimens of Diplopoda and Chilopoda.

Concerning the other main invertebrate collections (Annelida, Crustacea, Hexapoda and Mollusca), the MZUSP appears again as the most important depository institution in Latin America, including on its holdings the most diverse and the broadest geographical range series of the Neotropical fauna with around 7,000 lots of Annelida, 42,669 lots of Crustacea, 6,000,000 specimens of Hexapoda and 157,922 lots of Mollusca. The MZUSP collections also contain a considerable number of type specimens. In a recent survey, 23,058 type specimens were recorded, of which 6,797 are primary types (Holotypes, Neotypes, Syntypes, and Lectotypes).

There were also other important specific collections of terrestrial invertebrates at São Paulo state, mainly at ESALQ (Hexapoda of agricultural importance), FSP-USP (Diptera of medical importance), FFCLRP (Crustacea and Hexapoda: Hymenoptera and Diptera), UNICAMP (Hexapoda and Mollusca), UNESP campi of São José do Rio Preto (Hexapoda: Hymenoptera), Assis (Hexapoda: Ephemeroptera, Plecoptera and Trichoptera), Rio Claro (Hexapoda: Social Insects) and Botucatu (Hexapoda: Orthoptera).

The financial support provided by FAPESP for the growth of zoological collections in São Paulo was extremely important, with thousands of specimens collected and incorporated into the collections. A large part of the specimens incorporated into the collections of the state of São Paulo in the last 20 years was obtained during environmental assessment procedures, impact reports, and monitoring activities. With the economic development of Brazil, several new and large enterprises were implemented throughout the country, such as hydroelectric, wind farms, and solar power plants, as well as the growth of highway and rail networks, urban and industrial expansion, and all those activities demanded surveys and inventories, with the consequent collection of specimens of several groups of animals. For instance, during the execution of the environmental monitoring of the Usina Hidroelétrica de Jirau, in upper Rio Madeira in Rondônia state, from 2010 to 2014, there was a multi-taxon survey with a massive and standardized sampling effort. During this period, more than 500 specimens of 36 species of small nonvolant mammals (rodents and marsupials) were collected and deposited at the MZUSP; there were some important new records, as the first record of one specimen of *Rhagomys longilingua* to Brazil (Percequillo et al., 2017; but see Percequillo et al., 2011). Regarding the volant small mammals (bats), 630 specimens of 66 species, impressive numbers, with new records for the state of Rondônia (Brandão et al., 2016; Rocha et al., 2013; Rocha et al., 2015). Considering the arachnids, more than 21,000 lots were collected, with an impressive number of 245 species.

Another example refers to the environmental impact assessment studies that started in 2006 in the region of the upper Rio Juruena, one of the main tributaries of the Rio Tapajós basin, for the initial installation of nine cascade hydroelectric power plants. This environmental impact assessment work was carried out by a consulting company and the ichthyological material was sent to the Ribeirão Preto fish collection (LIRP) for confirmation of taxonomic identity and to be integrated into the collection, a requirement of the environmental agency. The collection campaigns were conducted quarterly until 2010 when the reservoirs of the hydroelectric power plans were constructed. From then on, the ichthyofauna monitoring program was started, being carried out every six months until now. Altogether, there were 15 years of uninterrupted shipping of ichthyological material from the Rio Juruena basin to the LIRP, which resulted in an increase of 2,435 lots belonging to more than 120 fish species.

Problems and Difficulties

Zoological collections are incomparable treasures and sources of knowledge, housing the authoritative records of the world's declining biodiversity. In the case of Brazil, such a value is drastically exacerbated because it is the country with the greatest planetary biodiversity, which is currently under severe threat (e.g., Garcia et al., 2021; Mataveli et al., 2022). These repositories also represent monumental investments in science by human society, and as such, their access must be facilitated, being its digitization and availability in virtual environments of extreme importance. Despite such urgencies, our collections are in desperate need of institutional support and commitment and are suffering from the lack of human and financial resources for their maintenance, safety, and modernization (more than 300 zoological collections in Brazil are in critical conditions, several of them unrecognized and unacknowledged by their mandatories; see https://www.youtube.com/watch?v=LPCIGi59gi8).

While we know that the origin of the obstacles related to biological/zoological collections rests on overlapping and complex philosophical, political, and budgetary layers, some of these issues will be revisited here as we believe that some of the solutions may be within FAPESP's reach. Here, we should also highlight that in the context of the disastrous reductions in the budget provided by the Brazilian federal government to the to the universities, museums, and research institutions (cf. Thomé & Haddad, 2019; Azevedo-Santos et al., 2021; Escobar, 2021a, b), FAPESP has played a major role providing a lifeguard for research and higher education activities, providing funds for the maintenance of some of the most important Brazilian biological/zoological collections, which are based in the State of São Paulo.

The difficulties of zoological collections are closely linked to (1) the lack of recognition of taxonomy as a robust science by peers and policy-makers; (2) the lack of trained professionals, both in relation to the theoretical and practical exercise of taxonomy and systematics (biology fields more intrinsically linked to collections), as well as in curatorial routines and collection management; and (3) legal, budgetary, and administrative impediments to the maintenance and permanence or continuity of collections, the raw material for taxonomy and systematics (cf. Ebach et al., 2011; Engel et al., 2021).

The lack of well-trained technical staff, specially systematists and taxonomists (Smith & Figueiredo, 2009), generates a tremendous impact on the knowledge of the national biodiversity (Paknia et al., 2015), including its conservation status, since the understanding and characterization of the biodiversity is the cornerstone of conservation. In fact, the impoverished economic and infrastructural situation of

natural history collections has several other consequences that can lead to its total inoperability, or to catastrophic situations such as the irreversible loss of its entire inventory. In addition to the obvious losses in terms of making the biodiversity known correctly as early as possible, the shortage of well-trained zoologists to identify specimens at a taxonomic level that is minimally sufficient for them to be cataloged and made available for study, causes a huge damming of zoological material, which is held in deposits, sometimes for decades. This is certainly a real problem for zoological collections in the State of São Paulo, especially for those that contain megadiverse groups and that routinely receive large lots of specimens of different groups, such as insects, crustaceans, and fishes.

It is perceived that, increasingly, multidimensional/integrative projects are sought after by research funding agencies, which therefore hold greater chances of receiving support, to the detriment of projects thought of as conventional, such as those of a taxonomic nature. However, well-done taxonomic reviews contributing to the effective understanding of the national biodiversity are dependent on time-consuming examinations of extensive series of specimens (which are often hidden in collection drawers and shelves), as well as thorough literature reviews, and whole nomenclatural work. The taxonomic work linked to the collections, therefore, due to its importance in providing the most fundamental data for almost all areas of biology (Ebach et al., 2011), must be recognized as a valuable science *per se*, receiving the proper prestige from research funding agencies.

The delay in publishing data from the collections is also aggravated by the lack of specialized technical staff in zoological collections, who today have to deal, in addition to day-to-day practices (preparation and maintenance of specimens, cataloging and borrowing, for example), with all the new image generation routines (radiographs, 3D computed tomography reconstructions), in addition to learning about computer technologies for data sharing. The digitalization of all analog or printed data from specimen labels, field notes, images, and more, is an urgent matter not only because it can increase the visibility and accessibility of the zoological collection, but also because it helps to preserve the long-term integrity of the specimens, as it prevents their excessive manipulation, allowing students, researchers and the general public to inspect metadata and images digitally. This process started not too long ago, but it has led to a considerable increase in the use of collections by society (Nelson & Ellis, 2019; Hedrick et al., 2020), but it still poses major technical and organizational challenges. Unfortunately, as a result of the economic crisis, public universities of the State of São Paulo and elsewhere have limited the hiring of technical support professionals, including those dedicated to curatorial work, to replace retiring staff members.

The side effect of the exponential growth of zoological collections in the State of São Paulo mentioned above is the proportional increase in demands for their uses, which are now calibrated with the expectation of overcoming, or, more realistically, alleviating the biodiversity crisis. For instance, there is a pressing need to audit data from collections to qualify them for large-scope investigations, such as global biogeographic and integrative meta-analyses (e.g., Canhos et al., 2015; Dagosta & Pinna, 2019; Batista et al., 2021; Dagosta et al., 2021), as well as the construction of official lists of endangered species (https://www.icmbio.gov.br/). These reviews, which depend on highly qualified professionals, are essential, both to update taxonomic identifications and to properly georeferencing the collection localities, so that they can be used at all scales of investigation. This is especially important in relation to ancient records, which are generally inaccurate, as they represent the historical testimony of a biota that is often no longer extant. This situation of lack of technical support in the collections is partially circumvented by the voluntary work of undergraduate, graduate, and post-doctoral students, and, more occasionally, by FAPESP technical training fellows linked to specific research projects, but these palliative solutions do not allow for continuity in the work and require a large investment of time, on the part of the curators, as they must continuously train people for this fundamental role of technical curation.

Another problem, apparently of lesser impact, concerns the acquisition of furniture (shelves, compacting cabinets) and supplies for routine use, such as those used for preparation and maintenance of specimens, such as containers (jars, steel boxes, drawers), special papers for labels and tags, basic supplies for fixing and preservation (alcohol, formaldehyde), etc. Although apparently low-cost for the most part, such items quickly run out and become expensive due to the high amount needed to process the ever-growing collections of the state of São Paulo, as shown here. Once again, in the absence of institutional resources for the acquisition of such items, shortages are intermittently supplied through auxiliary resources from scientific projects.

One of the most serious problems concerns the physical infrastructures that house the zoological collections in the State of São Paulo, which, for the most part, are old buildings not originally designed for this purpose. As a result, many of these buildings do not offer possibilities for expansions, have inadequate hydraulic and electrical installations, or even do not have conditions to receive adequate security devices. Furthermore, zoological collections are highly flammable, either because some of them preserve most of their specimens dry, such as birds and insects, or because of the flammable preservatives used to keep other types of animals, such as fishes, amphibians, and reptiles. Fire safety features, such as easily accessible escape routes, fire doors, and CO_2 devices, for example, are not available in many of the zoological collections in the State of São Paulo. Unfortunately, institutions that hold scientific collections and other museums and cultural institutions, in São Paulo and in other states, have had disheartening experiences in recent times.

One of the saddest episodes was the fire on the herpetological and arachnological collections of Instituto Butantan in 2010, which destroyed more than 70,000 specimens of snakes and approximately 60,000 lots (one-third of the collection) of the arachnids and centipedes. It is important to emphasize that this tragic event took place in São Paulo, one of the richest and culturally important states of the union, which was not able to protect from fires important and irreplaceable collections and cultural monuments, such as the Butantan, but also the Teatro Cultura Artística [2008], Memorial da América Latina [2013], Centro Cultural Liceu de Artes e Ofícios [2014], Museu da Língua Portuguesa [2015], Cinemateca Brasileira [2016], and more recently, UNESP Rio Claro [2022]). Another terrible impact on Brazilian Zoological collections was the fire on Museu Nacional/Universidade Federal do Rio de Janeiro, in 2018, which consumed thousands of specimens (including many lent by collections of São Paulo State), all lost forever, together with an important part of our history (Kury et al., 2018). Since 2010, after the Butantan tragedy, the MZUSP, which houses the largest zoological collections in São Paulo, has carried out deep renovations in its building, with the financial support of USP and FAPESP, to install modern security

systems (fire hydrants, smoke detectors, and thermal protection systems) together with the gradual replacement of wooden partitions with non-flammable materials and the installation of barriers and fire protection doors. At the same time, a trained fire brigade of employees has been created to coordinate the evacuation of the building, in the event of an emergency, and a service contract has been put in place to keep a team of civil firefighters on standby in the building 24 hours a day. Unfortunately, this series of actions performed at MZUSP has not yet been minimally replicated by other institutions that maintain collections in Brazil or even in São Paulo. Therefore, we urge those other universities, research centers, and research support institutions (public and private) to follow this type of procedure, putting in place programs envisioning the safety of the zoological collections representing historical inheritance.

Possible Solutions

Regarding the lack of new taxonomists, it is essential that FAPESP and universities in São Paulo encourage the training of new generations of taxonomists, especially in zoological groups for which specialists are rare or even nonexistent. In this sense, it is necessary to promote greater scientific emancipation in taxonomy, increasing the number of fellowships (Master in Science - MSc, Doctoral – DT, and Post-Doctoral - PDJ) intended for projects on taxonomy, while also promoting taxonomic projects that have greater independence and easing the requirement that the taxonomist advisor be an authority in the specific group that is intended to be reviewed.

It would be quite important the authorization to use FAPESP's Institutional Technical Reserve for the acquisition of items necessary for the routine maintenance of collections, which, although they have a low individual cost, must be purchased in large volumes, given their everyday use. In addition to this, these valuable resources also might be employed to implement safety measures to prevent fires and other damages that affect our collections. The scholarships of technical training, which currently can be requested only associated with research grant projects (regular and thematic projects) could be requested regularly, as other scholarships: this will provide the workforce to curators that are struggling to maintain the collections under their guard.

However, considering the huge amount of investment provided by FAPESP in our collections, it is quite important that the institutions benefiting from these resources take great responsibility to safeguard the collection. The mandatories of institutions that harbor collections should consider including resources on their budgets to collections to obtain safety certificates, ensuring their permanence for many generations to come. As stated above, we may even be able to reconstruct the buildings, collect new specimens and fill new cabinets, but the specimens lost are irreplaceable. Previous scientific hypotheses elaborated with them, will not be able to be tested, hampering an important aspect of the growth of biological thought.

Final Remarks

Zoological collections are a heritage of humanity and are essential not only for the improvement of our knowledge of biodiversity, but also with direct implications to the economy, ecology, and conservation, among other services provided by these biological resources. Zoological collections have central roles promoting scientific efforts to curb specific knowledge shortfalls, such as Linnean (deficiencies of taxonomic aspects; e.g., Prado et al., 2021) — including the decrease of "shelf-life" between specimens collection vs. species description —, Wallacean (representing geographic lack of distribution; e.g., Aguiar et al., 2020; Bogoni et al., 2022), and Raunkiaeran (representing important traits of life-history traits and ecomorphology; e.g., Crane et al., 2021), which are strongly persistent and biased across the tropics. Beyond the frontiers of the academy, zoological collections have a fundamental role in the dissemination of knowledge to broader society, through exposition initiatives and science outreach, increasingly frequent around the world.

Recently, Colella et al. (2020) stated that "Emerging infectious disease response hinges on sampling depth across space, time, and taxonomy, the very sampling enabled by museum biorepositories.". They also acknowledged that collections with information available on the web would be essential for effective global surveillance and mitigation of emerging infectious diseases, to fill a shortfall recognized by OneHealth approach regarding environmental components on the understanding and prevention of such outbreaks. The risk of episodes of viral diversification, spillover, and circulation, for example, is especially high in Brazil, since it is the country with the greatest planetary biodiversity (therefore, with numerous natural reservoirs; e.g., Bueno et al., 2022), which, at the same time, is undergoing dramatic environmental changes.

The Sociedade Brasileira de Zoologia (SBZ) and other zoological societies are organized in a group, under the leadership of the president of SBZ, the Forum das Sociedades Brasileiras de Zoologia (Forum), that is involved with the diagnosis of our collections to provide the policymakers at several administrative levels (from university deans to ministries of science, environment, and culture) crucial information to the establishment of more decisive regulatory marks for our collections. Moreover, the Forum is involved with the organization of courses and workshops to provide training to collection personnel and to provide even more value to the specimens housed in museums and collections.

Recently, FAPESP just opened a research grant program for submissions of proposals focusing on collections, called "Descoberta e Coleções", within the Biota Program, an important initiative that will bring resources for the generation of new data on our biodiversity, but also the qualification (including digitization, making data available on online repositories, etc.) of our collections. The Universidade de São Paulo also just opened a grant opportunity for the improvement of the infrastructure of collections. These are examples of the recognition of the value of these collections and our need to maintain these millions of specimens housed in institutions of São Paulo in appropriate conditions for several generations of scientists. Another breadth of hope was the publication of a note in late August by the Ministério da Ciência, Tecnologia e Inovação (Brazilian Ministry of Science, Technology and Innovation) creating the Rede Brasileira de Coleções Biológicas Científicas (Brazilian Network of Scientific Collections). This initiative aims to provide support and training to collection staff and to stimulate collections to provide their databases in one online system, that would be accessible to all sectors of society interested in biodiversity. This is, in fact, very important as it may bring a significant advancement in the knowledge of our collections and specimens housed by them, although most of our collections lack digitized information. We sincerely hope that this network sensitizes our policymakers, public power and private institutions to provide funding for the maintenance of our collections.

The Universidade Estadual de Campinas (UNICAMP) is about to inaugurate a new museum exhibition of the Museu de Diversidade Biológica, formerly known as Museu de Zoologia "Adão José Cardoso". This is an important and impressive initiative that reassures the strategic importance of our collections to the knowledge of our biodiversity and the transmission of this knowledge to society. Also, the biological collections of the Department of Biology, FFCLRP, at the University of São Paulo, on the Ribeirão Preto campus, have been relocated to compose a multi-user research facility, the Center for Documentation of Biodiversity (https://uspmulti.prp.usp.br/public/centrais/105), which will form, together, the embryo of the Museu da Biodiversidade da Universidade de São Paulo (cf. Bockmann et al., 2011).

These are important initiatives that reassures the strategic importance of our collections to the knowledge of our biodiversity and to the transmission of this knowledge to society. Research and teaching institutions in São Paulo that house specimens under their care start to value this important patrimony and this heritage as these collections must represent the most valuable testimony of the Brazilian biodiversity, records of our past and windows to our future, essential to our academic, scientific, cultural and social sovereignty. It is imperative that, for the correct preservation and development of this immense treasure of ours, government agencies, such as FAPESP (as well as other funding institutions, public and private) play a more active role in the preservation of these collections and start a continuous program to provide financial resources to the management and improvement of the collections, ensuring their long-term financial sustainability. Equally important is the creation and perpetuation of programs with the purpose of upgrading and maintaining the physical and technological infrastructure, ensuring the growth of the zoological collections and the tools and processes needed to make them fully accessible, both physically and digitally. Interrelated to all these issues addressed here are the recruiting, training, and supporting of human resources. A highly skilled collection workforce must be cultivated, being indispensable to the long-term sustainability of the zoological collections.

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Associate Editor

Carlos Joly

Conflicts of Interest

There is no conflict of interest.

Ethics

This study did not involve human beings and or clinical trials that should be approved by one Institutional Committee.

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