

Original Article

A comprehensive survey of mammal collections and genetic resources in South America: challenges and directions

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ABSTRACT

Natural history collections serve as crucial infrastructure for both basic and applied scientific research, providing temporal and spatial specimen data needed to understand biodiversity, environmental change, and emerging pathogens. This study surveyed mammal collections across South America to assess the scope and quality of this infrastructure. A detailed questionnaire was distributed to curators and collection managers from

May 2021 to February 2022, gathering information on institutional characteristics, collection size, taxonomic and geographical scope, preservation methods, genetic resource availability, percentage digitization, financial support, and challenges such as funding limitations. Our survey identified 141 collections; more than twice the number reported by the American Society of Mammalogists in 2018. South American collections house ~746000 catalogued specimens, including 452 primary type specimens, representing only a modest proportion of the vast mammalian diversity of South America. Collections are geographically concentrated in Argentina, Brazil, Colombia, and Peru, with a significant gap in the Guianas region and a decline in responses from Venezuela. The survey highlights four major challenges facing South American collections: staffing shortages, minimal cryogenic infrastructure, incomplete digitization, and sustainability issues. This initiative aims to raise awareness of collections in South America, plan for strategic growth, and strengthen research capacity to address pressing global issues, such as climate change, zoonotic disease transmission, and long-term conservation strategies.

Keywords: biodiversity research; biorepository; conservation; Mammalia; natural history museum; Neotropics

INTRODUCTION

Since the establishment of the first natural history museums in the 17th and 18th centuries, biological collections have served as essential scientific infrastructure for biodiversity research. The long-term accumulation of specimens provides irreplaceable temporal and spatial datasets crucial for understanding environmental change, biogeographical patterns, and the emergence of pathogens. With the advent of new methodologies, such as museomics (the retrieval and analysis of genetic material from preserved specimens; [Speer *et al.* 2022](#)), and advances in digital imaging techniques, such as micro-computed tomography, natural history collections have become increasingly valuable repositories of genomic and phenotypic data ([Bailey *et al.* 2016](#), [Raxworthy and Smith 2021](#), [Bertrand *et al.* 2022](#)).

Natural history collections are particularly vital for documenting and investigating biodiversity in megadiverse regions where taxonomic knowledge remains incomplete or rapidly evolving. South America exemplifies this context: it is one of the most biodiverse regions on the planet and, with >1570 native mammal species, hosts 23% of global mammalian diversity within only 12% of the continental area of the Earth ([Burgin *et al.* 2018](#), [MDD 2024](#)). Our understanding of mammalian diversity on the continent is still growing, with new genera and species regularly being described ([MDD 2024](#)). New mammal species descriptions occur not only for poorly known and highly species-rich taxonomic groups, such as rodents, bats, and marsupials, but also in well-studied orders, such as Primates, Pilosa, Artiodactyla, and Carnivora (e.g. [Gualda-Barros *et al.* 2012](#), [Helgen *et al.* 2013](#), [Miranda *et al.* 2018](#), [Sandoval *et al.* 2024](#)).

Although several new species discoveries have resulted from fieldwork in unexplored or poorly surveyed areas, most newly described species are derived from detailed studies of variation in specimens housed in natural history collections ([Cordeiro-Estrela *et al.* 2021](#)). In fact, natural history collections provide the infrastructure and expertise to document, study, and understand the basic biology of species and their environments ([Cook 2018](#), [Miller *et al.* 2020](#), [D'Elia 2024](#)), and they are central to any integrated research programme investigating different aspects of mammalian evolution, ecology, natural history, and conservation ([Cook and Light 2019](#), [NASEM 2020](#)).

Likewise, these collections are crucial for identifying and understanding mammalian species that serve as vectors or reservoirs for infectious diseases and the linked dynamics of the associated pathogens, thereby allowing for the development of

effective prevention and control strategies ([Han *et al.* 2016](#), [Thompson *et al.* 2021](#)). Technological advances have increased the value and importance of mammal collections for understanding host–pathogen associations and dynamics ([Colella *et al.* 2021](#), [Thompson *et al.* 2021](#)), emphasizing even more the importance of high-quality voucher and tissue preservation (e.g. frozen, ethanol, buffered) to address diverse research questions.

As one of the regions with the highest numbers of newly described mammal species ([MDD 2024](#)), South America plays a crucial role in global biodiversity. An inventory of natural history collections housing this diversity, including genetic resources and type material, is therefore essential for assessing the scope and quality of this crucial infrastructure. Given the many biodiversity hotspots in the region ([Mittermeier *et al.* 1998](#)), such an inventory can also help to identify key gaps in collection efforts and conservation priorities. By establishing a baseline of the location, size, and holdings of South American mammal collections, we will also be able to integrate such collections and their associated data better into biodiversity research, training, and education, in addition to responding to the growing needs of the life sciences research community in an ever-changing world ([Pyke and Ehrlich 2010](#), [NASEM 2020](#)). Furthermore, understanding the geographical and taxonomic scope of existing collection resources and the availability of different types of specimen preservation (e.g. frozen or ethanol-preserved tissues, skin, skeletons, whole body fluid) is paramount for planning future field studies, laboratory work, and data-mining investigations, in addition to establishing plans to support and improve infrastructure across the region ([Blom 2021](#), [Percequillo *et al.* 2022](#), [D'Elia 2024](#)).

South American mammal collections have long been under-represented in large-scale inventories. For instance, the last survey by the American Society of Mammalogists (ASM) documented only 16 collections in Brazil ([Dunnum *et al.* 2018](#)), whereas a later survey by the Brazilian Society of Mammalogy (SBMZ) identified 71 ([Chiquito *et al.* 2021](#)). Although a few national mammal societies and researchers have produced or consolidated directories for mammal collections in Brazil ([Chiquito *et al.* 2021](#); see also [Alvarez *et al.* 2021](#), [Percequillo *et al.* 2022](#)), Chile ([Ortiz *et al.* 2023](#)), and Colombia ([Rodríguez-Posada *et al.* 2020](#)), a comprehensive list of South American mammal collections is lacking. Moreover, there is no detailed inventory of which collections harbour genetic resources (e.g. frozen tissues) available.

Here, we present the results of a survey of mammal collections across South America in order to gain a better understanding of

the spatial distribution of these resources, their total holdings, taxonomic and geographical coverage, type material, staffing, digitization levels, and genetic resources. Overall, the survey provides a snapshot of the present state of mammal collections in South America, offering a foundation for future collaborative efforts aimed at improving infrastructure, management, preservation, and accessibility. Through this initiative, we hope to increase awareness and use of existing collections in South America, identify key challenges and limitations to their growth and sustainability, and promote the strategic growth of this foundational biodiversity research infrastructure.

MATERIALS AND METHODS

We conducted a survey of South American mammal collections using an optional questionnaire ([Supporting Information, Appendix S1](#)) hosted by Google Forms (Google LLC) from May 2021 to February 2022; four additional collections replied in 2024–2025. Our primary objective was to create a comprehensive directory of mammal collections in South America while also assessing their growth, maintenance practices, accessibility, and challenges. Mammal collections in South America were contacted by: (i) emailing curators mentioned in collections inventories published by the ASM ([Dunnum *et al.* 2018](#)) and SBMz ([Chiquito *et al.* 2021](#); see also [Bezerra 2012](#)); (ii) actively researching collection data; and (iii) soliciting additional responses through the Museums and Emerging Pathogens in the Americas (MEPA) Community of Practice ([Colella *et al.* 2021](#)), to reach a diverse array of collections, ranging from large national institutions to smaller, more regional, or specialized collections. This survey did not require a review by an Institutional Review Board or by the Brazilian Federal Research Ethics Commission system ([CONEP 2022](#): Resolution 674, Article 26).

Our questionnaire aimed to capture a range of information relevant to understanding the status and potential of mammal collections across the continent. The first section collected general information about each institution, including its name, acronym, and contact details (email, telephone number, and address), in addition to the year of establishment and institutional status (university-affiliated, public research institution, or private institution). The second section focused on characteristics of the collections themselves: their size (number of specimens), geographical breadth (local, national, or international), taxonomic scope at the order level, and number of type specimens, among other information.

Part of the survey was dedicated to the preservation and storage of genetic resources. Respondents were asked to provide details on the type(s) of tissue(s) collected (e.g. liver, muscle, ear clips), in addition to tissue storage conditions (e.g. ethanol, -20°C , -80°C , liquid nitrogen). This section provided detailed insight into the preservation modes and infrastructure available to various institutions, highlighting both advanced capabilities and resource limitations. Another aspect of the survey focused on digitization, to gauge the extent to which collections have been digitized, whether databases are available online, and how accessible specimen resources are to external researchers and the public (e.g. public databases or data aggregators, such as GBIF, SpeciesLink, or VertNet).

Last, the survey explored issues related to institutional support, such as access to funding and personnel. Respondents were asked about the financial resources available for collection maintenance and growth, in addition to the availability of full-time trained staff to manage and curate the collections. This helped to identify challenges in terms of sustainability and expansion, especially for smaller or less well-funded institutions. Curators and collection managers were encouraged to provide additional comments on anything not covered in the survey to identify the specific needs or challenges faced by different institutions, such as gaps in infrastructure or future goals.

RESULTS

Survey responses and geographical distribution of collections

A total of 114 responses from 111 institutions were received (see [Supporting Information, Appendix S2](#)), spanning 12 of 13 countries in South America ([Table 1](#)). [Three institutions (MACN, MFA, and UFES) replied more than once, because their tissue collections are separated administratively from their specimen collections. MFA also houses an osteological collection. Here, we regard these as distinct collections.] With the addition of data from 25 collections listed by [Dunnum *et al.* \(2018\)](#) that did not respond to our queries, we arrive at a total of 141 collections ([Table 1](#)). Notably, our survey increased the number of documented South American collections by $>112\%$ (from 66 documented by [Dunnum *et al.* 2018](#)). Our survey includes the first known collection in Guyana (the Centre for the Study of Biological Diversity at the University of Guyana, UG/CSBD) and the first collection in French Guiana (the JAGUARS collection in Cayenne). The National Zoological Collection of Suriname, the only collection from Suriname included in the ASM 2018 survey, did not participate in our survey. Likewise, of the four collections from Venezuela included by [Dunnum *et al.* \(2018\)](#), only one replied to our survey.

These 141 collections are unevenly distributed across countries, with notable concentrations in Brazil, Argentina, Colombia, and Peru, whereas regions such as the Guianas remain underrepresented ([Fig. 1](#)). Approximately 36% ($N=45$) of collections are located in Brazil, 20% ($N=21$) in Argentina, and 13% ($N=17$) in Colombia. Other countries have between one and nine mammal collections ([Table 1](#)). At the city level, Bogotá, Colombia is home to the highest number of collections ($N=6$), followed by Montevideo (Uruguay), Medellín (Colombia), Porto Alegre (Brazil), Asunción (Paraguay), and Ciudad Autónoma de Buenos Aires (Argentina), each with four collections. Santa Fé (Argentina), Santiago de Chile (Chile), Lima (Peru), Quito (Ecuador), and Rio de Janeiro (Brazil) host three collections each, and 13 other cities house two collections.

Characteristics of the collections

Establishment of mammal collections in South America began in the second half of the 19th century. Among the first institutions are the Museu Nacional (1842), Museu Paraense Emilio Goeldi (1866), and Museu de Zoologia da Universidade de São Paulo (1887) in Brazil; Museo Nacional de Historia Natural (1857) in Chile; and Museo Nacional de Historia Natural (1886) in Uruguay. In the first half of the 20th century, only 18 collections were

Table 1. Number of mammal collections and catalogued specimens in South America summarized by country.

Country	Present survey (2021)	ASM survey (2018)	Catalogued specimens (present survey)	Catalogued specimens (ASM + present survey)
Argentina	21	14 (7)	92009	104801
Bolivia	3	4 (1)	15176	15441
Brazil	45	16 (6)	293181	334950
Chile	6	8 (3)	15635	20589
Colombia	17	4	75484	75484
Ecuador	6	6 (1)	38389	38639
French Guiana	1	0	634	634
Guyana	1	0	351	351
Paraguay	5	5 (3)	5976	12646
Peru	4	3 (2)	55678	76185
Suriname	0	1 (1)		390
Uruguay	4	1	16761	16761
Venezuela	1	4 (3)	6783	49677
Total	114	66 (27)	616057	746548

The 'Present survey' column represents the number of unique collection responses to our survey. 'ASM survey (2018)' indicates the total number of collections identified in each country by [Dunnum *et al.* \(2018\)](#), with the number of identified collections that did not reply to our survey included in parentheses. The two rightmost columns represent the number of catalogued specimens found in collections by country for the present survey and for the combined data of our survey and that of [Dunnum *et al.* \(2018\)](#). Abbreviations: ASM, American Society of Mammalogists.

established ([Fig. 2A](#)); however, the rate of establishment increased significantly in the second half of the 20th century, with the creation of 39 new collections. This trend continued into the 21st century, with 43 new mammal collections established between 2001 and 2022.

The 114 South American mammal collections surveyed here house a total of 616057 catalogued specimens ([Table 1](#)); adding the data from 25 collections in the ASM survey that did not respond directly to our inquiries yields a total of 746548 specimens archived in South America. [Two collections (Museo de Ciencias Naturales e Historia, Instituto Montoya, Argentina and Colección del Centro Chaqueño de Conservación e Investigación, Paraguay) listed by [Dunnum *et al.* \(2018\)](#) did not provide holdings data; thus, the total number of collections with specimen counts is 139.] Brazil currently houses the most specimens ($N = 334950$), followed by Argentina (104801), Peru (76185), and Colombia (75484). Only 20 collections house ≥ 10000 specimens ([Fig. 2B](#); [Table 2](#)), accounting for about two-thirds of the total mammal specimens archived in South America. In turn, most collections ([Fig. 2B](#)) are medium-sized ($N = 63$; 1000–10000 specimens) or smaller ($N = 56$; < 1000 specimens). The collections surveyed in our study reported a total of 99207 specimens (16%) catalogued in the years between 2016 and 2021. Notably, one-third of the surveyed collections ($N = 36$) incorporated between 25% and 50% of their total volume of catalogued specimens within those 5 years ([Fig. 2C](#)). Furthermore, it is estimated that ~ 107547 uncatalogued specimens remain backlogged (i.e. unprocessed) in South American collections as of 2022.

Most of the surveyed mammal collections ([Fig. 2D](#)) were institutionally affiliated with universities, as part of their academic departments, natural history museums, or research institutes, with 71 collections at public universities and 13 at private universities. The remaining collections were distributed among other institutions, including independent museums ($N = 14$), public research institutions (12), or private institutions or non-governmental organizations (4).

Type material and catalogue

Considering data from this survey and from [Dunnum *et al.* \(2018\)](#), ≥ 452 name-bearing type specimens (holotypes, neotypes, or lectotypes) are housed in 53 collections. Six of these collections hold ≥ 20 type specimens (see [Supporting Information, Appendix S2](#)), representing 57% of the total. Additionally, 687 paratypes are housed in the collections that replied to our survey. Overall, ≥ 550 nominal taxa have type material in South American collections.

Ninety-six of the 114 surveyed collections (84%) have digital catalogues, whereas 18 lack digital databases. Among those with digital catalogues, the majority ($N = 84$) use Microsoft Excel, including 78 that use Excel as their sole 'database' system. Seven collections use a generic relational database system, such as Microsoft Access, LibreOffice Base, or FileMaker Pro. Five collections use the Specify collection management platform ([Beach 2018](#)), mostly in conjunction with Excel, and one collection uses Google-Form as its primary digital catalogue platform. Only eight collections follow Darwin Core data standards ([Wieczorek *et al.* 2012](#)).

As of early 2022, only 29 of the 96 digitized collections (30%) were partly or totally searchable online. Most of these catalogues ($N = 25$) are hosted at the Global Biodiversity Information Facility (GBIF) or their national nodes, such as Sistema de Información sobre Biodiversidad de Colombia (SiB-Colombia), Sistema de Informação sobre a Biodiversidade Brasileira (SIBBr), and Red Argentina de Datos y Colecciones Biológicas, Argentina (RADyCB); other public databases included SpeciesLink, Brazil (SIBBr), Centro Geoespacial para la Biodiversidad, Bolivia (CGB), and Catalogador de Información Biológica, Colombia (CEIBA, IAvH). Seven more collections were in the process of making their digital data publicly available when this survey was conducted.

Staff and resources

Twenty-one institutions (18%) do not have a full-time employee dedicated to managing their mammal collections ([Fig. 2E](#)). Additionally, 32% of collections were managed by only one full-time

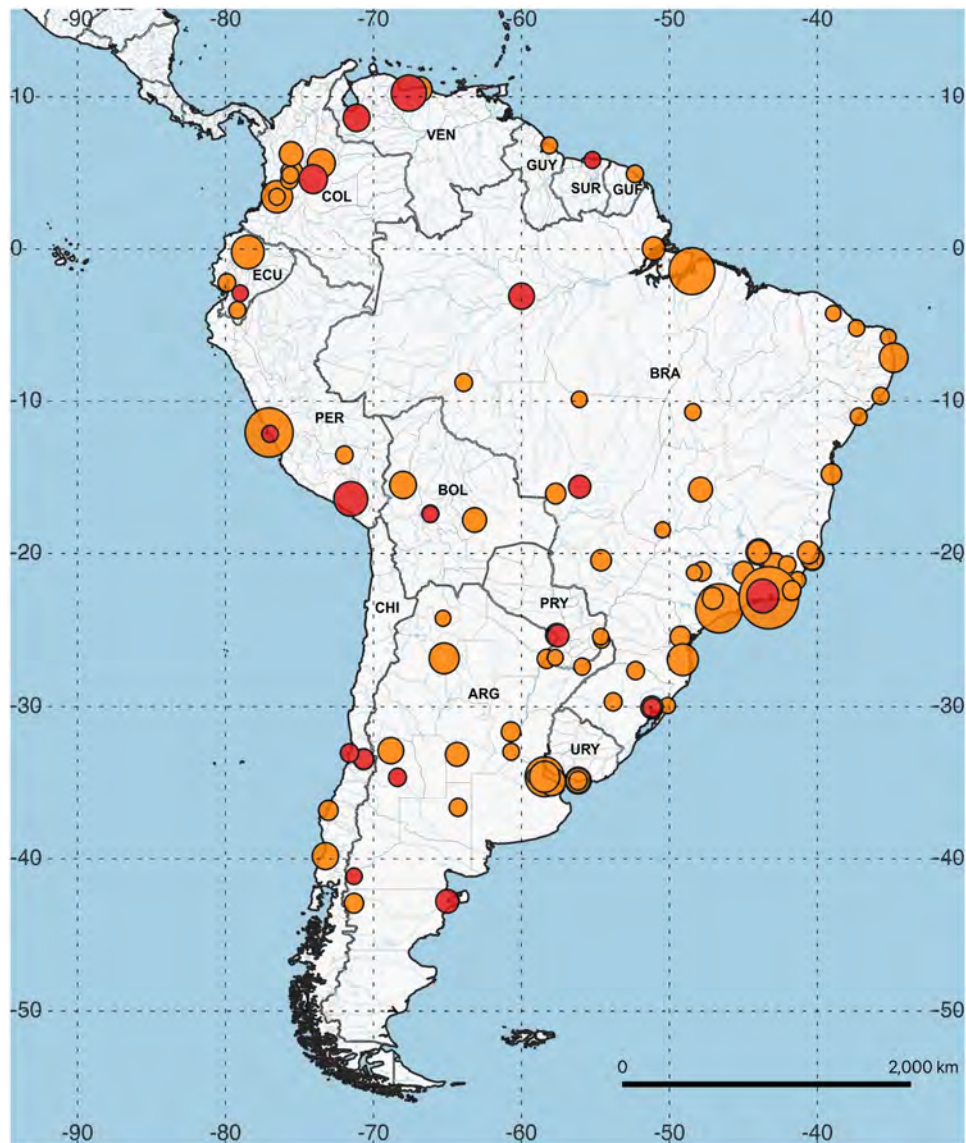


Figure 1. Geographical distribution of mammal collections in South America. Orange circles represent collections that responded to our survey; red circles represent collections documented by [Dunnum *et al.* \(2018\)](#) that did not respond to our survey. Circle size is proportional to number of catalogued specimens. South American countries are denoted by the following abbreviations: ARG, Argentina; BOL, Bolivia; BRA, Brazil; CHI, Chile; COL, Colombia; ECU, Ecuador; GUF, French Guiana; GUY, Guyana; PER, Peru; PRY, Paraguay; SUR, Suriname; URY, Uruguay; VEN, Venezuela.

employee, while 30% have two employees working in the collection. The remaining 19% of collections are supported by teams, ranging from three to nine full-time employees.

Although inherently subjective, 20 collections reported having ‘constant and sufficient’ financial support during the 5 years leading up to 2021. Most of the well-funded collections were small (10 have <1000 specimens) or medium sized (five have <10000 specimens), and the vast majority of those ($N=14$) were directly administered by universities. In contrast, 54 collections (47%) indicated that they lacked both constant and sufficient funding. Remaining collections reported either having constant but insufficient funding ($N=36$) or sufficient but inconsistent funding ($N=4$).

Four collections (Colección de Mamíferos de la Universidad Nacional de Río Cuarto, CUNRC; Escuela Politécnica Nacional,

Colección de Vertebrados, Sección de Mastozoología, MEPN-M; Museo Paraense Emilio Goeldi, MPEG; and Colección Biológica Museo de Itaipu—Mamíferos, CBMI-m) reported undergoing relocation or reorganization in recent years. It is also worth noting that two natural history institutions reported destructive fire incidents in the present century: Museu Nacional (Brazil) had their mammal exhibit collection annihilated in a fire in 2018 (the research collection was stored in a different building) and the Museo Gallardo (Argentina) suffered a fire in 2003, which destroyed its facilities and nearly 80% of its holdings, in addition to the information associated with the specimens.

Genetic resources

Among surveyed collections, 88 reported tissue holdings, totalling 106735 samples. Most tissue collections were relatively small,

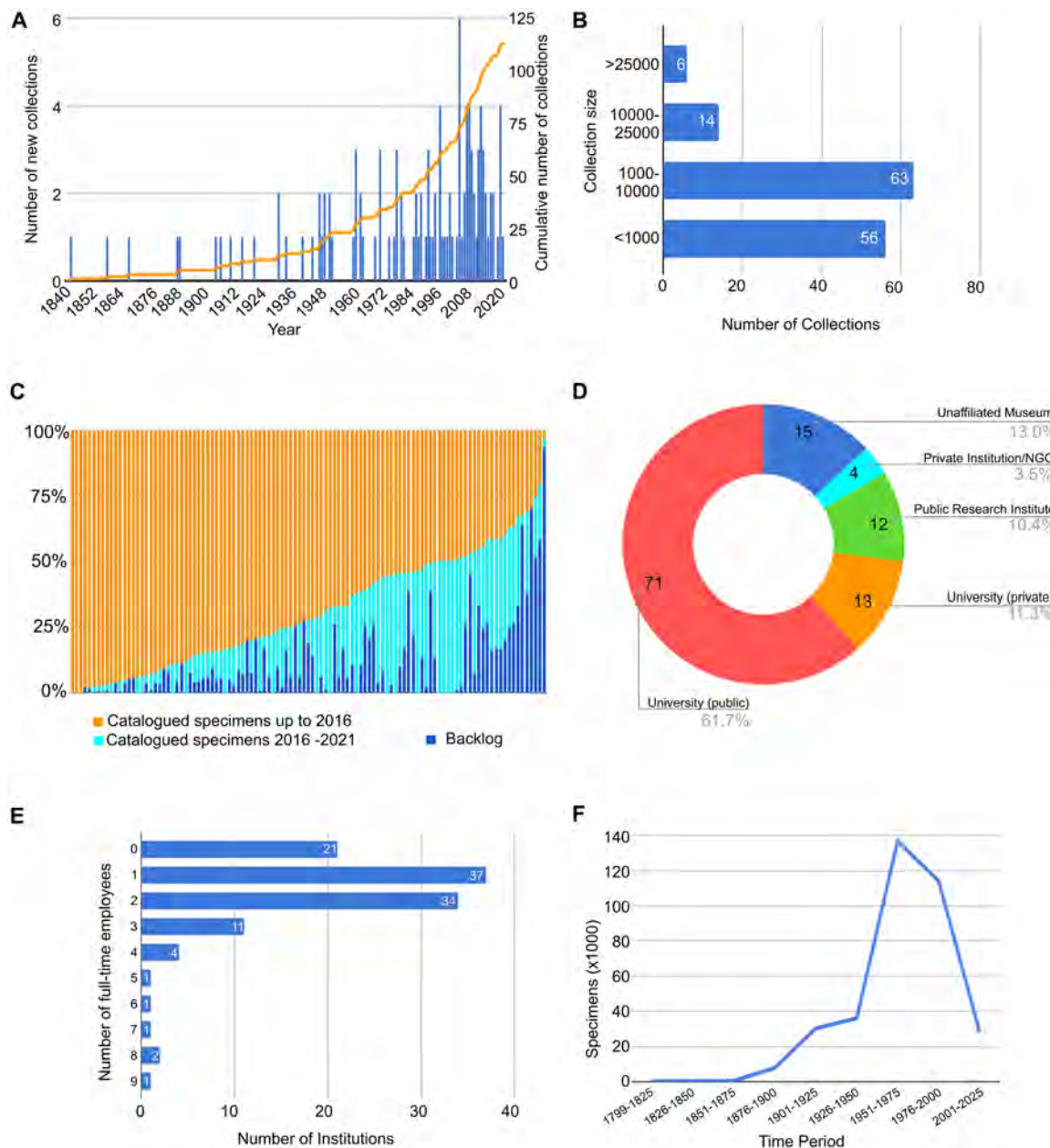


Figure 2. Historical trends and characteristics of mammal collections in South America. A, establishment of mammal collections (1840–2022) in South America, based on the present survey ($N = 113$; remaining 28 collections do not have data on establishment date). Number of established collections per year (blue bars, left vertical axis) and the cumulative number of collections (orange line, right vertical axis). B, distribution of mammal collection sizes, based on the total number of catalogued specimens, as of 2022 ($N = 139$; two collections do not have data on specimen figures). C, percentage of specimens catalogued prior to 2016 (orange), proportion catalogued between 2016 and 2021 (light blue), and the remaining proportion of backlog or uncatalogued specimens (dark blue) among mammal collections in South America, each represented by a single vertical bar, surveyed in 2021–2022 ($N = 109$). D, type of institution maintaining mammal collections in South America (2021–2022). ‘Unaffiliated Museum’ refers to independent museums not affiliated with universities or other institutions. E, number of full-time employed staff members devoted to mammal collections across South America. F, holdings of mammalian specimens of South American origin in North American and European natural history collections. Data were downloaded from the Global Biodiversity Information Facility (GBIF) using the search terms ‘Mammalia’, ‘Preserved specimen’, and ‘South America’, then filtered for European and North American collections and availability of collection date data. Specimen records were then pooled in 25 year increments and plotted in Microsoft Excel. Total specimens = 354549.

with 52 containing tissues from <1000 specimens and 26 containing tissue from ≥ 1000 specimens; 10 collections with tissue holdings did not have information on its size. Only two collections currently house tissues for >10000 specimens: Coleção Integrada

de Mamíferos Silvestres Reservatórios—COLMASTO/IOC/Fiocruz and Museo de Historia Natural de la Universidad Nacional Mayor de San Marcos. Despite a moderate correlation between overall collection size and volume of tissue holdings ($R^2 = 0.356$),

Table 2. Specimen holdings at the 20 largest mammal collections in South America.

Rank	Collection	Acronym	Country	Year established	Catalogued specimens
1	Museu Nacional/Universidade Federal do Rio de Janeiro	MN	Brazil	1842 ^a	89726
2	Museo de Historia Natural de la Universidad Nacional Mayor de San Marcos	MUSM	Peru	1918	52905
3	Museu Paraense Emílio Goeldi	MPEG	Brazil	1866	46903
4	Museu de Zoologia da Universidade de São Paulo	MZUSP	Brazil	1887 ^b	36683
5	Colección Nacional de Mastozoología, Museo Argentino de Ciencias Naturales 'Bernardino Rivadavia'	MACN-Ma	Argentina	1928	30127
6	Colección Nacional de Mamíferos 'Alberto Cadena García', Instituto de Ciencias Naturales, Universidad Nacional de Colombia	ICN-MA	Colombia	1959	25380
7	Museo de la Estación Biológica de Rancho Grande	EBRG	Venezuela	N/A	22894
8	Universidad Nacional de San Agustín de Arequipa, Museo de Historia Natural	MUSA	Peru	N/A	20100
9	Colección de Mastozoología, Museo de Zoología de la Pontificia Universidad Católica del Ecuador	QCAZ-M	Ecuador	1979	18058
10	Coleção Adriano Lúcio Peracchi	UFRRJ	Brazil	N/A	17000
11	Colección de Mamíferos de la Universidad del Valle	UV	Colombia	1962	15883
12	Coleção Zoológica da Universidade Regional de Blumenau	CZFURB	Brazil	2007	15267
13	Colección Fundación de Historia Natural Félix de Azara	CFA-MA	Argentina	2000	14400
14	Colección Mamíferos Lillo	CML	Argentina	1938	13882
15	Escuela Politécnica Nacional, Colección de Vertebrados, Sección de Mastozoología	MEPN-M	Ecuador	1946	12585
16	Coleção Integrada de Mamíferos Silvestres Reservatórios (COLMASTO/IOC/Fiocruz)	LBCE	Brazil	1984	11818
17	Coleção de Mamíferos da Universidade Federal da Paraíba	CM-UFPB	Brazil	1979	11782
18	Museo de Historia Natural La Salle	MHNLS	Venezuela	N/A	11000
19	Colección de Mamíferos del Instituto de Investigación de Recursos Biológicos Alexander von Humboldt	IAvH-M	Colombia	1995	10676
20	Colección Mastozoología, Museo de La Plata	MLP-Mz	Argentina	1908 ^c	10146

^aMuseu Nacional was created in 1818, but the 'Zoology Section', which houses mammals, was established in 1842 (Silva Maia 1852).

^bInitially part of the Museu Paulista (Percequillo *et al.* 2022).

^cIn 1908, the first mammal was officially added to the MLP Vertebrate Zoology collection. In 1935, the Mammal collection (MLP-Mz) was formally established.

many larger mammal collections have only recently begun to expand their genetic resource collections. Although dependent on the curatorial visions of each institution, variation in tissue collection sizes highlights the differing capacities and resources available to South American institutions for preserving high-quality genetic material.

Ethanol is the most widely used tissue preservation method across South American institutions ($N=82$), and ultra-cold freezing (-80°C) is used in 15 collections. Many collections combine preservation strategies (alcohol and freezing at -20°C or -80°C) to maintain the integrity of sensitive tissues, such as liver and muscle. Additionally, a few collections ($N=3$) have adopted specialized buffer solutions, such as lysis buffer, ethylenediaminetetraacetic acid (EDTA)-dimethyl sulphoxide (DMSO) solution, RNAlater™, or viral transport media (VTM), for tissue preservation. One collection (NUPECCE) has started to incorporate liquid nitrogen (LN_2) preservation for preservation of high-quality molecular sequence information (DNA and RNA) and living cells for culturing. This diverse range of preservation techniques underscores the variation in infrastructure and resources among South American institutions.

Liver and muscle are the most frequently preserved tissue types in South American collections (Fig. 3); among the 88 surveyed

collections with genetic resources, 65 institutions stored liver tissue and 62 stored skeletal muscle tissue. However, most collections preserve multiple tissue types from the same specimen. For example, 70 collections reported storing of more than three tissue types per specimen. Other preserved tissue types include heart ($N=17$), kidney ($N=14$), lung ($N=6$), spleen ($N=6$), intestine ($N=2$), and brain ($N=1$). Additionally, non-lethal tissue subsamples, such as ear ($N=6$), patagia ($N=3$), skin clips ($N=8$), faeces ($N=2$), and blood ($N=2$) are also represented in the collections. Five collections reported storing multiple tissues without specifying tissue types.

DISCUSSION

Baseline infrastructure of collections in South America

Our survey of mammal research collections in South America identified 141 collections, more than double those listed in the 2018 survey by the ASM ($N=66$; Dunnum *et al.* 2018). There are a few reasons for this dramatic increase: (i) rapid growth of collections over the last decades; (ii) recent increase in digitization of collection resources that has made collections more discoverable; (iii) establishment of collection committees in Latin American mammalogical societies, which increase the visibility of local

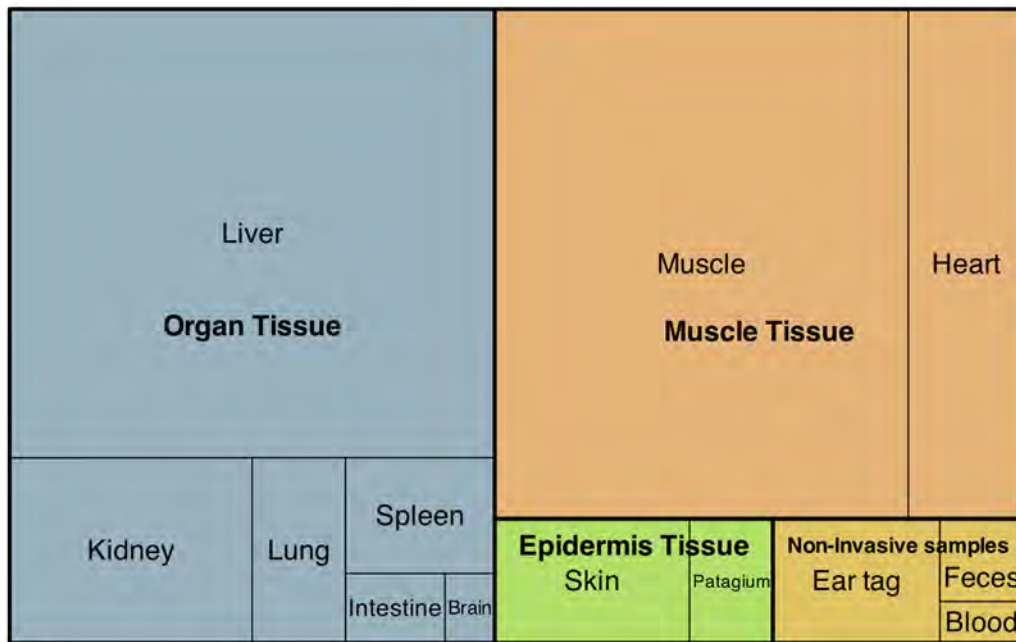


Figure 3. Types of tissues archived at the surveyed South American mammal collections as of 2022. Liver ($N = 63$) and muscle tissue, including skeletal muscle (61) and heart tissue (17), compose the vast majority of archived tissue. Organ tissue includes kidney (13), spleen (5), lung (5), intestine (2) and brain (1); epidermal tissue includes skin (7) and patagium (3); and non-invasive samples (9) include faeces (2), blood (2), and ear tags (8).

collections (e.g. Chiquito *et al.* 2021, Rodríguez-Posada *et al.* 2020); and (iv) an *in loco* collaborative effort to reach a broader network of collections. Such baseline information serves as a starting point for the continuing strategic development of South American research collections by benchmarking progress, highlighting priorities, and identifying shared challenges.

As of early 2022, 141 collections in South America house ~746000 catalogued mammal specimens, including 452 primary type specimens and 687 paratypes. Type specimens housed in South America represent only 2% of all mammal nominal taxa (including the types of synonyms; $N = 26963$; data from MDD 2024). Total type holdings are low, however, considering the diversity of species on the continent (23% of global mammalian diversity). This paucity of type specimens housed in South America is a consequence of a long history of extractive, colonial collecting practices since the 16th century (Sheets-Pyenson 1987, Bezerra 2015, 2016, Madruga 2022). The fact that nearly 98% of South American mammal type specimens are housed in institutions abroad presents an underappreciated but substantial impediment for local researchers conducting taxonomic work in the region (D'Elía 2024).

Representation of type material, however, is improving, with increasing field and taxonomic work led by South American institutions. It is worth noting that the recent trend of increased type series deposited in South American collections over the last decade corresponds to the rise in the number of systematists based in South American countries who are actively describing new taxa. Unlike during the 19th and 20th centuries, when most mammalian taxonomists were located in the Global North, South America has seen a significant rise in the number of taxonomic experts in the 21st century (Patton *et al.* 2015, D'Elía *in press*), reflecting a growth in regional scientific capacity (Lira-Noriega and Soberón

2015) and the improvement of structure and valuation of natural history collections. This increase in the number of collections and volume of catalogued material in South American mammal collections over the last decades contrasts sharply with the decline of South American holdings in collections in the Global North (Fig. 2F). This shift highlights a growing emphasis on regional ownership of biodiversity data and the need to strengthen local research infrastructure.

Challenges and opportunities

The number of mammal research collections and volume of specimens archived in South America have increased significantly over the last century (Fig. 2A). Nevertheless, there remains a pressing need for strategic temporal sampling of regions and taxa (Malaney and Cook 2018). Below, we highlight four major challenges facing natural history collections in general, and South American mammal collections in particular, and propose corresponding solutions.

Staffing shortages

Most collections are severely understaffed: half of all mammal collections in South America are maintained by one full-time or part-time staff member, with 19% of all collections having no full-time staff appointments. Lack of staff devoted to these resources threatens both their quality and sustainability, limits collaborative potential and training opportunities, and inhibits conservation- and health-related research (de Vivo *et al.* 2014).

With nearly 73% of all collections in South America located at universities, integrating these resources into graduate education, professional programmes (e.g. medical school), and classroom teaching will be crucial to training the next generation of scientists and natural resource managers. Documenting collection metrics,

such as collection growth, loan output, number and impact of publications, and the number of research grants and projects supported, can help to build administrative support, which will be necessary to hire full-time collection staff. Faculty-curators, with at least half- or quarter-time effort dedicated to growth and maintenance of collections, will be essential to ensuring growth, sustainability, and cross-disciplinary engagement of this primary biodiversity infrastructure.

Strategic expansion of cryogenic infrastructure

Frozen tissue collections are essential to advances in systematics, population genomics, virology, assessment of contaminants, and many other scientific fields (e.g. stable isotope chemistry), but these collections are expensive to initiate and require significant expertise to maintain. As of 2022, most collections in South America rely on conventional (commercial) freezer units with tissues in alcohol or other buffers for long-term storage, providing a system with a back-up against power outages. Long-term preservation and viability of tissues in these conditions, however, are not optimal (Soniati *et al.* 2021).

In contrast, ultra-cold and cryogenic freezing, at temperatures between -80°C and -196°C (LN_2), ensures long-term viability of genetic resources and maintains the quality and integrity of tissues (Zimkus and Ford 2014); guidelines and best practices now exist for development and maintenance of these resources (Phillips *et al.* 2019). Nevertheless, ultra-cold freezing requires significant infrastructure investments: ultra-cold freezers are expensive, and they require foolproof sources of electricity to maintain samples at stable temperature. Liquid nitrogen systems also require initially expensive infrastructure (cryogenic containers), and they are reliant on periodic replenishment of LN_2 . Tissues stored in mechanical freezers are susceptible to degradation during power outages, whereas cryogenic dewars can maintain ultra-cold temperatures for >20 days, even without electrical power. Given the energy instability facing many South American countries, upgrading genetic collection infrastructure to LN_2 storage is an important step towards securing long-term viability of genetic resources on the continent.

Liver and muscle are the preferred tissue types in South American collections. That bias might reflect a combination of ease of sampling, historical inertia, and a preference for higher DNA concentrations (Wong *et al.* 2012, Soniati *et al.* 2021). DNA quality, however, might decrease in liver tissue owing to the sensitivity of that tissue to environmental degradation during specimen preparation and archiving, or DNA extraction (Soniati *et al.* 2021). In turn, tissue-specific mutations make the selection of a single tissue less desirable for investigations of the nuclear and mitochondrial genomes (Samuels *et al.* 2013). In addition, RNA profiles differ across different tissues, and different pathogens and/or contaminants can be detected in different tissues. Therefore, additional tissue types (e.g. spleen, skin) should be preserved as part of a holistic sampling approach (Galbreath *et al.* 2019) to ensure that a diversity of biological materials is available to maximize later research applications (Lendemmer *et al.* 2020).

Data digitization and accessibility

Although most collections are digitized, 13% remain incompletely digitized, and many use basic data-management software (e.g.

Microsoft Excel or in-house solutions). Understanding the digitization status of collections is increasingly important in the context of global scientific collaboration and data sharing. Digitization workflows can be optimized through implementation of new technologies (Hedrick *et al.* 2020), including optical character recognition, a form of machine learning that can be used to recognize and transcribe text from a digital image (e.g. scanned data sheet) or through use of digital field catalogues, such as the Natural History Project Utility (NAHPU; <https://github.com/handika/nahpu>). A crucial first step for South America collections is the standardization of vocabulary structures under frameworks such as Darwin Core, which would facilitate interoperability among databases and with platforms such as GBIF and VertNet. Granted, as with traditional data digitization methods, implementation of new technologies requires the time and effort of dedicated and trained staff members, which, in turn, requires funding.

Sustainability

Although the adoption of new technologies and digitization represents a crucial step in enhancing South American mammal collections, it is equally essential to reaffirm the importance of preserving traditional voucher specimens (Buckner *et al.* 2021). Many collections (83% of those surveyed) face significant financial and logistical challenges in acquiring and maintaining basic supplies necessary for the physical preservation of vouchers. In particular, we highlight a sparsity of collections in the (non-Andean) northern part of the continent, especially in northwestern Amazon and Guianas regions; and an apparent decline in collection representation in Venezuela, with only one collection replying to our survey, in contrast to four collections reported by Dunnum *et al.* (2018).

Although our survey indicated a decrease in the number of reported mammal collections in Venezuela, this might reflect curator turnover and limited institutional response at the time, rather than a definitive loss of collections. For example, the Museo de Biología de la Universidad Central de Venezuela (MBUCV) responded and confirmed its continued activity. In the case of the Museo de la Estación Biológica de Rancho Grande (EBRG), the Colección de Vertebrados de la Universidad de Los Andes (CVULA), and the Museo de Historia Natural La Salle (MHNLS), we were unable to obtain direct survey responses, but follow-up communication with colleagues and curators suggests that these collections remain operational, at least in part. Nonetheless, it is important to acknowledge that these institutions currently operate under significant constraints in staffing, funding, and infrastructure, consistent with broader reports of the systemic challenges faced by Venezuelan science (Bifano 2009, Fraser 2016, Taylor 2024). Although these collections have not disappeared, their functionality might be limited, and their long-term viability remains uncertain. This observation highlights the urgent need for continued monitoring and support of biodiversity collections in politically and economically vulnerable regions.

Given the outsized role of mammals as hosts of emerging zoonotic diseases and sentinels of environmental quality (Schmitt *et al.* 2019), connecting biodiversity collections to public health and environmental monitoring initiatives are a few examples of ways to improve the sustainability of the specimen infrastructure (Miller *et al.* 2020). Strengthening the connection between South

American mammal collections and global networks is also a necessary step towards ensuring their long-term sustainability. Greater integration would open doors to international funding, specialized training, and much-needed improvements in infrastructure. Additionally, establishing national and continent-wide committees dedicated to systematic collections could help to coordinate efforts to address underrepresentation and institutional vulnerabilities, ensuring that the rich biodiversity of South America is properly documented and preserved.

Research network initiatives could also play a significant role in strengthening scientific collections and advocating for public policies to support their recognition and development at regional (e.g. [Bissoli-Silva *et al.* 2021](#)) to transnational scales. The MEPA network, for example, aims to connect the museum biorepository and biomedical communities better, in order to build capacity in the Americas, with a focus on Latin America ([Colella *et al.* 2021](#)). This initiative contributes to integrating South American mammal collections into the global museum network ([Bakker *et al.* 2020](#)), while facilitating a comprehensive assessment of their current state. Through bi-weekly meetings, MEPA intentionally connects diverse, international constituents to enhance understanding of the challenges faced by collections in Latin America, such as insufficient digital representation or institutional vulnerabilities, and help to identify potential areas for mitigation and collaboration moving forwards.

CONCLUSION

Natural history collections form critical infrastructure for both fundamental and applied scientific research, providing essential temporal and spatial data necessary to comprehend and address evolving environmental conditions and the emergence of novel pathogens. As these collections become increasingly interconnected through digital platforms, they form a global network ([Bakker *et al.* 2020](#)) that fosters international collaboration, facilitating the exchange of ideas and information across borders.

Beyond advancing integrative scientific approaches, natural history collections also play a pivotal role in capacity building through training and educational opportunities, for both scholars and the general public. These initiatives encompass authentic, hands-on experiences with physical collections, in addition to educational modules that leverage collection data to deliver place-based, question-driven lessons ([Cook *et al.* 2014](#), [Lacey *et al.* 2017](#)). By fostering the development of a skilled workforce, such capacity-building efforts are instrumental in addressing crucial societal challenges, including climate change, biodiversity loss, emerging pathogens, and environmental contamination.

The significant increase in the number of collections and catalogued specimens in South America highlights the rapid expansion of the capacity for scientific research in the region. This growth underscores the need for research funding agencies to allocate more resources to maintain and grow these collections, ensuring their long-term sustainability. As national repositories of biodiversity, these collections are not only vital for understanding the history of biodiversity but also for shaping its future ([Percequillo *et al.* 2022](#)). Strategic investment is therefore essential to maximize their scientific contributions and broader societal impact.

Science agencies in South American countries should play a key role in supporting natural history collections, by allocating dedicated funding to address the critical gaps, while fostering cross-continental collaborations to enhance resource sharing. Policy-makers should promote the integration of collections into national research agendas, emphasizing their role in biodiversity conservation, public health, and climate change mitigation. Capacity-building initiatives, including training programmes and institutional partnerships, are essential to develop skilled personnel and ensure the long-term sustainability of these collections. By recognizing biological collections as fundamental scientific infrastructure, science agencies can strengthen their contribution to both local and global challenges. These efforts not only safeguard biodiversity resources but also enhance their role in addressing global challenges, such as climate change, ecology and epidemiology of zoonotic diseases, and long-term conservation strategies.

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SUPPLEMENTARY DATA

Supplementary data is available at *Biological Journal of the Linnean Society* online.

CONFLICT OF INTEREST

None declared.

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DATA AVAILABILITY

Data underlying this study are available online at the *Biological Journal of the Linnean Society*.

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