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Original Article

The CARDUME initiative: integrating Brazil's scientific fish collections to promote research and biodiversity conservation

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ABSTRACT

Brazil hosts the highest fish diversity globally, underscoring the critical role of Brazilian Scientific Fish Collections (BSFCs) in biodiversity research and conservation. Despite their importance, BSFCs face persistent challenges. This study introduces the CARDUME network, the first nationwide initiative to assess BSFCs and propose strategies to enhance their role in ichthyology. Data from 74 collections across 25 Brazilian federal units reveal that most are affiliated with public universities and house 8502992 catalogued specimens in 906890 lots, including over 2600 primary types. Although digitization efforts are underway in 92% of BSFCs, only 37% currently share data online. Genetic resources are severely limited, with tissue samples available for just 3% of specimens. Significant funding disparities exist, with 70% of collections receiving less than USD170 annually. Gender inequality is also notable, with more male-curated than female-curated collections. Survey responses highlighted issues such as staff shortages, inadequate facilities, and limited resources for fieldwork and collection curation. CARDUME aims to address these gaps through collaboration, professional training, improvement of data quality, and increase of shared data, while also advocating for recognition by Brazilian institutions, funding agencies, and the government. *O resumo em português está disponível no material suplementar*.

Keywords: biodiversity; ichthyology; neotropical; South America

INTRODUCTION

Fishes represent living and fossil lineages of vertebrates with an astonishing variety of shapes, sizes, colours, and ecological adaptations (Nelson *et al.* 2016). Over 37000 extant species of fish have been described globally, yet this number is expected to rise significantly as scientists believe that many remain undescribed (Fricke *et al.* 2025). This extraordinary diversity reflects these lineages' long and complex evolutionary history, with the oldest representatives (agnathans) dating back at least 520 Myr (Long *et al.* 2019) and ray-finned fishes to more than 400 Myr (Hurley *et al.* 2007, Hughes *et al.* 2018). Fishes inhabit a wide range of aquatic environments, including deep marine oceans, subterranean freshwaters, and small mountain streams and lakes, as a result of their remarkable ability to adapt to diverse environmental conditions and ecological pressures (Bichuette and Gallão 2021, Facey *et al.* 2022).

Among aquatic habitats, freshwater environments stand out for their exceptional biodiversity. Despite covering only about 1% of the Earth's surface, rivers, lakes, and wetlands (Shiklomanov 1993) harbour nearly half of all known fish species (Fricke *et al.* 2025). This unbalanced high diversity is due to a combination of ecological and evolutionary processes, such as natural river fragmentation by waterfalls and rapids, which promotes population isolation and allopatric speciation (Dias *et al.* 2013). The rivers of South America served as natural laboratories for the radiation of several lineages over millions of years, shaping the extraordinary diversity found today in such rich, heterogeneous aquatic ecosystems as the Amazon, São Francisco, and Paraná–Paraguay river basins (Lundberg *et al.* 1998). This remarkable diversity has also been promoted by the distinct water types (black, white, and clearwater), which, along with historical climatic stability, further support niche diversification and long-term lineage persistence (Albert and Reis 2011). These processes were particularly important in diversifying what today represents one of the largest fish faunas on the planet, the Brazilian ichthyofauna. Current estimates indicate approximately 3200 freshwater species in Brazil (Melo *et al.* 2025), with nearly 100 new species being described yearly (Reis *et al.* 2016, Birindelli and Sidlauskas 2018). This remarkable species richness results from complex and continuous ecological and historical processes over time, driven by geological landscape modifications that have shaped the Brazilian hydrographic basins (Ribeiro *et al.* 2016, Dagosta and de Pinna 2019). While allopatric speciation is widely considered the predominant mechanism driving clade diversification in freshwater fishes, particularly in South American river systems, marine environments are shaped by different evolutionary pressures. In these settings, parapatric or sympatric speciation, facilitated by ecological adaptation to semi-permeable barriers, may play a more prominent role (Reis *et al.* 2016).

The marine fish diversity of South America is also remarkable, arising from a mosaic of habitats including extensive coral reefs, mangroves, and nutrient-rich upwelling zones, ecosystems that collectively support diverse and often endemic fish assemblages (Marceniuk *et al.* 2013, Moura *et al.* 2016). Overall, more than 4000 species are recorded in the shelf, slope, and deep-sea habitats of the Atlantic and Pacific coasts of South America, which accounts for about 23% of the roughly 18000 recognized marine fish species worldwide (Miloslavich *et al.* 2011, Reis *et al.* 2016, Fricke *et al.* 2025). Like freshwater species, new records and descriptions of marine fishes in the region have steadily increased in recent decades (e.g. Guimarães *et al.* 2004, Sazima *et al.* 1998, 2009, Nielsen *et al.* 2015, Pinheiro *et al.* 2015, 2016, Marceniuk *et al.* 2024). However, the number of marine fish taxonomists remains significantly lower than that of freshwater experts, limiting the rate at which new marine species are described (Reis *et al.* 2016). Another factor contributing to the slower rate of species description in marine environments is the costs and logistical difficulties often associated with collecting in these habitats, which generally require larger vessels, expensive equipment, and numerous staff.

Brazil, with its vast Exclusive Economic Zone spanning over 7500 km of coastline and encompassing four oceanic archipelagos (Saint Peter and Saint Paul Rocks, Fernando de Noronha, Rocas Atoll, and Trindade and Martim-Vaz), leads South America in both marine fish taxonomic research and overall fish richness. An estimated 2150 marine fish species have been recorded in the country (Carvalho-Filho 2024, Melo *et al.* 2025). However, ongoing taxonomic revisions continue to uncover hidden diversity in both coastal and deep-sea environments, progressing steadily as new generations of marine fish taxonomists emerge and national fish collections expand, especially in coastal regions (e.g. Marceniuk *et al.* 2024). The wealth of information uncovered over the past decades regarding Brazil's marine fish diversity has also provided new insights into the biogeography and diversification of fishes in the western South Atlantic (e.g. Floeter *et al.* 2008, Pinheiro *et al.* 2018, Araujo *et al.* 2022). Among the tools contributing to this advancement, DNA barcoding and related techniques have become increasingly widespread, particularly in Argentina and Brazil (Reis *et al.* 2016), also significantly contributing to an increase in the knowledge of the fish diversity of the region. Despite these recent advances, vast areas of the South American coastline and open oceanic habitats, particularly in Brazil, remain largely unexplored. As a result, new species are continuously discovered across a broad array of taxonomic groups, including hagfishes, sharks and rays, coral reef fishes, and deep-pelagic fishes (e.g. Mincarone 2000, Soares *et al.* 2015, Villarins *et al.* 2022).

Paradoxically, the surprising rate of discovery and description of new fish species in Brazil contrasts sharply with the country's declining investment in systematic research and science overall over the past decades (see Fernandes *et al.* 2017, Overbeck *et al.* 2018, Hallal 2021). This trend is especially alarming given the shortage of trained taxonomists and the urgent need to document the country's vast biodiversity, challenges that have been highlighted in recent national assessments (Boeger *et al.* 2024). Reflecting these limitations, several recently described species are known from only a few specimens (e.g. Melo *et al.* 2025) collected during scientific expeditions, underscoring how little is still known about the diversity of Brazil's aquatic fauna. Particularly in the case of freshwater species, distributions are often restricted to specific drainage systems, rendering some populations highly vulnerable to anthropogenic impacts (Vari 1988). When combined with limited sampling and documentation, such restricted ranges heighten the risk of losing species not only before they are formally described, but before specimens are vouchered in a collection. Deforestation, pollution, hydroelectric dams, and climate change pose severe threats to the integrity of Brazilian aquatic ecosystems and, consequently, to the survival of many species, including those undescribed and unrecognized by science (Reis *et al.* 2016).

In light of these threats, scientific research on the diversity, evolution, and distribution of fishes in Brazil plays a strategic role, not only in advancing biological knowledge but also in biodiversity conservation on a global level. Efforts to recognize and value the richness of Brazilian ichthyofauna must be paired with public policies that ensure the protection of aquatic ecosystems and mitigate human impacts. Biodiversity monitoring programmes, establishment of protected areas, and support for training new generations of taxonomists are essential to ensure that Brazil's unique fish diversity and habitats continue to be studied, conserved, and managed adequately for the benefit of future generations.

Natural History Collections (NHCs) are central to these efforts, playing a crucial role in the training and formation of new taxonomists and in advancing biological knowledge overall. In addition to preserving historical records (Ball *et al.* 2025), these collections provide the basis for a vast array of studies aimed at understanding biodiversity across all levels of organization (Rocha *et al.* 2014). As such, they are key to developing effective biodiversity policies and conservation strategies worldwide (Metzger 2024), especially in developing countries of the Global South, such as Brazil, which harbour a substantial portion of the known and yet-to-be-discovered biodiversity of the planet. Therefore, establishing the appropriate set of laws and regulations to promote NHCs is fundamental to advancing policies aimed at biodiversity conservation, guaranteeing the right of future generations to access ecosystem services.

The first hints of a body of legislation regarding scientific biological collections in Brazil can be traced back to the Convention on Biological Diversity (CBD), also known as the Biodiversity Convention. The CBD was opened for signature at the Earth Summit in Rio de Janeiro on 5 June 1992 (ECO-92), and entered into force on 29 December 1993, with 162 countries as signatories. The CBD has three primary objectives: the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of benefits derived from genetic resources. Its overarching goal is to encourage the development of national strategies for biodiversity conservation and sustainable use, making it a key instrument for global sustainable development. It includes three supplementary agreements: the Cartagena Protocol on Biosafety (effective in 2003), the Nagoya Protocol on Access and Benefit-sharing, and the Fair and Equitable Sharing of Benefits (latter two effective since 2014). Currently, 196 countries across all continents are signatories to the CBD.

Following the adoption of the CBD, Brazil began to formalize its commitments through a series of national legal instruments. The first steps were taken with Brazil, Decree 2/1994 and Brazil, Decree 2519/1998, which officially recognized the country's adherence to the Convention's principles. In 2002, Brazil enacted the National Policy for Biodiversity (PNB) through Brazil, Decree 4339, establishing the country's strategic framework for biodiversity conservation. The PNB is grounded in seven core principles: (i) advancing knowledge on biodiversity; (ii) conserving biodiversity; (iii) promoting its sustainable use; (iv) monitoring, assessing, preventing, and mitigating impacts on biodiversity; (v) regulating access to genetic resources and associated traditional knowledge, including benefit-sharing; (vi) promoting biodiversity education, awareness, and outreach; and (vii) strengthening legal and institutional mechanisms for biodiversity governance. In parallel, Brazil introduced a provisional measure in 2001 (Brazil, MP 2.186-16/2001) addressing the fifth component of the PNB, which was later replaced by the Brazilian Biodiversity Law (Brazil, Decree 13.123/2015). This law regulates access to genetic resources, the protection and use of associated traditional knowledge, and the equitable sharing of benefits derived from their use, aiming to promote biodiversity conservation and sustainable use.

While the Brazilian Biodiversity Law represents a key step toward regulating access to genetic resources and promoting benefit-sharing, its implementation has posed substantial bureaucratic challenges for the scientific community. The law applies to any scientific research involving Brazilian organisms, including derivative data that are publicly available (e.g. sequences in GenBank), and data from *in situ* observations that do not involve the collection of specimens. Despite these challenges, the law established the National Fund for Benefit Sharing (NFBS), which is tasked with funding actions to preserve Brazilian biodiversity, including recovering, establishing, and maintaining *ex situ* collections. Although the fund was formally established in 2015, it only became operational 10 years later, following the appointment of a financial institution to manage and administer its resources.

More recently, the Brazilian Senate approved a proposal for the National Policy for Biological Scientific Collections (NPBSC, Brazil, Law Project 1993/2024), which is currently under evaluation by the Brazilian Congress. This proposed law aims to strengthen, expand, and organize the management and maintenance of scientific biological collections in Brazil, while also ensuring the accessibility and preservation of associated data. Inspired by a State-level initiative in Paraná (Brazil, Resolution CEMA/PR 101/2017), the NPBSC formally recognizes Brazilian biological collections as national heritage and emphasizes the responsibility of host institutions for their integrity. Once enacted, this law is expected to provide financial, human, and infrastructural support to improve the curation, conservation, and overall management of these collections.

Two practical actions developed by the Brazilian government in recent years are also worth highlighting for their contribution to biodiversity knowledge and scientific collections. In 2018, the Brazilian System for Biodiversity Information (SIBBr) was established to organize, index, store, and disseminate information on Brazilian biodiversity and ecosystems (Brazil, Ordinance 6.223/2018). As part of the Global Biodiversity Information Facility (GBIF), SIBBr provides crucial data to support government conservation and sustainable use policies. In 2022, Brazilian law (Brazil, Ordinance 6.258/2022) recognized SIBBr as a formal network of scientific biological collections. In 2024, the Brazilian government allocated approximately R$500000.00 (c. USD100000.00) specifically for funding scientific collections, the largest direct federal investment in this area to date, reflecting a growing recognition of these collections for biodiversity research and management.

In addition to SIBBr, Brazil hosts a few other national and regional networks of biological collections that serve as important references for mobilizing biodiversity data, the Brazilian Network of Herbaria (https://www.botanica.org.br/a-rede-brasileira-de-herbarios/), and the Taxonline (https://www.taxonline.bio.br/). The latter is a network of biological collections established in 2005 in the state of Paraná, focused on gathering and distributing funding, support, and exchanging materials among zoological, botanical, and microbiological collections locally.

Building on these models and inspired by the proposed NPBSC, the Brazilian Society of Ichthyology (SBI) has launched the CARDUME network, aiming to integrate all scientific fish collections in Brazil. 'Cardume' means 'school of fish' in Portuguese, or fishes swimming together, symbolizing cooperation and collective movement. Proposed during the SBI biennial meeting in January 2025, the CARDUME initiative is in its early stages, with goals of improving collection infrastructure, fostering the training and formation of new generations of fish taxonomists, enhancing data and specimen curation practices, and promoting the exchange of specimens, experiences, supplies, equipment, and information among participating institutions.

This study presents the first formal initiative of the CARDUME network. Our main goal in this paper is to provide an overview of the current scenario of Brazilian Scientific Fish Collections (BSFCs), assessing critical data to support the future planning and management of such collections. We also address historical disparities in the establishment, funding, and development of fish collections in Brazil, proposing long-term actions to mitigate these structural inequities and strengthen national capacity in ichthyological research and conservation.

MATERIAL AND METHODS

Data collection

This study, as well as the CARDUME network, includes only Brazilian Scientific Biological Collections as defined by Brazilian law (Draft Bill 1993, 11 December 2024; and Resolution CEMA/PR 101, 25 September 2017). Under this concept, a Scientific Biological Collection is a set of biological materials that are properly treated, preserved, and documented according to standards and procedures defined by a curator or other responsible party, ensuring the safety, accessibility, quality, longevity, integrity, and interoperability of the deposited data. These collections belong to public or private institutions dedicated to teaching and research, museums, biodiversity conservation centres, and other entities that maintain biological collections for scientific, educational, and conservation purposes, with the primary goal of supporting scientific or technological research, *ex situ* conservation, and socio-economic development. For this study, all persons responsible for collections were informed of these restrictions once contacted and before sending their collection information.

The data for the collections were initially obtained from the following institutions: (i) SpeciesLink (https://specieslink.net/), a platform that provides free and open access to data, information, and tools to any individual or group, contingent upon data providers' commitment to making their non-sensitive data publicly available—this platform is organized by CRIA, a non-profit civil association focused on disseminating scientific and technological knowledge, promoting education, conserving natural resources, and fostering sustainable development and citizenship; (ii) SIBBr (https://sibbr.gov.br/); and (iii) an inventory of scientific biological collections (Marinoni *et al.* 2024) resulting from the project 'Proposal for the creation of the Brazilian Network of Biological Collections' by the Brazilian Ministry of Science, Technology, and Innovation—MCTI. Additional information on several collections was extracted from a global list of extant and historical collections of fishes, amphibians and reptiles by Sabaj (2020, 2025). We then compiled a list of all fish collections mentioned in these sources, including the names of the collections, acronyms, geographical localities (Brazilian State and city), the names of the responsible persons, and their email addresses. A complete list of

collections and their contact information is available as a supplementary file (Supporting Information Table S1).

Subsequently, an electronic form was developed to collect specific information from the collections. This form was sent via e-mail to one or more of the persons responsible for each collection, and included an informed consent statement, outlining the research objectives and ensuring participants' agreement for data use. The form included a series of questions related not only to fish vouchers but also to collection attributes, infrastructure, personnel, and data management. The data collected via this online form were automatically integrated into a master spreadsheet. Data cleaning was subsequently performed, including verification of numerical values and small orthographic errors. At this stage, individuals who filled out the forms were contacted to confirm their responses and/or to provide additional details. Once all data and information were verified, corrected, and standardized, the final spreadsheet (Supporting Information Table S2) was used for statistical analyses, including calculating averages, maximums, minimums, and standard deviations of numerical terms. The data were then summarized into the graphics, figures, and tables presented herein.

Information on graduate programmes (PPGs) related to biodiversity in Brazil was compiled from the CAPES Sucupira Platform (https://sucupira-v2.capes.gov.br/programas), a publicly available and official database maintained by the Brazilian Federal Agency for Support and Evaluation of Graduate Education (CAPES). We conducted a systematic search to identify all PPGs (140 in total) with a thematic focus on biodiversity, retrieving their names, year of establishment, and geographical location by Brazilian region (North, Northeast, Central-West, Southeast, and South). To ensure relevance to broader biodiversity studies, we excluded programmes exclusively dedicated to botany or entomology. The final dataset included only interdisciplinary or taxonomically broader biodiversity programmes. All data were accessed and downloaded on 2 May 2025.

Data analysis

The data compiled from fish collections across Brazil were integrated with spatial, institutional, and demographic variables. To examine geographical and ecoregional patterns, we mapped the distribution of collections, cumulative annual funding, and the gender demographics of curators and technicians across Brazil's geopolitical regions and major biomes, using spatial layers and visualizations built with the *ggplot2* package in R (Wickham 2011). Collection coordinates were spatially intersected with official shapefiles of the Brazilian States, regions, and ecoregions obtained from the Brazilian National Institute for Space Research (INPE 2025), using the *sf package* (Pebesma 2018). We aggregated the number of collections within each administrative unit and used regional and biome-level summaries to generate thematic maps. These included gender-based pie charts scaled according to annual funding brackets (<170, <850, >850, >1700 USD). To treat funding as a continuous variable in our models, we transformed categorical funding classes into approximate annual values in USD: <170 was converted to 85 USD, <850 to 510 USD, >850 to 1275 USD, and >1700 to 2550 USD. This transformation allowed us to reduce slope bias and avoid multiple comparisons in model outputs (Legendre and Legendre 2012).

To test for associations between funding categories and geopolitical regions or ecoregions, we applied chi-square (χ^2) tests (with simulated *P*-values based on 9999 Monte Carlo permutations). Moreover, we conducted two analyses of variance to test for differences in collection sizes between geopolitical regions and ecoregions, with subsequent post-hoc Tukey's tests (Legendre and Legendre 2012). To investigate the main drivers of collection size and funding, we built three generalized linear models (GLMs). In the first two models, predictor variables included city population size, species richness and sampling effort per State, collection age (based on the year of the first catalogued specimen), number of curators, distance to the nearest State capital, and gender demographics of curators and technicians (classified as males or females). For the model predicting collection size (i.e. the number of deposited specimens), the funding amount was included as an explanatory variable. Conversely, for the model predicting annual funding, collection size was added as a predictor. To test for an association between the number of lots per State, the number of graduate programmes per State, and the mean age of graduate programmes per State, we conducted the third GLM. In this last GLM, we treated the number of lots as our response variable, while treating the remaining two variables (and their interaction) as explanatory variables. All continuous variables were standardized before model fitting. Best-fit models were selected via stepwise Akaike Information Criteria procedures using both forward and backward selection (Akaike 1974, Legendre and Legendre 2012). Given the integer nature of the response variables, all three models were constructed using the Poisson family (Legendre and Legendre 2012).

All spatial operations, statistical analyses, and visualizations were performed in R (R Development Core Team 2020), using the *sf* (Pebesma 2018), *ggplot2* (Wickham 2011), and *dplyr* (Wickham *et al.* 2020) packages. The full analytical workflow, along with datasets and scripts, is available at https://doi.org/10.5281/zenodo.15369206.

RESULTS

Size and spatial distribution of collections

A total of 74 BSFCs were found in 25 federal units of Brazil (24 States plus the Federal District). The only Brazilian States not represented in our data sample were Roraima, located in the north of Brazil, bordering Venezuela and Guyana (Figs 1, 2), and Goiás, located in the centre of Brazil.

We found that the Southeast region leads in the number of BSFCs ($N = 21$), followed by the South ($N = 15$), North ($N = 13$), Central-West ($N = 13$), and Northeast ($N = 12$) (Fig. 2A). Considering major ecoregions, the Atlantic Forest and Cerrado host the largest number of collections ($N = 32$ each), followed by the Amazon rainforest ($N = 12$), Caatinga drylands ($N = 4$), Pampa grasslands ($N = 4$), and Pantanal wetlands ($N = 1$) (Fig. 2B). Overall, the growth of ichthyological collections in Brazil was accompanied by an increase in graduate programmes over time (Fig. 2E).

The majority of BSFCs are associated with public higher education institutions, accounting for 83% of the total. Public research institutions and museums affiliated with private institutions in Brazil each house five fish collections. Regarding institutional

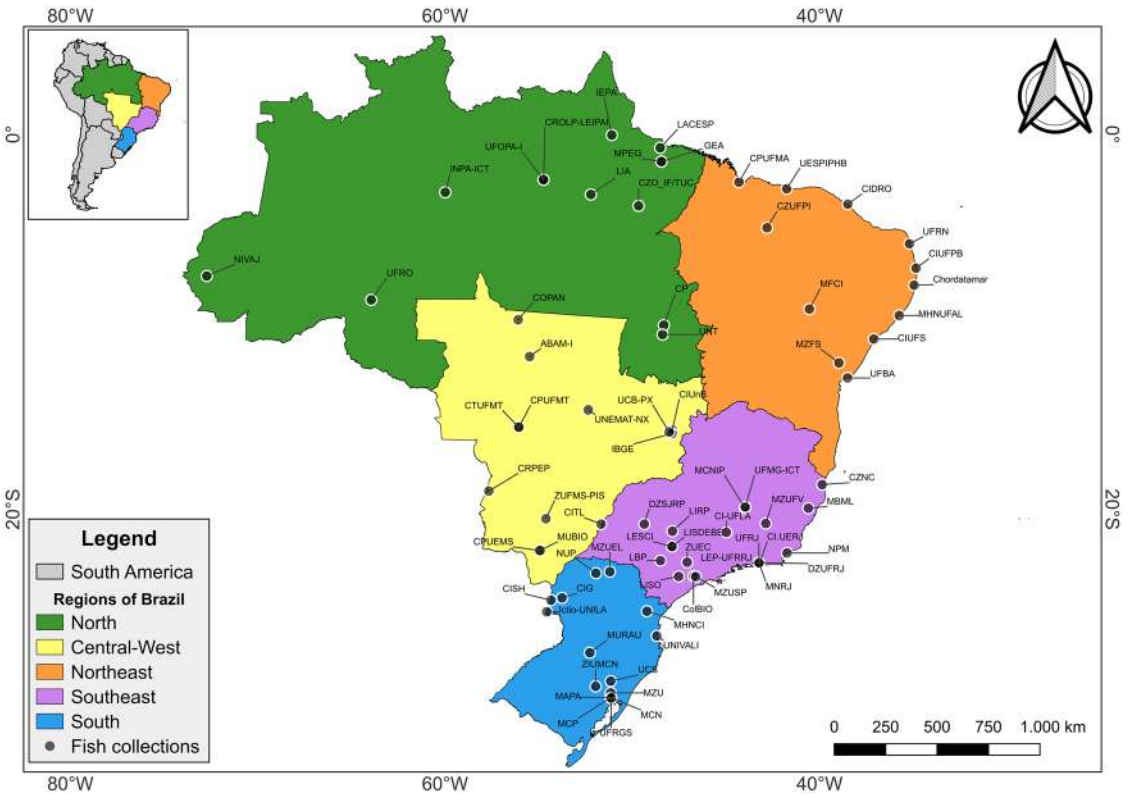

Figure 1. Map of Brazil's main geopolitical regions showing the distribution of 74 Brazilian Scientific Fish Collections, with their acronyms.

recognition (i.e. the official recognition of the collection by the university or major institution with which it is affiliated), 71% of the BSFCs are so recognized, 19% are in the process of being recognized, and 10% are still not recognized. Regarding geographical coverage, 40% of the collections have a national scope, with more than 25% of their deposited lots collected in States other than where the collection is located. The remaining 60% considered themselves as regional, i.e. at least 75% of their lots composed of specimens collected in the same Brazilian State in which the collection is located.

In total, BSFCs house 8502992 catalogued fish specimens in 906890 lots. The earliest collected specimen is recorded in the oldest collection (Museu Nacional, Universidade Federal do Rio de Janeiro—MNRJ) and dates to the year 1870. Considering the estimated backlog (specimens housed in the collections but not yet catalogued) of about 1300000 specimens according to our survey, BSFCs house an overall number of about 10000000 specimens.

Currently, 2646 primary types (holotypes, neotypes, lectotypes, and syntypes) are deposited in BSFCs. In addition, paratypes of 3886 species in 16278 lots are also present in BSFCs. The oldest holotype was deposited in 1902, and the oldest paratype dates back to 1903. Considering that about 5000 valid species have been recorded in the country, this indicates that around 1000 species were either described from other neighbouring countries or have their holotypes housed in foreign institutions. This is especially common for species described during the 19th and much of the 20th centuries, when it was standard practice for foreign naturalists to deposit all type specimens at their home institution.

A total of 266658 voucher specimens in 38 BSFCs have tissue samples available for genetic analyses, representing only 3% of the total number of specimens housed in the collections. Additionally, 39% of the collections lack access to direct genetic sequencing of the specimens and/or tissues due to the lack of equipment; 32% face this limitation because of insufficient funding for supplies and reagents. Only 29% of the BSFCs have full access to genetic sequencing within their institution, with most of these located in the South (7) and Southeast (7). The Central-West and Northeast regions each have only two collections with direct access to equipment, while only one is located in the North.

In terms of data management, 61% of the collections are fully digitized, while 30% are partially digitized and 8% still remain non-digitized. Digitization in BSFCs varies by region, collection size, and funding. Full digitization is more common in the Southeast and South, where collections are larger and receive more funding (Fig. 2). In contrast, the North and Central-West collections are smaller, less funded, and less digitized. Collections with over 20000 registered lots are more likely to be fully digitized, while those with fewer than 5000 lots tend to be partially or not digitized. Collections receiving over USD1000 annually show higher digitization rates compared to those receiving less than USD200. Regarding the hosting of collection data, 64% are stored locally, either on a computer in the researcher's office or lab, or in the collection itself; 25% use an institutional server; and 11% rely on a virtual server. Only 31% of the collections have dedicated IT support, either exclusively assigned or provided by the host institution.

The most commonly used tools for specimen management and cataloguing are spreadsheet editors (i.e. Excel, Access), adopted

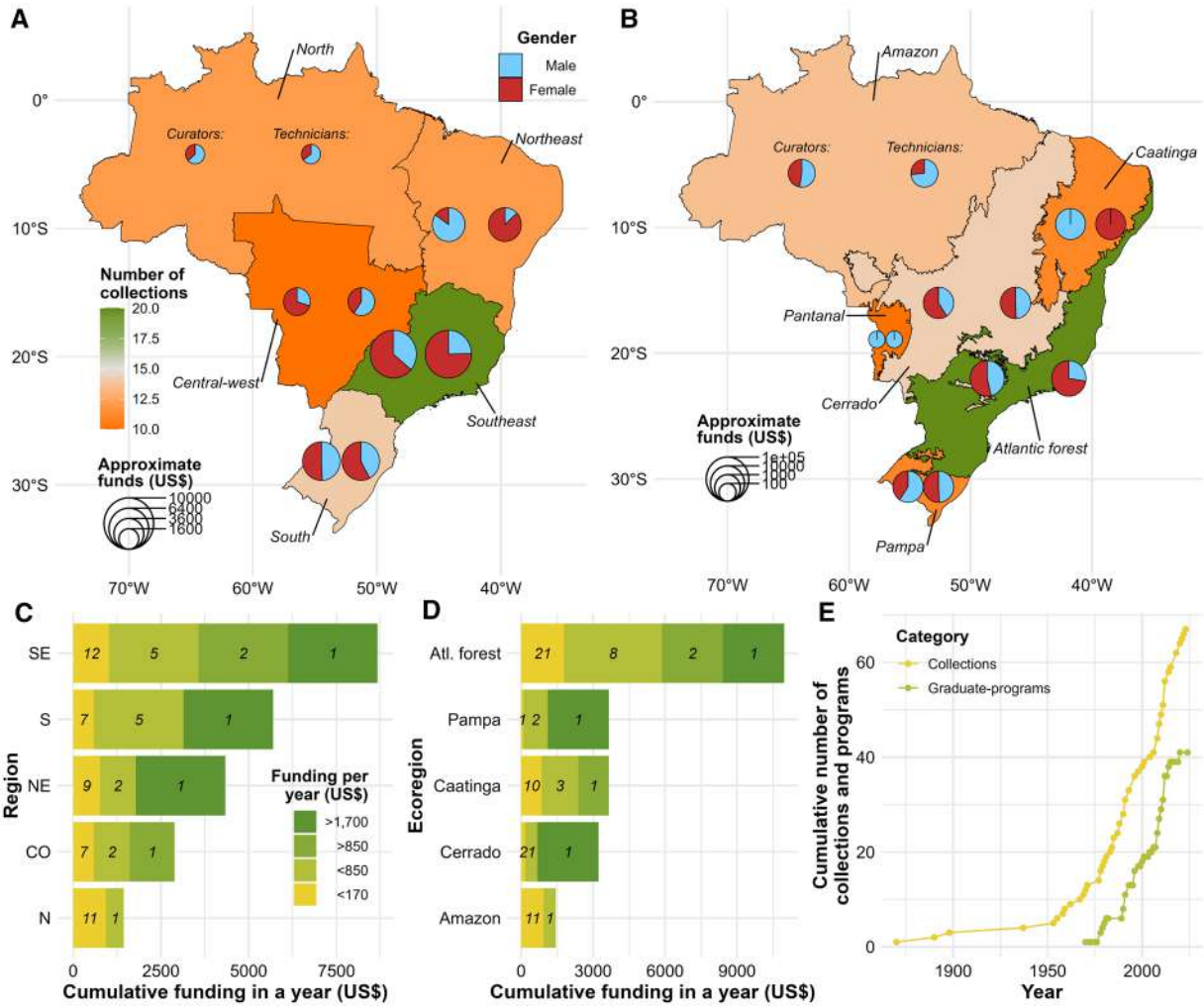

Figure 2. Spatial distribution, gender composition, and funding of ichthyological collections across Brazil. A and B, each (A) geopolitical region or (B) ecoregion is coloured by its total number of ichthyological collections, with darker shades indicating more collections. Pie charts indicate the proportion of male (blue) and female (red) curators (pie charts on the left) and technicians (pie charts on the right) in each geopolitical region. Concentric circles represent the approximate cumulative funding received per year by collections in each region, with larger circles indicating higher values. C, D, cumulative yearly funding directed to ichthyological collections across (C) geopolitical regions and (D) ecoregions. Each bar is segmented by the number of collections within that region receiving specific annual funding levels, with colour gradients ranging from light green (lower funding) to dark green (higher funding). The numbers in each segment show the collection count in that funding range.

by 70% of the BSFCs. The Specify Software (https://www.specifysoftware.org/) is the second most widely used platform, implemented by 23% of the institutions. Additionally, three institutions use proprietary software, and two use the Artedian system (https://artedi.nrm.se/fishbase_se/software/artedian/). Most collections do not have their data available for online access (63%). Among the 27 collections that do provide online data, all use either the SiBBR (https://sibbr.gov.br/), the SpeciesLink platform (https://specieslink.net/), or both. Additionally, seven of these collections also make their data available through their own institutional websites.

According to access policies, 95% of the collections are open to the scientific community, meaning that any interested researcher can visit and examine the specimens. Among these, the average number of visitors over the past 3 years ranged from one to 50, with a mean of 6.5 visitors per year. A total of 68% of the collections reported having made loans over the past 3 years, with an average of 130 specimens loaned per year in total.

Most BSFCs have a designated curator (67%); 16% have two individuals engaged in curatorial activities, 11% have three or more, and four collections (5%) currently have no curator. Among those collections with curators, the majority (83%) do not have positions exclusively dedicated to curation and research, sharing their responsibilities with other institutional duties such as undergraduate teaching. Only 16% of BSFCs have staff exclusively assigned to curatorial and research activities.

When asked about the number of higher education-level technicians working in their collections, the majority reported having either none (35 BSFCs) or only one (34), with very few collections having two or more technicians (only four BSFCs in total). Regarding mid-level technicians (i.e. those without higher-level formation), only a small fraction (13 BSFCs in total) indicated

having one or two technicians, with 60 collections reported as having no mid-level technical staff. Similarly, 52 BSFCs reported no support staff at all, while only 21 collections have at least one.

We found that ichthyological collections with a larger number of specimens (hereafter referred to as larger collections) tend to receive more funding ($\beta = 0.153$, SE = 0.0004, $z = 470.5$, $P < .001$; Fig. 3A), are located in regions with higher species richness ($\beta = 0.24$, SE = 0.0003, $z = 668$, $P < .001$; Fig. 3B), and are more often led by multiple curators (i.e. two or more; $\beta = 0.33$, SE = 0.0003, $z = 882.3$, $P < .001$; Fig. 3C). In addition, older collections ($\beta = -0.185$, SE = 0.0003, $z = -559.9$, $P < .001$; Fig. 3D) and those located in more densely populated cities ($\beta = 0.212$, SE = 0.0002, $z = 709.8$, $P < .001$; Fig. 3E) also tend to be larger. Together, these five predictors explained 48.47% of the variation in collection size (adjusted $R^2 = .502$). Alternative variables, such as sampling effort per state, distance to the nearest capital, and the gender of curators and technicians, were not included in the best models during stepwise selection (Supporting Information Table S3). Larger collections are often present in states with more graduate programmes, but this also depends on the programme's age ($\beta = 0.076$, SE = 0.0011, $z = 63.76$, $P < .001$; Fig. 3F). In this sense, larger collections are positively affected by the number of graduate programmes, but mostly in states with older programmes (Fig. 3F). The number of graduate programmes per State, graduate programme's age, and their interaction explained 75.20% of the variation in number of lots per State (see Table S4 for full coefficients).

Gender of the curators, researchers, and technicians

In terms of gender representation among BSFC curators, the majority of collections are curated exclusively by men (38), while a smaller proportion are curated exclusively by women (23). A few collections report mixed-gender teams, with either a male (three BSFCs) or female (two BSFCs) majority. Gender disparities among curators and technicians were observed in all regions, with an average male prevalence of 65% for curators and 52% for technicians. Only the North has slightly more female curators (54%). Collections in the Southeast and Northeast show the most pronounced gender bias, with 76% and 75%, respectively, of male curators. The disparities toward male curators are slightly lower in the South (67%) and Central-West (54%) collections. Collections in the Amazon, Caatinga, Pampa, and Pantanal are mostly led by male curators, while those in the Cerrado and Atlantic Forest have mainly female curators.

Among the collections with technical staff, gender representation is distributed across categories. A total of 25 collections reported having only male technicians, 24 reported only female technicians, five indicated a male majority, and two indicated a female majority. Twenty collections did not provide information on the gender of staff. Among the collections that provided gender of staff, men are slightly prominent on average (52%). Only Southeast (67%) and Northeast (56%) collections have a majority of female technicians. The gender bias toward male technicians is higher in the North and Central-West (67%), followed by the South collections (58%).

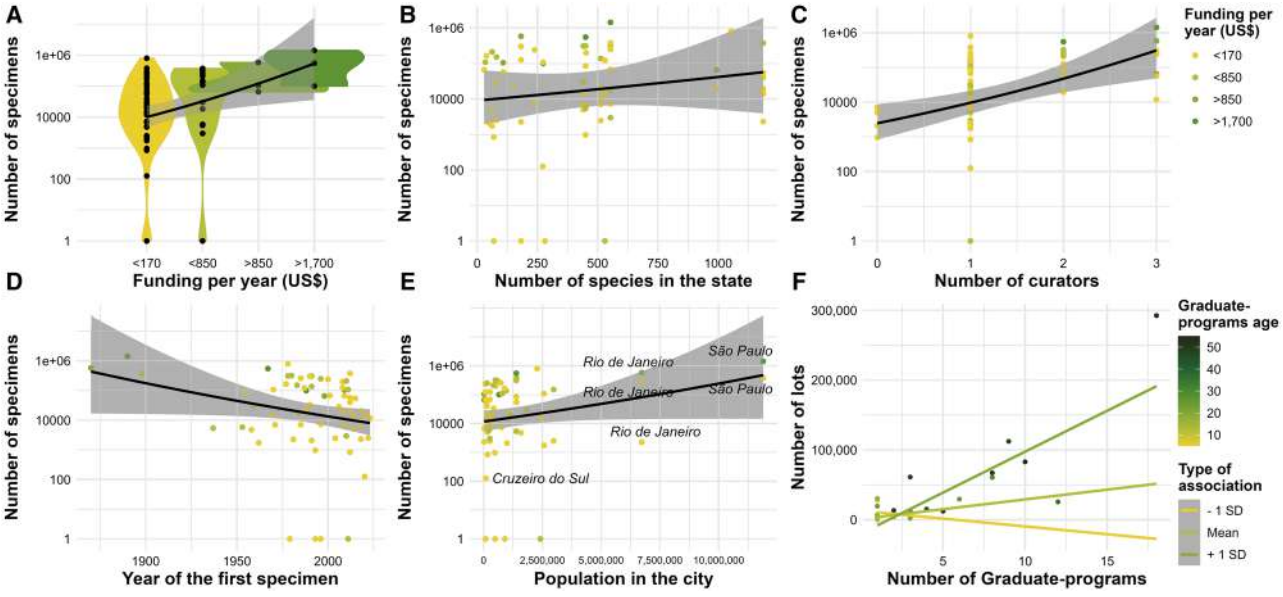

Figure 3. Associations between collection size of Brazilian Scientific Fish Collections and seven key predictors: A, annual funding (USD); B, species richness in the State (according to Tonella *et al.* 2023); C, number of curators leading the collection; D, year that the first specimen was deposited; E, population size of the city; and F, number of graduate programmes and graduate programme's age. The *y*-axis shows the number of specimens on a $\log_{10}$ scale, except in F, where the number of lots is presented. Points in A–E are coloured by funding level per year: yellow for less than USD175, light green for less than USD850, medium green for more than USD850, and dark green for more than USD1700. By contrast, in F, points are coloured by graduate programme's age, while coloured lines represent GLM predictions at different programme ages (young in yellow, and old in dark green). The black lines in A–E represent model predictions with 95% confidence intervals (shaded areas), and selected cities are labelled for reference in E.

Funding

In terms of institutional funding per year, 70% of BSFCs receive less than R$1,000.00 (approximately USD170) from their host institutions, 26% receive between R$1,001.00 and R$5,000.00 (~USD850), and only 4% receive more than R$10,000.00 (~USD1700).

When asked about the main sources of funding that support the operation and maintenance of their collections, about 41% (31 collections) reported relying on research projects led by staff associated with the collection. Additionally, several institutions combine this funding with other sources: five collections also benefit from other types of researcher-led projects, and nine receive additional support from service provision projects. A smaller number of collections (six) also reported financial aid from institutional units such as departments or research centres, while three collections reported support from higher-level institutional bodies alone. Less common funding sources include the curator's personal funds, individual donations or private support, state environmental agencies, and institutional budgets specifically allocated to collections. Notably, one collection reported receiving no financial support of any kind.

The Southeast receives the highest annual funding for ichthyological collections (~USD8,500), followed by the South (~USD5,500), Northeast (~USD4,000), Central-West (~USD2,500), and North (~USD1,500) (Fig. 2A, C). Funding is concentrated in the Atlantic Forest (~USD11,000), with lower but similar investments in the Pampa, Caatinga, and Cerrado (~USD3,500 each), and the least funding directed to the Amazon (~USD1,500). None of the collections from Central-West and North regions, nor those from the Amazon and Caatinga ecoregions, nor those curated exclusively by women, report an annual budget greater than USD1,700 (the highest funding category). Collections led by women are actually disproportionately underfunded, with over 80% receiving less than USD170 per year (the lowest funding category); only 52% of those curated exclusively by men operate with similarly low funding levels (Fig. 2B, D).

A total of 61 BSFCs reported receiving specimens collected via different types of environmental licensing studies conducted by third parties, usually private companies. Of these, 33 collections (54%) receive financial or material support from the companies or entities responsible for the studies, while 27 collections (44%) receive such material without any type of compensation. One collection reported receiving material voluntarily, without charging the responsible parties. Only 12 collections (16%) reported that they do not receive any material from environmental licensing activities.

We found that older ichthyological collections ($\beta = -0.29$, SE = 0.004, $z = -60.40$, $P < .001$) and those led by multiple curators (i.e. two or more; $\beta = 0.28$, SE = 0.006, $z = 43.79$, $P < .001$) receive more annual funding (Fig. 4A, B). In addition, gender composition of curators ($\beta = 0.591$, SE = 0.017, $z = 33.3$, $P < .001$; Fig. 4C) and technicians ($\beta = -0.51$, SE = 0.013, $z = -37.30$, $P < .001$; Fig. 4D) significantly influenced funding levels. Collections led by male curators receive approximately USD14,000 more annually than those led by female curators (Fig. 4C). Similarly, collections with predominantly male technicians receive about USD2,000 more per year than those with mostly female technicians (Fig. 4D). Together, these four predictors explained 30.40% of the variation in annual funding (adjusted $R^2 = .304$; see Supporting Information Table S4 for full coefficients). Variables such as population size, species richness in the State, sampling effort, number of specimens, and distance to the nearest urban centre were not retained in the best models during stepwise selection (Table S5).

Infrastructure (equipment) and security (fire prevention)

Regarding analytical infrastructure, the majority of collections (89%) reported having stereomicroscopes and microscopes available for morphological analyses directly associated with the collection. Six collections (8%) also have access to X-ray and computed tomography (CT) scanning equipment. Three (4%) reported having a CT scanner but no X-ray equipment, while four (5%) reported having an X-ray but no CT scanner. Three collections (4%) reported having no access to any of the listed equipment.

A total of 66% of the collections reported not having a fire prevention system in place, while 19% stated that a system exists but

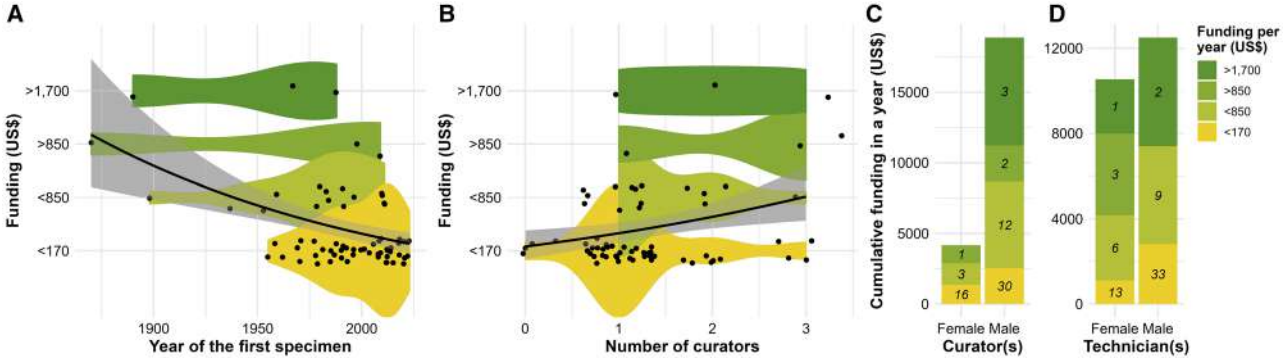

Figure 4. Effects of (A, B) institutional and (C, D) gender-related factors on annual funding received by Brazilian Scientific Fish Collections. A, older collections, indicated by earlier years of the first deposited lot of specimens, tend to receive higher annual funding (USD). B, the positive relationship between the number of curators and annual funding. A and B include violin plots representing the distribution of funding values across funding brackets (<170, <850, >850, and >1,700 USD per year), with the black dots indicating observed values and the black line showing the fitted model with a 95% confidence interval (grey shading). C, D, stacked bar plots of cumulative funding received per year by collections led by curators and technicians of different genders. Numbers within segments indicate the number of collections in each funding bracket. The background colours in all plots correspond to funding categories, from yellow (<170 USD/year) to dark green (>1,700 USD/year).

is either not maintained or does not adequately protect the collection. Only 15% reported having an effective fire safety system.

Challenges

Respondents reported a wide range of challenges affecting the functioning and sustainability of their collections. The most frequently mentioned issues were the lack of researchers or curators directly associated with the collection, the lack of institutional support, and insufficient funding from research agencies. Additionally, many collections suffer from a shortage of technical staff at both the medium and higher education levels, inadequate physical infrastructure (e.g. insufficient space), absence of fire protection systems, and a lack of institutional resources for routine maintenance. These constraints directly impact the long-term preservation, accessibility, and development of the collections, especially when curators must divide their time between teaching and administrative duties.

In addition to the challenges already mentioned, the maintenance and development of BSFCs face a range of structural and institutional barriers according to the survey. The most frequently cited issues revolve around six main axes: (i) the lack of continuous and specific financial support, which affects the acquisition of basic supplies (e.g. alcohol, glassware), the upkeep of facilities, and the execution of essential activities such as fieldwork for collection of more specimens and curation of specimen loans; (ii) insufficient institutional recognition, often reflected in the absence of formally designated curator positions and low prioritization by university administrators; (iii) a critical shortage of trained personnel, including technical staff and taxonomists, with existing curators frequently overwhelmed by unrelated administrative duties; (iv) inadequate infrastructure, including limited physical space, outdated equipment, and lack of IT support for digitization and data sharing; (v) the absence of national public policies specifically aimed at supporting biological collections, with sporadic and highly competitive funding opportunities that often exclude smaller or regional institutions; and (vi) low visibility and limited integration across collections, hindering broader collaborations and making it difficult to demonstrate their scientific and societal relevance. These interconnected factors significantly impact the long-term sustainability, accessibility, and scientific output of fish collections in the country.

DISCUSSION

BSFC historical perspectives

The origins of BSFCs are deeply linked to the colonial dynamics that characterized the first four centuries of European presence in the region (mostly represented by Portugal, France, and the Netherlands). During this period, numerous accounts of local biodiversity were assembled and published (e.g. de Léry 1578), driven primarily by the intent to exploit the natural resources of the newly acquired colonies. When biological specimens were collected, they were typically dispatched to European institutions. As early as the 16th century, a limited number of Brazilian animals reached Europe via commercial trade routes, contributing to some of the earliest zoological descriptions of the Brazilian fauna, including fishes (Teixeira and Papavero 2014).

A more systematic approach to the documentation of Brazilian fauna and flora emerged in the 17th century during the Dutch occupation of Pernambuco (1630–1654). This effort culminated in the publication of *Historia Naturalis Brasiliae* (1648) by Georg Marcgraf (1610–1644) and Willem Piso (1611–1678), which featured some of the earliest and most accurate descriptions of Brazilian fishes (Trevisan and Bockmann 2023). The accompanying watercolours and natural history illustrations represent some of the earliest visual records of the country's ichthyofauna (Trevisan and Bockmann 2023).

Large-scale natural history expeditions began in the 18th century, conducted by both European and Brazilian naturalists, including Alexandre Rodrigues Ferreira (1756–1815) and José Mariano da Conceição Veloso (1742–1811). These expeditions yielded extensive ichthyological material, much of which was transported to European institutions, where many specimens are still housed (Ceríaco 2021, Ceraco *et al.* 2023). Notably, Veloso (not Ferreira) assembled one of the earliest curated fish collections, which was recently re-identified in Portuguese museums (Ceraco *et al.* 2023).

The 19th century represented a major inflection point, particularly with the transfer of the Portuguese royal court to Rio de Janeiro in response to the Napoleonic invasions. With the capital of the Portuguese empire relocated to Brazil, a series of scientific and cultural initiatives were implemented, including the founding of the *Museu Real* in 1818, later renamed the *Museu Nacional* (now MNRJ). Although this institution laid the groundwork for permanent zoological collections in Brazil, field research during this period remained dominated by foreign naturalists such as Johann Baptist von Spix (1781–1826), Francis de Castelnau (1802–1880), and Louis Agassiz (1807–1873), and the majority of specimens continued to be sent to institutions in Europe and North America.

The ichthyological holdings of the MNRJ expanded considerably during the latter half of the 19th century. Concurrently, the institutionalization of scientific research extended to other urban centres, marked by the establishment of the *Museu Paraense* (now MPEG) in 1866, and the *Museu do Estado* in 1890 (which later evolved into the *Museu Paulista*, and whose zoological collections eventually formed part of the MZUSP). The oldest preserved ichthyological specimen currently housed in a Brazilian collection dates from 1870 and is held at the MNRJ. Other 19th century specimens are also preserved at MZUSP and MPEG (Marinho *et al.* 2019, W.B. Wosiacki, pers. comm.). The first primary types deposited in Brazilian collections date back to 1902 (MZUSP) and 1903 (MNRJ).

During the first half of the 20th century, the establishment of new ichthyological collections in Brazil was limited. However, this scenario changed markedly after 1965 with the formal structuring of graduate education in the country, and especially following the implementation of the first National Plan for Graduate Education in 1974 (Fig. 2E). This plan recognized graduate education as a strategic element of Brazil's scientific development and played a pivotal role in expanding the national academic infrastructure, particularly within federal universities (Hostins 2006, Alves and Oliveira 2014). As a result, the number of university-based ichthyological collections increased substantially, a trend that continues into the present day.

A notable finding is the significant growth in the number of BSFCs since the 1990s (Fig. 2D). Brandão *et al.* (1998) identified 44 Brazilian institutions maintaining zoological collections, of which only 20 included fish. Our inventory indicates that the number of BSFCs increased from 40 in 2000 to nearly 70 by 2020. Currently, ichthyological collections may surpass those of any other animal group in Brazil, including insects. For instance, earlier estimates identified 30 collections of amphibians (Peixoto 2003), 31 of reptiles (Prudente 2003), and 26 of mammals (Mendes and Souza 2003). Despite the increasing number of ichthyological collections, the total number of specimens deposited in BSFCs, nearly 10 million specimens (Supporting Information Table S2), is relatively low compared to that of other countries, and surely insufficient for the understanding of Brazilian fish diversity.

For context, a comparable survey conducted from 1973 to 1975 (Collette and Lachner 1976) estimated holdings of 34 million specimens among 124 fish collections in the USA (including Guam and Puerto Rico). By 1995, the estimated total number of specimens rose to over 60 million in about 109 US collections, of which 82 were considered permanent (Poss and Collette 1995). By 2017, 38 of the US collections surveyed by Poss and Collette (1995) had added over 15 million catalogued specimens (Singer *et al.* 2018), yielding a new total exceeding 75 million. As of 2025, one of the largest fish collections in the USA, the Burke Museum Ichthyology Collection, has approximately 13 million specimens, including eggs/larvae (10 million) and otolith pairs (2.6 million) (K. Pearson Maslenikov, pers. comm. 5 July 2025). Apart from the Burke Museum, the five largest US fish collections hold over 19.3 million catalogued specimens: Tulane University (7.41 million), University of Michigan (3.57), Natural History Museum of Los Angeles County (~3), National Museum of Natural History (2.78) and University of Florida (2.57). Another 15 collections have 1 to 2.4 million catalogued specimens each.

Our analysis also shows that 83% of BSFCs are housed in public higher education institutions, highlighting the central role of public universities in Brazilian scientific development (McManus *et al.* 2021). Conversely, the limited representation of private institutions underscores systemic weaknesses in the private education sector, reflecting both the broader challenge of engaging private actors in science and education and their general disinterest in investing in initiatives lacking immediate financial returns. These limitations are partially attributable to Brazil's complex bureaucracy and high tax burdens on businesses and individuals (Cavalcanti 2021). Furthermore, the predominance of collections in academic institutions means that curators and technicians often juggle collection management with teaching responsibilities, frequently without formal recognition of their work in collections. A similar conundrum was identified among US fish collections 50 years ago (Collette and Lachner 1976).

Size and spatial distribution of collections

This study presents the first comprehensive survey of BSFCs. In 2019, the *Boletim da Sociedade Brasileira de Ictiologia* (SBI) published a series of articles describing 22 BSFCs. In contrast, the present assessment documents a significantly larger number of BSFCs, 74 in total, distributed across 25 of the 27 Brazilian federal units (26 States plus the Federal District) (Figs 1, 2). These figures are comparable to those of nations. For context, the USA, with a territory approximately 11% larger than Brazil's and a Gross Domestic Product roughly 1300% higher, hosts about 100 fish collections (Sabaj 2025). On a broader scale, Mexico maintains 747 biological collections across 237 institutions (CONABIO 2016), and Colombia houses 272 collections in 115 institutions, containing approximately 1 million specimens (RNC 2025). It remains unclear what proportion of these collections include ichthyological material. Periodic surveys of fish collections in the USA (e.g. Collette and Lachner 1976, Poss and Collette 1995) revealed fluctuations in the number of collections that are active at a given time. It is not uncommon for ostensibly 'permanent' collections to be shuttered and transferred to other institutions (Sabaj 2020). The CARDUME network not only provides a detailed snapshot of the current status of BSFCs, but will be essential to track changes in collections (especially transfers), staffing, and resources over time.

The geographical distribution of BSFCs reveals a split between institutions with national and regional scopes: while 40% have a national focus, the majority (60%) operate regionally. This regional emphasis is valuable for capturing local biodiversity, but it also reflects limitations in the scope and scale of research conducted by some Brazilian institutions and the low financial support those collections receive. Notably, no collection houses more than 25% of its specimens from outside Brazil. In contrast, collections in countries such as the USA, Canada, France, and Germany frequently contain significant holdings from abroad. Such a rough proportion, however, is biased by the megadiverse fish fauna in Brazil that encompasses a much larger number of species (considering freshwater only, almost four times the number of species from the USA, 13 times those from Canada, and approximately 35 times that of France and Germany). While this international coverage broadens research potential, Brazil's unparalleled biodiversity provides a strong foundation for domestic research even in the absence of globally scoped collections.

The distribution and size of BSFCs are historically associated with population density (Fig. 3E) and financial investment (Figs 2, 3A), with larger and better-funded collections located predominantly in the South and Southeast regions. Although this trend is unsurprising, it raises concerns about underrepresentation in regions of high biodiversity, particularly in the North, where most of the Amazon rainforest is located (Fig. 2).

Scientific collections are the backbone of global biodiversity knowledge (Troudet *et al.* 2017). In Brazil, 72% of all ichthyological records available in GBIF originate from fish collections (IBGE 2023). However, these data represent only about one-third of all fish records deposited in BSFCs, indicating that a large volume of valuable data remains unpublished and inaccessible.

Digitalization of Brazilian ichthyological collections began in the late 1980s, as noted by Brandão *et al.* (1998), aligning with international efforts to digitize biodiversity data. Currently, 61% of BSFCs are fully digitized, and an additional 31% are in the process of digitization. Despite this progress, 63% of BSFCs do not share their data online. Even among collections that do provide data, outdated IT infrastructure and insufficient funding hinder the maintenance of digital platforms and data management systems.

BSFCs currently house 2646 primary type specimens (Supporting Information Table S2). This is a relatively high number, considering that approximately 5000 fish species are currently known from Brazil, many of which are not endemic but have broader geographical distributions. Furthermore, BSFCs are relatively recent initiatives, and the community of researchers dedicated to fish systematics in Brazil is even more recent.

Another critical shortfall is the availability of genetic material. Only 3% of BSFC specimens have associated tissue samples for genetic analysis, substantially limiting the integration of molecular tools into ichthyological research. Furthermore, 71% of collections report that they are unable to conduct genetic sequencing due to a lack of equipment or funding. Strengthening infrastructure and increasing financial support for molecular research would greatly enhance the scientific capacity and international relevance of BSFCs.

Gender of the curators, researchers, and technicians

The data on BSFCs reveal persistent gender disparities in both curatorial and technical roles, despite some signs of regional balance. A clear majority of collections are curated exclusively by men (38), compared to those curated exclusively by women (23). Mixed-gender teams are rare, and when present, they tend to have a male majority (five collections) more often than a female majority (three collections). This pattern highlights women's systemic underrepresentation in leadership and aligns with broader trends in zoological societies, where women have only recently begun attaining positions of power (Slobodian *et al.* 2021). Comparable disparities were documented in US museum collections (Beverung 2009, Lopes 2016) and Latin American herbaria (Lobato-de Magalhães *et al.* 2018). Our analysis suggests this gender imbalance stems partly from institutional inertia: larger and older collections remain predominantly male-led, while female curators are typically relegated to smaller collections with less funding, weaker institutional support, and lower prestige. Notably, all three collections receiving more than USD700 in annual institutional support are led by men. Notably, the Southeast region—which receives the highest institutional funding—exhibits the most pronounced gender disparity in curatorship, with 76% of positions held by men. Conversely, the Central-West and North regions show greater gender balance yet receive the lowest funding. Strikingly, the North—the only region with female predominance in curator roles (54%)—is also the least financially supported. Furthermore, technical support for informatics, typically provided by host institutions, is predominantly available to smaller collections led exclusively or primarily by men (16 out of 25) than by women (5 out of 20).

Looking at biome-specific patterns, male curators predominate in collections located in the Amazon, Caatinga, Pampa, and Pantanal. Conversely, the Cerrado and Atlantic Forest host more collections under female leadership. These variations may indicate that local institutional cultures, hiring practices, and perhaps access to training and professional networks influence gender representation. Nevertheless, there are several strategies to minimize the gender gaps and other social biases (see Diele-Viegas *et al.* 2022 for a list of actions), but we first need to recognize the structural biases and historical inequalities that lead to them.

In 2017, women members of the SBI initiated a group dedicated to discussing and promoting the participation of women in ichthyology. This initiative, called Ictiomulheres, has been responsible for addressing gender and minority-related issues at all SBI meetings, investigating the gender inequality scenario in Brazilian ichthyology, and for publishing an e-book that honours Brazilian female researchers who inspire the new generation of ichthyologists through their life's work (Soares *et al.* 2024). A previous article by Wosnick and Palmeira-Nunes (2020) honours the Brazilian women who have contributed to Amazonian elasmobranch research (ElasMulheres). Discussing these topics and supporting women and other minority groups in ichthyology is a crucial first step toward improving equity and diversity in the academic world.

Funding, infrastructure (equipment), and security (fire prevention)

As a signatory of the CBD, established during the World Conference on Environment and Development held in Rio de Janeiro in 1992, Brazil is recognized both for its sovereignty over its biological resources and its responsibilities regarding their conservation. The CBD emphasizes that *in situ* conservation strategies should be complemented by *ex situ* approaches, which involve the preservation of components of biological diversity outside their natural habitats, such as in biological collections.

Despite Brazil's participation in the CBD, there is no discernible correlation between this involvement and an increase in ichthyological collections, primarily due to the lack of consolidated historical data on federal investments allocated to their maintenance. Moreover, financial support from the federal government for such collections has been sporadic and largely dependent on the priorities of the current administration.

In 2003, the Ministry of Science and Technology introduced the Guidelines and Strategies for the Modernization of Brazilian Biological Collections and the Consolidation of Integrated Information Systems on Biodiversity (Kury *et al.* 2006), marking an unprecedented governmental effort to align with the CBD objectives. Nevertheless, investments in ichthyological collections remain minimal, with most receiving less than USD170 annually from their host institutions. The majority of funding originates from researchers' individual projects, although only 41% of ichthyological collections are affiliated with active researchers.

A broader initiative, however, was launched in 2024 by the Ministry of Science, Technology, and Innovation (MCTI) in collaboration with the Financier of Studies and Projects (FINEP). This public call, the 'Chamada Pública MCTI/FINEP/FNDCT/Identidade Brasil, Recuperação e Preservação de Coleções 2024' (FINEP 2024), allocated R$250 million for the recovery and preservation of scientific and cultural collections, including zoological repositories. However, smaller collections continue to face disadvantages, as funding tends to favour institutions with higher scientific output, typically concentrated in the southeastern region.

This funding imbalance is also evident in the infrastructural disparities among collections (Figs 2, 3A, 4A, B). While basic analytical instruments such as stereomicroscopes and compound microscopes are available in the majority of institutions (89%), access to advanced technologies such as X-ray and CT scanning

is limited to only 8% of collections. This significantly restricts the scope of on-site scientific research. Furthermore, structural vulnerabilities persist: 66% of collections lack any fire prevention system, and only 15% report having adequate fire safety infrastructure.

These deficiencies underscore the urgent need for increased and more equitably distributed funding, as well as strategic investments aimed at enhancing both analytical capabilities and risk mitigation. Addressing these issues is essential to ensure the long-term preservation, accessibility, and scientific utility of Brazil's ichthyological collections.

CONCLUSION

While BSFCs represent an invaluable reservoir of biodiversity data and scientific heritage, they face significant challenges in terms of staff and funding. Addressing these issues will require strategic investments, policy support, and interdisciplinary collaborations aimed at strengthening institutional capacity, promoting data accessibility, and integrating genetic and digital technologies into collection management practices. Doing so will not only enhance the scientific utility of these collections but also contribute meaningfully to Brazil's efforts in biodiversity conservation and sustainable development.

Survey respondents identified numerous structural and institutional challenges affecting the sustainability of BSFCs. Chief among these were insufficient and inconsistent funding, lack of institutional support and recognition, shortage of trained personnel (curators, technicians, taxonomists), and inadequate infrastructure. These challenges disproportionately affect women curators, who are more likely to work in under-resourced institutions with lower funding levels and weaker institutional backing. To be able to address all these shortcomings, we must first recognize them and the structural biases and historical inequalities that lead to them. Collections also face difficulties in acquiring essential materials, conducting fieldwork, and digitizing data due to limited resources. The absence of national policies, low inter-collection integration, and visibility further exacerbate these issues. Curators often juggle multiple responsibilities, reducing time for curation. Collectively, these constraints compromise the long-term preservation, accessibility, and scientific contribution of BSFCs at both national and regional levels.

The CARDUME Initiative, integrating BSFCs to promote Research and Biodiversity Conservation, is intended to help overcome all of the above-mentioned shortfalls. In fact, all of the surveyed researchers demonstrated expectations when asked about the CARDUME initiative. For them, the network should facilitate the communication between curators and technicians of different institutions, promote training courses on digitalization and collection management, improve the quality of the specimens' identification and metadata, and increase the sharing of Brazilian Biodiversity data. These actions would especially help the BSFCs considered small and remote, to improve their structure and share their data with the world. The CARDUME initiative should be capable of demonstrating the importance of biological collections to their institutions, funding agencies, and the Brazilian government, and demand them to follow the National Policy for Biological Scientific Collections (NPBSC, Draft Bill 1993/2024) and take responsibility for financially supporting the management of the specimens.

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CONFLICT OF INTEREST

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DATA AVAILABILITY STATEMENT

The data underlying this article are available in the article and in its online supplementary material.

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