Biota Neotropica 22(spe): e20221406, 2022
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
Thematic Review

Marine planktonic and benthic organisms: an ocean of diversity in the collections of the State of São Paulo

***Michela Borges*[1]*, *Mônica A.V. Petti*[2], *Marcelo V. Fukuda*[3], *Valéria Cassano*[4], *Mutue T. Fujii*[5] & *A. Cecília Z. Amaral*[1,6]**

[1]*Universidade Estadual de Campinas, Instituto de Biologia, Museu de Diversidade Biológica, Rua Monteiro Lobato, CEP 13083-862, Campinas, SP, Brasil.*
[2]*Universidade de São Paulo, Instituto Oceanográfico, Coleção Biológica "Prof. Edmundo F. Nonato", Praça do Oceanográfico, 191, CEP 05508-120, São Paulo, SP, Brasil.*
[3]*Universidade de São Paulo, Museu de Zoologia, Av. Nazaré, 481, CEP 04263-000, São Paulo, SP, Brasil.*
[4]*Universidade de São Paulo, Instituto de Biociências, Departamento de Botânica, Rua do Matão 277, 05508-090, São Paulo, SP, Brasil.*
[5]*Instituto de Pesquisas Ambientais, Av. Miguel Estéfano 3687, CEP 04301-012, São Paulo, SP, Brasil.*
[6]*Universidade Estadual de Campinas, Instituto de Biologia, Departamento de Biologia Animal, Rua Monteiro Lobato, 255, CEP 13083-862, Campinas, SP, Brasil.*
**Corresponding author: borgesm@unicamp.br*

BORGES, M., PETTI, M.A.V., FUKUDA, M.V., CASSANO, V., FUJII, M.T., AMARAL, A.C.Z. **Marine planktonic and benthic organisms: an ocean of diversity in the collections of the State of São Paulo**. Biota Neotropica 22(spe): e20221406. https://doi.org/10.1590/1676-0611-BN-2022-1406

Abstract: Brazil is characterized as a megadiverse country, and one of the factors that guarantees the knowledge and preservation of this biodiversity is an improvement in the biological collections. They represent a country's biological, scientific, cultural, and genetic heritage and their preservation depends on a joint effort of researchers, institutions, and public authorities. Marine biological collections of invertebrates and algae of the state of São Paulo represent a high percentage of the national collections, with five biological collections deposited in state institutions. Currently, these collections safeguard the vast majority of the state's marine collection and make up one of the largest in the country. Therefore, the objective of this research is to present information on marine biological collections in the state of São Paulo, their current status, funding, and future perspectives, creating communication opportunities and considering the factors that impact their development. Support from the São Paulo Research Foundation (FAPESP) surpasses state limits, since many studies address broader areas and/or establish diverse partnerships with other institutions from outside São Paulo. This is reflected in the taxonomic and geographic scope of the biological collections in the state, since these host specimens/species from different regions of the country, or even from other countries. However, it is worth mentioning that it is not enough to invest in expeditions to enrich the collections without valuing the training of qualified personnel, both for the collections maintenance and for their taxonomic refinement.
Keywords: *Marine collections; biodiversity; ex situ conservation.*

Organismos planctônicos e bentônicos marinhos: um oceano de diversidade nas coleções do Estado de São Paulo

Resumo: O Brasil é caracterizado como um país megadiverso e uma das prioridades no conhecimento e conservação dessa biodiversidade é seguramente a melhoria das coleções biológicas. Estas representam patrimônio biológico, científico, cultural e genético de um país, e sua preservação depende de um esforço coletivo de pesquisadores, instituições e do poder público. Com relação às coleções biológicas marinhas de invertebrados e algas, o estado de São Paulo representa uma alta porcentagem do acervo nacional, com cinco principais coleções depositadas em instituições estaduais. Atualmente estas coleções salvaguardam a grande maioria do acervo marinho estadual e compõem um dos maiores do país. Assim sendo, o objetivo desta pesquisa é o de apresentar informações sobre as coleções biológicas marinhas do estado de São Paulo, estado atual, financiamentos e perspectivas futuras, criando oportunidades de comunicação e considerando os fatores que impactam o desenvolvimento das mesmas. O apoio financeiro da Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) às instituições paulistas extravasa os limites do estado, visto que muitas pesquisas abordam áreas mais abrangentes e/ou estabelecem parcerias diversas com outras instituições não paulistas. Isso se reflete inclusive na abrangência taxonômica e

geográfica das coleções biológicas do Estado, uma vez que estas mantêm espécimes/espécies de diferentes regiões do país, ou mesmo de outros países. No entanto, vale ressaltar que não basta investir em expedições de coleta para enriquecimento das coleções sem valorizar a formação de pessoal qualificado, tanto para a curadoria dos acervos quanto para o refinamento taxonômico.

Palavras-chave: *Coleções marinhas; biodiversidade; conservação ex situ.*

Importance of the Collections

Biological collections are a fundamental source of information for studies that involve governmental and/or educational strategies, such as biodiversity conservation, ecosystem monitoring, environmental impact assessment and habitat recovery. They play a central role in the study of biodiversity, as they constitute the foundations of its essence, being the basis for the study of taxonomy, systematics, evolution, and biogeography of living and/or extinct organisms.

One of the priorities in biodiversity conservation, including the marine, is the improvement of biological collections, either through the sampling of material and/or the taxonomic refinement of the organisms (Migotto & Marques 2006). It is based on reliable collections that researchers can present consistent results, from the community composition to population structures, including patterns of distribution, among others.

What is not known is not preserved, and it is in this context that biological collections play a crucial role. The activities carried out in collections are fundamental to the advancement of scientific knowledge and research, including oceanographic research, being one of the major goals of the "Ocean Decade" (2021–2030), established by the UN to promote our knowledge and improve ocean management. Biological information associated with environmental data allows for the understanding of patterns of change in biodiversity and their impacts on society, resulting from the natural dynamics of systems or human interventions in the environment. The exchange of information on marine biodiversity associated with environmental variables is a current demand that requires not only results published in specialized journals, but also knowledge and skills for different analyses. Thus, the collections contribute to the advancement of science ensuring the quality of data and information for the scientific community and society in general.

There is no way to affirm, for example, the existence of environmental and community changes without a historical record of both the species occurrence and the associated environmental variables. In this way, biological collections present several potentials, such as the ability to record changes in communities that may result from several factors, as climate change and environmental impacts (Magurran et al. 2010). These changes can be analyzed by: changes in biogeographic patterns, e.g., modifications in species distribution, new occurrence records, presence of invasive species, among others; changes in community structure, such as in abundance and ranking of dominant species; changes in phenology, such as decreased temporal synchronicity between prey/predator; interaction between ocean warming and other stressors (comparison between impacted zones and pristine zones) and investigation of intermittent oceanographic phenomena, such as the influence of the presence/absence of El Niño and La Niña on marine organisms (Edwards et al. 2010).

However, a collection only serves all these purposes if it is organized, with the species correctly identified and their information available in databases, as established by the United Nations Convention on Biological Diversity (MCT 2006). Although the actions suggested for the consolidation of biological collections aim to promote the qualification of the taxonomic and geographic records associated with the specimens, a great part of the collections remains unidentified or is only named at more inclusive taxonomic levels (Bebber et al. 2010, Wheeler et al. 2012, Yeates et al. 2016). Given this scenario, efforts must be made to translate this material into knowledge and biodiversity conservation (Bebber et al. 2010). The challenge of knowing, conserving and sustainably using Brazilian biodiversity, with regard to scientific collections, is directly related to their proper structuring and maintenance (MCT 2006).

With its marine biological collections, including invertebrates and algae, the state of São Paulo currently holds a high percentage of the national collection, with five main collections located in state institutions: the Museum of Zoology and the Oceanographic Institute, both of the University of São Paulo (MZUSP and IOUSP, respectively), the Museum of Biological Diversity of the State University of Campinas (MDBio), the Herbarium of the Institute of Biosciences of the University of São Paulo (IB-USP) and the Herbarium (SP) of the Institute of Environmental Research (IPA), former Institute of Botany (IBt) (Figure 1). Currently, these collections safeguard the vast majority of the state's marine organisms. For invertebrates, they contain about 15 high taxonomic groups, the largest being Mollusca, Crustacea, Annelida, and Echinodermata (Figure 1). Other smaller collections, especially of Crustacea, are maintained in different state institutions in which there are specialists (Table 1). In the case of algae, smaller herbaria, mostly located in universities, maintain algae mainly from continental sites.

Zoological Collections and Herbaria

The history of the **Museum of Zoology of the University of São Paulo (MZUSP)** dates back to the last decades of the 19th century, with a mixed origin involving explorations along the current state of São Paulo and characters closely related to the current National Museum of the Federal University of Rio de Janeiro. Preceding the creation of the University of São Paulo itself, which would only take place in 1934, an important milestone occurred with the establishment of the Geographical and Geological Commission of the Province of São Paulo, in 1886: the North American geologist and geographer Orville Derby, who until then was associated with the National Museum, was hired to lead the Commission, organizing efforts to establish a collection based on the material gathered by its exploratory expeditions, an incipient collection to which was soon added that of the Sertório Museum, then relatively well-known in the city of São Paulo (Lopes 2009). With the inauguration of the Museum Paulista as a natural history museum on September 7, 1895, it was of fundamental importance for its development during the following years to have the German zoologist Hermann von Ihering serving as its first Director, a scientist who enjoyed a certain prestige in European circles, and was at that time a traveling naturalist at the National Museum.

Marine Collections

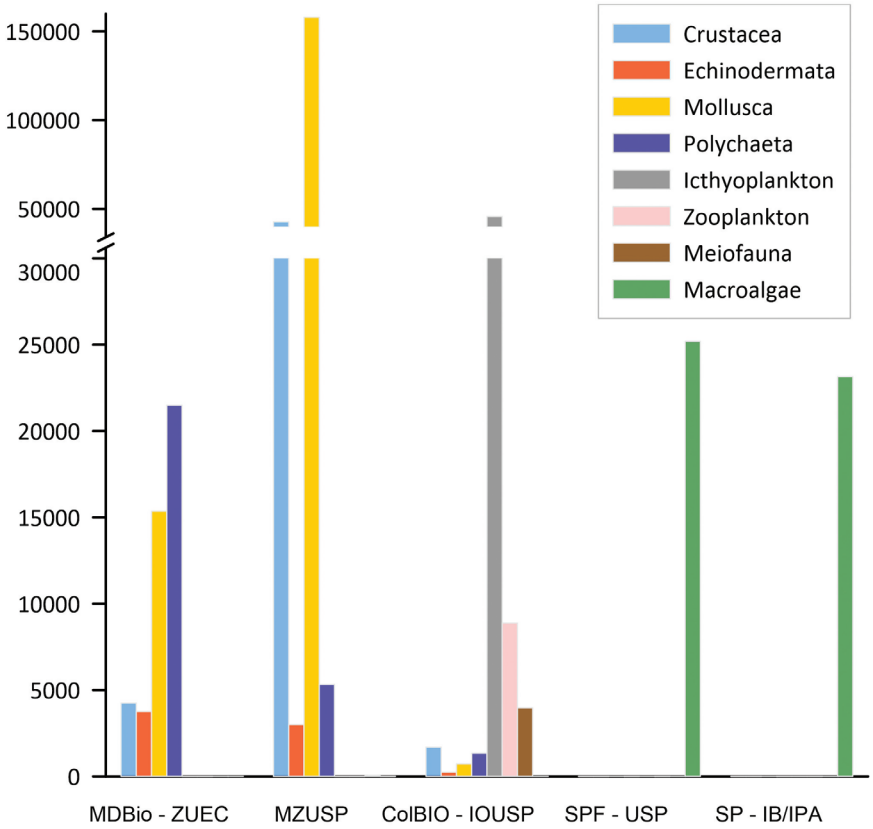

Figure 1. Number of records of the main groups of marine organisms deposited in the largest collections of the state of São Paulo. MDBio-ZUEC, Museum of Biological Diversity of the Institute of Biology of the State University of Campinas; MZUSP, Museum of Zoology of the University of São Paulo; ColBIO-IOUSP, Biological Collection "Prof. Edmundo F. Nonato" of the Oceanographic Institute of the University of São Paulo; SPF-USP, Herbarium of the Institute of Biosciences of the University of São Paulo; SP-IPA, Herbarium "Maria Eneyda P. Kauffmann Fidalgo" of the Institute of Environmental Research.

Along more than four decades the Museum Paulista was an important center for exhibitions and research, with a continuous increase in its collections, but gradually acquiring more accentuated features of a historical museum; in 1939, the zoological part was separated from the rest of the collection, forming the Department of Zoology of the Secretariat of Agriculture, Industry and Commerce of the State of São Paulo, which would be transferred to the building it currently occupies in 1940–1941. Almost 30 years later, in 1969, the Department was formally transferred to the University of São Paulo, becoming the USP's Museum of Zoology (Taddei et al. 1999, Oliveira 2003).

The Museum of Biological Diversity of the Institute of Biology of the State University of Campinas (MDBio) emerged in the early 1990s as a "Museum of Natural History", a depository of collections, mainly of vertebrates, originated from research carried out by the Institute's professors. As of 2006, with the incorporation of new collections, especially of marine invertebrates, and a new purpose, it became "Museum of Zoology", since its collection was represented exclusively by zoological items and pieces. In 2013, the Neotropical sound archive "Jacques Vielliard (FNJV)", which was founded in 1978 at the Institute of Biology and represents, today, one of the five largest collections of its kind in the world, and the largest in Latin America, was incorporated into the collection of the Museum of Zoology (ZUEC). In 2021, from the merger between the Museum of Zoology (ZUEC) and Herbarium (UEC) (also from the Unicamp Institute of Biology), the current Museum of Biological Diversity (MDBio) emerged, with two major areas: Zoology and Botany. MDBio-ZUEC is a university museum, linked to the Institute of Biology of the State University of Campinas, which houses a zoological collection, composed of invertebrates, vertebrates, animal products, images, sounds and videos, in addition to recent samples of genetic heritage in the form of animal tissue and/or extracted genetic material.

The Biological Collection "Prof. Edmundo F. Nonato" of the Oceanographic Institute of the University of São Paulo (ColBIO), inaugurated in 2012, maintains one of the largest Brazilian collections of marine organisms collected in Brazilian waters from the 1950s to the present day. In addition, it has numerous samples of Antarctic invertebrates, from several Brazilian expeditions, mainly in areas close to the Brazilian Antarctic Station "Comandante Ferraz" (King George Island, South Shetlands). The name of the collection is a tribute to Professor Emeritus of IOUSP Edmundo F. Nonato, a great supporter of oceanographic studies in Brazil and one of the pioneers to use FAPESP (São Paulo Research Foundation) resources for the development of his research. The current biological collection at IOUSP is of inestimable historical value, representing more than seven decades of oceanographic research.

The Herbarium of the Institute of Biosciences of the University of São Paulo (SPF) was created in 1932 by Prof. Wilson Hoehne as a vascular plant collection at the Faculty of Pharmacy and was transferred

Table 1. Main marine collections (invertebrates and macroalgae) in the state of São Paulo.

Taxa/Collection	Start of Collection	Species	Lots	Specimens	Holotypes	Paratypes	Other Types	Curators/Contact
Museum of Zoology, University of São Paulo – MZUSP								
SiBBr – Sistema de Informação sobre Biodiversidade (www.sibbr.gov.org)								
Annelida								
"Polychaeta"		315	5333	32100	78	248	2	Marcelo V. Fukuda / mvfukuda@usp.br
Arthropoda								
Crustacea	1880		42669	~1000000	380	887	8	Marcos D. S. Tavares / mdst@usp.br
Bryozoa		200	1385		37	119	48	Marcelo V. Fukuda / mvfukuda@usp.br
Chordata		45	133		29	48	1	Marcelo V. Fukuda / mvfukuda@usp.br
Cnidaria & Ctenophora		387	8709	10000+	19	35	20	Marcelo V. Fukuda / mvfukuda@usp.br
Echinodermata		230	3004	15679	16	3	3	Marcelo V. Fukuda / mvfukuda@usp.br
Mollusca	1880	~22000	157922	~1500000	428	768	56	Luiz R. L. Simone / lrsimone@usp.br
Nemertea		8	33	~50	3	6	0	Marcelo V. Fukuda / mvfukuda@usp.br
Priapulida			3	3				Marcelo V. Fukuda / mvfukuda@usp.br
Porifera		28	422					Marcelo V. Fukuda / mvfukuda@usp.br
Tardigrada			50	100+				Marcelo V. Fukuda / mvfukuda@usp.br
Museum of Biological Diversity, Institute of Biology, University of Campinas – MDBio – IB/UNICAMP								
SiBBr – Sistema de Informação sobre Biodiversidade (www.sibbr.gov.org); speciesLink (www.specieslink.net)								
Annelida								
"Polychaeta"	2006	827	22309	168291	122	878	11	A.Cecília Z.Amaral / ceamaral@unicamp.br Tatiana M. Steiner / tatims@unicamp.br
Arthropoda								
Crustacea	2011	160	4249	58283	2	2		Michela Borges / borgesm@unicamp.br
Brachiopoda	2012	4	7					Michela Borges / borgesm@unicamp.br
Bryozoa	2016	18	58		4			Michela Borges / borgesm@unicamp.br
Chordata								
Ascidiacea	2016		133					Michela Borges / borgesm@unicamp.br
Cnidaria	2016	24	72					Michela Borges / borgesm@unicamp.br
Mollusca								
Aplacophora	2016	7	251	952	4	19		Flávio D. Passos / flaviodp@unicamp.br
Bivalvia	2008	317	7856	40535	4	30		Flávio D. Passos / flaviodp@unicamp.br
Cephalopoda	2012	5	8	15				Flávio D. Passos / flaviodp@unicamp.br
Gastropoda	2008	306	7242	156701	3	18		Flávio D. Passos / flaviodp@unicamp.br
Polyplacophora	2012	1	3	37				Flávio D. Passos / flaviodp@unicamp.br
Echinodermata								
Asteroidea	2007	17	562	1157				Michela Borges / borgesm@unicamp.br
Crinoidea	2007	1	16	24				Michela Borges / borgesm@unicamp.br
Echinoidea	2007	8	71	185				Michela Borges / borgesm@unicamp.br
Holothuroidea	2007	6	105	199		3		Michela Borges / borgesm@unicamp.br
Ophiuroidea	2007	153	3210	53900	1	2		Michela Borges / borgesm@unicamp.br
Nemertea	2012		25					Michela Borges / borgesm@unicamp.br
Porifera	2016		89					Michela Borges / borgesm@unicamp.br
Biological Collection "Prof. Edmundo F. Nonato" – Oceanographic Institute – ColBIO/USP								
SiBBr – Sistema de Informação sobre Biodiversidade (www.sibbr.gov.org)								
Annelida								
"Polychaeta"	2015	235	910	~5000		39		Monica A. V. Petti / mapetti@usp.br
Arthropoda								
Crustacea								Monica A. V. Petti / mapetti@usp.br
Amphipoda		3	3					Monica A. V. Petti / mapetti@usp.br
Decapoda	2015	110	148	999				Monica A. V. Petti / mapetti@usp.br
Isopoda		99	851					Monica A. V. Petti / mapetti@usp.br

Continue...

...Continuation

Taxa/Collection	Start of Collection	Species	Lots	Specimens	Holotypes	Paratypes	Other Types	Curators/Contact
Mysida			15					Monica A. V. Petti / mapetti@usp.br
Stomatopoda		6	10	23				Monica A. V. Petti / mapetti@usp.br
Tanaidacea		1	50					Monica A. V. Petti / mapetti@usp.br
Brachiopoda	2015	2	5					Monica A. V. Petti / mapetti@usp.br
Chordata								
Cephalochordata	2015	1	1	12				Monica A. V. Petti / mapetti@usp.br
Tunicata	2014	109	879					Tito M. C. Lotufo / tmlotufo@usp.br
Cnidaria	2015	13	22					Monica A. V. Petti / mapetti@usp.br
Echinodermata								
Asteroidea		12	15	48				Monica A. V. Petti / mapetti@usp.br
Crinoidea	2015	3	3	33				Monica A. V. Petti / mapetti@usp.br
Echinoidea		8	10	61				Monica A. V. Petti / mapetti@usp.br
Ophiuroidea		1	1	4				Monica A. V. Petti / mapetti@usp.br
Mollusca								
Bivalvia	2015	148	240	1141				Monica A. V. Petti / mapetti@usp.br
Cephalopoda		2	2	6				Monica A. V. Petti / mapetti@usp.br
Gastropoda		273	402	2124				Monica A. V. Petti / mapetti@usp.br
Polyplacophora		3	5	18				Monica A. V. Petti / mapetti@usp.br
Scaphopoda		10	15	564				Monica A. V. Petti / mapetti@usp.br
Nematoda	2016	254	2399	23990				Thais N. Corbisier / tncorbis@usp.br
Foraminifera	2017	3	5	5	2	2		Silvia H. M. Sousa / smsousa@usp.br
Ichthyoplankton	2012	220	45680	~500000				Mario Katsuragawa / mkatsura@usp.br
Zooplankton	2012		8872					Mario Katsuragawa / mkatsura@usp.br
Faculty of Philosophy, Sciences and Letters of Ribeirão Preto, University of São Paulo – FFCLRP/USP								
Arthropoda								
Crustacea	1995	567	7100	295000		4	1359 (Genbank)	Fernando L. Mantelatto / flmantel@usp.br
Institute of Biology, São Paulo State University – IB/UNESP (Campus do Litoral Paulista)								
Arthropoda								
Crustacea	1994	52	385	12758				Marcelo Pinheiro / marcelo.pinheiro@unesp.br
Herbarium of the Institute of Biosciences, University of São Paulo – SPF								
			speciesLink (https://specieslink.net/col/SPF-Algae/)					
Algae	1949	2530	25190		50	15	8	Valéria Cassano / vcassano@usp.br
Herbarium "Maria Eneyda P. Kauffmann Fidalgo" (SP), Institute of Environmental Research – IPA								
			speciesLink (https://specieslink.net/col/SP-Algae/)					
Algae	1920		23866		15	9	13	Andréa Tucci / atucci@sp.gov.br

to the Botany Department in the 1960s, where it was added to the marine algae collection (Mello-Silva et al. 2015). The marine algae herbarium of the USP Biosciences Institute (SPF-Algae) was created in 1949 from the collection of Prof. Aylthon Brandão Joly, who effectively initiated the systematic study of algae in Brazil. The foundation of algae studies at IB-USP by Prof. Joly, with subsequent training of Brazilian phycologists, increased the collection of the SPF-Algae over the years, making it one of the largest herbaria in Latin America.

The Herbarium "Maria Eneyda P. Kauffmann Fidalgo" (SP) of the Institute of Environmental Research – IPA (formerly Institute of Botany – IBt) has a long history, which begins in 1917 with the arrival of the founder and creator of the Botany Institute, Frederico Carlos Hoehne. He created the Horto Oswaldo Cruz, next to the Butantan Institute, with the purpose of studying medicinal plants (Hoehne 1940). Only in 1942, it was renamed Institute of Botany and finally, in 2021, with the unification of the Botany, Forestry and Geological Institutes, the Institute of Environmental Research – IPA was created. The SP herbarium is the third largest in Brazil, with national and international recognition and indexation, maintaining intense exchange with similar institutions around the world (Barbosa 2013). Among the main collections, we highlight that of the *Geographic and Geological Commission of the Province of São Paulo* and part of the collection of the *Commission of Telegraphic and Strategic Lines from Mato Grosso to Amazonas*, among others (Instituto de Botânica 1995). However, the algae collections are much more recent.

The Cryptogams section was only created in 1960, and the technical-scientific divisions Phytotaxonomy and Botanical Garden, in 1969. It is in the Phycology section, belonging to the Phytotaxonomy division, that the study of continental and marine algae began (Teixeira 1988).

Presentation of the Collections and Their Importance

The establishment of a United Nations Sustainable Development Goal (SDG) exclusive for the ocean (SDG 14 – *Conserve and sustainably use the oceans, seas and marine resources*) was a major achievement for the ocean research community, and the Decade of the Ocean is an essential tool for raising awareness and providing the necessary support for scientific activities that promote the generation of data, information and technology in order to achieve this objective. In this context, biological collections play a fundamental role in organizing, maintaining, and conserving samples of marine organisms collected over decades, mainly in the Southwest Atlantic.

The marine invertebrate collections at MZUSP were initiated from the beginning of the Museum Paulista, since Hermann von Ihering, who had malacology as one of his main interests, brought an important collection with more than 2000 pieces of mollusks from Europe upon his arrival in Brazil, in 1880. Since the beginning, the collection was increased by occasional new samples and various expeditions, many of these with the participation of von Ihering himself, but also some carried out by traveler naturalists associated with the Museum. The collections also grew through exchanges and purchases, practices that are maintained to this day.

Today, the marine invertebrate collections at the MZUSP are under the responsibility of the Invertebrate Service, a section of the institution's Scientific Division. These are represented by about 20 phyla and are subdivided into three collections – 'Carcinology', 'Malacology', each containing their respective phylum, and the rest grouped under the 'Marine invertebrates and other collections'.

Currently, the Invertebrate Service collections house more than 2.5 million specimens, considering the cataloged and listed specimens alone, with emphasis on the Malacology (~1.5 million specimens) and Carcinology (~1 million specimens) collections (Figure 1; Table 1). The amount of type material is also noteworthy, with almost 1000 lots of holotypes and more than 2100 of paratypes, numbers that are continuously increased by taxa described not only by MZUSP researchers, but also by specialists from other institutions at the national and even international level. Part of the information about the collection is available in open access, both for national researchers, through the 'Brazilian Biodiversity Information System' (SiBBr) platform, and for foreigner researchers, through the 'Global Biodiversity Information Facility' (GBIF).

The Museum of Biological Diversity – Zoology (MDBio) maintains zoological collections with a wide geographic and taxonomic scope. There are more than 40 scientific collections, kept in humid and/or dry environment, which include about 1 million invertebrates, among which approximately 500,000 make up the marine collections. Of these, the most representative are Mollusca, Annelida, Crustacea and Echinodermata (Figure 1; Table 1).

The MDBio – ZUEC marine collection is among the four largest in Brazil, and among the three largest in the state of São Paulo. It houses in its scientific collections type material of about 500 species, including holotypes, paratypes and neotypes (http://www.ib.unicamp.br/museu_zoologia/colecaotipos). In particular, the Annelida "Polychaeta" collection stands out for the great representation of types, housing 122 holotypes and more than 889 other types.

This marine collection began in 2006 and, since then, has shown significant growth, with emphasis on "Polychaeta" (~169,000 specimens), Gastropoda (~156,000), Ophiuroidea (~53,000), Crustacea (~52,000) and Bivalvia (~41,000). The Polychaeta and Ophiuroidea collections currently represent the largest in Brazil, with digitized data available via the internet. Mollusca collections have grown considerably, especially Gastropoda. A great deal of material was incorporated into the Crustacea collection, especially Amphipoda. One of MDBio's strengths is the digitization of all its scientific collections and the availability of data online through the speciesLink network (http://splink.cria.org.br/) (http://www.ib.unicamp.br/museu_zoologia/colecoes_curadores), an information system that integrates primary data from scientific collections, developed and managed by the 'Environmental Information Reference Center' (CRIA), also available in the 'Brazilian Biodiversity Information System' (SiBBr) and the 'Global Biodiversity Information Facility' (GBIF) (Canhos et al. in press). MDBio is today one of the few national museums that makes data associated with its scientific collection available online. More than 90% of the collection is cataloged and digitized, but it is important to note that there are at least 70,000 specimens, especially "Polychaeta", Mollusca, and Crustacea, awaiting cataloging.

All collections are supervised by specialist curators and technical support from the Museum's own staff, in addition to CNPq (National Council for Scientific and Technological Development), FAPESP and institutional (SAE/UNICAMP) scholarships. In parallel with the process of digitizing the collections, MDBio has invested efforts in digitizing the records referring to the sample and the environmental parameters obtained during the collection and the images, mainly of the type specimens, making them available on its institutional page (www.ib.unicamp.br/museu_zoologia and https://www2.ib.unicamp.br/fnjv/) and through speciesLink. The consultation of MDBio's collections has resulted in publications in impact journals, such as PlosOne, Frontiers and Journal of the Marine Biological Association (JMBA).

The design of ColBIO arose from the need to organize numerous samples of marine organisms that were in different laboratories and did not have the necessary conditions for adequate long-term storage. Thus, given the possibility offered by PETROBRAS in 2007, two projects were approved: Infrastructure, and Research and Development. Since then, a lot of work has been carried out, and the official inauguration of ColBIO was done in 2012. Some taxonomic groups in the collection have a greater number of lots and taxonomic refinement as a result of specialists working at the institution. The highest numbers of identified species refer to ichthyoplankton, polychaetes, crustaceans, mollusks, tunicates, and nematodes (Figure 1; Table 1).

Although ColBIO holds sporadic exhibitions and presentations of its collection, the deposited samples and the database serve primarily for research. Each sample has information in spreadsheets, which include records referring to the identification and to the environmental variables obtained during the sampling. The collection includes several groups of organisms from the pelagic (zooplankton, ichthyoplankton, adult fish) and benthic environment (mainly crustaceans, mollusks, polychaetes, echinoderms, tunicates) from shallow and deep areas of the Brazilian

and Antarctic waters. The collection also has items taken from adult fishes that provide important information about the biology of the groups in terms of age and growth (otoliths), feeding (stomachs), and reproduction (gonads). In addition to these already cataloged and listed samples, an expressive number, over 10,000, belonging to recent and older projects, still need to be organized. It is not possible to estimate the number of specimens stored, as many samples, such as zooplankton, were not sorted and are deposited in lots.

Two other smaller institutional collections, exclusively containing Crustacea Decapoda, make up the state collection, both maintained on campuses of universities in São Paulo: the Faculty of Philosophy, Sciences and Letters of Ribeirão Preto of the University of São Paulo (FFCLRP – USP) and the State University of São Paulo, Campus of Litoral Paulista (UNESP – CLP). Both collections began in the mid-1990s and contain a considerable collection of decapod crustaceans: around 300,000 specimens at FFCLRP – USP and 13,000 at UNESP – CLP (Table 1).

The marine algae collections of the state of São Paulo are distributed in two main large collections, SPF-Algae, in the herbarium of the Institute of Biosciences of the University of São Paulo (IB – USP), and SP-Algae, in the herbarium of the Institute of Environmental Research (IPA). Other smaller collections and/or for teaching purposes are distributed in herbaria of private universities, such as the HUSC herbarium of Universidade Santa Cecília (UNISANTA), and public ones, located in regions further away from the capital, as in the case of some campuses of the State University of São Paulo (UNESP), which house the SJRP-São José do Rio Preto and BOTU-Botucatu herbaria, and the UEC herbarium of the State University of Campinas (UNICAMP), which houses collections mostly of continental algae.

The collections of the large herbaria SPF-Algae and SP-Algae have specimens of nearly all the species known from the Brazilian coast, as well as representatives from about 30 other countries, highlighting, for example, the collections of calcareous algae and of economic importance for Brazil and of algae from Antarctica. The curation of the two collections is carried out by specialized curators following global museum standards and has the technical support of the institutions themselves and also of scholarship holders.

Currently, the SPF-Algae collection includes 25,190 exsiccates representing about 10% of the total SPF collection, today with 253,000 records in total. The SPF-Algae still has a representative number of nomenclatural types (72), the majority of Brazilian species, and some of them, foreigners, acquired by donation. The SP-Algae herbarium currently houses 23,866 seaweed exsiccates and 37 nomenclatural types, representing about 7% of the approximately 340,000 records available on speciesLink (Figure 1; Table 1).

The volume of exsiccates and type materials deposited in SPF-Algae and SP-Algae make them reference herbaria, fundamental for research in Brazil and abroad, whose importance is reflected in the number of queries and annual loans requested, leading to the revision of at least part of the deposited material and taxonomic improvement of the collections. The queries to the collections have resulted in publications in medium and high impact journals in the area of phycology, such as the Journal of Phycology, Phycologia, European Journal of Phycology, Botanica Marina, Phytotaxa. These results have culminated in an expansion of knowledge on the marine biodiversity, with better species delimitations and corrections of misapplied names for Brazil, besides the definition of new species and nomenclatural updates.

Since 2004, information about the collections has been made available digitally through the speciesLink network, a system developed with the support of FAPESP and other research funding institutions. Data from 20,525 exsiccates deposited in SPF-Algae (about 80% of the collection) and about 23,000 exsiccates from SP-Algae (about 70% of the collection) have already been digitized and are being progressively made available by speciesLink, promoting accessibility and virtual consultation to collections. However, the frequent nomenclatural changes, in addition to the need to include geographic coordinates of the collection sites, which was initially not customary, require constant corrections.

The challenge of sequencing the DNA of seaweed type specimens deposited in different herbaria around the world has been overcome with some success, establishing direct links between ancient specimens and genetic species, which reinforces the value of phycological collections as a genetic heritage.

Promotion of Research Versus Development of Biological Collections

Biological collections represent a country's biological, scientific, cultural, and genetic heritage, and their preservation depends on a collective effort by researchers, institutions, and public authorities. Funding for various research projects, in the different areas of science, can result in the maintenance of biological collections, if they somehow help institutions in the conservation/curation of the collections.

Financial support from the São Paulo Research Foundation (FAPESP) to institutions in São Paulo goes beyond the limits of the state, as many studies address broader areas and/or establish diverse partnerships with other institutions outside São Paulo. This is also reflected in the taxonomic and geographic scope of the biological collections, since they maintain specimens/species from different regions of the country, and even from other countries.

Research and curatorial activities at the USP Museum of Zoology have been traditionally broadly supported by FAPESP in its various forms of funding, from large institutional projects to the granting of scholarships to students, from undergraduate to post-doctoral fellowships – numbers that, unfortunately, have declined in recent times. In a quick query to the 'FAPESP Virtual Library' (https://bv.fapesp.br/pt/instituicao/1522/museu-de-zoologia-mz/, accessed on 05/07/2022), with data only from 1992 onwards, a total of 519 grants and scholarships directly granted to MZUSP students and researchers can be found, which does not include researchers based in other institutions who developed their work based largely or entirely on the collections of the MZUSP, helping in the enrichment of these collections and emphasizing their importance.

In the case of the MDBio-ZUEC, there were several FAPESP grants that collaborated, directly or indirectly, with the composition and maintenance of the marine collection, among them the thematic ones: Biota/FAPESP – Marine Benthos – "Marine Benthic Biodiversity in the State of São Paulo" (period: 2001–2006); Biota/FAPESP – Araçá – "Biodiversity and functioning of a subtropical coastal ecosystem: subsidies for integrated management" (2012–2017) and Biota/FAPESP – Collections – "Consolidation of scientific collections of marine invertebrates: strategies for biodiversity conservation" (2019–2024), as well as smaller ones, such as: "Ex situ conservation of biodiversity: inventory,

expansion and strengthening of the collection of Marine Invertebrates at the Natural History Museum of the State University of Campinas" and "Taxonomic studies, expansion and computerization of the collections of marine invertebrates from the Museum of Zoology of the State University of Campinas, with emphasis on Echinodermata".

Other projects with mixed funding (FAPESP and other funding agencies) collaborated with the formation and maintenance of the collections, such as: REVIZEE/Score Sul-Benthos – "Assessment of the Sustainable Potential of Living Resources in the Exclusive Economic Zone"; HABITATS – "Environmental Heterogeneity of the Campos Basin"; and AMBES – "Environmental Characterization of the Espírito Santo Basin". Such projects sampled a large number of marine animals, from different groups, in the most diverse regions, including the state of São Paulo, on beaches, rocky shores, mangroves and unconsolidated infralittoral, from the intertidal zone to great depths. This material was part of several research projects and is currently deposited in biological collections of institutions in São Paulo, such as the Museum of Zoology at USP and the Museum of Biological Diversity at UNICAMP. Part of the funding invested in these projects helped in the structuring of these collections through the purchase of mobile storage cabinets, in addition to fire resistant cabinets to protect the types. More recently, a FINEP (Funding Authority for Studies and Projects) grant was approved for the construction of a new building to house the Zoology and Botany collections of MDBio, to which the collections will be transferred.

The IOUSP Biological Collection (ColBIO) has samples in its collection from numerous institutional projects supported by Brazilian and international funding agencies, ranging from small-scale individual projects to large interdisciplinary programs. In relation to FAPESP, several projects were financed from the 1970s onwards, sampling planktonic, nektonic, and benthic communities. Among the most comprehensive, we can mention: "Sardine-Anchovy Recruitment Project" (SARP) of COI/UNESCO (MCT/BMFT, COI, FAPESP, CNPq, 1985–1994); "Oceanography of the inner shelf of São Sebastião (FAPESP, 1993–2000); "Importance and characterization of the continental shelf break for living and non-living resources" (CNPq/PADCT, FAPESP, 1994–2001; and "The influence of the estuarine complex of Baixada Santista over the adjacent continental shelf ecosystem" (ECOSAN) (FAPESP, 2004–2008).

Recently, in a huge joint effort, USP and FAPESP invested in the acquisition of two research vessels, "Alpha-Crucis" and "Alpha Delphini", to investigate, mainly, deep waters, an environment poorly sampled until now (Costello et al. 2010). These research platforms will expand the existing collection, as well as fill an important gap in knowledge regarding the species that inhabit the deep regions of the South Atlantic. Thus, three major projects could be financed by FAPESP: "Biodiversity and connectivity of benthic communities in organic substrates (whale bones and wood) in the deep Southwest Atlantic" (BioSuOr, 2011–2017), "Diversity and Evolution of Fish of Deep Ocean" (DEEP-OCEAN, 2018–current) and "BEnthic COnnections Of high southern Latitudes" (BECOOL, 2020–current). It is important to highlight the project "Platform for studies on marine biodiversity of the Brazilian southeast coast and the Antarctic region" (FAPESP, 2015–2018), specially designed for the organization of samples of the Biological Collection of IOUSP and for the implementation of an information system of free access that contextualized the marine environment in which the samples were collected. See also Marques et al. (in press) about FAPESP marine and coastal biodiversity studies.

Regarding herbaria that maintain seaweeds, FAPESP funding has been directly intended for infrastructure or support for research projects, especially those aiming at knowledge of the biodiversity that benefit the maintenance of collections. This support promoted the restructuring of herbaria and the acquisition of consumables, securing suitable conditions for the functioning and conservation of botanical collections. The SPF general herbarium has undergone infrastructure expansions and improvements in recent decades, including its adaptation to accommodate the marine algae collection in the same physical space as the other SPF collections, culminating in a total area of 380 m^2 (Mello-Silva et al. 2015). Two main research grants were financed by FAPESP, and resources were also allocated to the phycological collection. One of them, the 1998 Infrastructure call for proposals, "Expanding, recovering and capacitating the SPF Herbarium", promoted a major restructuring of the collection with renovations and acquisition of furniture and equipment, enabling the installation of a system to control thermo-hygrometric conditions, improving environmental conditions and conservation of the collection and increasing the storage capacity of the herbarium, with the entire collection of plants having been accommodated in mobile storage systems, optimizing the space to promote the growth of the collection. The second project, within the regular line, "Expansion of the collection, renovation of assembly material and digitization of the collections of the SPF herbarium", promoted the installation of larger mobile storage systems, which enabled the transfer and accommodation of the phycological collection (SPF-Algae) in the Herbarium building, as well as accommodated the bryophytic collection, carpoteca and xyloteca. Still within the regular line, the international cooperation project "Diversity and phylogeny of the *Laurencia* complex (Rhodophyta) in the tropical and subtropical Atlantic Ocean" (2018–2020) had specific resources for the assembly of exsiccates and maintenance of the phycological herbarium, and whose collections in the countries involved in the project (Spain, Mexico, Portugal, USA and Venezuela) increased the collection of marine algae in the SPF-Algae.

The SP herbarium, in particular the SP-Algae, also obtained resources within the FAPESP Infrastructure call for proposals, with the thematic project within BIOTA "Phycological Flora of the State of São Paulo", with which it was possible to adapt the laboratories to start the studies involving molecular tests aiming at taxa certification, in addition to improving the facilities for the preparation of the exsiccates and other steps of the protocol for the maintenance of algal collections, including *in vitro* culture laboratory. Subsequently, with Research Assistance – BIOTA Program – Thematic "Diversity of red macroalgae (Rhodophyta) of the state of São Paulo" based on barcoding, morphology and geographic distribution (RHODO-SP), the adaptation of the molecular biology laboratory in the Nucleus of Phycology at the then Institute of Botany, gave a great boost to the knowledge of macroalgae biodiversity in Brazil, especially red algae, resulting in several theses and dissertations on the topic of algal biodiversity. Subsequently, the regular project within the BIOTA/FAPESP Program "Phylogenetic and phylogeographic approach, based on molecular data, in representatives of Ceramiales and Gelidiales (Rhodophyta) in Brazil" and the project "Historical rescue of macroalgae holotypes from the Brazilian coast and molecular label of topotypes" (PROTAX – CNPq/FAPESP) were fundamental to leverage the knowledge of marine macroalgae

biodiversity off the Brazilian coast. The projects aimed to molecularly certify the type-species described from the Brazilian territory and add a molecular tag to facilitate comparisons with morphologically related taxa and avoid the perpetuation of misunderstandings, since algae have a simple and often convergent morphology.

In the last 10 years, at least eight regular FAPESP research grants that focused on the taxonomy and molecular phylogeny of seaweeds have allocated resources to the SPF-Algae and SP-Algae herbaria for the assembly of exsiccates following international standards and maintenance of the collections in order to guarantee the longevity of the collections. CAPES (INCT – Virtual Herbarium), CNPq, FAPESP and institutional scholarships (Unified Undergraduate Student Scholarship Program, PUB/USP) were important for the maintenance of the material and their curatorship.

It is important to emphasize that the investment in the preservation and maintenance of the material in biological collections, whose sampling efforts frequently have high costs, means to strengthen national science, safeguarding voucher specimens of past research project and providing/enabling new studies at a lower cost, since the stage of "collection" or "field work" can often be suppressed or at least minimized. It is estimated that many millions of dollars are saved annually by the scientific community and, therefore, by the whole society, because of the biological collections deposited in museums, herbaria, or co-generic institutions, since many of the field trips, which take time and money, can be replaced by visits to collections (Suarez & Tsutsui 2004).

Future Perspectives

The *ex situ* collections, scientific and non-scientific, represent a biological, cultural and genetic heritage, enabling the nation to know its biodiversity and, thus, form the basis of public policies for preservation and sustainable exploitation, generating wealth for the country and its population.

The possibilities of generating knowledge within a biological collection have undergone major reinterpretations in recent times, largely thanks to new explorations made possible by emerging technologies. As an example, access to molecular data from material already part of collections has been increasingly explored in several institutions around the world, a practice that has been referred to as *museomics* (Rowe et al. 2011, Buerki & Baker 2016, Totoiu et al. 2020). Such initiatives have made studies of different natures possible, by accessing different levels of knowledge "hidden" in the material in scientific collections, such as spatial and temporal testimonies, expanding the understanding of Natural History Museums not only as places of storage of specimens, but as repositories of a vast genetic pool ("biobanks" – see Bi et al. 2013, Yeates et al. 2016).

In addition to classical uses, the new approaches emphasize the importance of all efforts made in a quality curatorial practice, since what is kept in a biological collection are not merely specimens, but testimonies with countless layers of information linked to them (following the extended specimen concept; cf. Lendemer et al. 2020) – information that can be used in a wide spectrum of studies, from ecological and related to conservation policies, to public health, such as tracking pathogens (Schindel & Cook 2018; Cook et al. 2020). The value of biological collections must therefore be understood as something multilayered, with the safeguarded specimens being sometimes unique testimonies of a historical, ecological and evolutionary profile. With the new uses of collections, consequently, their proper maintenance becomes imperative not only to understand past processes, but also in our quest to understand and anticipate future events. A modern view of the importance of Museums, therefore, should emphasize the strategic role that their collections carry, by concentrating all these levels of information, in addition to others that may eventually be unlocked by future technologies and approaches.

As a result, collections promote the exchange, integration and use of information, reinforcing the publication of data, new discoveries, documentation and accessibility.

All the collections mentioned here are available for online queries, directly in the database or through contact with the curator. These collections are at different stages of data processing and the databases are in different online repositories (Table 1). The process of incorporating the material into the collections, from preparation for cataloging to the availability in a database, involves continuous dedication of trained people. Information on Brazilian marine biodiversity, in general, is dispersed and unavailable in digital form, despite being critical to achieve the goal of completing inventories of species diversity and distribution (Miloslavich et al. 2011). In addition, any environmental assessment and/or monitoring study in the country currently requires that all material collected be deposited in regular scientific collections. The trend is for the number of biological samples to grow exponentially.

However, there is a consensus that, in order to strengthen biological collections, regular and constant financial investments are necessary, with institutional and governmental commitment, in the most diverse spheres involved. The inestimable value of zoological, botanical and phycological collections goes beyond the enormous importance of voucher materials for scientific research in the areas of taxonomy and phylogeny, essential for the correct application of a taxon name and classification systems propositions, but they are also fundamental for teaching, ecological and chemical studies, assessment of geographic distribution, definition of the conservation status of species and priority areas for their conservation (Alves et al. 2018, Araújo et al. 2002).

The collections of seaweeds, for example, deposited in museums and herbaria tell the history and witness environmental changes, such as the disappearance of habitats for the development of certain animals and/or algae, due to population growth and urbanization that occurred in the last 60–70 years; such a record can help prevent and avoid irreversible environmental disasters.

In this context, how can we strengthen the marine collections of the state of São Paulo?

Since funding agencies such as FAPESP finance research in a wide array of areas of Biological Sciences, many of which carry out in situ collections, it would be of vital importance that this material, obtained through systematized sampling efforts and intended for scientific study, be deposited in recognizably consolidated collections and with permanent curatorial activities, since it represents voucher material of research with public investment.

It is worth mentioning that it is not enough to invest in sampling expeditions to enrich the collections without valuing the training of qualified personnel, both for curating the collections (specialized technicians) and for their taxonomic refinement (taxonomists). Thus, it is essential to: offer training courses and lectures on collections, focusing on biodiversity,

ecological, economic, public health, cuisine, arts, among others; sharpen students' curiosity about invertebrate and algae communities, teaching them how to correctly collect and preserve testimonies to prepare samples that will be included in biological collections; organize workshops with local residents, for example, where seaweeds occur, to show how to use biomass as biofertilizers and dehydrated material for various uses, including botanical art, with exhibitions.

One of the main challenges to encourage the study of many collections deposited in museums that have incomplete identifications would be the creation of a funding program for infrastructure, both institutional and via scientific funding agencies, aiming at personal and collection safety, in addition to training of taxonomists, so that there is no discontinuity of support to meet the proper maintenance of collections.

As already reported by De Vivo et al. (2014), Brazilian regulatory and development agencies have adopted a uniform policy for judging researchers, using the same productivity criteria, without any distinction for experience in the curatorial role. In line with these authors, we reinforce that this procedure is in fact harmful to the development of museums and biological collections, as well as to the advancement of knowledge of biodiversity in our country, since the taxonomic study as well as the curatorial experience, unlike other areas of biology, require more time and improvement for the development of specific skills, which gives the researcher a differentiated experience.

Encouraging exchanges of animal lots and exsiccates between large institutions, inside and outside the country, is essential to increase taxonomic diversity and to obtain specimens that can be compared with each other, thus promoting a more integrated science focused on the conservation and maintenance of the biological collections.

In addition, all the scientific community needs to value this heritage and contribute to its maintenance, depositing their collections/research material in consolidated institutions.

Acknowledgements

The authors are grateful to Carlos A, Joly for reviewing the manuscript. We are also grateful to everyone who provided information about the collections, including curators, researchers and technicians, of marine invertebrates and macroalgae: Andréa Tucci (Institute of Environmental Research), Fernando L. Mantelatto (Faculty of Philosophy, Sciences and Letters of Ribeirão Preto – FFCLRP, USP), Henrique Borgatto de Almeida Dias (UNESP – Botucatu campus), José Rubens Pirani (Institute of Biosciences – USP), Luiz Ricardo Lopes de Simone (Museum of Zoology – USP), Marcelo Pinheiro (UNESP – Campus do Litoral Paulista), Marcos Domingos Siqueira Tavares (Museum of Zoology – USP), Maria Fernanda Calió (Institute of Biology – UNICAMP), Orlando Necchi Jr. (UNESP – São José do Rio Preto campus), Vivian de Lima Viana (Institute of Biosciences – USP), Viviane Yuri Jono (Institute of Biosciences – USP), Zélia Rodrigues de Mello (UNISANTA).

Thanks are also due to the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the Productivity grant to A.C.Z. Amaral [Proc. 30155/2019-7], V. Cassano [Proc. 304141/2020-8] and M.T. Fujii. [Proc. 311195/2021-0]; and to the São Paulo Research Foundation – FAPESP [Proc. nº 2014/15168-7, 2016/50370-7, 2017/50341-0, 2018/10313-0 and 2019/12551-8].

Associate Editor

Carlos Joly

Conflicts of Interest

All authors had projects funded and were reviewers of many projects submitted to BIOTA-FAPESP during their careers.

Ethics

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

References

ALVES, F.M., LEHN, C.R., DAMASCENO-JÚNIOR, G.A., SARTORI, A.L.B., POTT. A., POTT, V.J., BORTOLOTTO, I.M., ISHII, I.H., SALIS, S.M., URBANETZ, C., BUENO, M.L. & SCIAMARELLI, A. 2018. Coleções Botânicas do estado de Mato Grosso do Sul: situação atual e perspectivas. Iheringia, Sér. Bot. 73(supl.): 93-100.

ARAÚJO, E.L. MOURA, A.N., SAMPAIO, E.V.S.B., GESTINARI, L.M.S. & CARNEIRO, J.M.T. 2002. Biodiversidade, conservação e uso sustentável da flora do Brasil. Sociedade Botânica do Brasil. Universidade Federal Rural de Pernambuco, 262 p.

BARBOSA L.M. (org.). 2013. V Simpósio de Restauração Ecológica: Políticas Públicas para a Conservação da Biodiversidade. São Paulo. 36 p.

BEBBER, D.P., CARINE, M.A., WOOD, J.R., WORTLEY, A.H., HARRIS, D.J., PRANCE, G.T. 2010. Herbaria are a major frontier for species discovery. Proceedings of the National Academy of Sciences, 107(51): 22169-22171.

BI, K., LINDEROTH, T., VANDERPOOL, D., GOOD, J.M., NIELSEN, R. & MORITZ, C. 2013. Unlocking the vault: next-generation museum population genomics. Mol. Ecol. 22: 6018-6032.

BUERKI, S. & BAKER, W.J. 2016. Collections-based research in the genomic era. Biol. J. Linn. Soc. 117: 5-10.

CANHOS, D.A.L., ALMEIDA, E., ASSAD, A.L., BUSTAMANTE, M., CANHOS, V.P.C., CHAPMAN, A.D., GIOVANNI, R., IMPERATRIZ-FONSECA, V.L., LOHMANN, L.G., MAIA, L.C., MILLER, J., NELSON, G., PETERSON, A.T., PIRANI, J.R., SOUZA, S., STEHMANN, J.R., THIERS, B. speciesLink: rich data and novel tools for digital assessments of biodiversity. Biota Neotrop. 22(Suppl. 1). In press.

COOK, J.A., ARAI, S., ARMIÉN, B., BATES, J., BONILLA, C.A.C. et al. 2020. Integrating biodiversity infrastructure into pathogen discovery and mitigation of emerging infectious diseases. Bioscience 70(6): 531-534.

COSTELLO, M.J., COLL, M., DANOVARO R., HALPIN, P., OJAVEER, H. & MILOSLAVICH, P. 2010. A census of marine biodiversity knowledge, resources, and future challenges. PLoS ONE, 5(8):1-15.

De VIVO, M., SILVEIRA, L.F. & NASCIMENTO, F.O. 2014. Reflexões sobre coleções zoológicas, sua curadoria e a inserção dos museus na estrutura universitária brasileira. Arquivos de Zoologia do Museu de Zoologia da USP. 45(10): 105-114.

EDWARDS, M., BEAUGRAND, G., HAYS, G.C., KOSLOW, J.A. & RICHARDSON, A.J. 2010. Multi-decadal oceanic ecological datasets and their application in marine policy and management. Trends in Ecology & Evolution 25(10): 602-610.

FAPESP VIRTUAL LIBRARY. https://bv.fapesp.br/pt/instituicao/1522/museu-de-zoologia-mz/ (last acess in 05/07/2022).

HOEHNE F.C. 1940. Relatório anual do Departamento de Botânica do Estado (referente ao exercício de 1939). Secretaria da Agricultura, Indústria e Comércio, São Paulo.

IB.UNICAMP.BR/MUSEU_ZOOLOGIA. https://www.ib.unicamp.br/museu_zoologia (last acess in 20/07/2022).

IB.UNICAMP.BR/FNJV. https://www2.ib.unicamp.br/fnjv/ (last acess in 20/07/2022).

INSTITUTO DE BOTÂNICA, 1995. Relatório Anual. São Paulo, Secretaria do Meio Ambiente, 83 p.

LENDEMER, J., THIERS, B., MONFILS, A.K., ZASPEL, J. & ELLWOOD, E.R. 2020. The extended specimen network: a strategy to enhance US biodiversity collections, promote research and education. Bioscience 70: 23-30.

LOPES, M.M. 2009. O Brasil descobre a pesquisa científica: os museus e as ciências naturais no século XIX, 2ª. Ed. Hucitec, São Paulo.

MAGURRAN, A.E., BAILLIE, S.R., BUCKLAND, S.T., DICK, J.M., ELSTON, D.A., SCOTT, E.M., SMITH, R.I., SOMERFIELD, P.J. & WATT, A.D. 2010. Long-term datasets in biodiversity research and monitoring: assessing change in ecological communities through time. Trends in Ecology & Evolution. 25(10): 574-582.

MARQUES, A.C., MIGOTTO, A.E., KITAHARA, M.V., DIAS, G.M., COSTA, T.M., OLIVEIRA, M.C. Marine and coastal biodiversity studies, 60 years of research funding from FAPESP, what we have learned and future challenges. Biota Neotrop. 22(Suppl. 1). In press.

MCT (MINISTÉRIO DA CIÊNCIA E TECNOLOGIA). 2006. Diretrizes e estratégias para a modernização de coleções biológicas brasileiras e a consolidação de sistemas integrados de informação sobre biodiversidade / Adriano B. Kury et al. – Brasília, Centro de Gestão e Estudos Estratégicos: MCT.

MELLO-SILVA, R., PIRANI, J.R. & JONO, V.Y. 2015. Herbário da Universidade de São Paulo, São Paulo (SPF). Edição Especial Herbários do Brasil – 66º Congresso Nacional de Botânica. UNISANTA Bioscience. 4(6): 450-454.

MIGOTTO, A.E. & MARQUES, A.C. 2006. Invertebrados Marinhos. In: Lewinsohn, T. (Org.). Avaliação do Estado do Conhecimento da Biodiversidade Brasileira. Ministério do Meio Ambiente, Brasília, p.149-202.

MILOSLAVICH, P., KLEIN, E., DIAZ, J.M., HERNANDEZ, C.E., BIGATTI, G., CAMPOS, L., ARTIGAS, F., CASTILLO, J., PENCHASZADEH, P.E., NEILL, P.E., CARRANZA, A., RETANA, M.V., ASTARLOA, J.M.D., LEWIS, M., YORIO, P., PIRIZ, M.L., RODRÍGUEZ, P., YONESHIGUE-VALENTIN, Y., GAMBOA, L. & MARTÍN, A. 2011. Marine Biodiversity in the Atlantic and Pacific Coasts of South America: Knowledge and Gaps. PLoS ONE. 6(1): 1-43.

MUSEU_ZOOLOGIA/COLECOES_CURADORES. http://www.ib.unicamp.br/museu_zoologia/colecoes_curadores (last access in 20/07/2022)

MUSEU_ZOOLOGIA/COLECAOTIPOS. http://www.ib.unicamp.br/museu_zoologia/colecaotipos (last access in 20/07/2022)

OLIVEIRA, C.H.S. 2003. Museu Paulista: espaço de evocação do passado e reflexão sobre a história. An. Mus. Paul. São Paulo, N. Sér. 10/11: 105-126.

ROWE, K.C., SINGHAL, S., MACMANES, M.D., AYROLES, J.F., MORELLI, T.L., RUBIDGE, E.M., BI, K. & MORITZ, C.C. 2011. Museum genomics: low-cost and high-accuracy genetic data from historical specimens. Mol. Ecol. Res. 11: 1082-1092.

SCHINDEL, D.E. & COOK, J.A. 2018. The next generation of natural history collections. PLoS Biol. 16(7): e2006125.

SPECIESLINK NETWORK. http://splink.cria.org.br/ (last access in 20/07/2022)

SUAREZ, A.V. & TSUTSUI, N. D. 2004. The value of museum collections for research and society. Bioscience, 54(1): 66-74.

TADDEI, V.A., MARTINS, U.R., De VIVO, M. & PERCEQUILLO, A.R. 1999. O acervo das coleções zoológicas do Estado de São Paulo. In Biodiversidade do Estado de São Paulo, Brasil: síntese do conhecimento ao final do século XX, 7: Infra-estrutura para a conservação da biodiversidade (M.C.W. Brito & C.A. Joly, eds). FAPESP, São Paulo, v.7, p. 53-67.

TEIXEIRA, A.R. 1988. Resenha histórica do Instituto de Botânica de São Paulo. Ciência e Cultura. 40(11): 1045-1054.

TOTOIU, C.A., PHILLIPS, J.M., REESE, A.T., MAJUMDAR, S., GIRGUIS, P.R., RASTON, C.L. & WEISS, G.A. 2020. Vortex fluidics-mediated DNA rescue from formalin-fixed museum specimens. PLoS ONE 15(1): e0225807.

WHEELER, Q.D., KNAPP, S., STEVENSON, D.W., STEVENSON, J., BLUM, S.D., BOOM, B.M., BORISY, G.G., BUIZER, J.L., DE CARVALHO, M.R., CIBRIAN, A., DONOGHUE, M.J., DOYLE, V., GERSON, E.M., GRAHAM, C. H., GRAVES, P., GRAVES, S.J., GURALNICK, R.P., HAMILTON, A.L., HANKEN, J., LAW, W., LIPSCOMB, D.L., LOVEJOY, T.E., MILLER, H., MILLER, J.S., NAEEM, S., NOVACEK, M.J., PAGE, L.M., PLATNICK, N.I., PORTER-MORGAN, H., RAVEN, P.H., SOLIS, M.A., VALDECASAS, A.G., VAN DER LEEUW, S., VASCO, A., VERMEULEN, N., VOGEL, J., WALLS, R.L., WILSON, E.O. & WOOLLEY, J.B. 2012. Mapping the biosphere: exploring species to understand the origin, organization and sustainability of biodiversity. Syst. Biodivers. 10(1): 1-20.

YEATES, D.K., ZWICK, A. & MIKHEYEV, A.S. 2016. Museums are biobanks: unlocking the genetic potential of the three billion specimens in the world's biological collections. Curr. Opin. Insect Sci. 18: 83-88.

Received: 15/08/2022
Accepted: 07/10/2022
Published online: 28/11/2022