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Thematic Review

The contribution of the BIOTA/FAPESP Program to the advancement of the knowledge on terrestrial invertebrates

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Abstract: The variability of the organisms living in a given area constitute what is referred to as biodiversity, one of nature's fundamental properties, responsible for the balance and stability of ecosystems. The loss of biodiversity has been of great concern to scientists, especially because of the role played by human activities in this regard, able to lead to irreversible circumstances. The São Paulo Research Foundation (Fundação de Amparo à Pesquisa do Estado de São Paulo, FAPESP) plays a major role in supporting research efforts in the most diverse branches of science. In the late 1990´s, FAPESP launched a major program to promote research on biodiversity, named BIOTA/FAPESP. So far, this program has financed the conduction of 26 projects, involving research activities in most of Brazil, while focusing mainly the State of São Paulo. These projects have generated about 1140 publications in peer-reviewed journals of high standard, providing relevant information, including the original description of 1187 species and 76 genera, the complementary description of 350 species, as well as a number of inventory works, biological studies, etc. The program has also been instrumental in the establishment or adequacy of research facilities and training of new taxonomists. Most extensively studied groups of terrestrial invertebrates include Insecta of the orders Hymenoptera, Lepidoptera and Diptera, and Arachnida of the subclasses Araneae and Acari. Distinct projects have also contributed to the detection of organisms potentially useful as biological control agents and in the determination of maps of major interest for the establishment of public policies. In the future, priority groups for study should include the Annelida and the Nematoda, for the potential both have as beneficial organisms, or for the potential some Nematoda have as organisms harmful to plants and animals.
Keywords: *Invertebrates; distribution; taxonomy; bibliography; biodiversity.*

A contribuição do Programa BIOTA/FAPESP para o avanço no conhecimento sobre os invertebrados terrestres

Resumo: A variabilidade dos organismos em uma determinada área constitui o que se denomina biodiversidade, uma das propriedades fundamentais da natureza, responsável pelo equilíbrio e estabilidade dos ecossistemas. A perda da biodiversidade tem sido uma grande preocupação para os cientistas, principalmente pelo papel desempenhado pelas atividades humanas, com potencial para desencadear circunstâncias irreversíveis. A Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) desempenha um papel importante no apoio às pesquisas nos mais diversos ramos da ciência. No final da década de 1990, a FAPESP lançou um grande programa de fomento à pesquisa em biodiversidade, denominado BIOTA/FAPESP. Até o momento, este programa financiou a realização de 26 projetos, envolvendo atividades na maior parte do Brasil, embora tenham como foco principal o estado de São Paulo. Esses projetos geraram cerca de 1.140 publicações em periódicos de alto impacto, fornecendo informações relevantes que incluem a descrição original de 1.187 espécies e 76 gêneros e a descrição complementar de 350 espécies, além de diversos trabalhos de inventário, estudos biológicos etc. O programa também tem sido fundamental para o estabelecimento ou adequação de instalações de pesquisa científica e o treinamento de novos

taxonomistas. Os grupos de invertebrados terrestres mais estudados incluem os Insecta das ordens Hymenoptera, Lepidoptera e Diptera, e os Arachnida das subclasses Araneae e Acari. Projetos distintos também têm contribuído para a detecção de organismos potencialmente úteis como agentes de controle biológico e na determinação de mapas de áreas preferenciais para o estabelecimento de políticas públicas. No futuro, os grupos prioritários de estudo devem incluir os Annelida e os Nematoda, pelo potencial que ambos têm como organismos benéficos, ou pelo potencial que alguns Nematoda têm como organismos prejudiciais a plantas e animais.
Palavras-chave: *Invertebrados; distribuição; taxonomia; bibliografia; biodiversidade.*

Introduction

Organisms sharing a given area constitute communities, whose members interact under the influence of environmental factors (Capra, 2022). The variability of these organisms constitutes what is referred to as biodiversity, which involves not only the number and relative abundance of species (taxonomic biodiversity), but also the type and relative abundance of traits they possess (functional biodiversity) (Diaz, 2001). It has long been determined that the higher the variability, the more complex and stable is an ecosystem, i.e., the area in which the interactions occur. The loss of biodiversity has been of great concern to scientists, especially because of the role played by human activities in this regard, which can lead to irreversible circumstances. Quite often, losses have been catastrophic in recent decades and led humans to seek more seriously the adoption of conservation practices to reduce their intensity. But the adoption of conservation practices requires previous knowledge about the constitution of the natural environment and details about local ecology.

In line with this trend, the scientific communities of several countries have sought support from governmental or private research funding institutions, to allow the conduction of studies intended to unveil details of the local flora and fauna, their interaction and the effect of environmental factors on those organisms. The São Paulo Research Foundation (Fundação de Amparo à Pesquisa do Estado de São Paulo, FAPESP) is part of this context. FAPESP was created in 1960 and since then it has played a leading role in supporting research initiatives of Brazilian specialists of the most diverse branches of science. It has been significantly proactive along the years, permanently seeking to detect opportunities and study topics of interest to São Paulo State society, as its budget is generated by taxes paid by the inhabitants of this important southeastern Brazilian state. By doing so, FAPESP intends to benefit closely the whole Brazilian society and, ultimately, mankind. As a rule, FAPESP´s financed research projects are conducted within predetermined programs resulting from the analyses of matters of major public interest, among initiatives raised by proactive members of the scientific community, again mainly of the State of São Paulo, and their collaborators.

Significant aggressions to biological resources around the globe have become progressively more evident, leading international agencies to worry about the possible consequences to mankind. This led the United Nations Environment Program to convene an Ad Hoc Working Group of experts on biological diversity in November 1988, to explore the need for an international convention on "biodiversity". That process evolved, leading to the preparation of such a document that was opened for signature in 1992 at the United Nations Conference on Environment and Development (UNCED), more commonly known as ECO-92, in Rio de Janeiro. Since then, the term biodiversity has become meaningful to a continuously growing number of people around the world. Details about the convention are available at the Convention on Biological Diversity (2022).

BIOTA/FAPESP is one of the major public research programs concerned specifically with the study of biodiversity, including the determination of the constituent organisms of natural environments as well as matters about their conservation and use. The detailed history of the evolution of the BIOTA/FAPESP Program was presented by Carlos A. Joly in the foreword of a series of publications under the central theme titled "Biodiversity of the State of São Paulo, Brazil: synthesis of knowledge at the end of the 20th century", in Joly & Bicudo (1999). As discussed in that document, ECO-92, represents a milestone in society's awareness of the need to protect the environment around the globe. This shift in course was considered necessary to ensure human survival in a changing world. The relevance of FAPESP in the establishment of the work agenda to support its execution in the State of São Paulo is well known by Brazilian researchers. FAPESP's administration embraced the principles of that important theme and since then it has been actively committed to supporting the initiatives financially and otherwise.

As FAPESP's first effective supportive action, FAPESP's Coordination of Biological Sciences and its Scientific Board organized a workshop to discuss the study of biodiversity in São Paulo with leaders of the scientific community of that state, of other regions of Brazil and of invited countries, which took place on April 8, 1996. Themes analyzed in that workshop included the discovery, mapping and analyzes of the origin, diversity and distribution of the flora and fauna of São Paulo State, to evaluate the possibility of sustainable exploitation of plants or animals of potential economic importance and to assist the formulation of conservation policies (Rodrigues et al. 2008). The project was then designated BIOTASP/FAPESP (the name soon changing to BIOTA/FAPESP, used hereafter in this document). That initial discussion was followed by several preparatory meetings of research leaders, culminating with the workshop "Bases for the Conservation of Biodiversity in the State of São Paulo", on August 2, 1997.

As a result of that workshop, a basic format was defined for use by interested parties in the proposition of the first research projects that, together, would constitute the BIOTA/FAPESP Program. After the proper evaluations by international experts, the Coordination Group and FAPESP Board of Directors, 18 projects were approved, constituting the first series of projects of that program. Since its installation, the Coordination Group has been led by Carlos A. Joly, from the Department of Plant Biology of the Institute of Biology of the University of Campinas. The establishment of this program took place at about the same time similar programs were implemented by the National Science Foundation (NSF) in the United States to address the taxonomy crisis. One of these, known as PEET, led to the training of a significant number of young taxonomists (Rodman & Cody, 2003). Other complementary

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programs were sponsored by NSF (Wheeler, 2004), and by other world organizations (*e.g.*, The Royal Society, 2021).

One of the first steps determined by the BIOTA/FAPESP Coordination Group as necessary was the preparation of a landmark document, to describe the standing knowledge about the flora and fauna and the availability of infrastructure and trained personnel to carry out research on biodiversity in São Paulo State. The series of publications "Biodiversity of the State of São Paulo, Brazil: synthesis of knowledge at the end of the 20th century" (Joly & Bicudo, 1999) represents that landmark. The series comprises seven volumes, each dealing with one of the following subjects: (1) Microorganisms and viruses, (2) Macroscopic fungi and plants, (3) Marine invertebrates, (4) Freshwater invertebrates, (5) Terrestrial Invertebrates, (6) Vertebrates, and a final volume (7), dealing with the in-situ and ex-situ conservation infrastructure of the different groups of organisms concerned.

With regard to the present article, volume 5, on terrestrial invertebrates (Brandão & Cancello 1999), is the most relevant. This was divided in 27 chapters, the first two dealing with the class Gastropoda of the phylum Mollusca, as well as the subclass Oligochaeta of the class Clitellata of the phylum Annelida. The remaining treated groups belonged to the phylum Arthropoda, which was divided as follows: subclasses Acari, Araneae, Opiliones and Scorpiones of the class Arachnida of the subphylum Chelicerata; subphylum Myriapoda; the following orders of the class Insecta of the subphylum Hexapoda: Heteroptera (Myridae and Pentatomoidea), Isoptera, Odonata, Coleoptera (Cerambycidae, Curculionidae), Hymenoptera (Apiformes, Bethylidae, Chalcidoidea, Formicidae, Ichneumonoidea, Sphecidae), Lepidoptera, Diptera-Drosophila and Siphonaptera. Most chapters began by presenting estimates of the approximate numbers of species known in the world, in Brazil and in the State of São Paulo, followed by various sorts of information, mainly on the taxonomy and ecology of each group. The final chapter summarized the information presented under each group. That document represents an important registration of the "status quo" of the State of São Paulo biodiversity.

When BIOTA/FAPESP program was conceived, a term was not set for its conclusion, given the magnitude of the topics to be covered. We are currently celebrating the first 20 years of the creation of this ongoing program. In this publication, we provide an overview of the program in that period and summarize its accomplishments concerning the terrestrial invertebrates. The results of the sponsored projects and their contribution to the knowledge of biodiversity were quantified and the complete references listed. Finally, we present a set of perspectives in order to connect these early initiatives with what is projected for the future in regard to FAPESP´S support to biodiversity studies.

Material and Methods

Initially, the projects concerning terrestrial invertebrates participating in the BIOTA/FAPESP program and the resulting articles were extracted from "Biblioteca Virtual da FAPESP" (FAPESP Virtual Library: https://bv.fapesp.br/pt/), an online database for research projects supported by FAPESP. A contact with the leaders of the different projects was made, indicating our interest in the preparation of this work and requesting their help in locating the literature generated by activities of the projects. That was followed by a direct search in the internet of publications acknowledging the support provided by BIOTA/FAPESP, followed by new contacts with project leaders to complement the information.

Each article was then examined for qualification of the contribution and for an estimation of the number of papers dealing with each aspect considered relevant for this publication. Graphs were plotted using Microsoft Excel.Data®.

Results and Discussion

1. The BIOTA/FAPESP projects and the protagonists

An analysis of the project titles submitted to FAPESP since its creation reflects the change in research priorities in Brazil and probably elsewhere along the same time. Until the end of the 1990's, that is, before the creation of BIOTA/FAPESP, priority was given to projects conducted in agricultural or planted forest areas, and referring to organisms causing economic damage by reducing plant yield or quality (pest organisms). Studies of invertebrates in natural environments were apparently of lower priority, disregarding the actual or potential effect of those animals on crops nearby or on the quality of life of people or domesticated animals.

The BIOTA/FAPESP projects reflected a breakthrough in research prioritization, along the lines of what had been determined as new concerns in ECO-92. Great value was given to projects dealing with the determination and understanding of the flora and fauna of explored as well as of natural habitats, with a view to their possible sustainable use. That happened in contrast with the "genomic age", supported by FAPESP's large "Genoma Program", attracting most political and institutional attention between the late 1990's and the early 2000's. In fact, internationally renowned taxonomists strongly denounced at that time the unbalance between resources dedicated to traditional taxonomic activities (mostly dedicated to morphology but complemented with biological and ecological characteristics of the organisms) and to what was referred to as "phylogeny", dealing mostly with molecular phylogenetic analyses (Wheeler, 2004; Carvalho et al. 2007, 2008).

Four projects referring to different groups of terrestrial invertebrates were approved in the initial phase of the BIOTA/FAPESP program, all starting in 1999 and 2000 (Table 1). Other 22 projects were approved subsequently, six of which are still ongoing.

A large number of investigators have participated in these projects. To date, at least 375 established and training researchers (post docs and students at different levels) have participated in projects dealing with terrestrial invertebrates, making use of resources provided predominantly by BIOTA/FAPESP. From an applied point of view, each of such projects was or is headed by a researcher affiliated to a São Paulo research institution, who establishes the necessary partnership with professionals of complementary specializations, from Brazil or elsewhere. As expected, most of the researchers are from São Paulo institutions (until now, nearly 100 researchers), but researchers from several Brazilian states are also engaged, either as official project members, or collaborating in specific research topics and then co-authoring the generated articles. Also associated are researchers from other countries, mainly from the USA, South American and European countries. Many of these researchers, in addition to contributing remotely to the progress of the project, have also been awarded grants as visiting scientists, allowing them to conduct part of the research activities in Brazil, in association with Brazilian counterparts.

Table 1. Concluded and ongoing research projects of the BIOTA/FAPESP program concerning the terrestrial invertebrates between 1999 and 2021.

Project	Project Number	Project Leader	Duration
Diversity of mites and other associated arthropods in the State of São Paulo	98/07099-0	G.J. Moraes	1999–2004
Species and interaction diversity in plants and phytophagous insects	98/05085-2	T.M. Lewinsohn	1999–2004
Richness and diversity of Hymenoptera and Isoptera along a latitudinal gradient in the Mata Atlântica the eastern Brazilian rain forest	98/05083-0	C.R.F. Brandão	2000–2004
Lepidoptera of the State of São Paulo: diversity, distribution, resources, and use for analysis and environmental monitoring	98/05101-8	K.S. Brown Junior	2000–2007
Biodiversity of Arachnida and Myriapoda of the State of São Paulo	99/05446-8	A.D. Brescovit	2001–2006
Biodiversity of arachnids (except mites) in the Cantareira State Park, São Paulo, Brazil	00/05729-9	R.P. Rocha	2000–2003
Geographic limits and causal agents of Diptera endemism in the Atlantic Forest	03/10274-9	D.S. Amorim	2004–2009
Fauna and flora from forest fragments in the northwest region of São Paulo State: the basis to biodiversity conservational studies	04/04820-3	O. Necchi Junior	2005–2010
Biodiversity and sustainable use of pollinators, with emphasis on Meliponini bees	04/15801-0	V.L. Imperatriz-Fonseca	2006–2010
Bioluminescent coleopterans (fireflies) of the Atlantic Rainforest: biodiversity and use as environmental indicators	06/51911-0	V. Viviani	2007–2009
The SISBIOTA Diptera Brazilian network: a long-term survey of Diptera from unexplored central areas of Brazil	10/52314-0	C.J.E. Lamas	2011–2014
Dimensioning and exploration of the diversity of biological control agents of agricultural pests: entomopathogens and edaphic predatory mites	10/52342-4	I. Delalibera Júnior	2011–2014
Natural history, phylogeny and conservation of Neotropical Lepidoptera	11/50225-3	A.V.L. Freitas	2011–2014
Diversity and taxonomy of feather mites (Arachnida: Acari: Astigmata) on birds of Brazil	11/50145-0	F.R.A. Hernandes	2011–2016
Systematics, biogeography and biology of Orthocladiinae (Diptera: Chironomidae) with description of new taxons for the neotropics (emphasis on the Atlantic Rainforest and the description of immature stages)	11/50162-1	H.F. Mendes	2012–2014
Taxonomy, systematic and phylogeography of Attini	11/50226-0	M. Bacci Junior	2012–2015
Populational characterization of orchid bees (Apidae, Euglossini) from São Paulo State using geometric morphometrics of wings, mitochondrial DNA variability and cuticular hydrocarbons	11/07857-9	T.M. Francoy	2011–2015
Dimensions US-BIOTA São Paulo: integrando disciplinas para a predição da biodiversidade da Floresta Atlântica no Brasil	13/50297-0	C.Y. Miyaki	2013–2022
Ecology of interactions, behavioral ecology, and genetics of neotropical ant populations	14/23141-1	P.S.M.C. Oliveira	2015–2017
Phylogenetic systematics and biogeography of Diptera in the Atlantic Forest: analysis of form, time and space emphasizing the infraorder Tabanomorpha (Diptera, Brachycera)	17/11768-8	C.M.D. Santos	2018–2020
Edaphic mites: diversity, relationship with the microbiota and ecology in natural and cultivated areas in Brazil, with the preparation of databases and keys to identify selected groups	17/12004-1	R.C. Castilho	2018–2023
Morphological and molecular systematics and biogeography of mygalomorph spiders of Atlantic Forest	17/11985-9	J.P.L. Guadanucci	2018–2023
Molecular ecology of neotropical ants	17/16645-1	P.S.M.C. Oliveira	2018–2020
Synergistic effect of multiple mutualists on plants: how bacteria, ants and bees contribute to the evolution of a hyper-diverse lineage of legumes	19/19544-7	A. Nogueira	2021–2026
Countering the taxonomic impediment of aculeate wasps: micro and macroregional visions of the neotropical fauna	19/09215-6	F.B. Noll	2020–2025
Dimensions US-BIOTA-São Paulo: more to the blow fly than meets the eye: understanding evolutionary and genetic origins of diverse trophic specializations	20/05636-4	T.T. Torres	2021–2025
Unveiling the real diversity of Diptera (Insecta) in Brazil: human resources training and development of new tools for the taxonomy of little-known lineages	21/08741-6	C.J.E. Lamas	2021–2023

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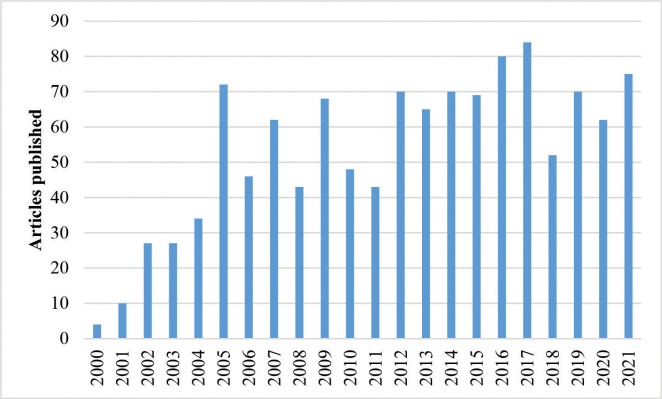

Figure 1. Number of articles published by BIOTA/FAPESP projects dealing with terrestrial invertebrates between 2000 and 2021.

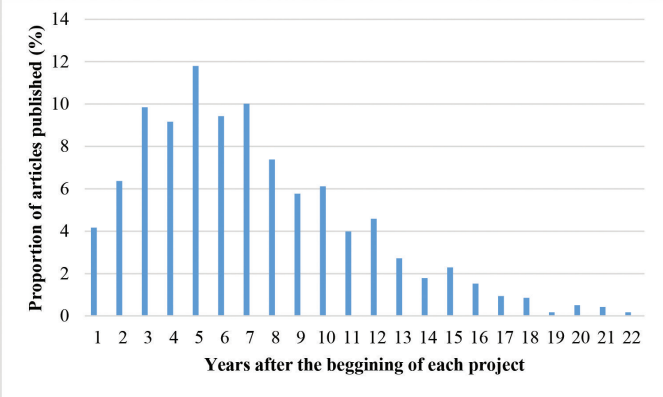

Figure 2. Proportions of articles published by each BIOTA/FAPESP project dealing with terrestrial invertebrates, from the first year a project was initiated (5-year projects).

2. *Pattern of publication and treated taxonomic groups*

Appendix 1 of this document lists the articles resulting from the projects dealing with terrestrial invertebrates, totaling over 1140 publications. The vast majority of these were published in journals of high standards and of international circulation, and therefore within the reach of the international scientific community.

The number of annual publications increased steadily in the first five years since the beginning of the program, reaching a maximum of approximately 60–80 per year with the implementation of new projects. This level has been maintained over the years (Figure 1), reflecting a pattern in which the peak production in terms of publications takes place from the third to the seventh year from the beginning of each project (whose average duration is about five years), with about 50% of all articles being published within the duration of each project (Figure 2). In the preparation of this article, it became evident that many projects continued to generate results in a regular basis for many years after their official termination. This "late" production may be due to the insufficient time to conclude the work while the project was running or may result from the proposition of complementary studies conceived as a consequence of promising findings and making use of specimens and data obtained in the course of the project. These alternatives seem typical of taxonomic works.

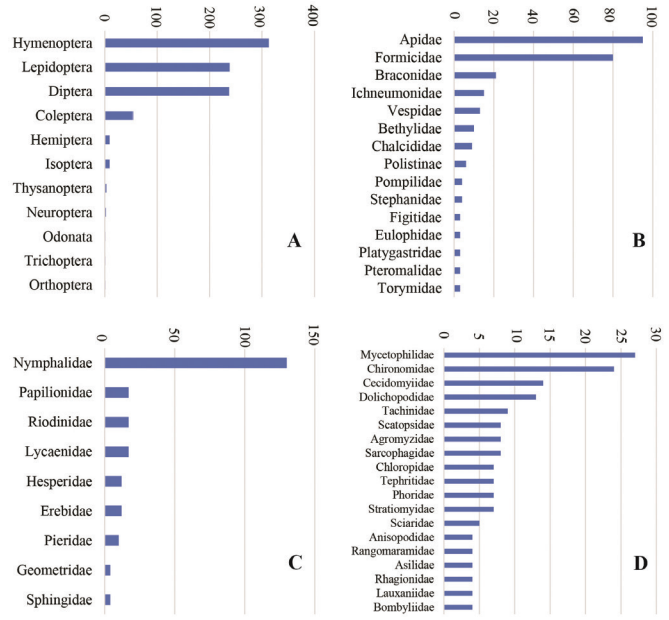

Figure 3. Insect orders (A), and families of Hymenoptera (B), Lepidoptera (C) and Diptera (D) with the largest numbers of articles published by BIOTA/FAPESP projects between 2000 and 2021.

Until now, the groups of invertebrates studied in all projects include exclusively species of the subclass Insecta (of the class Hexapoda), the class Arachnida and the subphylum Myriapoda, all belonging to the phylum Arthropoda (Table 1). Within the Insecta, species of the following orders have been studied: Coleoptera, Diptera, Hemiptera, Hymenoptera, Isoptera, Lepidoptera, Neuroptera, Orthoptera, Psocodea, Thysanoptera and Trichoptera. Within the Arachnida, the studied taxa belonged to the subclasses Acari, Araneae, Opiliones, Ricinulei, Schizomida and Scorpiones.

2.1. *Publications per taxonomic group*

Among insects, the megadiverse orders Hymenoptera, Lepidoptera and Diptera were most represented in studies funded by the program, with 313, 238 and 237 articles, respectively (Figure 3A). On the other hand, Coleoptera, the most diverse insect order, was the object of 58 articles, a much lower number of studies than those three orders. Among the Hymenoptera, Apidae (bees) and Formicidae (ants) were the two best represented families, with 94 and 78 articles, respectively (Figure 3B). Nymphalidae (116 articles) and Mycetophilidae (27 articles) were the families of Lepidoptera and Diptera, respectively, with the highest number of publications (Figures 3C, D). Other orders were dealt with in 26 articles, totalizing 872 articles dealing with Insecta.

In the Arachnida, about 124 publications have dealt with species of Araneae, 154 with species of Acari and 51 with species of other subclasses. Within the Araneae, species of 63 families have been dealt with; but most of the publications referred to Ctenidae, Salticidae, Pholcidae and Scytodidae (Figure 4A). Within the Acari, species of 70 families were reported, but most of the publications referred to Phytoseiidae and Eriophyidae (Figure 4B). All spiders are known to be predators, while some are known to cause severe health problems. Not by chance, the spider family with the largest number of publications (Ctenidae) contains one of the main groups of poisonous spiders in

Table 2. Number of articles published by BIOTA/FAPESP projects between 1999 and 2021 dealing with different scientific matters: NG: new genera; NS: new species; RD: redescriptions; TK: taxonomic keys; TC: taxonomic catalogs; TR: taxonomic revisions; EC: ecology; SU: surveys; BC: biological control; BI: biology; AC: cladistic analyzes.

	NG	NS	RD	TK	TC	TR	EC	SU	BC	BI	AC
Acari	18	178	30	26	9	7	25	47	25	9	2
Araneae	11	251	101	2		18	16	11		5	30
Opiliones	5	41	39	10		9	5	3		2	1
Ricinulei		1									
Schizomida	2	3									
Scorpiones		4					3	1			1
Pseudoscorpiones	1	1									
Coleoptera			4				6	6		4	2
Diptera	24	492	138	71	30	40	9	12		3	24
Hemiptera		8	19	1		1	3	1			5
Hymenoptera	4	193	79	29	8	18	111	27		27	13
Isoptera	2	8		1			1	4			
Lepidoptera	10	62	16	8	1	5	30	16		35	59
Neuroptera		2		1							
Orthoptera	2	2		1				1			
Psocodea		4		1			1	2			
Thysanoptera								1			
Trichoptera		2						1			

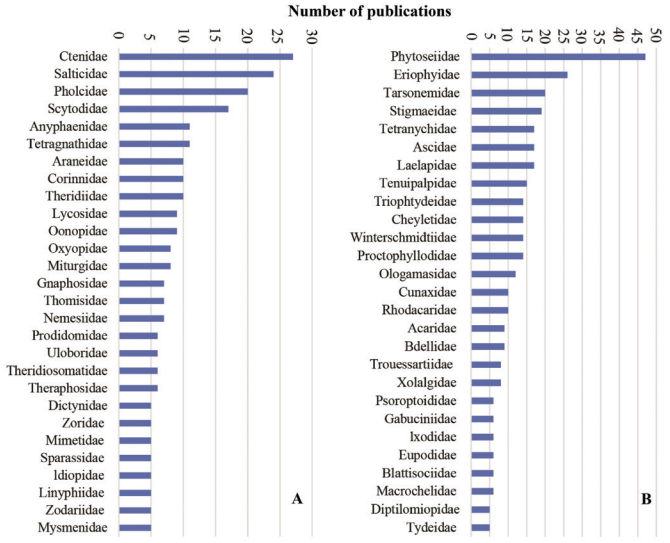

Figure 4. Families of Araneae (A) and Acari (B), both Arachnida, with the largest numbers of articles published by BIOTA/FAPESP projects between 2000 and 2021.

Brazil, of the genus *Phoneutria*. Conversely, a wide array of feeding habits is known for the mites; within the two most extensively studied mite groups in BIOTA/FAPESP projects, the Phytoseiidae constitute the most important group of plant inhabiting predatory mites, whereas all Eriophyidae are phytophagous, and several are major pests.

2.2. Original and complementary species description

As expected, the vast majority of the works carried out refers to the description of new taxa (Table 2). In total, 773 new species of Insecta and 479 of Arachnida were described, as well as 42 new genera of Insecta and 37 of Arachnida. These are impressive numbers in the international scenario, while compatible with the assumedly high Brazilian invertebrate diversity, the effort of the research groups and the financial support provided by FAPESP.

In addition, a large number of complementary descriptions (or redescriptions) has been generated by the different projects. Altogether, 256 species of Insecta and 170 species of Arachnida were complementarily described, with the provision of new information about them, based on newly collected specimens or on new examination of type specimens. When carefully done, complementary descriptions of taxa deserve the same or higher scientific value in comparison with the description of new taxa, as these could be seen as helpful in the confirmation of earlier hypotheses (i.e., previous descriptions of new species). Many of the oldest taxonomic descriptions are not sufficiently detailed, hampering or preventing today the correct recognition of the taxa. Yet, these cannot be just ignored in new works. This situation usually leaves taxonomists in great dilemma, requiring them to reexamine the corresponding type specimens to be able to conclude an identification; quite often, the reexamination is not possible because the types can no longer be located or cannot be done by different reasons. Additionally, even for the adequately described species, complementary descriptions quite often are of utmost importance to show the expected variations of

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each species, within the type locality or between different localities in which the species is found.

As scientific equipment improves, taxonomic descriptions have become more detailed. Every technical improvement implies the need for reexamination of voucher or type specimens, to confirm or reinterpret previous classification hypotheses. If the type specimens still exist, or good new material can be collected, detailed redescriptions of old species can be extremely valuable (Poulin & Presswell 2016). There are also philosophical improvements such as the recognition of homology, standardization of systems for naming structures, placing descriptions in a phylogenetic context, for example, often not done in old descriptions. Hence, the complementary description of 426 species of arthropods represents a significant taxonomic contribution.

2.3. Ecology, distribution, faunistic composition

Many of the works conducted in BIOTA/FAPESP projects are surveys to determine the invertebrate fauna present in specific regions of São Paulo State and other parts of Brazil. It is estimated that until now these projects have allowed the conduction of around 71 faunistic surveys to determine Insecta, and 62 to determine Arachnida groups. Each of these involved the collection, respective processing and identification of dozens of species and subspecies, contributing to the knowledge of the distribution of each taxon and to the knowledge of the faunistic constitution of each region. Most of the surveys were accompanied by the collection of information on the corresponding abiotic factors (as well as of biotic factors, such as plant or animal hosts), thus allowing the ecological analysis of the collected invertebrates. This type of analysis was reported in around 160 publications on Insecta and 49 publications on Arachnida, as those of Rego et al. (2009), Castro & Moraes (2010), Silva & Brandão (2010, 2014), Cancello et al. (2014), Santos et al. (2016), Justino et al. (2016), Andrade et al. (2017), Campbell et al. (2019), Azevedo et al. (2020a), Brown et al. (2020), Santos et al. (2020), Amorim et al. (2022). Even among ecological studies, a small number of publications addressed issues related to ecosystem services, as done by Giannini et al. (2012, 2013).

From a taxonomic point of view, the contribution regarding the elaboration of taxonomic keys has also been significant (113 works for Insecta and 38 for Arachnida), as well as the taxonomic revision of different groups, usually of the species within given genera (103 works for the Insecta and 34 for Arachnida) and the cladistic analyzes (99 publications for Insecta and 15 for Arachnida), many of which preceded by the aforementioned revisions. A considerable part of the cladistic analyzes involved molecular data, which were made available in the GenBank and could be used in subsequent studies.

2.4. Other evaluations and integrative taxonomy

Other topics considered in these projects referred to aspects of cytogenetics, ecology and biochemistry of different taxonomic groups. Works of these types are significant complements to those aimed at determining taxa, sometimes taking advantage of unique opportunities, which may lead to possible sustainable use of certain beneficial organisms in the future. From an applied point of view, several studies have been carried out to understand details about the biology of terrestrial invertebrates (69 for Insecta and 16 for Arachnida).

Also significant are the studies to determine the potential of terrestrial invertebrates as biological control agents. Twenty-five studies were dedicated to the evaluation of the potential of predatory mites for pest control, namely predators belonging to the order Mesostigmata, especially of the families Laelapidae, Macrochelidae and Phytoseiidae. In addition, several studies investigate the use of insects as bioindicators for habitat diagnostics and monitoring. In turn, cytogenetics and biochemistry works may still be useful in works now known as "integrative taxonomy".

2.5. Databases

Recently, information gathered by some of the projects supported by the BIOTA/FAPESP has been used to compose databases, such as those presented by Shirai et al. (2019) for Nymphalidae butterflies, Santos et al. (2018) for Atlantic Forest butterflies, and Silva et al. (2022) for Atlantic Forest ants, among others under development. These databases represent a great optimization of the efforts made by distinct projects, as they will allow the continuity in the use of generated data. In addition, a few projects were involved with the development of computational tools, such as those presented by Hirakama et al. (2009), Hammoud et al. (2019a, 2019b) and Santos & Fuhlendorf (2019). Tools of this type can offer new perspectives and analytical facilities that were previously not possible to be performed.

Until now, 28 taxonomic catalogs of insects and nine of arachnids have been published. These represent major taxonomic contributions, benefiting not only local researchers, but researchers worldwide, interested in the taxonomy of the treated groups, synthetizing and listing all the pertinent literature. Some of these have been made available on the internet and have been widely visited by researchers and the general public worldwide. These constitute excellent examples of the eighth step of what Evenhuis (2007) listed as important points to be considered by taxonomists in their regular work.

2.6. Geographical scope of the work carried out

As expected, most of the organisms studied were collected in the State of São Paulo. However, many studies were carried out with organisms collected in practically all Brazilian states. In addition, certain studies, especially those concerned with the taxonomic revisions and cladistic analyzes, also considered organisms collected in other countries of the Neotropical Region, or even, a few, in other biogeographic regions of the planet.

Regarding insects, 277 studies (each corresponding to one publication) were conducted in the State of São Paulo, followed by the states of Rio de Janeiro, Santa Catarina, Paraná and Minas Gerais, with respectively 84, 79, 75 and 71 studies. The states with the lowest representations were Piauí, Rio Grande do Norte, Amapá and Tocantins, with respectively 8, 9, 10 and 10 studies. Such analysis demonstrates the need for greater efforts to expand the knowledge of terrestrial invertebrates in the Brazilian north, northeast and mid-western regions. As mentioned by Marques & Lamas (2006), the proportional lack of knowledge about the taxa of terrestrial invertebrates (including Hexapoda) in Brazil is alarming and represents a responsibility the country cannot neglect. In this sense, once again BIOTA/FAPESP assumes a leading role. Although it is aimed at funding research carried out by researchers located in the State of São Paulo, the analysis of the projects approved throughout the program's history demonstrates the gradual territorial expansion addressed by them. Thus, while the first projects, initiated mainly between 1999-2010, covered basically only

that state, the projects approved since then have been dedicated to the study of biodiversity in other states as well. Additionally, many studies provided first records of high-ranking taxa (e.g. families, subfamilies, tribes or genera) in South America, in Brazil or in different Brazilian states (e.g. Rheims & Brescovit, 2006; Silva et al. 2013; Lamas et al. 2015; Riccardi et al. 2018; Fachin et al. 2018; Carmo-Neto et al. 2019; Falaschi et al. 2019; Azevedo et al. 2020a; Barros et al. 2021; Mendes et al. 2022).

The prestige of the work conducted within BIOTA/FAPESP projects has led to invitations to Brazilian researchers to collaborate with similar studies in other countries, allowing the exchange of publishable information, with benefits to both sides of the partnership. Exchanges of this type have benefitted the knowledge of the arthropod fauna of the Neotropical region. Since the beginning of the project, countries of this region have been mentioned in 325 publications about biodiversity, especially Colombia, Argentina, Peru, Ecuador and Costa Rica, which were mentioned respectively in 41, 29, 27, 25 and 22 studies.

2.7. Reference collections

BIOTA/FAPESP has played a fundamental role in the development and maintenance of biological collections in the State of São Paulo (see also Borges et al., in press; Mamede & Simão-Bianchini, in press), mostly in the Natural History Museums. These are institutions responsible for collecting, preserving, organizing and interpreting material evidence of our biological heritage and whose missions are materialized in their collections, which are extensively used for research, teaching and extension purposes.

The importance of museums for the conduction of taxonomic works and the continuous validation of proposed new species names along time was stressed by Wheeler (2004), in his contention regarding the role played by traditional taxonomy in comparison with what has been provided by phylogenetical studies based on molecular analyses. As appropriately discussed by the author, descriptions of new taxa are proposals of new hypothesis, which should be validated as new specimens of the same or related groups are discovered, studied and deposited in museums.

With regard to terrestrial invertebrates, the Museum of Zoology of the University of São Paulo, an institution that brings together the largest and most representative collections of this fauna in Latin America, and the Museum of Biological Diversity (former Museum of Zoology) at the University of Campinas (UNICAMP) play a major role. In regard to the Arachnida, this is the case with Butantan Institute, University of São Paulo (Piracicaba campus and Museum of Zoology) and São Paulo State University (São José do Rio Preto and Rio Claro campuses). For the insects, financial support was provided to Museum of Zoology, Faculty of Public Health, Faculty of Phylosophy, Sciences and Letters, "Luiz de Queiroz" College of Agriculture, all of the University of São Paulo; São Paulo State University (Botucatu, Jaboticabal, Rio Claro and São José do Rio Preto campuses); as well as Museum of Biological Diversity at Unicamp.

Many of the institutions whose researchers participated in BIOTA/FAPESP projects used the opportunity to improve their reference collections, increasing the number of deposited organisms and improving the infrastructure. It is worth noting that the collections formed within the scope of projects aimed at the study of biodiversity function as actual databases for similar studies years ahead, even after the official closure of a given project.

2.8. Contribution to the private sector

BIOTA/FAPESP Program initially prioritized the generation of basic information considered essential for future development of applied research, envisioning benefits to society, the actual donor of the program funds. Thus, the ultimate goal of a large part of the program is to know the organisms that constitute the biota of São Paulo State and to delineate means to conserve them adequately and to make possible their sustainable use. Therefore, it is first necessary to name and identify the organisms (taxonomic studies), to understand their evolutionary relationships (phylogenetic systematics studies) and their context (ecological studies), moving then on to the study of details of their biology and potential for practical use. Usually, a gap must be admitted between the discovery and the possible practical "exploration" of the organisms, but all of the above steps are equally important. Hence, taxonomy cannot be viewed just as a service to provide names to organisms, so that these can be used by "true" research practitioners (Carvalho et al. 2008). On the contrary, taxonomic works are essential for the meaningful attribution of names to organisms, which is necessary for the meaningfulness of other disciplines, as phylogeny, quite differently from the concepts of some authors in the past (Godfray, 2007).

As an example, among the studies carried out so far, the detection of a species of predatory mite (*Stratiolaelaps scimitus*; Laelapidae), found in the course of one of the projects, has allowed the implementation of its practical use in the country, mainly for the control of edaphic insect pests known as "fungus gnats" (Diptera: Sciaridae) (Castilho et al. 2009). This predator was known to occur in other countries, in some of which it was already used for the control of pests of that group. Its finding in Brazil, in works related to the BIOTA/FAPESP, resulted ultimately in the establishment of colonies by a private Brazilian company and its registration for practical use (PROMIP 2022).

In addition, the project entitled "Biodiversity and sustainable use of pollinators, with an emphasis on Meliponini bees" gave rise to a patent called "Automated system for collecting data on bee behavior in hives" (Patent application number: PI 0902909-5 A2). The aim of this patent is to automate data collection on bee behavior in hives, obtained from temperature, humidity and bee activity sensors, under laboratory conditions and in nature. Likewise, the venoms of Hymenopteran insects are extensively studied for the development of antifungal, antiparasitic, and anticancer compounds (Costa-Lotufo et al. in press).

2.9. Contribution to the establishment of public policies

The São Paulo State Secretary of the Environment has made use of the rich source of scientific information obtained by BIOTA/FAPESP to assist in decision making. The work "Guidelines for the Conservation and Restoration of Biodiversity in the State of São Paulo" was based on thematic maps produced by specialists in different areas of knowledge, to visualize the regions with greater biological diversity and, therefore, requiring stricter environmental protection. Such collaboration has allowed the development of public policies aimed at: 1- improving the inspection of critical and threatened areas; 2- developing more rigorous norms of environmental licensing and 3- creating new Conservation Units.

Additionally, the program has also contributed to the development of public health program. This includes studies regarding the relationship between invertebrate vectors, especially mosquitoes, and public health (Pinter et al. in press).

2.10. Training of new professionals

One of the main demands of BIOTA/FAPESP to project leaders has always been the inclusion of undergraduate and graduate students as part of the research teams. This is consistently taken as particularly important, in order to maintain in good order the taxonomic competence of the different taxonomic groups. Thus, since the beginning of BIOTA/FAPESP Program, nearly 300 of the participants of projects on terrestrial invertebrates were or have been students. Of these, 129 were undergraduate students or students that had recently graduated, granted through the "Technical Training" and "undergraduate research" programs. Of the remaining, 95 were master and 75 were doctorate students, conducting their graduate research as part of the projects.

Additionally, one of the activities officially established in one of the projects (Edaphic mites: diversity, relationship with the microbiota and ecology in natural and cultivated areas in Brazil, with the preparation of databases and keys to identify selected groups) refers to an intensive training on mite taxonomy, with the participation of 15–20 people (professionals or students, mainly graduate) at each year. With the available infrastructure, in part obtained with the support of BIOTA/FAPESP, the training was incorporated as an institutional priority, and should be continued even after the end of the specific project to which it is currently linked.

It is also worth mentioning the partnership of FAPESP with the Brazilian National Council for Scientific and Technological Development (CNPq), within the scope of the PROTAX Call (Program to Support Research Projects for the Training of Human Resources in Biological Taxonomy), to co-finance proposals submitted by the São Paulo State researchers. This Program has supported research projects seeking to train specialized human resources in taxonomy, to provide the demand of Brazilian research institutions in times of taxonomic impediment and biodiversity crisis (Alves et al. 2018; Santos & Carbayo 2021).

2.11. Perspectives – new challenges

Presently, the study of biodiversity is of interest not only to scientists, but basically all sectors of society. The concept of biodiversity and its relationship with ecosystem services were summarized by Quijas & Balvanera (2013), and several papers have been published about this subject worldwide, given the effect of biodiversity on different sectors of society. As an example, one of these papers was recently published by the Swiss Re Institute (2020), to evaluate the implications and opportunities of the decline of biodiversity and ecological services on the insurance and reinsurance industry.

The present analysis of the advances achieved in the BIOTA/FAPESP program since its creation allows the suggestion of relevant topics to be addressed in the near future. There is enough room for the development of projects concerning groups that have not been contemplated so far, especially in the phyla Annelida and Nematoda. These are groups of scientific relevance, still not sufficiently known in Brazil and that have the potential to be economically explored in different ways. While many nematodes have the potential to damage animals and plants, other nematodes as well as the Annelida have the potential to be used as beneficial organisms. Both phyla have been studied by Brazilian researchers in relation to their practical importance, due to the role of the Annelida in the physicochemical properties of the soil and of the Nematoda as parasites of animals and plants. From a taxonomic or ecological point of view, in-depth study of these in natural environments, would be relevant. As an example, recent studies have suggested free-living nematodes to be of interest in maintaining populations of predatory mites, which are important in the biological control of plant pathogenic nematodes and harmful insects (Azevedo et al. 2019, 2020b). But the species of free-living species their ecological characteristics are poorly known in Brazil; also, their role as food sources for small soil inhabiting predators is inadequately known, but assumed to be important. In addition to Nematoda, estimated by Hodda (2011) to account for about 25,000 species worldwide, several other groups informally referred to as worms (e.g. flatworms, annelids) are so little known that it is hardly possible to estimate how unknown they are (Marques & Lamas 2006).

Even within the arthropods, there are orders that have not yet been properly studied within BIOTA/FAPESP, as the Coleoptera for example, in disagreement with their partially known diversity in São Paulo and Brazil. Worldwide, this is the largest animal order, with almost 400,000 species (Zhang, 2011). For this and other arthropod groups, we still need substantial resources to improve our knowledge on their taxonomy, biology, biochemistry and ecology, envisioning not only the knowledge of their intraspecific diversity, but also of their possible sustainable use. We still have a long way to go. According to the Catálogo Taxonômico da Fauna do Brasil (2022), about 94,000 species of arthropods have been reported from Brazil. Continued efforts, with the support of BIOTA/FAPESP, may increase that number considerably.

Natural history studies are essential to advance the understanding of the functional roles of species and, consequently, to understand the functional dynamics of ecosystems in the Anthropocene. It is through understanding this component that more effective conservation practices can be proposed and adopted. From an applied point of view, emphasis could be given to the conduction of studies of aspects of the use of naturally occurring parasitoids and predators of insect, mites and nematodes pests. These could include both conservation and augmentation biological control strategies and could be associated with the efforts dedicated to the taxonomy and ecology of native natural enemies.

Also, of fundamental importance will be the continued effort in training, for the replacement of retiring professionals along the years and to give attention to groups in which taxonomic expertise is insufficient in Brazil. Thus, the inclusion of students in new projects, as well as the establishment of new basic courses for the recognition of invertebrates of greater interest to people of different specialties, are considered highly desirable. But the training of new specialists is of little use if they cannot find a place to work in the taxonomic groups they have been trained. Hence, emphases should be given to the inclusion of new taxonomists in research teams of different institutions, as taxonomists cannot be replaced by professionals of other specialties.

Initiatives to strengthen the structures of reference collections and museums and to enhance professional capabilities are also considered important, due to the need to preserve type and voucher specimens, and to facilitate the conduction of taxonomic works. Adequate support for

preventive procedures is essential to avoid tragic events, as unfortunately experienced by Butantan Institute a few years ago, and more recently by the National Museum in Rio de Janeiro.

All those needs should be taken into consideration, in the establishment of the new phase of BIOTA/FAPESP, or in the establishment of similar endeavors in São Paulo state or elsewhere.

Supplementary Material

The following online material is available for this article:

APPENDIX 1: Publications resulting from BIOTA/FAPESP program.

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Conflicts of Interest

The authors declare that they have no conflict of interest related to the publication of this manuscript.

Ethics

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

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