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Thematic Review

Marine and coastal biodiversity studies, 60 years of research funding from FAPESP, what we have learned and future challenges

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Abstract: In this study we survey and analyze 300 projects related to marine biodiversity funded by FAPESP from 1972 to 2021, of which 46 were nested in the BIOTA Program. From a unique project in the 1970's, the number gradually increased until 2009, when BIOTA promoted a call on marine biodiversity, which led to a boost in the number of funded projects in the subsequent years. The geographical range of the projects expanded over the years and, from studies based on the coast of São Paulo State, the focus gradually shifted to broader areas of the Brazilian coast, then to other areas of the Atlantic, and eventually became global. The majority of projects focused on coastal benthic organisms living on hard-bottom. In terms of taxa, six groups accounted for about 60% of the projects (viz. Crustacea, Actinopterygii, Mollusca, Chondrichthyes, Cnidaria, and Rhodophyta), but it is observed an increase in the number of groups studied over the decades. The 300 projects refer to a set of 82 different topics, of which the top five are taxonomy, phylogeny, community, "omics", and pollution. The analyses show a long-standing effort in marine biodiversity surveys, with ongoing updated approaches regarding scope and methods. Research on strategic areas is discussed, including deep-sea and marine microbiota. Climate change and the increasing pressure of human activity on the ocean, including pollution, acidification and invasive species, are among the main challenges for the future. Projects producing and using basic research data in an integrative and transdisciplinary way offer multiple perspectives in understanding changes in ecosystem functioning and, consequently, are essential to support public policies for the conservation and sustainable use of marine biodiversity at different scales. UNESCO's Decade of Ocean (starting 2021) is a window of opportunity to strengthen marine research, to promote national and international collaboration, to build up networks involving the public and private sector, but particularly to draw society's attention to the importance of knowing marine environments and using ocean resources in a sustainable way. The advancement of ocean literacy is one of the main legacies for future generations promoted by integrated research programs such as BIOTA-FAPESP.

Keywords: *BIOTA-FAPESP Program; Oceanographic Vessels; Research Development; São Paulo State; Ocean Biodiversity.*

Estudos de biodiversidade marinha e costeira, 60 anos de financiamento à pesquisa da FAPESP, o que aprendemos e desafios futuros

Resumo: Neste estudo levantamos e analisamos 300 projetos relacionados à biodiversidade marinha financiados pela FAPESP entre 1972 a 2021, dos quais 46 foram realizados no Programa BIOTA. De um projeto único na década de 1970, o número foi aumentando gradativamente até 2009, quando o BIOTA promoveu uma chamada sobre biodiversidade marinha, o que impulsionou o número de projetos financiados nos anos seguintes. A abrangência geográfica dos projetos se expandiu ao longo dos anos e, a partir de estudos baseados no litoral do Estado de São Paulo, o foco gradualmente se deslocou para áreas mais amplas da costa brasileira, depois para outras áreas do Atlântico, e acabou se tornando global. A maioria dos projetos se concentrou em organismos costeiros, bentônicos, em substrato consolidado. Em termos de táxons, seis grupos responderam por cerca de 60% dos projetos (Crustacea, Actinopterygii, Mollusca, Chondrichthyes, Cnidaria e Rhodophyta), mas observa-se um aumento no número de

grupos estudados ao longo das décadas. Os 300 projetos referem-se a um conjunto de 82 temas diferentes, dos quais os cinco principais são taxonomia, filogenia, comunidade, "ômicas" e poluição. As análises mostram um esforço de longa data em pesquisas de biodiversidade marinha, com abordagens atualizadas em relação ao escopo e métodos. A pesquisa em áreas estratégicas é discutida, incluindo os estudos sobre a microbiota marinha e em águas profundas. As mudanças climáticas e a crescente pressão da atividade humana sobre o oceano, incluindo poluição, acidificação e espécies invasoras, estão entre os principais desafios para o futuro. Projetos de produção e uso de dados de pesquisa básica de forma integrada e transdisciplinar oferecem múltiplas perspectivas de compreensão das mudanças no funcionamento dos ecossistemas e, consequentemente, são essenciais para subsidiar políticas públicas de conservação e uso sustentável da biodiversidade marinha em diferentes escalas. A Década do Oceano da UNESCO (a partir de 2021) é uma janela de oportunidade para fortalecer a pesquisa marinha, promover a colaboração nacional e internacional, construir redes envolvendo os setores público e privado, mas principalmente para chamar a atenção da sociedade para a importância de conhecer os ambientes marinhos e utilizar os recursos oceânicos de forma sustentável. O avanço da "alfabetização" oceânica é um dos principais legados para as gerações futuras promovidos por programas integrados de pesquisa como o BIOTA-FAPESP.

Palavras-chave: *Biodiversidade Oceânica; Embarcações Oceanográficas; Estado de São Paulo; Pesquisa e Desenvolvimento; Programa BIOTA-FAPESP.*

Introduction

The ocean is essential to all known life as it regulates/balances the climate of the planet. Coastal protection provided by coral reefs (Hearn 1999) and mangroves (Othman 1994, Menéndez et al. 2020), oxygen production by phytoplankton (Falkowski et al. 2003), food resources for billions of people (FAO 2020), a library for medical bioactive compounds (Chbel et al. 2020) are only a few from many important environmental services provided by the marine realm and products or subproducts of its teeming life (Figure 1). In fact, the ocean harbors an amazing biodiversity, with representatives of most known life forms, several of which, including whole phyla, are unique to marine ecosystems. It has been cataloged 240,137 valid species (WoRMS 2022), but we are still not sure how many eukaryotic species inhabit the ocean, and although experts predict that nearly 2.2 million marine species exist (Mora et al. 2011), methodologies/extrapolations diverge in two folds of magnitude (*i.e.* from 300,000 [Costello et al. 2012] to over 10,000,000 [Grassle & Maciolek 1992]). Thus, in times of ever-increasing anthropogenic challenges, multi/inter/transdisciplinary scientific approaches are necessary not only to understand marine life but also to describe how this life influences and is influenced by the environment and humanity. Furthermore, there is an urgent need to communicate such integrative science to engage society and stakeholders to plan and act for a healthier and, consequently, more resilient, and predictive ocean.

Despite this vital importance, we have more detailed maps from the Moon and spent more funds in understanding Mars' atmospheric circulation than that of the ocean. Relatively little attention has been given to protect the ocean, its biodiversity, and its ecological services (Jackson et al. 2001, Laffoley et al. 2021) and, concomitantly, the negative impacts of human activity have grown to staggering amounts and are taking their toll in an unprecedented magnitude (Worm et al. 2006, Miles 2009, Hoegh-Guldberg & Bruno 2010, McCauley et al. 2015).

This dissonant scenario between humankind and the ocean demands actions towards the knowledge and sustainable use of the oceans. Therefore, 2021 was set as the first year of the Decade of Ocean Science for Sustainable Development (UNESCO, 2021). Under the motto "the science we need for the ocean we want", the Decade proposes 10 goals largely based on greater knowledge of marine biodiversity. Therefore, it is clear that achieving established goals of social and environmental importance depends on an uninterrupted process of research, technology and innovation development, which meanders from providing infrastructure to capacity building to qualifying human resources. Such strategic state policy has been implemented by the São Paulo Research Foundation (FAPESP) "a public foundation, funded by the taxpayer in the State of São Paulo, with the mission to support research projects in higher education and research institutions, in all fields of knowledge" (FAPESP 2021). Over the years, FAPESP has developed integrated research programs in order to strengthen and coordinate studies in strategic areas. Among those, the FAPESP Research Program on Biodiversity Characterization, Conservation, Restoration and Sustainable Use (BIOTA-FAPESP 2021), created in 1999, directly promote the knowledge of biodiversity in all its complexity, including evaluating the sustainable exploitation, as well as formulating the basis for conservation policies. More recently, the FAPESP Research Program on Global Climate Change (FAPESP Mudanças Climáticas 2021) also harbors projects dealing with marine biodiversity.

The main objective of this study is to survey and evaluate the contribution of FAPESP, particularly the BIOTA Program, in promoting research in marine biodiversity across the last six decades. We used these data to identify gaps and areas of interest as a suggestion for new funding lines, especially within the BIOTA Program. Since the analysis is based exclusively on research projects from the State of São Paulo supported by FAPESP, an important caveat is that the data does not represent the entire development of the area in Brazil, nor does it include other national and international support for São Paulo researchers. On top of that, as Brazil holds an extensive coastline, there are several other research groups working on marine biodiversity in other Brazilian states.

Data from 1992 to 2021 were collected from the FAPESP Virtual Library (FAPESP Biblioteca Virtual 2021), and those from 1962 to 1991 were directly compiled from FAPESP's database. The survey included projects granted by FAPESP in areas of Biological Sciences (Botany, Ecology and Zoology) and Earth Sciences (Oceanography), general demand, as well as those included in BIOTA and Global Climate Change programs. The survey for 2021 was carried out

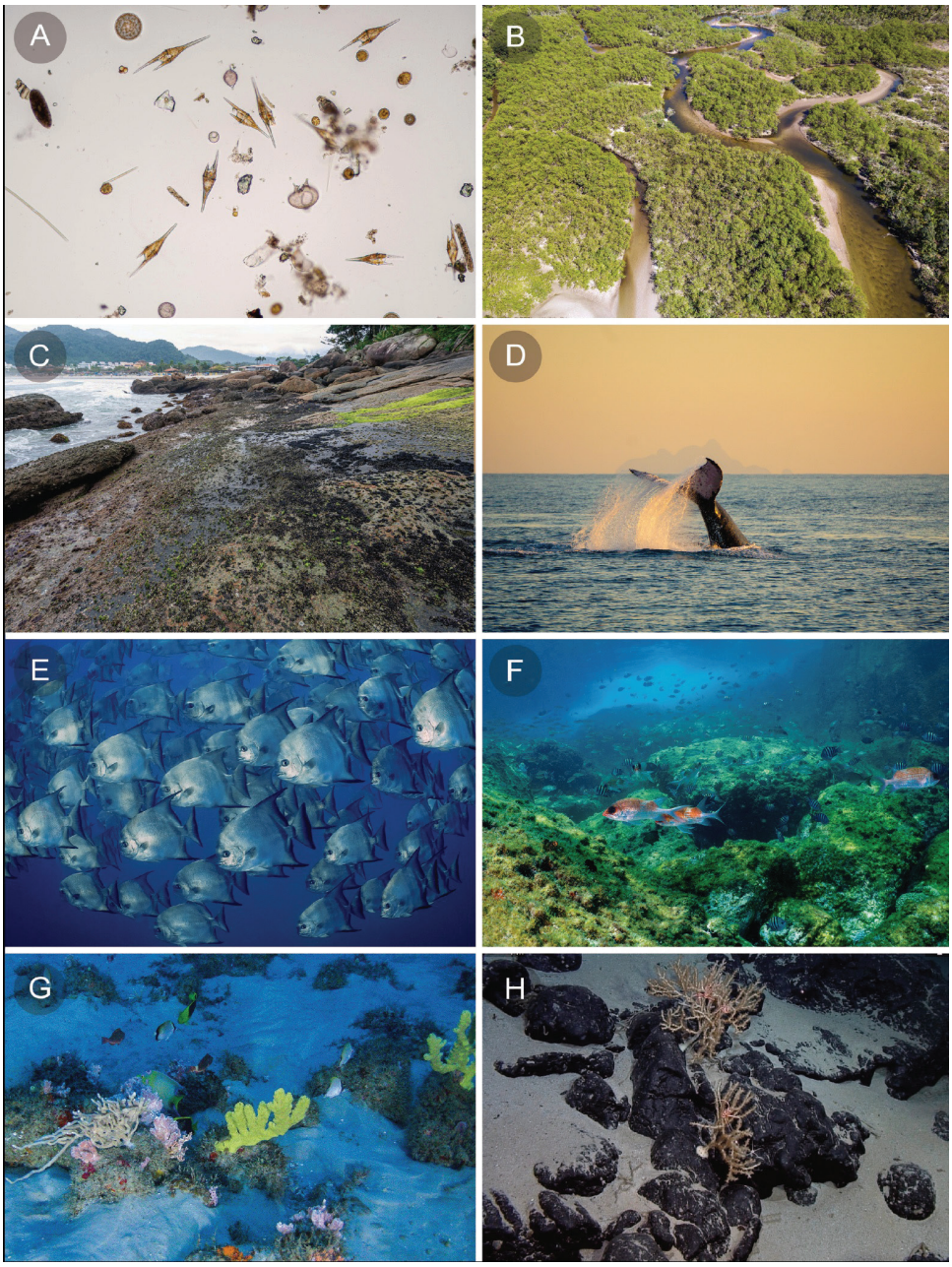

Figure 1. Examples of the teeming marine life from Brazil: A – phytoplankton under the microscope; B – mangrove ecosystem in the municipality of Ubatuba; C – rocky shore in the municipality of Ubatuba; D – a juvenile of *Megaptera novaeangliae* in the São Sebastião channel (the silhouette of the main island of the Alcatrazes Archipelago is seen in at the background); E – large school of *Chaetodipterus faber* at the Alcatrazes Archipelago; F – rocky reef at the Alcatrazes Archipelago illustrating different types of algae, invertebrates, and fishes; G – mesophotic reef off Amazon (photo courtesy of Francini-Filho, R.B.); H – deep-sea gorgonians and associated echinoderms at the Rio Grande Rise (photo from the Iatá-Piuna project, Shinkai 6500 – courtesy of Sumida, P.Y.G.).

based on all areas of knowledge. The modalities of these projects were "Regular" (2-year grants), "Thematic" (5-year grants), "Young Investigators" (5-year grants), and "Research Partnership for Technological Innovation Program'' (FAPESP Research Grants, 2021). Visiting scholars and student scholarship grants, as well as institutional infrastructure grants, were not considered in the analyses. Overall 300 projects dealing with marine biodiversity were funded by FAPESP from 1972 to 2021, of which 46 were nested in the BIOTA Program and 13 in the Global Climate Change Program (Table S1).

Marine Biology Research Funded by FAPESP

At the time of FAPESP foundation (1962), the state of São Paulo already had institutions performing research on marine biodiversity, *viz.* the Botany Institute (1917); the Fisheries Institute (1927); the University of São Paulo (USP – Institute of Bioscience, 1934; Museum of Zoology, 1895; Institute of Oceanography, 1946; Center for Marine Biology, 1955; Faculty of Philosophy, Sciences and Letters at Ribeirão Preto, 1964); the State University of São Paulo (UNESP – Institute of Biosciences, Letters and Exact Sciences at São José do Rio Preto, 1955; Institute of

Bioscience at Rio Claro, 1958); and, just after, the Institute of Biology at the State University of Campinas (UNICAMP, 1967). More recently, other state and federal universities that include research groups working on marine biodiversity have been created: the UNESP Coastal Campus (2002); the Federal University of ABC (UFABC, 2005); and the Sea Institute (IMar) from the Federal University of São Paulo (UNIFESP, 2007). Historically, 47 public and private institutions had projects funded by FAPESP. The distribution of the projects, however, is unequal when considering research institutions. The top four are USP (66%), UNESP (9%), UNICAMP (9%), and UNIFESP (6%) (Table S1). Until the 1980s, projects were highly concentrated at USP (82%), dropping to 74%, 68%, 57% and 56%, respectively in the 1990s, 2000s, 2010s, and 2021.

The first and only marine biodiversity project funded by FAPESP in the 1970s was on protein synthesis of tunicates in 1973 (Figure 2) and, since then, the number of funded projects has increased expressively. The BIOTA-FAPESP Program debuted in 1999 and was relatively successful in promoting continental based biodiversity projects and syntheses (Joly et al. 2010, 2011) but had little influence on the number of marine biodiversity related projects. In 2009, this program promoted the "Biota FAPESP + 10" workshop to discuss the accomplishments and the research gaps of the program and also to establish goals for the next 10 years. This workshop generated a science plan for the next decade of funding within the BIOTA (Joly et al. 2010, see the supplemental material for the science plan). One of the gaps highlighted was research on marine biology, which led to a call for proposals in the same year (FAPESP 2009). The call led to an increase in the number of funded projects in 2010 and 2011, attracting the attention of researchers working in marine biodiversity and encouraging them to join the BIOTA Program (Figure 2).

In addition to that, FAPESP also provided other modalities of support that directly or indirectly contributed to the development of studies on marine biodiversity. A program dedicated to improve the infrastructure related to laboratories, multi-user equipment, collections, libraries, information technology, and vivaria facilities was created in 1994 and, during its five years of existence, awarded at least 69 institutional grants, investing around USD 786,8 million (inflation adjusted; FAPESP 1999). Infrastructural grants continued to be subsidized by FAPESP after 2000 through other programs, and it is worth noting the support to acquire two oceanographic vessels for multi-institutional use in 2012 and 2013, the Alpha Crucis and the Alpha Delphini, the first being 64 meters long, taking 40 people on board, and having an autonomy of 40 days, therefore able to operate at open sea for weeks-long scientific cruises (Figure 2). Also aiming to promote the area, BIOTA organized international meetings, *viz*. the "Workshop on Marine Biodiversity: Current Advances on Bioprospecting, Biogeography and Phylogeography" (FAPESP 2010); "Marine Data Management: Perspectives and Research" (FAPESP 2012); "Marine algae from biodiversity to biotechnology" (FAPESP 2013); "Workshops of the BIOTA/FAPESP Araçá Project" (FAPESP 2014, 2016), as well a special session in a series of workshops celebrating the 20 years of the BIOTA-FAPESP Program (FAPESP 2020). Several other talks or sessions were dedicated to marine biodiversity in many other workshops promoted by BIOTA (programs and presentations available at https://fapesp.br/eventos/).

The increase in the number of projects, in addition to the infrastructure improvement and human resource development, was accompanied by an increase in the scope and complexity of the research in several dimensions. First, there was a clear expansion of the geographical range of the projects over the decades (Figure 3). More than 50% of the studies until the 1990s were based on the coast of the State of São Paulo. The focus gradually shifted to broader areas of the Brazilian coast, then to other areas of the Atlantic (since the 1980s), and eventually became global (from the 1990s). Studies on oceanic islands and Antarctica have always been occasional, and in part related to specific national programs (Figure 3).

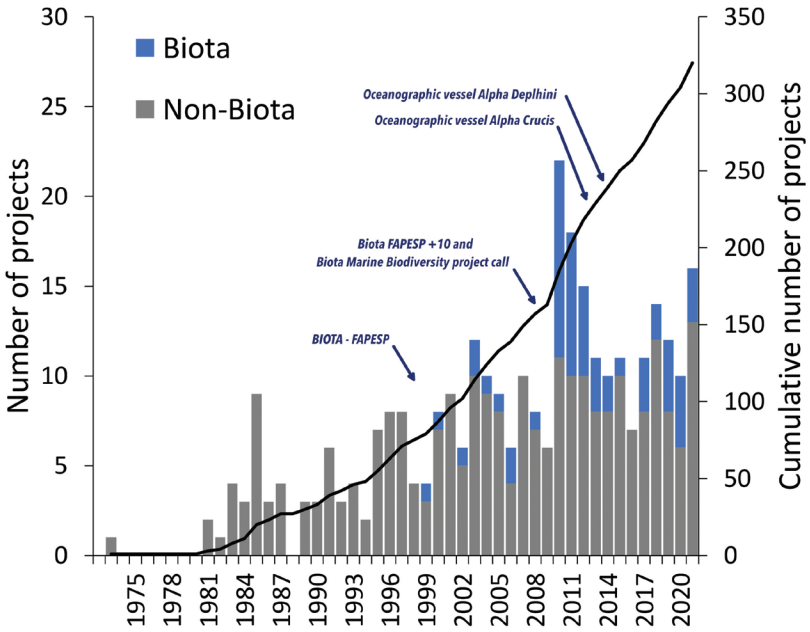

Figure 2. Number of marine-related projects supported by FAPESP between 1972 and 2021, both per year and accumulated over time. The BIOTA-FAPESP program (in blue) started in 1999.

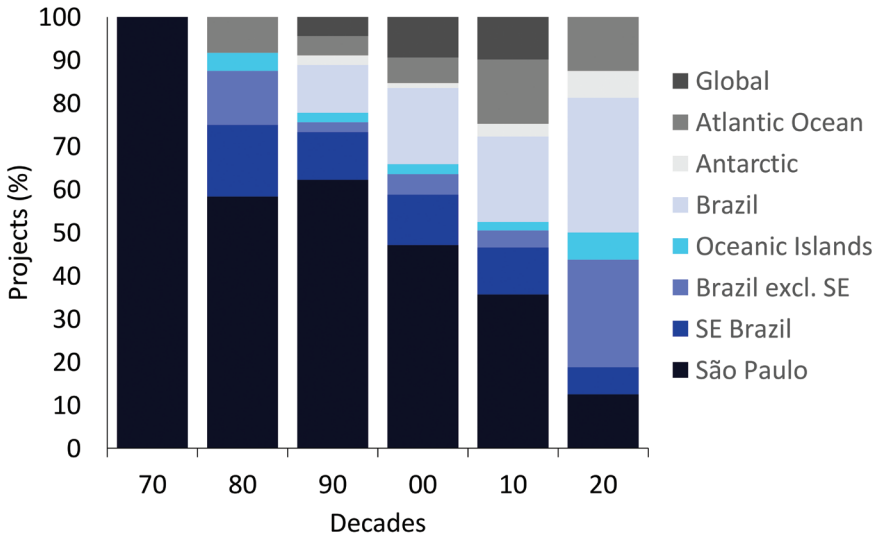

Figure 3. Geographical range of FAPESP research projects over the decades, in percentage. Number of projects with available geographic information: 70s: 1; 80s: 21; 90s: 44; 00s: 80; 10s: 95; 20s: 14 (only the projects starting in 2021).

Within the FAPESP funded projects, most focused on benthic organisms. Plankton and nekton communities combined were the subject of no more than 40% of the projects, while studies on meiofauna have been incipient. Regardless of the studied community, more than 80% of the projects were limited to the coastal zone. Studies on insular, oceanic, sublittoral, and deep-sea organisms gradually started in the 1980s, which together represent less than 25% of projects. At the same time the proportion of projects focusing on hard-bottom increased at the expense of the proportion of those on estuaries and soft-bottom (Figure 4).

In terms of taxa, six groups account for about 60% of the projects (*viz*. Crustacea, Actinopterygii, Mollusca, Chondrichthyes, Cnidaria, and macroalgae, mainly Rhodophyta). However, as seen for geographical ranges, there has always been an increase in the number of groups studied over the decades (1970s: 1; 1980s: 12; 1990s: 23; 2000s: 25; 2010s: 33) (Figure 5; Table S1). Part of that is a consequence of broader projects granted by the BIOTA-FAPESP Program, including poorly studied taxa (*i.e.*, those with few or no Brazilian researchers, individually accounting for up to 0.6% of the projects), as well as other groups with an intermediate proportion of studies (*i.e.*, accounting between 0.6 and 4% of the projects).

Within the FAPESP funded projects, most taxa have been studied in taxonomic projects (Figure 6), except Foraminifera, which was mostly restricted to sedimentological and paleoceanographic surveys, and Actinopterygii, a group of economic and social relevance frequently subject of studies in applied science, biological oceanography, and ecosystem ecology. Macroalgae projects were related to applied sciences and biological oceanography, from prospection of bioactive compounds to biodiversity surveys, while the macroalgae group Rhodophyta was mainly related to taxonomy.

The 300 projects supported by FAPESP related to marine biodiversity refer to a set of 82 different topics, in a comprehensive thematic portfolio (Figure 7). Overall, the top 5 topics are taxonomy (present in 99 projects), phylogeny (49), community (39), omics (34), and pollution (34). Historically, in the 1980s, projects focused on the basic areas of taxonomy, physiology, and community ecology. Since then, taxonomy has been constantly growing, and leveraging studies in phylogeny since the 1990s. The breadth and robustness of the taxonomy has, in fact, been a remarkable historical feature of Brazilian science in biodiversity, standing out worldwide, modernizing and dealing with the country's megabiodiversity (Marques & Lamas 2006). On the other hand, community ecology and physiology, in addition to morphology and population ecology, have remained stable even with the increase in the total number of studies over the decades. In the 1990s, studies on environmental issues started, growing rapidly in number, such as those in the areas of pollution and climate change. The emergence of these studies coincided with the Eco 92 in Rio de Janeiro, which awakened Brazilian society and the scientific community for tackling environmental causes. Concomitantly, the number of projects with omics approaches (e.g., genomics, transcriptomics, etc) and conservation has increased significantly (Figure 8).

The results of the historical analysis show a long-standing effort in biodiversity surveys funded by FAPESP. These studies have updated their approaches regarding scope (including phylogeny and biogeography) and methodologies, especially concerning the use of genomic tools. The ecological approach has also been modernized, starting from a descriptive ecology of communities, populations, and autecology to more comprehensive macroecology and functional ecology, even if still incipient. There have always been studies relating ecological processes with the main anthropogenic stressors, especially those acting on coastal biota. This is particularly important for areas under strong urbanization and/or exploitation, such as the coast of São Paulo, one of the largest urban regions of the Southwestern Atlantic. In this sense, the use of nature-based solutions for coastal restoration and planning has the potential to leverage actions that jointly meet human demands on the coast and minimize impacts on native biota.

Future Challenges

Based on solid principles of multidisciplinary oriented science, research qualification, infrastructure improvement, relatively stable

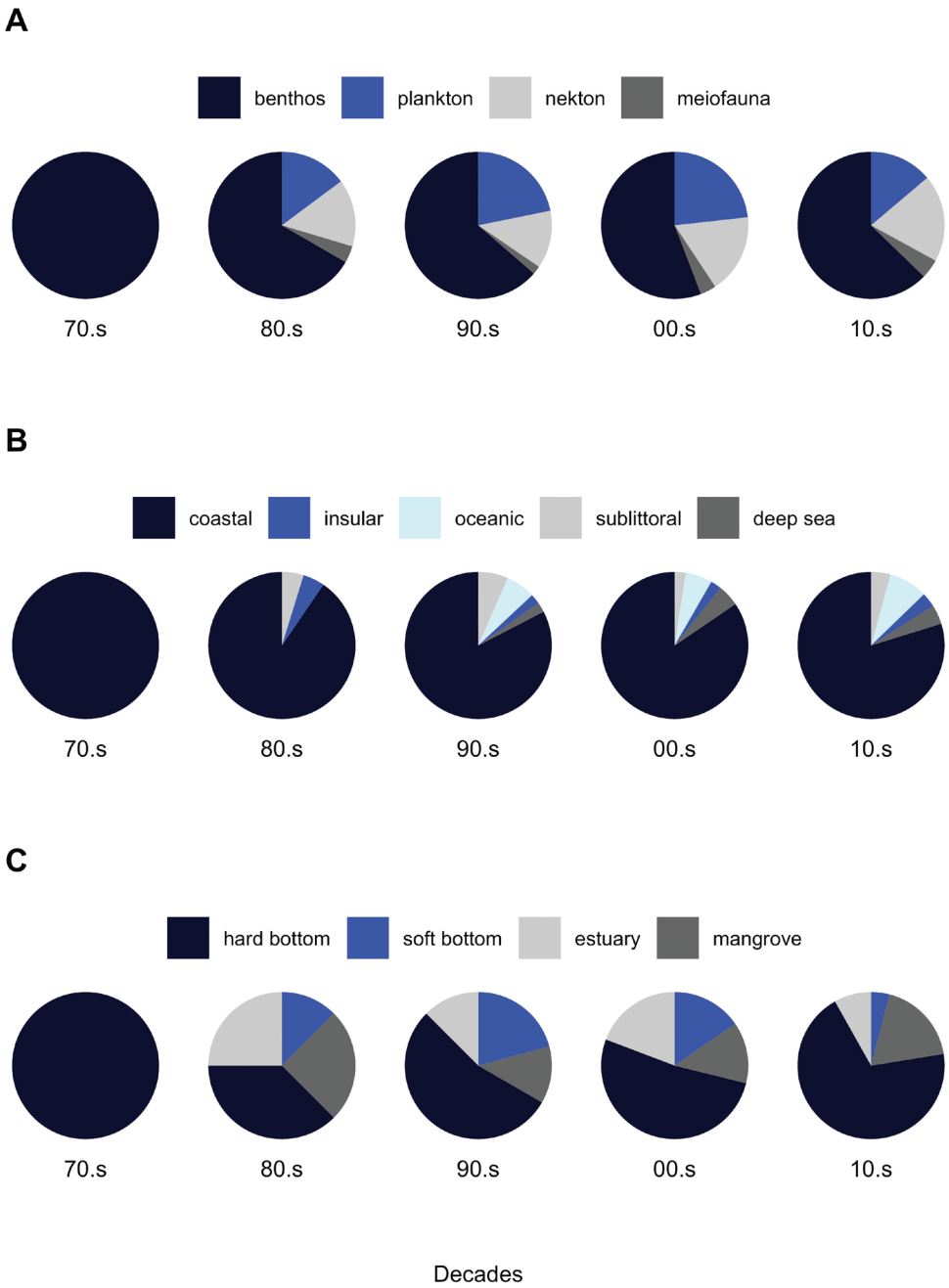

Figure 4. Information about the community (A), region (B), and habitat (C) of FAPESP research projects over the decades. Number of projects with available information: A – 279 projects (70s: 1; 80s: 29; 90s: 51; 00s: 87; 10s: 99; 20s: 12, only the projects starting in 2021). B – 270 projects (70s: 1; 80s: 24; 90s: 44; 00s: 88; 10s: 99; 20s: 14, only the projects starting in 2021). C – 240 projects (70s: 1; 80s: 24; 90s: 41; 00s: 78; 10s: 87; 20s: 9, only the projects starting in 2021).

funding levels, capacity building, and national and international collaboration, FAPESP has been a driving force for all scientific fields in the São Paulo State, influencing scientific research at national and international level. Key examples reflecting this vision from FAPESP are: (i) the funding for large-scale, innovative, long-term, multidisciplinary, and usually multi-institutional research (*e.g.*, Thematic Project modality, 1990), which expanded collaboration between research groups/areas; (ii) the launch of the Genome Program (1997–2008), which established high throughput sequencing facilities and qualified human resources to work in this area; (iii) the BIOTA Program (since 1999), an instrumental action in promoting, integrating, and fostering a multitude of scientific research related to biodiversity characterization, conservation, and restoration; (iv) Global Climate Change Program (since 2008), aiming to integrate and coordinate research that will aid in scientifically informed decisions regarding risk assessments, mitigation and adaptation strategies; and (v) bilateral joint funding agreements with foreign agencies, higher education, and research institutions and companies (*e.g.*, the SPRINT Program). In that sense, FAPESP's funding policies have been one of the most important factors changing the hitherto prevalent approaches of incremental research to more ambitious theoretical or problem-driven projects, committed to inter- and transdisciplinarity. This paradigm shift has the

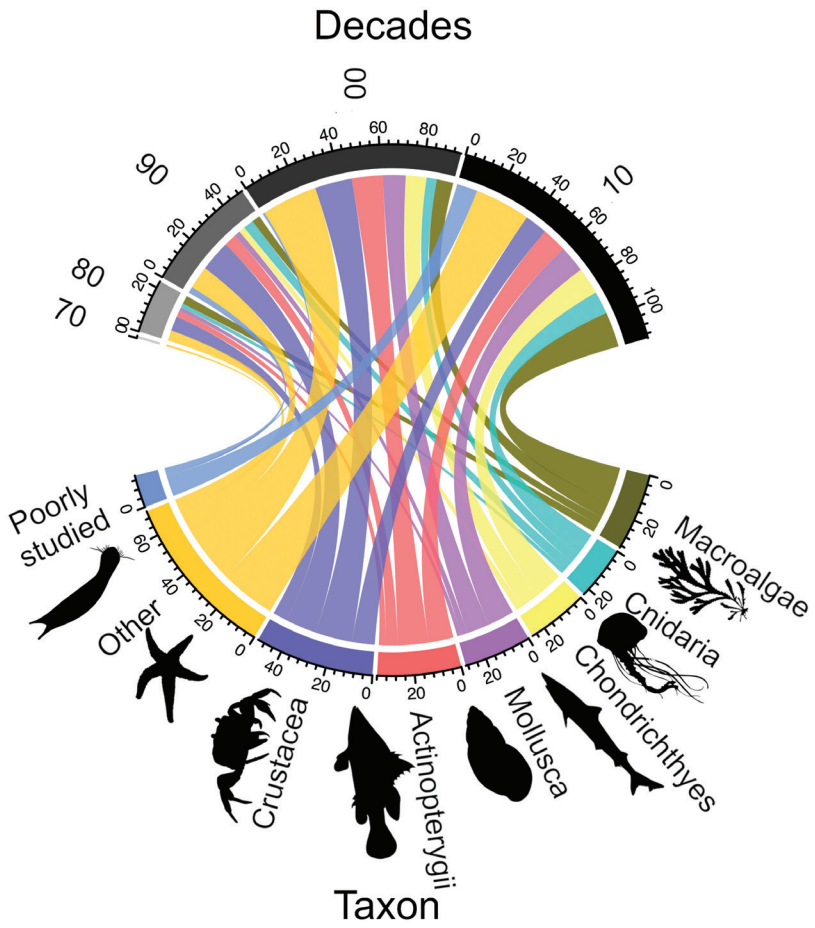

Figure 5. Groups included in FAPESP research projects over the decades. "Other" includes Foraminifera, Angiosperms, Annelida, Nematoda, Echinodermata, Urochortada, and Mammalia. "Poorly studied" groups are those that were studied in up to two projects funded by FAPESP (~ 0.6 % of the total) and include Archaea, Chlorophyta, Eubacteria, Testacea, Phaeophyceae, Porifera, Platyhelminthes, Gastrotricha, Bryozoa, Testudines, and Aves. Number of chords represents the number of studies on each taxa and decade.

potential to leverage a corresponding shift in the traditional view of biodiversity studies, *i.e.* one that does not focus on processes, to studies that consider biodiversity as "a collection of dynamic systems linking seemingly disparate biological and cultural components and requiring an understanding of the system as a whole" (Sterling et al. 2010). In the context of this elegant vision of biodiversity, and based on the history of projects financed by FAPESP, we can identify some knowledge gaps in the portfolio of projects dedicated to marine biodiversity (Figures 4–6). Although some of these gaps may be filled in the near future, many would depend on the establishment of new and broad research efforts.

One of the knowledge gaps that need attention is deep-sea research. The implementation of a comprehensive program to support research projects targeting the world's largest ecosystem in all its dimensions is urgent. Brazil has one of the largest Marine Economic Exclusive Zones (totaling 3.6M km^2 that could be enlarged to nearly 4.5M km^2), mostly located in waters deeper than 1,000 m. A better understanding of this immense and almost unknown ecosystem will allow adequate management planning and, consequently, the conservation of deep-sea resources. In this context, the two oceanographic vessels available in the state of São Paulo, both financed by FAPESP, are already part of the infrastructure for this endeavor, but so far, such infrastructure has not yet leveraged comprehensive research on the deep-sea. The main challenges to achieve this are the high costs of equipment and vessels *per diem*, integration between interested teams, as well as the lack of trained human resources. To overcome these challenges, dedicated integrative programs should foster the usage of the facilities by interested researchers, promoting a network among different institutions (*e.g.*, http://coralprof.org/). In a way, this collaborative network could be inspired by the FAPESP genome projects. In 1997, FAPESP funded the first genomic network in Brazil that had the goal to sequence and annotate the genome of a phytopathogen (*Xylella* Genome Project). This successful initiative, a network that initially included 30 laboratories at different institutions in the state of São Paulo, not only achieved its goal, but also established sequencing facilities in different institutions and trained human resources, being instrumental to boost the use of DNA sequencing and analyses, which were rapidly transferred to other research fields, including marine biodiversity. The model of integrative objectives based on common funding and strategy, especially incorporating capacity building at all levels, could provide the critical mass to increase demand and greatly stimulate scientific advancement in the area.

Another model and important example of the integration between knowledge fields is observed in the traditional area of taxonomy of marine organisms. This seminal basic area is largely responsible for

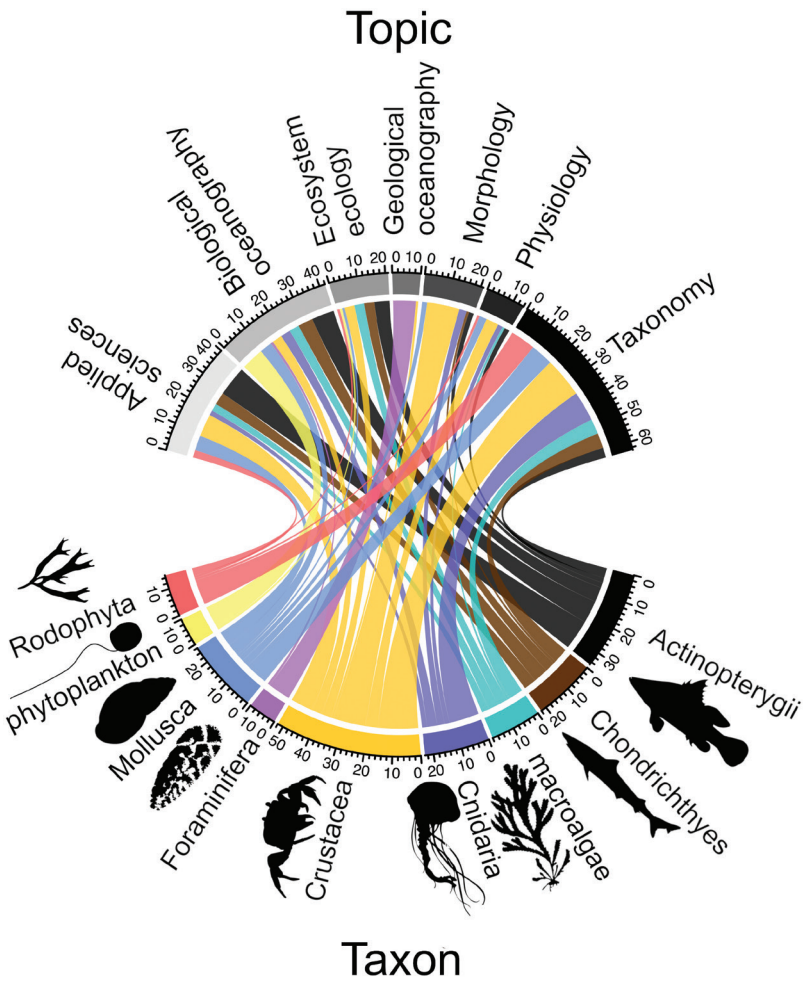

Figure 6. Association between the most studied groups and topics of FAPESP research projects. Number of chords represents the number of studies on each group and topic.

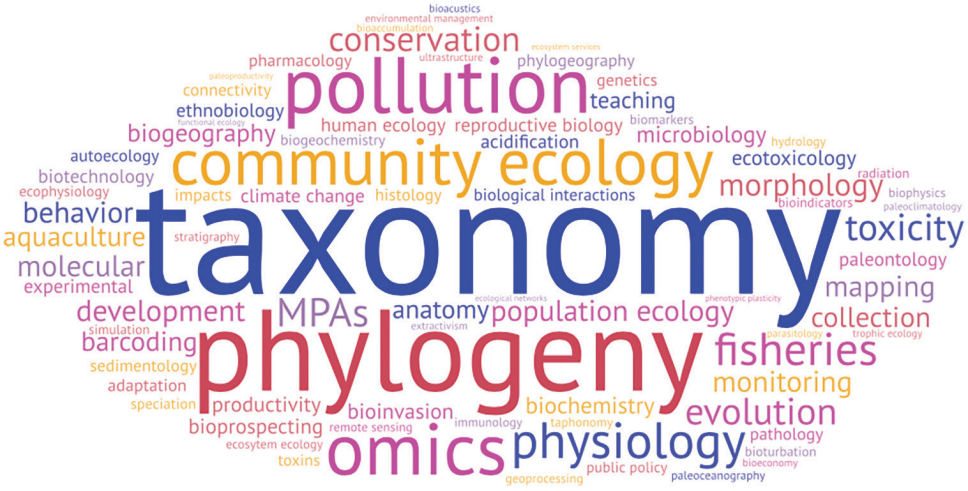

Figure 7. Representation of the most common research topics related to marine biodiversity funded by FAPESP from 1970 to 2021. More frequent words appear larger.

grounding deeper inferences about marine biodiversity. Taxonomists have been adopting different methodologies and tools to study biodiversity, including the sequencing of molecular markers. The process of integrating areas is, however, a continuous effort. Currently, the use of molecular inferences for the study of marine biodiversity is in transition to large-scale molecular analyzes (genomics, transcriptomics,

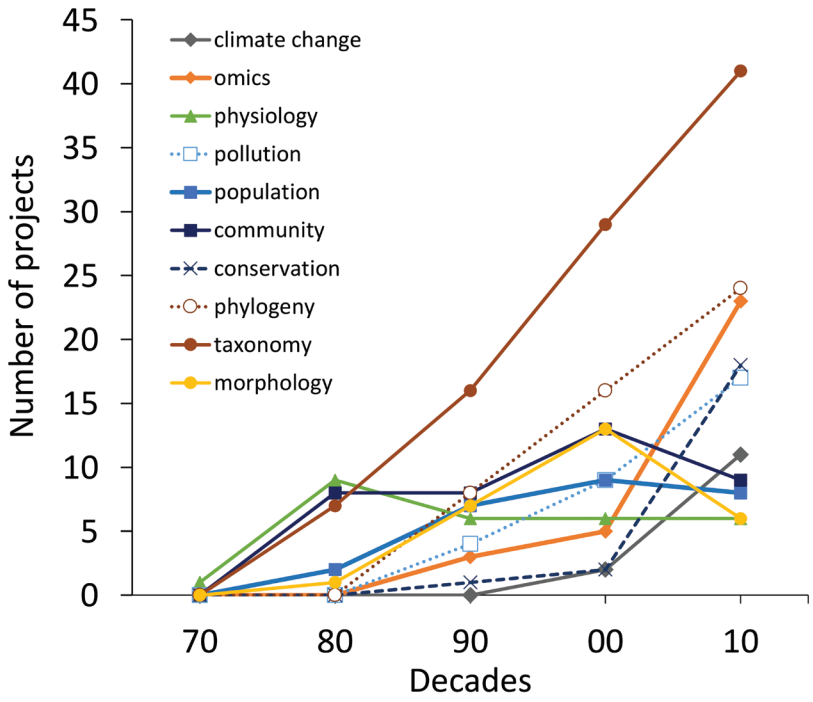

Figure 8. Top trending topics of FAPESP research projects over the decades. Number of projects: 70s: 1; 80s: 32; 90s: 54; 00s: 98; 10s: 119; 20s: 16 (only the projects starting in 2021).

metabolomics, metagenomics). The use of new tools (such as omics) for studies in taxonomy and evolution, ecology, physiology, among others, are of paramount importance to improve the understanding of the processes that influence the origin, distribution, sustainable uses and conservation of biodiversity. But, more importantly, this process serves as a model for the development of science with an interdisciplinary and integrative vision.

Relatively few of the projects on marine biodiversity funded by FAPESP have so far focused on the microbiota. Microorganisms have been shown to play key functions on marine ecosystems, including energy flux, biogeochemical cycles, among others, but still little is known on processes that regulate their activity (Moran 2015). The research on microbial communities, not only in the water column, but also associated to other organisms such as invertebrates or macroalgae, is a strategic field for understanding processes in the ocean, as well as a rich source for biotechnological applications. BIOTA-FAPESP placed a call on microorganism's biodiversity in 2011 (FAPESP 2011) that resulted in three projects in marine microbiota, two of those in mangroves.

A further relevant policy is the continuous funding for long-term projects related to the Sustainable Development Goals (United Nations 2015), including socioeconomic and environmental issues related to climate change, ocean acidification, macroecology and biogeography, invasive species, among others. These projects, in addition to producing and using basic research data in an integrative and transdisciplinary way, offer multiple perspectives in understanding changes in ecosystem functioning and, consequently, are essential to support public policies for the conservation and sustainable use of biodiversity at different scales. The IPCC projections and the steady increase of human population in coastal areas highlight the importance and urgency of research on marine and coastal biota. Climate change and human occupation and activities have been a constant threat, impacting marine and coastal environments with unprecedented effects on their biota. Ecosystems that provide important services, such as mangroves and coral reefs, are highly vulnerable. The effects of climate change – such as acidification, warming and sea level rise – have threatened survival and, thus, increased the risk of extinction of marine and coastal biota. Moreover, human activities have been facilitating the expansion of invasive species and, therefore, studies that support mitigation, monitoring and management actions are necessary. This is particularly relevant considering that the number of FAPESP funded research projects on these themes is either decreasing or incipient, highlighting the importance of promoting strategies and/or training of human resources in these areas. Linked, but not restricted to the above, and also requiring more research attention, are those poorly studied marine organisms such as meiobenthic invertebrates, plankton, and mesopelagic animal communities.

The ever-increasing necessity to make scientific results available to society must be assumed as common ground in research projects. In other words, researchers who receive funding from FAPESP should be further stimulated to include outreach and educational components especially targeted to the community in general and elementary and high school students in particular, in the form of websites, mobile applications, books (physical and digital), videos, etc. In that sense, the Decade of Ocean is a window of opportunity to strengthen marine research, to promote national and international collaboration, to build up networks, involving the public and private sector, but particularly to draw society's attention to the importance of knowing marine environments and using ocean resources in a sustainable way. The advancement of ocean literacy is one of the main legacies for future generations promoted by integrated research programs such as BIOTA-FAPESP.

We conclude that the studies of marine biodiversity, as shown in the projects financed by FAPESP, are transposing the paradigm of incremental and monothematic research to the consolidation of inter/transdisciplinary research networks, through innovative and audacious projects. These marine research networks should further encourage the inclusion of stakeholders of public and private sectors. Such a scenario can lay the foundations for a proposal of a marine Research, Innovation and Dissemination Center (CEPID). Indeed, the body of evidence that FAPESP projects have already raised, with a substantial amount of high quality data (demonstrated by its products ranging from high level publications and databases to influence on public policies), has decisively contributed to the construction of a society based on science.

Supplementary Material

The following online material is available for this article:

Table S1 – Projects (300) funded by FAPESP from 1972 to 2021, dealing with marine biodiversity, of which 46 were nested in the BIOTA Program and 13 in the Global Climate Change Program.

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Conflicts of Interest

All authors had projects funded and were reviewers of many projects submitted to BIOTA-FAPESP during their careers. MCO was a member of BIOTA-FAPESP coordination.

Ethics

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

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