Knowledge of Brazilian benthic marine fauna throughout time

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Abstract

The ecosystems of Brazil's continental shelf and oceanic islands comprise a variety of environments that display unique geomorphological and geophysical features and biotic components. The quest to attain knowledge of Brazilian marine fauna is hampered by coastline length, biodiversity, a high rate of endemism, and a shortage of specialized researchers. Based on a systematic bibliographic review, the article offers an overview of the history, current knowledge, and outlook for the field of marine biodiversity in Brazil. Our findings show that government initiatives have afforded greater knowledge of Brazilian marine fauna species and opened new perspectives, including reliance on complex tools to describe benthic marine habitats in terms of their geological, geophysical, and biotic composition.

Keywords: benthic marine fauna; knowledge of marine biodiversity; historical record of knowledge of biodiversity; Brazil.

Brazil's 7,400-kilometer-long coast is home to a variety of ecosystems that display unique geomorphological and geophysical features and biotic components, comprised of communities of associated organisms (Knoppers, Ekau, Figueiredo, 1999; Diaz, Solan, Valente, 2004). The occurrence and number of species and the way they occupy spaces are related to these geomorphological and geophysical features as well as to features intrinsic to biological interaction (Greene et al., 1999; Diaz, Solan, Valente, 2004). This set of components constitutes the region's specific diversity, which forms the functional foundation of ecosystems. The topic is of great interest to Brazil's scientific community and government sector; furthermore, it is a right of citizens to have knowledge about these ecosystems, since, as Lana (jul.-dez. 2003) has emphasized, diversity is an inherent feature of our surrounding environment.

Improving knowledge of species diversity is a major challenge, particularly given the geographic size and diversity of environments found in Brazil and the country's high rates of endemism (Couto, Silveira, Rocha, 2003; Joly et al., 2011). Access to the marine environment is even more challenging, not only because of tidal regimes and the surf along the coastline but because special training and specialized equipment is needed to investigate certain areas, such as the infralittoral. The situation is even more complex when the research area involves the continental shelf or oceanic islands, where sophisticated vessels, highly trained personnel, and complex equipment are required. The present article follows the historical trajectory of the challenge of acquiring knowledge on marine species diversity in Brazil.

To organize the information to be used in this text, we adopted the approach of a systematic review of the literature. We conducted bibliographic surveys using specialized electronic search tools that included BIREME (PAHO/WHO's Latin American and Caribbean Center on Health Sciences Information); the LILACS (Literatura Latino-americana e do Caribe em Ciências da Saúde, Latin American and Caribbean Health Sciences Literature) database; MEDLINE (Medical Literature Analysis and Retrieval System Online), which is the US National Library of Medicine's life science database; Scielo (Scientific Electronic Library Online); Google Scholar; Portal Capes, maintained by Brazil's eponymous federal research funding agency; SIBiNet (Sistema Integrado de Bibliotecas da Universidade de São Paulo [USP]), the integrated library system of the University of São Paulo; and USP's bibliographic databank, Portal Dedalus (Global Online Catalogue). The following keywords were searched, in Portuguese and in their English equivalent: "biodiversidade marinha no Brasil"/"marine biodiversity in Brazil;" "biodiversidade marinha no Brasil revisões"/"marine biodiversity in Brazil revision;" and "conhecimento da biodiversidade marinha no Brasil"/"knowledge on marine biodiversity in Brazil." Articles were included in the bibliography when they met one of two criteria: publication in an indexed journal or presentation of a general review of knowledge on marine biodiversity in Brazil (specific taxonomic surveys were not included). We deemed these strategies appropriate as our primary goal was to obtain a historical overview of the field of marine biodiversity in Brazil, along with an assessment of both current knowledge and future outlook.

Physical characterization of the Brazilian coast

Spalding et al. (2007) proposed a global system for dividing coastal regions and continental shelves into what are called Marine Ecoregions of the World (Meow), comprising 12 realms, 62 provinces, and 232 ecoregions. Realms are the broadest systems spatially; grouped within them are provinces, defined by the presence of biota displaying some evolutionary relation; lastly, provinces are sub-divided into ecoregions, which are characterized by homogeneous species composition. According to Spalding et al. (2007), the Brazilian coast comprises the biogeographic realms known as the Tropical Atlantic and Temperate South America. The Tropical Atlantic realm contains the provinces of the North Brazil Shelf and Tropical Southwestern Atlantic; Brazil's southern coast is part of the Warm Temperate Southwestern Atlantic province and belongs to the Temperate South America realm.

Along its 7,400km, the Brazilian coast is affected by a number of ocean currents and rivers with sizeable discharges that rise up local influence (Arnault, 1987; Dominguez, Bittencourt, Martin, 1983; Ekau, Knoppers, 1999; Knoppers, Ekau, Figueiredo, 1999). The formation of the present coastal plains, associated with large river mouths in the Northeast and Southeast, was described by Dominguez, Bittencourt, and Martin (1983); according to the authors, these broad coastal environments, peculiar to Brazil's coast, were built through processes of sea level lowering over the past five thousand years, with the exposure of coastal sediments, river load, and coastal drift. Webb (1995) showed evidence of an extensive interior seaway in the Amazon region during the Middle Miocene, which accounts for the occurrence of marine-related species in the Amazon river. As a result, quite diverse environments are found along the coast, such as the estuarine environments where fresh river water mixes with ocean water to produce variations in salinity, which are associated with the growth of mangrove swamps, coastal marshes, lagoons, rocky shores, sandy beaches, and carbonatic, lateritic, and arenitic reef structures. Similarly, benthic environments on the continental shelf consist of muddy and sandy seabeds, carbonatic and arenitic reef structures, and large extensions of recently described coralline algae beds, called rhodoliths (Amado Filho et al., 2012; Pereira Filho et al., 2012; Bastos et al., 2013; Moura et al., 2013).

The shelf varies in width depending upon region of the country, attaining its greatest widths in the North (nearly 320km) and in the Southeast and South (around 220km); in the Northeast, it is only some twenty to 50km wide, except in the vicinity of the Abrolhos Bank, where it stretches 220km beyond the coastline (Ekau, Knoppers, 1999). Tidal amplitudes also differ markedly along the coast, reaching 8m in the North but ranging from 20cm to 2m in the South (Ekau, Knoppers, 1999).

A number of articles have characterized Brazil's ocean currents, including Arnault (1987); Knoppers, Ekau, and Figueiredo (1999); and Miloslavich et al. (2011). This information can be summarized as follows: in terms of the influence of ocean currents on the Brazilian shelf, the South Equatorial Current reaches the continent in Northeast Brazil, from there flowing both northward (Guiana Current or North Brazil Current) and southward (Brazil Current). The Brazil Current begins around the state of Pernambuco, flowing along the edge of the shelf to northern Argentina, between 10ºS and 40ºS. Brazil Current waters are characteristically warm, with temperatures ranging from 18ºC to 28ºC and salinity from 35 to 36ppm, therefore

categorizing them as Tropical Water. The Brazil Current extends to a depth of 200m, making it a surface current. Due to its temperature and density, the South Atlantic Central Water (SACW) flows underneath the Brazil Current, transporting the colder sub-Antarctic Water of the Malvinas (Falkland) Current. The SACW may reach the surface at certain spots, called resurgences; this occurs at cape Santa Marta, in the state of Santa Catarina, and Cabo Frio, in the state of Rio de Janeiro. Once on the surface, the SACW circulates northward, reaching the state of Espírito Santo roughly at what is known as the Vitória Eddy (Vórtice de Vitória; approximately 20ºS) (Guimarães, 2003). Arnault (1987) observed a seasonal variation in the velocity of these currents, which tends to drop off in the spring. Forster et al. (2007) estimated that the Atlantic Equatorial waters have displayed high surface temperatures since the Middle Cretaceous. Paleotemperatures were determined not to exceed current temperatures by more than 3ºC to 9ºC, although a brief period (approximately 150,000 years) of cooling took place during Cretaceous oceanic anoxic event 2. Marine currents produce specific conditions that, in conjunction with the geomorphological features of an environment, engender habitats that display a characteristic biota.

The concept of biodiversity

Biodiversity, which reflects the richness, or number, of species, is the result of a process of evolution in the genetic variability of the organisms that survive natural selection (Joly et al., 2011). Losses in biodiversity can never be recovered since the steps of a never-to-be-repeated evolutionary process vanish along with the unique species genome (Lana, jul.-dez. 2003; Joly et al., 2011). Because every species is a functional part of a habitat, which consists of species interactions with the physical environment and with the other species co-existing therein, the environment pays a high price for lost biodiversity, in ecological, spatial, and temporal terms.

Global awareness of the importance of biodiversity has incited much interest in nominal knowledge of this biodiversity and of its functional purpose within the ecosystem to which it belongs. Research on systematics and taxonomy, which uses enlightening, innovative tools like molecular analyses, in combination with analyses of the morphology of groups, has therefore played an increasingly vital role; the same holds true for ecological studies of population structures and ecosystem communities. This information supports management and conservation plans and provides indications of large-scale environmental processes and their consequences, like global warming.

Early information on marine biodiversity in Brazil

The earliest research on biodiversity in Brazil began with the arrival of the Dutch physician Willem Piso and the German naturalist George Marcgrave, who accompanied Dutch colonizers to the Northeast; their studies were published in 1648 in *Historia Naturalis Brasiliae* (Ihering, 1914; Françoso, 2010). The book presents 301 species of flora, with two hundred plates, and 367 species of fauna, with another 222 plates (Ihering, 1914). Until the nineteenth century, it was the chief register of the region's nature and inhabitants for that period (Françoso, 2010).

Subsequent fauna records were the product of research expeditions to the Amazon region by naturalists like Alexandre Rodrigues Ferreira, in 1783 (Souza, 1977), and Alexander von Humboldt, who in the early nineteenth century traveled 2,150km of the Orinoco river in the Venezuelan Amazon and recorded the region's fauna and flora (Humboldt, 1850). In accounts like those of Saint-Hilaire (first half of the nineteenth century) and of Avé-Lallemant ([1859] 1980), references to marine fauna along the Brazilian coast focus on how this resource was used: Saint-Hilaire mentions cooking and eating oysters on the coast of Rio de Janeiro State and Avé-Lallemant comments on the whitewash made from fire coral (Millepora, Cnidaria) in Porto Seguro, Bahia.

The earliest studies of marine fauna along the coast of Brazil involve some records of the occurrence of deepwater organisms collected with dredges, especially Crustacea, Mollusca, and Echinodermata; examples of this include research by expeditions to South America on the HMS Challenger (1873-1876) (Bate, 1888) and the French scientific ship Calypso (1961-1962). The latter vessel made essential contributions to knowledge of Brazilian marine fauna during two expeditions, one in late 1961 (from Fernando de Noronha, Pernambuco, to Mar del Plata, Argentina) and the other in early 1962 (from Rio Grande do Sul to Recife), when plankton and benthic animals were collected from a broad array of groups (Gaudy, 1963; Forest, 1966; Zibrowius, 1970).

In his visit to Brazil while aboard the Beagle from February to June 1832, Charles Darwin reported the presence of fish of the genus *Diodon* (porcupine fish), as well as groupers and sharks, near the archipelagos of São Pedro e São Paulo and Fernando de Noronha; in the vicinity of Bahia, he also observed transparent floating organisms with independent filaments, which were apparently Cnidaria jellyfish (FitzRoy, 1839; Darwin, Neve, Browne, 1989).

Starting in the latter half of the twentieth century, institutes of marine biology research were established in a number of South American countries, including Chile, Argentina, and Brazil; in Brazil, USP established its Oceanographic Institute (Instituto Oceanográfico). Brazil's first actual oceanographic vessel was the Navy's Almirante Saldanha training ship, reclassified as an oceanographic vessel in 1959 following a voyage to occupy Trindade Island; it began its oceanographic activities in 1964.

Human resource challenges in the production of data on biodiversity

The description of biodiversity entails comparative studies of characters of different natures. These comparative studies involve the description of diversity per se, along with the search for order among described components and also for processes that will explain this possible order (Amorim, 2002). The result is an organized reference system of biodiversity, that is, a biological classification system, which is the object of the sub-field of biology known as systematics (Amorim, 2002).

As demand for information on biodiversity has increased, a number of authors of recent studies have called attention to an emergent issue: the lack of specialists actually working in the field of systematics (Migotto, Marques, 2003; Marques, Lamas, 2006). In a broad study on current systematics knowledge in Brazil, Marques and Lamas point to a worldwide decline in the number of such experts and note a drop in their numbers in Brazil from

the 1980s to the 1990s. The same authors observe a regional disparity, with researchers tending to be concentrated in the Southeast (47.7% of researchers employed by a research or academic institute and 51.7% of all researchers) and South (20.7% and 21.6%), followed by the Northeast (14.2% and 12.4%), North (13.3% and 10.5%), and Central-West (4.1% and 3.7%). To address this shortage of systematists, Marques and Lamas (2006, p.161-166, 170) suggest "action strategies" encompassing the following: (1) training specialized researchers, with concern as to their geographical locations; (2) attaining knowledge of Brazilian fauna and scientific production in zoology; (3) communicating this knowledge; (4) maintaining consonance with the interests of society.

Looking specifically at marine biodiversity, Joly et al. (2011) searched the database of the National Council for Scientific and Technological Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico, CNPq) and identified roughly 114 research groups in the fields of taxonomy, ecology, genetics, bioprospecting, and ecotoxicology. Mirroring what is observed in systematics, marine biodiversity research groups are concentrated in the Southeast, with nationwide distribution as follows: 48.4%, Southeast (28% in Rio de Janeiro and 20.4% in São Paulo); 30%, Northeast; 18%, South; and 3.6%, North.

State of knowledge

Among current animal species in Brazil, excluding insects, 65% are marine (Lana, jul.-dez. 2003). Among the thirty to 35 Phylums of invertebrates, 16 to 18 are solely marine, eight are mostly marine, and seven include marine representatives (Migotto, Marques, 2003). Migotto and Marques note that little research has been done on most of these groups and much is left to be discovered about their diversity and about extensive oceanic areas that shelter ecosystems new to science.

Couto, Silveira, and Rocha (2003) note that although Brazil is recognized as one of the countries boasting the greatest wealth of species, efforts to gain knowledge of this biodiversity in marine areas have been quite meager compared to other countries. As a result, a large share of Brazil's coast, continental shelf, and deep ocean remain unknown. Among factors contributing to this scenario, the authors cite length of coast, diversity of environments, and richness of species, with a high rate of endemism, all of which present challenges to research in the field. According to the authors, 8,100 species of marine organisms have been identified on the Brazilian coast, but despite this great diversity there are few taxonomists and research institutes in Brazil doing such studies.

In a broad review of the magnitude of global marine species diversity, Appeltans et al. (2012) state that some 226,000 eukaryotic marine species have been described, of which 170,000 are synonyms, 58,000-72,000 have been collected but not yet described, and 482,000-781,000 more species have yet to be sampled. In Brazil, two notable reviews have been produced on the state of knowledge of biodiversity, Lana (jul.-dez. 2003) and Lewinsohn and Prado (2005), both discussed below.

Lana (jul.-dez. 2003) cites the total number of existing species that have been described worldwide as 1.5 million and the estimated number of species yet to be sampled as 13 million, based on the Biodiversity Global Assessment, conducted around 1995 by 1,500

scientists, with the support of the United Nations Environment Programme, which is, according to Lana, the most reliable source for estimates. Lana (jul.-dez. 2003) cites the number of marine species reported worldwide as two hundred thousand, of which three thousand are pelagic and the remainder benthic; this includes both macrofauna, represented mainly by the Phylums Mollusca, Arthropoda (Crustacea), and Anellida (Polichaeta), as well as meiofauna, organisms that live in sedimentary environments, especially Nematoda and Arthropoda (Crustacea, Copepoda), not yet studied much. Lana notes that most knowledge of benthic marine diversity relates to shallow waters, in depths of up to thirty meters, while greater knowledge is needed of deeper regions, such as the mesophotic regions of the shelf and slope, along with the abyssal plains.

In the case of Brazil, Lewinsohn and Prado (2005) calculate that 168,640-212,650 species have been described among all groups of living creatures, and they believe the number of unknown species is seven times higher. Among benthic marine fauna groups, especially those found to be the most common and abundant by the REVIZEE/Score South (mentioned in greater detail later), the authors report the following numbers: 300-400 species of Porifera; 470 species of Cnidaria; thirty species of Sipuncula; 2,400-3,000 species of Mollusca; 1,000-1,100 species of Anellida; 2,040 species of Crustacea; 329 species of Echinodermata; 284 species of Bryozoa; and four species of Brachiopoda.

Global initiatives: Census of Marine Life

The twentieth-century finding that the oceans have been changing as a result of over-exploitation, pollution, and climate change, in combination with the awareness that only 0.1% of the oceans are known to science, prompted a global initiative to invest in marine biodiversity studies. An international research program entitled the Census of Marine Life was created with the goal of describing and assessing the diversity, abundance, and distribution of marine life (O'Dor, Yarincik, 2003).[1] As the broadest collaborative effort ever established among marine researchers, the ten-year program (2000-2010) engaged some 2,700 scientists from more than eighty countries, organized in national and regional committees. Based on the samples analyzed to date, 1,200 new species have been described; the initiative has also resulted in 2,600 publications, 24 audio-visual resources available in fifty languages and 57 countries, as well as a number of science and popular books; and more information are expected from the samples that are been analysed (Costello et al., 2010).

In Brazil, 9,103 species have been identified in the 2,520,000-km^2 area of the Exclusive Economic Zone (EEZ; information farther on in article), with the following contributions from the major taxonomic groups: 22% crustaceans, 20% mollusks, 14% fish, 3% protists, 9% plants and algae, 11% annelids, 6% cnidarians, 3% other invertebrates, 3% echinoderms, 4% sponges, 1% bryozoans, 2% other vertebrates, and 1% ascidians (Costello et al., 2010; Miloslavich et al., 2011).

One initiative of the Census of Marine Life was the creation of the Ocean Biogeographic Information System (OBIS), a geo-referenced databank on the occurrence of species that serves the purpose of compiling, cataloging, and disseminating the information produced by the Census (Costello, Vanden Berghe, 2006; Costello et al., 2010; Miloslavich et al., 2011).[2]

OBIS has a node in Brazil, called the Biogeographic Information System for the Tropical and Subtropical Western South Atlantic (WSAOBIS). This Brazilian continuation and expansion of OBIS is an initiative of the University of São Paulo (Universidade de São Paulo, USP), with the support of Petrobras. The Brazilian node is coordinated by two USP researchers, Fábio Lang da Silveira, of the Biosciences Institute (Instituto de Biociências), and Rubens Lopes, of the Oceanographic Institute (Instituto Oceanográfico). Drawing from publications or spreadsheets by authors/researchers, the system provides information on records of the occurrence of specimens that have been identified taxonomically, geo-referenced, and plotted on maps and whose taxonomic classification has been revised and updated. In the case of Brazil, the database holds 27 spreadsheets with information on the coast and platform (EEZ), from French Guiana to Uruguay and from 1997 to the present.[3]

Virtual databanks like OBIS, GBIF (Global Biodiversity Information Facility), WoRMS (World Register of Marine Species), ITIS (Integrated Taxonomic Information System), and EoL (Encyclopedia of Life), which compile information on global marine biodiversity, including occurrence records and taxonomic information, have come to constitute valuable tools in cataloging and communicating this knowledge (Costello, 2004; Costello et al., 2010; Costello et al., 2013; Miloslavich et al., 2011).

Nationwide initiatives: REVIZEE

The United Nations Convention on the Law of the Sea (Convenção das Nações Unidas sobre o Direito do Mar, CNUDM), in force since November 16, 1994, introduced the EEZ as a new concept in marine space, whereby exclusive rights to explore, exploit, conserve, and manage both living and non-living natural resources within this space are guaranteed (CNUDM, 1997). According to the document, Brazil's EEZ covers an area of 3,500,000km^2, which corresponds to the area extending from the outer limit of territorial waters (i.e., 12 nautical miles) to two hundred nautical miles off the coast (Figure 1). Within a context of conservation and management, the Convention determines that the potential sustainable yield of living resources be assessed so that they are not endangered by over-exploitation.

In order to implement research in Brazil to obtain knowledge of biodiversity and assess the potential sustainable yield of living resources within the EEZ, the Interministerial Commission on Marine Resources (Comissão Interministerial para os Recursos do Mar) established a program for the Assessment of the Potential Sustainable Yield of Living Resources in the Exclusive Economic Zone (Avaliação do Potencial Sustentável de Recursos Vivos na Zona Econômica Exclusiva). Known as the REVIZEE Program, the initiative is a multidisciplinary, integrated effort that engages Brazil's specialized scientific community (Amaral et al., 2003; Amaral, Rossi-Wongtschowski, 2004). Since its inception in 1995, REVIZEE has taken shape as Brazil's broadest and most complex program in the ocean sciences in terms of the investment of material resources and researcher involvement (Amaral et al., 2003; Amaral, Rossi-Wongtschowski, 2004).

Operationally, Brazil's EEZ is divided into four regions, called Scores; within each, the REVIZEE Program is coordinated and executed by researchers from local institutes. The regions are distributed as follows: (1) North coast, from the mouth of the Oiapoque river to

the mouth of the Parnaíba river; (2) Northeast coast, from the mouth of the Parnaíba river to Salvador, including the oceanic island Fernando de Noronha, the Rocas Atoll, and the archipelago of São Pedro e São Paulo; (3) Central coast, from Salvador to cape São Tomé, including the Vitória-Trindade undersea mountain chain and the islands of Trindade and Martin Vaz; (4) South coast, from cape São Tomé to the Chuí stream (Amaral et al., 2003; Amaral, Rossi-Wongtschowski, 2004).

Amaral et al. (2003) and Amaral and Rossi-Wongtschowski (2004) have presented part of the program's findings for benthic fauna on the platform and slope in the South Score (60-808 meters); 1,035 taxa were identified, corresponding to 83% of the total number of collected individuals. In terms of frequency of occurrence and abundance, the main recorded groups were: Porifera, Cnidaria, Sipuncula, Gastropoda, Bivalvia, Scaphopoda, Polychaeta,

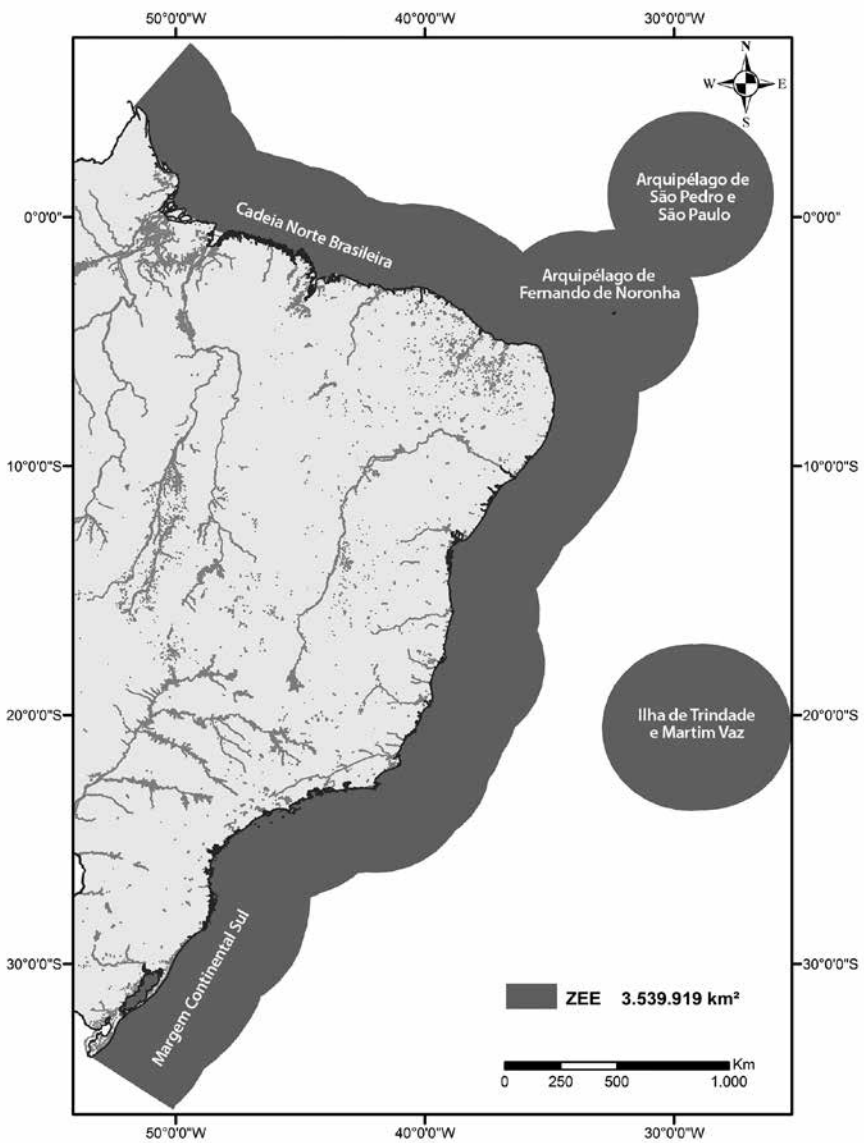

Figure 1: Map of the Brazilian coast, showing its territorial waters and the boundaries of the Exclusive Economic Zone (EEZ) (Source: http://eco4u.wordpress.com/2011/06/22/governo-brasileiro-quer-construir-navios-de-pesquisa-para-explorar-e-mapear-o-mar-territorial/plataforma/)

Crustacea, Ophiuroidea, Bryozoa, and Brachiopoda (Amaral, Rossi-Wongtschowski, 2004). In terms of benthic marine species, 55 new species were identified and 124 new occurrences of genera and species were recorded, as an overall finding for the Brazilian coast (MMA, 2006).

Data surveyed under the REVIZEE Program can be consulted on the OBIS databank.

Outlook

Among the authors who have addressed the study of marine diversity in Brazil (see Couto, Silveira, Rocha, 2003; Lana, jul.-dez. 2003; Migotto, Marques 2003; Marques, Lamas, 2006; Joly et al., 2011), there is a consensus that the following are needed: more researchers working in the systematics of marine taxonomic groups; greater knowledge of how marine ecosystems function, including geomorphological and geophysical aspects, such as the structures of the populations and communities that interact within these environments; greater organization and accessibility of generated data, including the deposit of biological material in reference collections and virtual databanks; and the broad communication of these findings in science and popular journals, since, as pointed out by Lana (jul.-dez. 2003), biodiversity is no longer merely an ecological concept but is also considered a global resource. In this regard, the Brazilian government has implemented both federal- and state-level initiatives to foster marine research, as shown in the following section.

Government initiatives to support research on diversity in Brazil

In order to foster research on diversity in Brazil, encompassing therein marine diversity, national and state research agencies have established grant applications (*editais*) for broad projects. Some of the available grants are listed below.

I) Nationwide

1) Programa Archipelago e Ilhas Oceânicas (Archipelago and Oceanic Island Program); CNPq grants (2009 and 2012 are the latest)

> The program seeks to support research projects "that endeavor to understand the dynamics of the various South Atlantic island ecosystems (Rocas Atoll and the archipelagos of Fernando de Noronha, Trindade and Martim Vaz, and Abrolhos), as well as those in the Atlantic Equatorial, where the archipelago of São Pedro e São Paulo lies" (CNPq, s.d. a).

2) Sisbiota Brasil: Sistema Nacional de Pesquisa em Biodiversidade (National Biodiversity Research System); CNPq grant

The program seeks to "foster and expand knowledge of Brazilian biodiversity, improve the predictive capacity of responses to global changes, especially land use and cover change, along with climate change; research should be associated with human resource training, environmental education, and science communication. Topics addressed under the program include: (a) expansion of knowledge of biodiversity; (b) standards and processes related to biodiversity; (c) monitoring biodiversity; (d) development of bioproducts and uses of biodiversity" (CNPq, s.d. b).

3) Peld: Programa de Pesquisa Ecológica de Longa Duração (Long-term Ecological Research Program); CNPq grant

Program focus is on "establishing permanent research sites in a variety of biomes and ecosystems in Brazil, integrated into a network that will develop and accompany long-term ecological research with the purpose of obtaining relevant information on aspects essential to the conservation of biodiversity and the sustainable use of the natural resources found in Brazilian ecosystems" (CNPq, s.d. c).

4) Protax: Programa de Capacitação em Taxonomia (Taxonomy Training Program); CNPq grant

The program is a partnership between CNPq, Capes, the Ministry of Education and Culture, and the Ministry of Science and Technology. "Its goal is to foster human resource training in taxonomy and curatorship related to the national scientific and technological development of the subject matter, attracting young undergraduate and graduate students," (CNPq, s.d. d).

5) Programa IODP/Capes-Brasil (IODP/Capes-Brazil Program)

The program represents "Brazil's adhesion to the Integrated Ocean Drilling Program (IODP). The IODP is an international marine research program that uses heavy drilling equipment mounted on vessels to monitor and sample the subseafloor environment" (Capes, 9 ago. 2012).

6) Programa Pró-Amazônia Azul (Pro-Amazon Blue Program); Capes

The program is meant to "foster the training of PhDs in the ocean sciences, in regions where there is a shortage of research personnel and of human resource training opportunities in specific areas of demand, with the expectation [that these individuals will] return to their region of origin to practice their profession" (Capes, s.d. a).

7) Programa Ciências do Mar (Ocean Sciences Program); Capes

The program is meant to "foster and support joint research projects in Brazil using the human resources and infrastructure available at institutes of higher education, research institutes, businesses, and/or other related institutions eligible under the grant, making it possible to develop scientific and technological research projects and including the training of graduate-level and, in supplementary fashion, undergraduate-level human resources" (Capes, s.d. b).

II) Statewide

Along the same line as the federal initiatives, state governments have also channeled efforts into stimulating research on marine diversity within their jurisdictions, as exemplified by the programs below.

1) BIOTA-FAPESP: Instituto Virtual da Biodiversidade (Virtual Institute of Biodiversity). FAPESP research program on biodiversity characterization, conservation, restoration, and sustainable use, in the state of São Paulo; granted by Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP, São Paulo Research Foundation)

Renewed through 2020, the program was originally set up in 1999 with the goal of "surveying and characterizing the biodiversity of the state of São Paulo and defining mechanisms for its conservation, economic potential, and sustainable use" (Fapesp, s.d.).

2) Programa Apoio ao Estudo da Biodiversidade do Estado do Rio de Janeiro (Program to Support the Study of the Biodiversity of the State of Rio de Janeiro); granted by Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ, Rio de Janeiro State Research Foundation)

Initiated in 2010, "this program is aimed at financing interdisciplinary research projects that involve the expansion of knowledge of biodiversity as well as its conservation and sustained use in the state of Rio de Janeiro" (Faperj, s.d.).

Final considerations

Studies on marine biodiversity in Brazil, along with federal and state government initiatives to stimulate research, like the REVIZEE and BIOTA-FAPESP programs, have furthered knowledge of Brazil's marine biodiversity and, most importantly, led to the definition of short- and medium-term research priorities.

In terms of the main gaps in knowledge of diversity, Lana (jul.-dez. 2003) points to the need for detailed taxonomic knowledge in ecological and biochemical studies. When we realize that the entire flow of an ecosystem depends upon its biodiversity, having precise nominal knowledge of the species comprised within it gains a new dimension. According to Lana, a shortage of human resources (systematists and taxonomists) and the unequal geographic distribution of these specialists – that is, a greater concentration in Brazil's Southeast and South – hampers the possibility of acquiring this knowledge. Other studies addressing the same question, such as those by Migotto and Marques (2003) and by Marques and Lamas (2006), call attention to these same issues and suggest that they can be mitigated by investing in graduate programs in zoology across Brazil and in training specialists (systematists and taxonomists) in Brazil's major centers as well as in the areas of the country where demand for these human resources is greatest.

In the same context, Joly et al. (2011) list other requisites for meeting the challenge of acquiring greater knowledge of diversity, such as the development of information systems for cataloging and making available the data produced on biodiversity; investments in the restoration of degraded areas that have impacted biodiversity in various places around the country; identification and monitoring of invasive species; assessment of the impact of climate change on biodiversity; investments in the field of environmental education; and partnerships with international institutions where biological material from Brazil can be deposited while guaranteeing its repatriation, if only in virtual form.

Looking specifically at the results of marine environment research under the BIOTA-FAPESP program, Joly et al. (2011) cite the following as priority targets for new investments: studies on mangrove swamps; the monitoring of economically relevant species; the use of data on key species in the implementation of conservation policies; studies of endangered and invasive species; the training of specialized human resources in the field of taxonomy; bioprospecting studies on marine organisms to foster sustained use; and support for greater cooperation with international initiatives, like OBIS, with the purpose of cataloging and communicating information. The authors believe that the acquisition of the oceanographic vessel Alpha Crucis by BIOTA-FAPESP and by the FAPESP Research Program on Global Climate Change (Programa FAPESP de Pesquisa sobre Mudanças Climáticas Globais), to support research projects by USP's Oceanographic Institute, paves the way for an important qualitative leap in research on marine biodiversity in Brazil.

More recently, studies in ecology have used broader approaches that involve taxonomic characterization in conjunction with long-term monitoring of the flux and functions of marine ecosystems, such as that published by Francini Filho et al. (2013) on the reef environments of the Abrolhos archipelago. Government programs to stimulate research on biodiversity in Brazil with a focus on long-term monitoring have fostered the acquisition of new knowledge on the functions of marine ecosystems.

The importance of this type of research is ever more apparent, since species diversity within ecosystems is related to the physical structure of the environment and its function (see Lana, jul.-dez. 2003; Joly et al., 2011; Francini Filho et al., 2013). In this context, studies describing the geomorphological and geophysical environment of the seabed have yielded essential information on these areas, especially in mesophotic zones of the Brazilian shelf, and have uncovered ecosystems previously unknown to science. Studies that rely on acoustic mapping, imaging using remotely operated vehicles (ROV), and technical diving, such as those presented in Moura et al. (2013), have revealed a mosaic of habitats on the Abrolhos Bank continental shelf, where the largest recovering of rhodolith beds has been recorded (Amado Filho et al., 2012), in association with reef environments and sandy seabeds. Using the same tools, such characteristic structures as the sinkhole-like depressions on the Abrolhos Bank continental shelf were described by Bastos et al. (2013). Thanks to the application of these observation and data collection techniques to such hard-to-reach environments, Cavalcanti et al. (2013) described the biotic functions of these structures. Pereira Filho et al. (2012) also described the importance of rhodolith beds in the composition of mesophotic environments in the Vitória-Trindade chain, only recently discovered.

The outlook is for new studies of Brazilian marine biodiversity to involve interactions between geomorphological, geophysical, and biological approaches. Combined reliance on such tools as side-scan sonar, ROVs, and technical diving is vitally important to acquiring knowledge of ecosystems and their functions, especially in areas like mesophotic regions, practically unknown before. It is hoped that new studies will result in other discoveries about the biodiversity of these underexplored areas.

NOTES

[1] See http://www.coml.org.

[2] See http://www.iobis.org.

[3] See http://obisbr.cria.org.br/obisnobrasil/obisnobrasil/.

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