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Chondrichthyan systematics in Brazil depicted: historical overview, research trends and future perspectives

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Brazil comprises one of the world's biodiversity hotspots of the chondrichthyan fauna, currently with 12 orders, 44 families, 90 genera and over 200 species of sharks, batoids, and chimaeras. These species inhabit marine, estuarine and freshwater realms of coastal and oceanic zones from the North equatorial central to the South-western Atlantic Ocean. Reporting on species occurrence in Brazil goes back to the pre-Linnaean Period. The golden era of the European Zoological studies put in place the knowledge on the local fauna with many Brazilian endemic and native species being officially described. The birth of Ichthyology in Brazil in the early 20th century, however, represents the milestone for the Chondrichthyan Systematics in the country when national scientists published the first list of species. This study provides an historical overview of the Chondrichthyan Systematics research in Brazil through a literature review of peer-reviewed publications in shark taxonomy, phylogenetics and morphology. Scientific trends of over 120-year period of dedicated investigations are herein pointed out regarding research scope and subject area, methodology, target study taxa, and gender diversity. Research recommendations and priorities are further given to assist researchers and interested stakeholders on future efforts in shark science and conservation in the country.

Keywords: Biodiversity research, Brazilian waters, Elasmobranchii, Holocephali, Taxonomy.

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O Brasil compreende um hotspot de biodiversidade da fauna de peixes Chondrichthyes, atualmente com 12 ordens, 44 famílias, 90 gêneros e mais de 200 espécies reconhecidas de tubarões, raias batóides e quimeras. Estas espécies habitam ambientes marinhos, estuarinos e dulcícolas de zonas costeiras e oceânicas do Oceano Norte Equatorial ao Atlântico Sudoeste. Registros da ocorrência de espécies no Brasil remonta do período Pré-Lineano. A era de ouro dos estudos zoológicos na Europa contribuiu para o conhecimento da fauna local com a descrição oficial de várias espécies nativas e endêmicas. O nascimento da Ictiologia no Brasil no início do século 20, contudo, representa o marco para a Sistemática de Chondrichthyes, quando cientistas nacionais publicaram a primeira lista de espécies registradas no país. Este estudo apresenta uma leitura histórica da pesquisa em Sistemática de Chondrichthyes no Brasil através de uma revisão da literatura de artigos revisados por pares sobre a taxonomia, filogenética e morfologia de peixes cartilaginosos. Tendências em pesquisa para o período de mais de 120 anos de dedicadas investigações científicas são aqui apontadas com relação ao escopo, área de estudo, metodologia, taxa-alvo estudado, e diversidade de gênero. Recomendações e prioridades em pesquisa são também indicadas para assistir cientistas e outras partes interessadas em esforços futuros da ciência e conservação de tubarões, raias e quimeras no país.

Palavras-chave: Águas brasileiras, Elasmobranchii, Holocephali, Pesquisa em biodiversidade, Taxonomia.

INTRODUCTION

Brazil represents one of the world's largest biodiversity hotspots of chondrichthyan fishes (Lucifora *et al*., 2011; Dulvy *et al*., 2014). It is estimated that the country currently comprises 12 orders, 44 families, 90 genera (Fricke *et al*., 2023) and over 200 species (SV, FFP, KS, work in progress). National sharks, batoids, and chimaeras are distributed along the equatorial tropical to temperate South-western Atlantic Ocean in a wide range of ecosystems, occurring in freshwater, brackish, and marine waters of inland river basins, and coastal and offshore zones as well as insular shelves and deep oceanic slopes. The gigantic profile of freshwater and marine realms under the Brazilian Federal jurisdiction have fostered a wide variability of habitats and phenotypic characters, species richness, high endemicity, and, possibly, revealing the exceptional evolutionary adaptability and the chondrichthyan diversity in the country.

Evidence of Chondrichthyes species in Brazil date back to the colonial time as it was mentioned in Pero Vaz de Caminha's letters relating the Portuguese expeditions to the "New World" under Pedro Álvares Cabral leadership in the 16th century, as well as through the narratives of Frei Cristóvão de Lisboa (Rosa, 2009). Pre-Linnaean sources that specifically accounted for the diversity of South American fishes such as Marcgrave (1648) and Willughby (1686) included Brazilian records of sharks, batoids and chimaeras at that time. Progress in zoological studies and the Systematics foundation during the 18th century boosted the recognition of the first native nominal species (Rosa, 2009).

Ichthyological Systematics in the country commenced with the contributions of foreign naturalists and collection of specimens through scientific expeditions conducted during the 19th century. Nevertheless, its effective implementation arose much later in the beginning of the 20th century through the works of Alípio de Miranda-Ribeiro, the father of the Brazilian Ichthyology. Today, Brazil represents a solid Chondrichthyan research hub and accounts for one of the largest scientific communities, especially regarding taxonomic, phylogenetic, and biogeographic studies of marine and freshwater shark species. This scenario reflects 120 years of historical contributions to the Chondrichthyan biodiversity and evolutionary knowledge known to date. The efforts of the Sociedade Brasileira para o Estudo de Elasmobrânquios (SBEEL), which turned 39 years of foundation in 2023, also uplifted this scientific field through the dissemination of shark research, contribution to capacity building, and by strengthening conservation awareness and management countrywide and regionally.

Biodiversity knowledge and museum specimen data generated from Systematics research are an essential tool to inform conservationists and decision makers for better management of Chondrichthyan species, which are naturally vulnerable to threats such as overexploitation, habitat degradation, climate change and pollution (Stein *et al*., 2018). It is thus imperative to pinpoint the progress in Chondrichthyan Systematics research so far to guide scientific policy and implementation, allocate scientific and research funding, improve local human capacity and strengthen knowledge-based information for conservation purposes. The present study thus aimed to chronologically retrieve the historical contributions to the Chondrichthyan Systematics in Brazil through a comprehensive research overview since 1903, reveal current research trends and provide recommendations for future research.

MATERIAL AND METHODS

Historical overview. A combination of data taken from literature review and personal communications of experts, curators, and collection managers were used to reconstruct the history of the Chondrichthyan Systematics in Brazil. Peer-reviewed scientific studies (*e.g*., articles, books, book chapters, guides, checklists) related to the taxonomy, phylogeny, and comparative anatomy of extant taxa from Brazil were incorporated into the analysis. We adopted the terminology 'shark research' to include all studies related to sharks, batoids and chimaeras. Fisheries reports or data from fishery statistics and abstracts of scientific meetings were excluded. Literature review included publications from 1903 to 2023 and were compiled from the "Portal de Periódicos da Capes" (an online scientific database of scientific publications available to Brazilian institutions), Google Scholar, and Web of Science. Additionally, personal libraries of experts were consulted to incorporate early literature that were absent in online repositories.

The following English keywords were used for searching these databases: "shark", "rays", "skates", "stingrays", "freshwater rays", "elasmobranch", "taxonomy", "phylogeny", "anatomy", "Chondrichthyes", "Southwestern Atlantic Ocean" and "Brazil", besides their Portuguese translations: "tubarão", "raias", "raias com ferrão", "raias de água doce", "elasmobrânquios", "taxonomia", "filogenia", "anatomia", "Oceano Atlântico Sudoeste" and "Brasil".

The historical overview was subdivided into different time periods from the Linnaean to the Modern eras. We also cited pre-Linnaean resources as these were relevant to trace the primary native Brazilian nominal species described in later taxonomic accounts. "A coleção de Peixes do Museu Nacional do Rio de Janeiro" (Schreiner, Miranda-Ribeiro, 1903), the first national publication in Brazilian Ichthyology, accounts for the origin of Ichthyological Systematics for historical purposes.

Analyses of research trends. We determined the year 1903 as a starting date to gather and retrieve data for analysis of research trends within the country. To reveal research trends in Shark research, detect knowledge gaps and identify research challenges, each study was classified as follows: A) research subject area: taxonomy, morphology, phylogeny; B) research scope: description, revision, checklist, identification guide, first record, new record, DNA barcoding, comparative anatomy, descriptive anatomy, molecular species delimitation, high- and low-level interrelationships; C) data source: morphological, molecular or integrative (more than one source of evidence) (definitions according to Mayr *et al*., 1953). Target study groups were classified by family and "multi-taxa" was applied to denote those studies whose target taxa comprised more than two families. We also ranked gender diversity in publications by examining the total number of female and male authors per publication either as first/last authors isolated or first and last authors combined. Gender definition was established on the author's first names and followed a binary male/female score system. The complete list of papers analyzed is provided in Tab. **S1**.

RESULTS

Brazilian historical overview. Linnaean period. The earliest reporting of Brazilian Chondrichthyan species is available in the pre-Linnaean resources of Marcgrave (1648) and Willughby (1686). Eight species were listed as vernacular in Marcgrave's study: "Puraquê", "Araguagua", "Cucuri", "Aiereba", "Jabebiretê", "Raja sp. altera (jabebara)", "Narinari", and "Tiburonis sp. minor" (Miranda-Ribeiro, 1907). These species are currently assigned to the following valid nominal species: *Pseudobatos percellens* (Walbaum, 1792) for "Puraquê", *Pristis pristis* (Linnaeus, 1758) for "Araguagua", *Scyliorhinus cabofriensis* Soares, Gomes & Carvalho, 2016 for "Cucuri", *Paratrygon aiereba* (Walbaum, 1792) (not Müller, Henle, 1841) for "Aiereba", *Hypanus guttatus* (Bloch & Schneider, 1801) for "Jabebiretê", *Aetobatus narinari* (Euphrasen, 1790) for "Narinari", and *Sphyrna tiburo* (Linnaeus, 1758) for "Tiburonis sp. minor".

Linnaeus (1758) in Systema Naturae apparently did not examine Brazilian specimens at that time but he referred to Marcgrave and Willughby's accounts to describe *S. tiburo*. Because syntypes of *S. tiburo* are unknown and its type-locality is regarded as "America" at its best this species is not considered to be the first nominal species described from Brazilian waters. Other species originally described from elsewhere in Linnaeus (1758) that are known to occur in Brazil today through subsequent works are: *Gymnura altavela* (Linnaeus, 1758), *Squalus acanthias* Linnaeus, 1758, *Carcharodon carcharias* (Linnaeus, 1758), *Prionace glauca* (Linnaeus, 1758), *Galeorhinus galeus* (Linnaeus, 1758), *Sphyrna zygaena* (Linnaeus, 1758), and *Callorhinchus callorynchus* (Linnaeus, 1758). The Spotted

eagle ray or "raia-chita" *A. narinari* was described by Euphrasen (1790) based on 'Narinari Brasiliensibus' from Brazil of Marcgrave (1648:175) and later reproduced in Willughby (1686:66–67), but also included specimens from St. Barthelémy in the Caribbean Sea. The type-locality of this species was undoubtedly reiterated in Euphrasen (1792), Kottelat (2013) and again in Fricke *et al*. (2023). The lectotype (lost) for this nominal species, an illustration provided in Marcgrave's account, was later designated in Kottelat (2013). *Aetobatus narinari* thus represents the first native nominal species described from Brazil according to this evidence and based on the Principle of Priority of the International Code of Zoological Nomenclature (ICZN, 1999). *Pseudobatos percellens* was described later by Walbaum (1792) thus does not representing the earliest native nominal species described for the country as stated in Rosa (2009) and Gadig, Rosa (2014). A third species, *Myliobatis jussieui* Cuvier, 1829, was also described based on pre-Linnaean sources as of Jussieu (1721).

Bonnaterre (1788) in his "Tableau encyclopédique et méthodique des trois regnes de la nature Ichthyologie" also contributed to the knowledge of the local Chondrichthyan fauna when describing the following species: *M. mobular* (Bonnaterre, 1788), *Alopias vulpinus* (Bonnaterre, 1788), *Lamna nasus* (Bonnaterre, 1788), *Ginglymostoma cirratum* (Bonnaterre, 1788), *Heptranchias perlo* (Bonnaterre, 1788), *Hexanchus griseus* (Bonnaterre, 1798), *Echinorhinus brucus* (Bonnaterre, 1788), and *Dalatias licha* (Bonnaterre, 1788). Other species described during this period included *Cetorhinus maximus* (Gunnerus, 1765), *Pristis pectinata* Latham, 1794 and *Mobula birostris* (Walbaum, 1792). However, these species were only recognized in Brazilian waters much later in the 19th century with the efforts of other fish taxonomists. A possible explanation for this is that scientific expeditions to the "New World" were extremely rare during that time due to the political exclusivity over the Brazilian waters and lands under the Portuguese Kingdom, and usually were associated to Portuguese, French and Dutch settlements' expeditions (Vanzolini, 1996). Two main political and societal events completely changed this scenario in the following century: the advent of the Portuguese Royal family to the country in 1808 in Rio de Janeiro; and in 1817 over the influence of the Austrian archduchess, D. Leopoldina, who officially implemented the zoological research in Brazil accompanied by a European scientific committee (Papavero, 1971; Vanzolini, 1996).

Post-Linnaean period. Intensive naturalist expeditions in the South Atlantic Ocean and the South American rivers during the 19th century resulted with the description of the majority of the Brazilian natives and/or endemics, totalizing 39 nominal species of sharks and rays; for instance, *Isistius brasiliensis* (Quoy & Gaimard, 1824), *Rhinoptera brasiliensis* Müller, 1836, *Rhizoprionodon lalandii* (Valenciennes, 1839), *Zapteryx brevirostris* (Müller & Henle, 1841), *Narcine nigra* Duméril, 1852, *Potamotrygon henlei* (Castelnau, 1855), and *P. constellate* (Vaillant, 1880). The diversity of Brazilian native/endemic freshwater batoids was intensively acknowledged with the studies of Müller, Henle (1841), Schomburgk (1843), Castelnau (1855) and Garman (1913) while marine species were more sporadically known after Müller (1836), Olfers (1831), Ranzani (1839), and Regan (1903). These efforts clearly evidenced from the upsurge of the Zoological research in Europe and North America that also had impacted the country.

Exploration of the Brazilian waters was undertaken by foreign naturalists from European and North American museums or universities, mainly as part of governmental

and private efforts to stimulate Zoological research. PA Delalande who accompanied the botanist A de Saint-Hilaire from the Muséum National d'Histoire Naturelle onboard the L'Hermione (1816–1822) came to Brazil (Papavero, 1971) and collected elasmobranchs (*e.g.*, *Rioraja agassizii* (Müller & Henle, 1841), *R. lalandii*) in several Brazilian provinces, including the coastal areas of Rio de Janeiro, Espírito Santo, São Paulo, Paraná, Rio Grande do Sul and Santa Catarina. The L'Uranie (1817–1820) expedition around the world with Quoy and Gaimard describing the cookiecutter shark *I. brasiliensis*. The expedition "Les parties centrales de L'Amérique du Sud: Rio de Janeiro a Lima et de Lima au Para" (1843–1847) under leadership of FL de Castelnau and support from the French government resulted on the listing of nine nominal species of native elasmobranchs and description of four novel freshwater species collected in Rio de Janeiro, Bahia, Araguaia and Tocantins River basins. The Thayer Expedition to Brazil (1865–1866) under leadership of the Swiss ichthyologist L Agassiz from the Museum of Comparative Zoology – Harvard University, USA (MCZ), collected over 120 specimens in Bahia, Ceará, Piauí, Amazonas, Pará and Rio de Janeiro. Agassiz and his wife narrated their tropical experience in Agassiz, Agassiz (1868) and described with passion their close relationship with D. Pedro II who fully supported this expedition at the point to collect a specimen of *Sphyrna lewini* (Griffith & Smith, 1834) (MCZ S–314, Rio Grande do Sul, Brazil). Agassiz published several fish species accounts but did not describe any elasmobranch species. His collection was later studied in Garman (1913), who made one of the most exhaustive scientific inputs to the Chondrichthyan Systematics until then. D Bourget (year 1863), CF Hartt (year 1867) and the Hassler Expedition (1872) also collected specimens in Brazil that are today part of the MCZ's holdings.

The Natural History Museum (NHM, London) fish collection of Brazilian specimens was in majority acquired as a gift from the collections of the Portuguese helminthologist Wucherer who dedicated his academic life in Bahia, as well as through donation and/or purchase via von Ihering and his son. The former was a German naturalist that immigrated to the country in 1880 and worked for museums in Germany and the UK as well as the Museu Nacional da Universidade Federal do Rio de Janeiro collecting specimens especially from Rio Grande do Sul state. Later, H Ihering became the first director (1894–1916) of the Museu Paulista whose natural history collection became part of the Museu de Zoologia da Universidade de São Paulo (Nomura, 2012). This author published several articles related to fish diversity and biology, (*e.g.*, Ihering, 1893) even though he was an expert in malacology systematics and biology. Rodolpho von Ihering, however, played a major role in synthesizing vernacular names of fish species in tupi and Portuguese (*e.g.*, Ihering, 1940). E Goeldi, a Swiss ichthyologist and first director (1894–1916) of the Museu Paraense in Belém (Sanjad, Güntert, 2015) also sent out many specimens from the Amazonian Atlantic coast as a gift/exchange to the NHM. The Albatross expedition (1883–1900) further collected specimens of *S. tiburo* (in Bahia, year 1887) in the country while M. Ruth in 1878 collected a specimen of *Pristis* sp. from Pará.

Systematic studies particularly from French, German, British and American taxonomists during the golden era for Zoological Systematics recognized several wide-ranging species in Brazil including *S. zygaena* as *Zygaena malleus* (Valenciennes, 1822), *Prionace glauca* (Linnaeus, 1758) as *Carcharias hirundinaceus* Müller & Henle, 1839 and *Rhinoptera bonasus* (Mitchill, 1815) as *R. lalandii* (Valenciennes, 1841). Müller, Henle

(1841) recognized the occurrence of *R. porosus* (Poey, 1861) but this was listed as *R. terraenovae* (Richardson, 1837). Castelnau (1855) reported *Hypanus say* (Lesueur, 1817). *Pteroplatea valenciennii* Duméril, 1865 synonym of *Gymnura altavela* (Linnaeus, 1758) was described as a new species. Ihering (1893) listed *Mustelus canis* (Mitchill, 1815), *Squalus americanus* Mitchill, 1815, and *Myliobatis aquila* (Linnaeus, 1758) in which the latter two species are synonyms of *Carcharias taurus* (Rafinesque, 1810) and *Myliobatis ridens* Ruocco, Lucifora, Díaz de Astarloa, Mabragaña & Delpiani, 2012, respectively.

Birth and rise in the 20th century (Fig. 1). The early times: Miranda-Ribeiro (1903–1939). Chondrichthyan Systematics in Brazil developed later on in the beginning of the 20th century with the birth of the Brazilian Ichthyology through a series of publications of the "mineiro" naturalist Alípio de Miranda-Ribeiro from the MNRJ, between 1903 and 1939. Miranda-Ribeiro first co-authored the article "A coleção de Peixes do Museu Nacional do Rio de Janeiro" (Schreiner, Miranda-Ribeiro, 1903) which came to light as a result of the research efforts of Carlos Schreiner, former sub-director of the Zoology section of this museum, who died before its completion. Later, the first edition of "Fauna brasiliense (Peixes). Tomo II. Desmobranchios" (Miranda-Ribeiro, 1907) was published as an individual authorship. These studies represent pioneer scientific attempts of listing and describing national species that were conceptualized, written and published by a Brazilian specialist, and that provided in detail a global outline of the Systematics research of the group in Brazilian waters. A total of 18 and 31 nominal species of sharks and rays, respectively, were listed in these studies, including the first record of species (*e.g.*, *Mustelus canis* (Mitchill, 1815), *Squalus blainvillei* (Risso, 1816), *Squatina squatina* Linnaeus, 1758, *Mobula birostris* (Walbaum, 1792), *Pristis pectinata* Latham, 1794); some of which today are known to represent more than one valid species in Brazil), and the description of two native species (*Atlantoraja castelnaui* (Miranda-Ribeiro, 1907) and *Scyliorhinus haeckelli* Miranda-Ribeiro, 1907) were also provided. In the second edition of "Fauna brasiliense (Peixes)", Miranda-

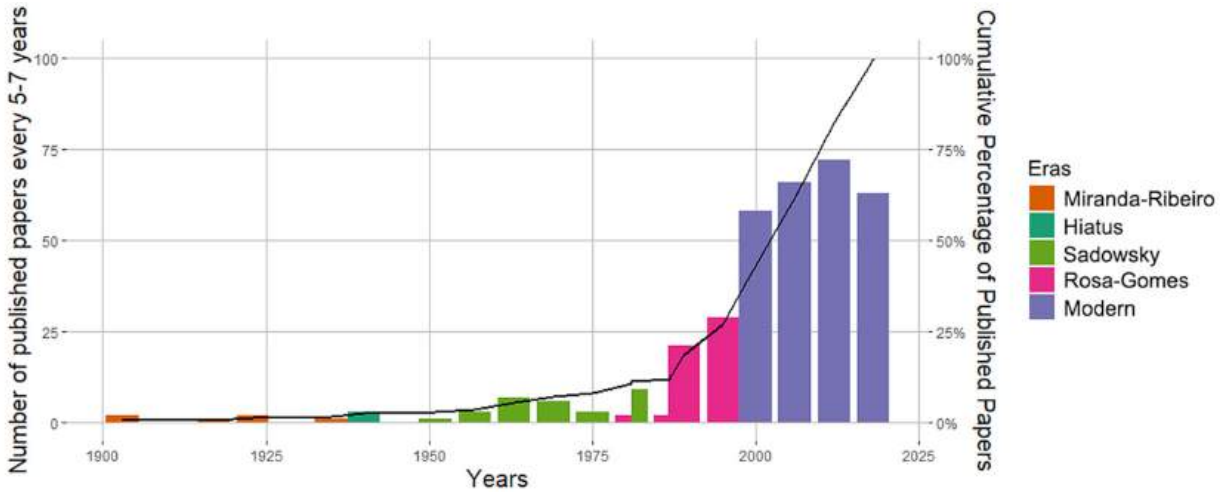

FIGURE 1 | Number of publications every 5–7 years regarding each era: orange, Miranda-Ribeiro (1903–1939); dark green, Hiatus (1940–1950); light green, Sadowsky (1951–1988); pink, Rosa-Gomes (1980–1999); purple, Modern (2000–2023). Scale to the left, absolute number of publications; scale to the right, cumulative percentage of published papers, as shown by the black line on top of graph.

Ribeiro (1923) described one more native species, *Narcine blachypleura* Miranda-Ribeiro, 1923 whose taxonomic status is still uncertain. Miranda-Ribeiro actively contributed to document, list and describe elasmobranch species having published works related to the ichthyological collections holdings in the MNRJ and the Museu de Zoologia da Universidade de São Paulo (MZUSP) (*e.g.*, Miranda-Ribeiro, 1918, 1928, 1937) until his death in 1939.

The hiatus (1940–1950). After Miranda-Ribeiro, a few important studies or new data on Brazilian Chondrichthyes Systematics were added (*e.g.*, Carvalho, Samaya, 1942; Dalcina, 1943; Batista, 1944). The main contributions to the knowledge of the Brazilian fauna during this time were achieved by non-native researchers who lived and worked in North America. Such contributions include the list of coastal Brazilian fishes of Fowler (1941) and the regional systematic reviews of Bigelow, Schroeder (1948, 1953) that reported, respectively, 53 and 49 chondrichthyan species. The limited financial resources imposed by the World War II and other political issues during this time possibly resulted in impediments of zoological studies in the country and worldwide. As an example, the Brazil-USA Scientific Cooperation (MNRJ and Stanford University) between 1943 and 1955 (Sá, Britto, 2018) did not provide significant inputs to the local fauna as expected.

An impressive number of refugees who were favored from multi-nations diplomatic treaties came to live and work in Brazil afterwards, having a positive impact on the future of shark research in the country. Victor Sadowsky, a 30-year-old Lithuanian marine biologist whose academic career was interrupted due the war in Europe, arrived in São Paulo coming from Poland and changed the course of studies in the upcoming years.

Starting over: Sadowsky (1951–1988). Financial and scientific research investments in Oceanography from off the Southwestern Atlantic Ocean between the 1950–1970's decades expanded shark Systematics studies. The studies of Victor Sadowsky who was based at the Instituto Oceanográfico da Universidade de São Paulo (IOUSP) made long-term contributions to the field. His early research interests, however, were on inland fish farming till 1951 when Sadowsky coordinated the creation and building of this research station by invitation of the IOUSP former director, Wladimir Besnard, who became his close friend (Nomura, 1990). Sadowsky dedicated his studies to the taxonomy, biology and anatomy of the local marine fauna, including fish and associated parasites caught at the Cananéia Biological Station, Southern Brazil. His first elasmobranch study (Sadowsky, 1958) refers to the feeding habits of *Manta ehrenbergii* (Müller & Henle, 1841) (= *Mobula birostris*). The description of *Sphyrna nana* Sadowsky, 1964 (= *S. media*) and the publication of a list of elasmobranch species occurring in the region in Sadowsky (1967) are examples of his contributions to the national Chondrichthyan taxonomy. Several accounts related to first records and biology of species caught by experimental gillnets were successively published between 1965 and 1973 (*e.g.*, Sadowsky, 1965, 1967, 1968, 1970a,b, 1971a,b,c, 1973). These studies resulted from numerous research expeditions coordinated by Sadowsky in the tropical and subtropical waters of the western South Atlantic Ocean onboard the IOUSP R/V "Prof. W. Besnard" during the 1970's.

Undoubtedly, Sadowsky became the first national scientist to devote efforts to long-term studies on cartilaginous fishes, especially marine sharks and batoids, bringing up

the Brazilian Chondrichthyan research into the spotlight and bridging the research gap of the earlier period. At total, Sadowsky published 16 articles related to the taxonomy of Chondrichthyes from Brazil. He established valuable contacts with renowned shark experts, including JA Garrick (New Zealand), S Springer (USA), J D'Aubrey (South Africa), and E Siccardi (Argentina) which resulted in important partnerships and collaborations such as the description of *Scyliorhinus besnardi* (Springer & Sadowsky, 1970) (= *S. haeckelli*) and the recognition of his works in relevant shark literature of that time (*e.g.*, Compagno, 1984; Garrick, 1982).

Sadowsky' legacy had a major impact on subsequent research in Systematics of elasmobranch fishes from Brazil even after his retirement in 1979 as he inspired a variety of eminent experts in the country. Figueiredo (1977), for instance, in the first edition of "Manual de peixes marinhos do Sudeste do Brasil" examined numerous specimens collected by Sadowsky. This study represents one of the most comprehensive accomplishments in the Brazilian Chondrichthyan Systematics in which 72 species were listed (for more detail about the contributions of J. L. Figueiredo, see Rosa, Gadig, 2014). Lucena, Lucena (1981) also included Sawdosky's specimens when listing the marine fishes from the Ichthyological collection of the Museu de Ciências da Pontifícia Universidade Católica do Rio Grande do Sul (MCP-PUCRS). After retirement, Sadowsky continued to contribute towards shark taxonomy with the collaboration of A. F. de Amorim and C. A. Arfelli from the Instituto de Pesca de Santos (São Paulo) through reporting of first occurrences from off Southeast-South Brazil. This includes *Odontaspis noronhai* (Maul, 1955), *Lamna nasus* (Bonnaterre, 1788), *Etmopterus gracilispinis* Krefft, 1968 and *Isistius plutodus* Garrick & Springer, 1964 in Sadowsky *et al*. (1988, 1986, 1985, 1984, respectively).

Contemporary to Sadowsky, some individual initiatives were published in Sasso, Santos (1961) who investigated the dentition of *Carcharias taurus* (as *Odontaspis* sp.) as well as Miranda-Ribeiro (1961) and Barcellos (1963) who provided taxonomic listings, biological aspects of species and pinpointed the economic importance of certain taxa to local artisanal fisheries. Penna (1967) published the first comprehensive list of Brazilian sharks, as an initiative from a collaborative consortium of the MNRJ.

Rosa-Gomes (1980–1999). Because of investigations on comparative anatomy and phylogeny of elasmobranch fishes came to light with assiduity during the 80–90's decades, it depicts the Rosa-Gomes era. Substantial changes in the classification using Cladistics and novel discussions on the inner and outer phylogenetic relationships of higher taxa were first introduced here at this stage. Starting with the culmination of the PhD thesis of R. S. Rosa in 1985 on the family Potamotrygonidae whilst at the Virginia Institute of Marine Science, College of William and Mary, USA. The first native genus of freshwater rays, *Plesiotrygon* Rosa, Castello & Thorson, 1987, was then supported in Rosa *et al*. (1987). Rosa has worked for over 40 years since 1977 when he became Professor at the Universidade Federal da Paraíba (UFPB), Northeastern Brazil. His performance has played a role in disseminating Chondrichthyan Systematics and conservation in Brazil and South America as recently highlighted in Viana *et al*. (2020) and has published over 22 papers on the subject.

Concomitantly, U. L. Gomes, former professor at the Universidade do Estado do Rio de Janeiro (UERJ), initiated investigations on the dentition, anatomy of the vertebral

column, clasper skeleton, pectoral and pelvic girdles, and neurocranium for descriptive purposes. A series of studies came to light targeting the sharpnose sharks of the genus *Rhizoprionodon* Whitley, 1929 in Gomes, Reis (1991), and species of Rajiformes, Myliobatiformes and Carcharhiniformes in Carvalho, Gomes (1992), da Cruz Lima *et al*. (1997), Gomes *et al*. (1997b), Souza *et al*. (1999). Gomes' contributions date back to the 1980's though when providing data on new species occurrences in Brazilian waters such as for *Rhincodon typus* Smith, 1829 in Santos *et al*. (1988) and *Cetorhinus maximus* (Gunnerus, 1765) in Tomás, Gomes (1989). Later, Gomes and collaborators released the book entitled "Catálogo das coleções ictiológicas do Departamento de Biologia Animal e Vegetal, Instituto de Biologia" in Gomes *et al*. (1997a), representing the largest species account published at that time with over 100 nominal species of sharks, batoids and chimeras recognized. Since then, Gomes published over 55 articles in Systematics (Tab. **S1**), becoming one of the most productive experts in the country (for more details on his biography, see Soares *et al*. (2022).

Rosa-Gomes era coincides with the SBEEL foundation in Rio Grande, Rio Grande do Sul State in 1995. Before becoming a society, it was known as "Grupo de Trabalho sobre Pesca e Pesquisa de Tubarões e Raias no Brasil (GTPPTR)" and founded in July 1985 through the joint efforts of Amorim, Arfelli and Rosa under Sadowsky's support. In that same year, the first Brazilian national meeting in Santos (São Paulo) was held with a handful of early career researchers having the chance to build up a new network of experts and discuss ideas of practical research on biology and natural history. The society thus has been determinant to promote national research and contribute towards scientific and community engagement. SBEEL furthermore has dedicated to strengthening conservation actions in Brazil and has been responsible for directly planning, preparing and delivering of the Brazilian National Plan of Action for the Conservation and Stock Management of Elasmobranch fishes whose first edition was released in 2005. SBEEL initiative has definitely influenced decision makers on protecting endangered sharks and batoids nationwide to avoid the collapse of populations and species.

Many regional checklists and identification guides also became evident in this period after national scientific incentives in marine explorations. The Brazilian Program for Evaluating the Living Marine Resources in the Exclusive Economic Zone (REVIZEE) between 1995–1998 comprised the first national initiative of concatenated multidisciplinary scientific surveys for this purpose and emphasized research dealing with potential fishing stocks, species diversity, marine topography, and ocean chemistry and biology of coastal and deep-water marine organisms, including cartilaginous fishes. REVIZEE oceanographic expeditions undergone within four major areas subdivided according to regional boundaries: North, Northeast, Central, and South. Lessa *et al*. (1999) summarized the data available from these areas, providing information regarding the diversity, abundance, distribution, and ecology of elasmobranchs at a national level. Rosângela Lessa, professor at the Universidade Federal Rural de Pernambuco (UFRPE) and female pioneer in shark research in Brazil since the 1980's, conducted extensive surveys off the Western Equatorial Atlantic region.

Afterwards, studies on sharks, batoids and chimeras were a product of localized initiatives of oceanographic institutions in the Northeast, South and Southeast Brazil as well as occasional surveys on landings of artisanal fisheries and fish markets, including Gadig, Moreira Junior (1992), Amorim *et al*. (1998), and Menni, Lessa (1998). Taxonomic

accounts that report first records and new species occurrences prevailed in this era and only a handful number of taxa was targeted in more comprehensive studies such as Vooren, Silva (1991) for angelsharks and Gallo-da-Silva *et al*. (1997) for cownose rays. Phylogenetic studies were not yet solid here except for Carvalho (1996), who brought the country into the spotlight of the elasmobranch research community after reiterating the Hypnosqualean hypothesis on the evolutionary relationships between sharks and batoids.

Both Rosa and Gomes' inputs in the subject area surpass the turn of the century in the history of Chondrichthyan Systematics in Brazil having a thorough influence over successive generations of shark experts. Publications related to the recognition of novel species, taxonomic accounts and revisions have been provided till recently in partnership with current and former students, colleagues and collaborators. The first generation of researchers that were under their influence and that has been active today include Getúlio Rincón (Universidade Federal do Maranhão), Patrícia Charvet (Universidade Federal do Ceará) and Marcelo Carvalho (former Universidade de São Paulo).

Modern systematics in the 21st century (2000–today). Scientific productivity over the last 23 years has been recurrent and strong, which thus set Brazil as one of the world's leading shark research hubs. The quality and scope of publications has also stood out with more comprehensive studies of taxa currently prevailing. Phylogenetic studies of native and non-native taxa using morphological characters have been slowly implemented. Descriptive anatomical studies of species and comparative anatomy for evolutionary inferences have been widely employed, especially for Squatiniformes, Squaliformes, Carcharhiniformes (*e.g*., Mello, 2009; Carvalho *et al*., 2012; Moreira *et al*., 2018; Silva *et al*., 2018), and Myliobatiformes and Rajiformes in Afonso, Gallo (2001), Oddone, Vooren (2008), Shibuya *et al*. (2010), Bini *et al*. (2015), and Cunha *et al*. (2016). Regional taxonomic revisions have been implemented to provide morphological separation between species and elucidate regional synonyms using comprehensive examination of specimens (*e.g*., Silva, Carvalho, 2011; Loboda, Carvalho, 2013; Vaz, Carvalho, 2013; Fontenelle, Carvalho, 2017; Petean Carvalho, 2018; Soares, Carvalho, 2019). Meanwhile, checklists and species listings have still been provided as seen in Gadig, Gomes (2003), Soto, Mincarone (2004), Nunan, Senna (2007), Gomes *et al*. (2010, 2019), and thus constantly updating the number of species of sharks, batoids and chimeras recognized in the country. Novel species were also widely recognized in this period within a variety of taxa, including Dasyatidae stingrays and Rajidae skates in Gomes *et al*. (2000), Gomes, Paragó (2001), Gomes, Picado (2001), Santos, Carvalho (2004), Carvalho *et al*. (2005), Petean *et al*. (2020) deep-water species such as deep-water catsharks in Soto (2001a,b) and Soares *et al*. (2019), dogfish sharks in Viana *et al*. (2016), electric rays in Rincon *et al*. (2001), rabbitfishes in Soto, Vooren (2004), freshwater rays in Carvalho, Ragno (2011), and Fontenelle *et al*. (2014).

Application of innovative methodologies for data sampling also helped to evolve the Modern Systematics in the country. The pioneer study of Solé-Cava *et al*. (1983) provided data for genetic frequencies of allozymes to identify species of *Squatina* occurring in Southern Brazil. Subsequent molecular data related studies focusing on DNA barcoding and molecular species delimitation have been published for freshwater rays, lamnid and carcharhinid sharks, guitarfishes, sawfishes, and stingrays.

Research trends in shark systematics within the 120-year period. Over the period 1903–2023 a total of 354 scientific publications related to Systematics of Chondrichthyes from Brazil were produced (Fig. 1). Miranda-Ribeiro era has a total of six publications, followed by three publications during the Hiatus era. Thirty-two studies were published in the Sadowsky era, and 54 in Rosa-Gomes era. The Modern era, which comprises the last 23 years, exhibited a total of 259 publications with an average of 11 studies per year (Fig. 1).

Research subject area. Taxonomic studies have been the major focus (70.1%) followed by morphological (22.3%) and phylogenetic ones (7.6%) (Fig. 2A).

Research scope. Taxonomic scopes comprise almost all categories mentioned in Material in Methods, except high-level interrelationships. Within the taxonomy subject area, checklists, new record, description, and revision together represent 72.6% of total studies published between 1903–2023 while first record and DNA barcoding exhibit 10.9% and 8.9%, respectively. The other five categories were represented by less than 8% of taxonomic papers (Tab. 1).

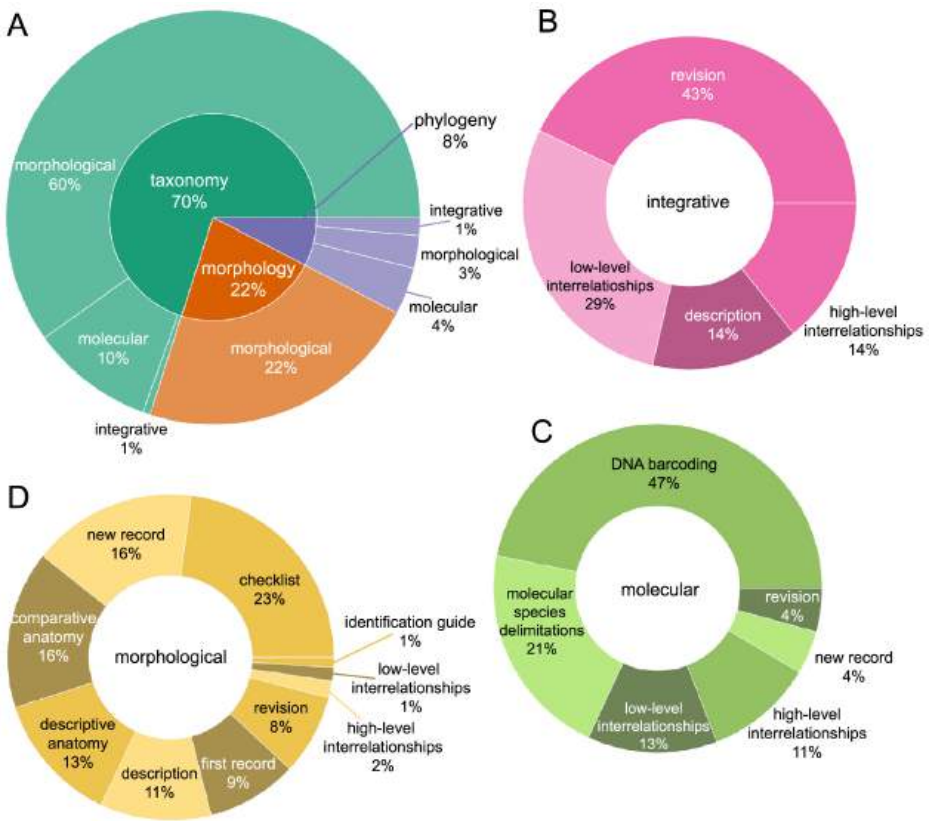

FIGURE 2 | Percentages of papers within (**A**) three distinct subject areas (taxonomy (green), morphology (orange), and phylogeny (purple) on the inner circle, and data sources (morphological, molecular, integrative) on the outer circle. Percentage of papers under one of the 12 research scopes (checklist, comparative anatomy, description, descriptive anatomy, DNA barcoding, first record, high-level interrelationships, identification guide, low-level interrelationships, molecular species delimitations, new record, and revision) using each of the data sources: (**B**) integrative; (**C**) molecular; (**D**) morphological.

TABLE 1 | Percentage of studies under distinct research scopes within each one of the subject areas.

Subject area	Research scope	% of studies within each subject area
Morphology		
22.3%		
	Comparative anatomy	53.1
	Description	1.2
	Descriptive anatomy	43.0
	High-level interrelationships	2.5
Phylogeny		
7.6%		
	Comparative anatomy	7.4
	Description	3.7
	High-level interrelationships	33.3
	Low-level interrelationships	40.7
	Molecular species delimitations	11.1
	Revision	3.7
Taxonomy		
70.0%		
	Checklist	27.8
	Comparative anatomy	1.2
	Description	12.9
	Descriptive anatomy	2.0
	DNA barcoding	8.8
	First record	10.8
	Identification guide	1.2
	Low-level interrelationships	0.4
	Molecular species delimitations	2.8
	New record	20.5
	Revision	11.2

Within Morphology, only four research scopes were identified and the two most expressive were comparative anatomy (53.2%) and descriptive anatomy (43.0%). Finally, within phylogenetic studies, low- and high-level interrelationships were the most common scopes with 40.7% and 33.3% of studies, respectively (Fig. 3B).

When analyzing the Research Scopes regarding the Data Source used, within integrative data, revision was the most common (42.9%) (Fig. 2B); within molecular, DNA barcoding (46.8%) (Fig. 2C), and within morphological, checklist (23.0%), followed by new records (16.3%) and comparative anatomy (16.7%) (Fig. 2D).

Data source. Morphological-based methodology stands out, representing 84.7% of the total studies on Systematics of Chondrichthyes, while those based exclusively on molecular data are 13.3%, and research combining two or more data sources (integrative) correspond to only 2.0% (Fig. 2A). Within phylogeny subject area, 48.1% of studies were based on molecular data, 33.3% morphological, and 18.5% integrative; while within taxonomy, 85.5% on morphological, 13.7% molecular, and 0.8% integrative. Phylogenetic research is the only area herein considered in which molecular-based data is larger than morphological (Fig. 2A).

Targeted study taxa. Most manuscripts focused on single species, genus, or family-level (68.9%), followed by those focused on two or more taxa (multi-taxa, 27.7%). Some studies focused on Batoidea as a whole, and 10 studies on the orders Carcharhiniformes (4), Squaliformes (3), Lamniformes (1), Rajiformes (1), and Rhinopristiformes (1). Among those working on family-level or lower taxa, 17.6% regarded Potamotrygonidae and 13.5%, Carcharhinidae, whereas 29 families have been mentioned in less than 10 manuscripts in a total of 37. Excluding those multi-taxa papers, the majority comprised research on Batoidea (46.7%), followed by Galeomorphi (36.5%), Squalomorphi (15.6%), and Holocephali (1.2%). Potamotrygonidae was the most studied group within the subject areas "taxonomy" (12.1%) and "phylogeny" (18.5%), while within "morphology", Carcharhinidae (19.0%) was the most studied family (Fig. 3).

Of the few manuscripts that integrate different data sources (7), two regarded Potamotrygonidae and the other five were on distinct families. Among the 47 manuscripts using molecular data, 17% concerned Carcharhinidae and 36.2%, multi-taxa. Finally, among the 300 manuscripts using morphological data, 12.3% concerned Potamotrygonidae and 27.0%, multi-taxa.

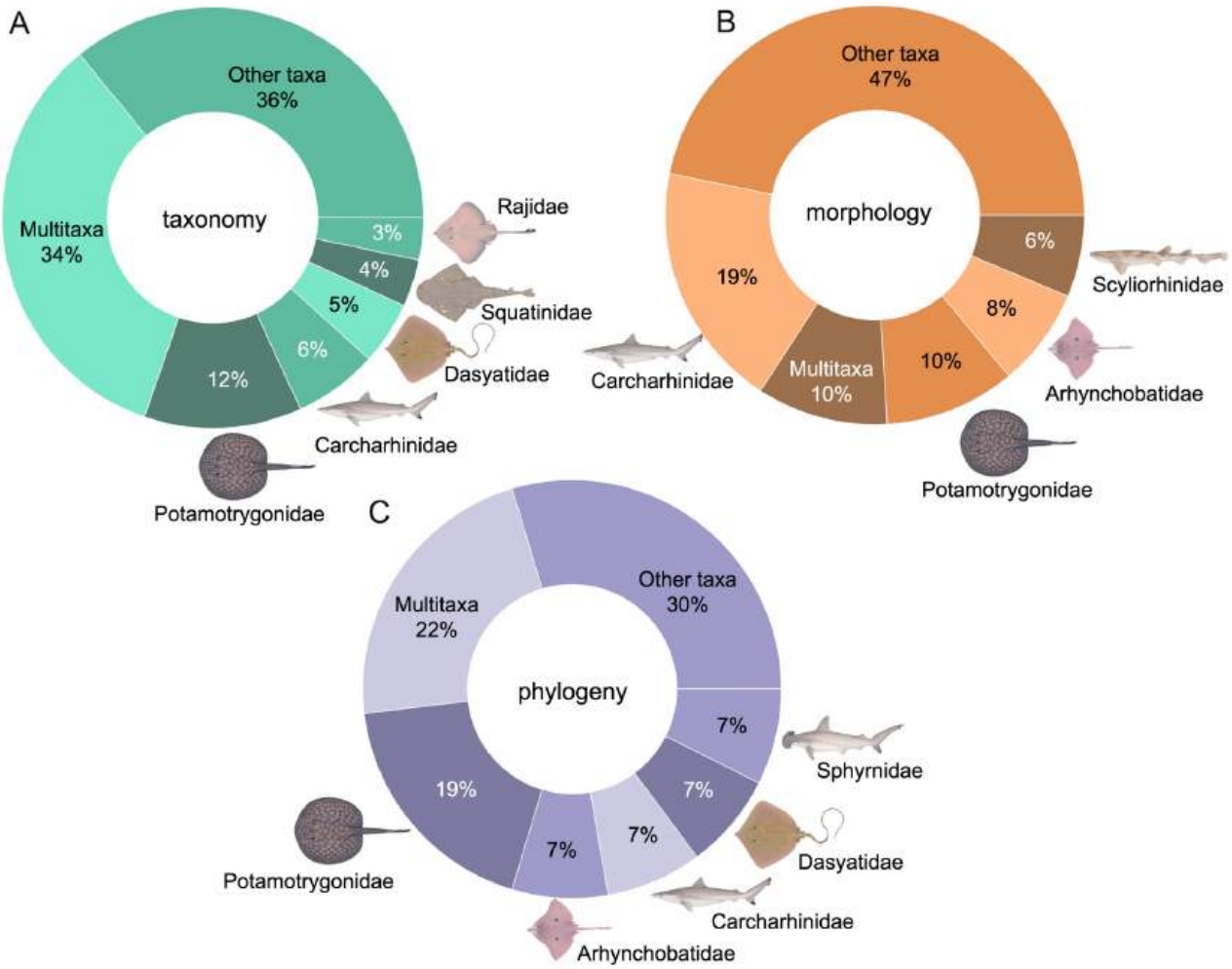

FIGURE 3 | Percentage of studies focused on each family or on two or more (multi-taxa) within the subject areas (**A**) taxonomy, (**B**) morphology, and (**C**) phylogeny.

Taking into account the eight most-cited families (Potamotrygonidae, Carcharhinidae, Dasyatidae, Scyliorhinidae, Arhynchobatidae, Rajidae, Sphyrnidae, and Squatinidae) as those that were studied in more than 10 papers (Figs. 4–5), morphological data used in taxonomical and morphological studies were the only ubiquitous data source and subject area among them. Phylogenetic studies based exclusively on morphological data are lacking for Potamotrygonidae, Carcharhinidae, Dasyatidae and Squatinidae. Research focused on Rajidae (Fig. 5) was only based on morphological data within taxonomy and morphology, without any studies performing phylogenetic analyses, or using integrative and molecular data, demonstrating a clear gap in systematic studies. Besides, Scyliorhinidae and Arhynchobatidae, when the only target taxa of a study, also lack studies based exclusively on molecular data.

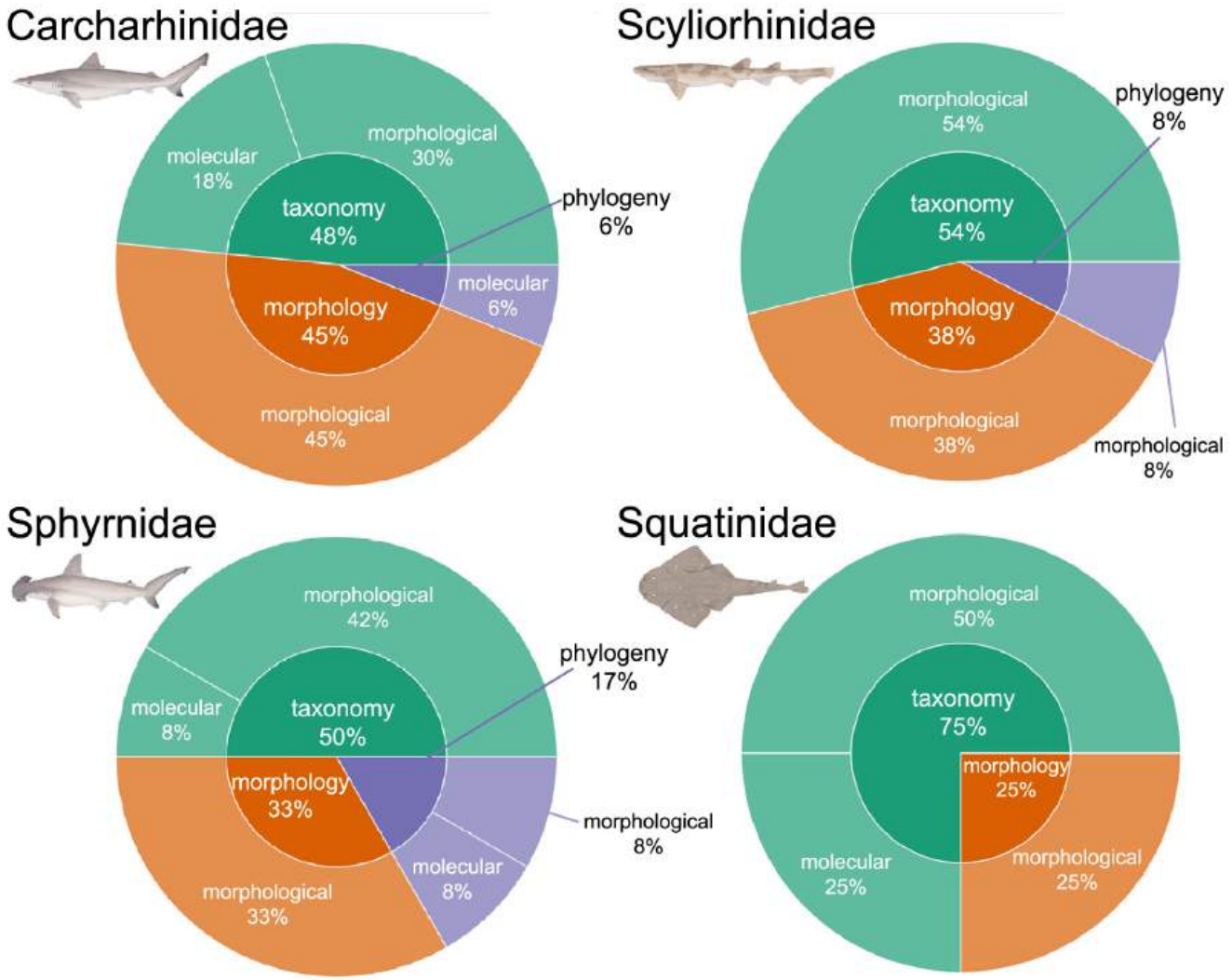

FIGURE 4 | Percentage of studies within the shark families Carcharhinidae, Scyliorhinidae, Sphyrnidade, and Squatinidae, and within subject areas taxonomy, morphology, and phylogeny.

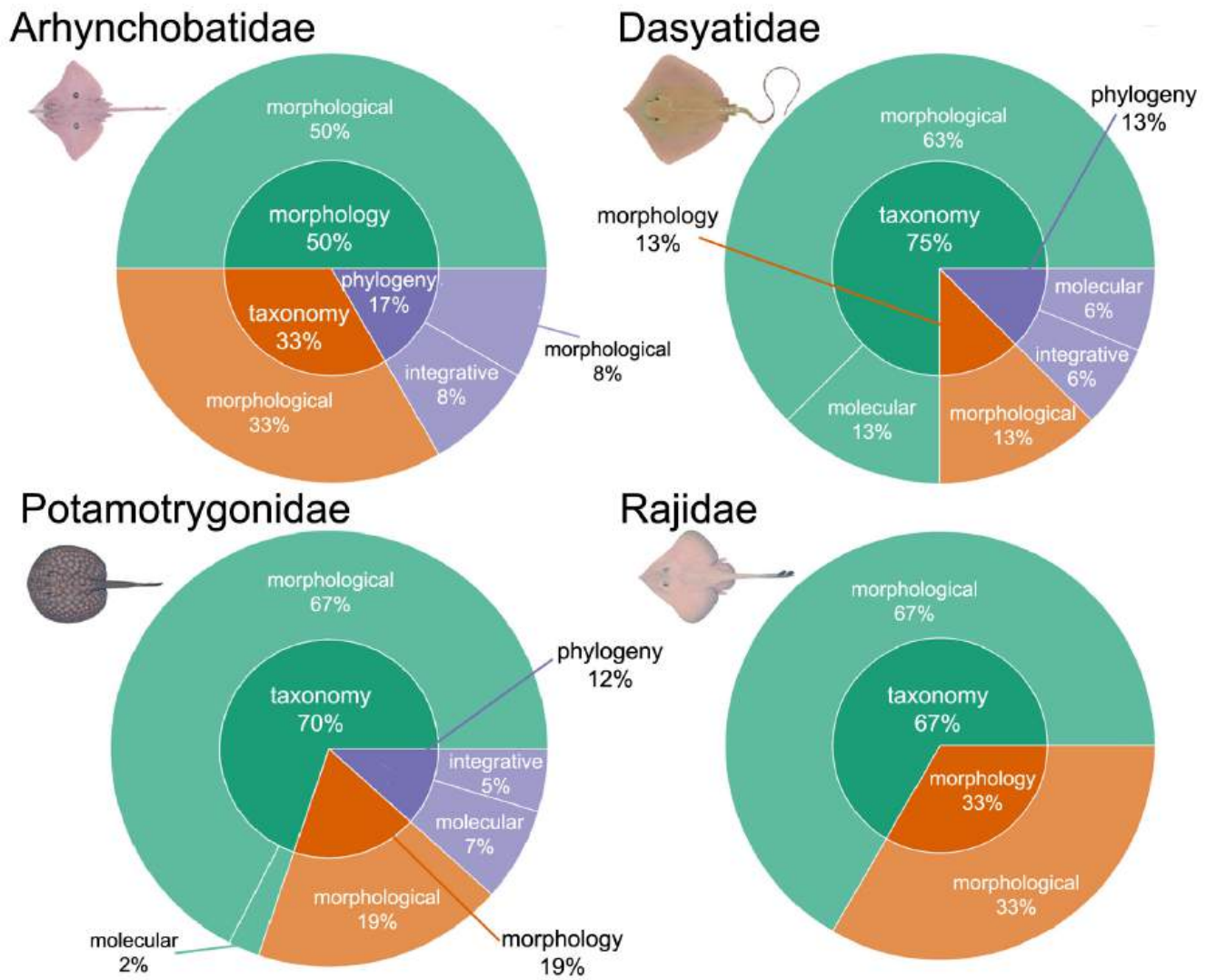

FIGURE 5 | Percentage of studies within the batoid families Arhynchobatidae, Dasyatidae, Potamotrygonidae, and Rajidae, and within subject areas taxonomy, morphology, and phylogeny.

Authorship and gender diversity. There is an average of 3.23 authors by study, ranging from 1 (14.7%) to 15 (0.3%), with two authors being the most common (30.5%) (Fig. 6A). Of the 52 studies authored by only 1 person, 5.8% were women and 94.2% were men. Of all 354 studies, 20.3% were first-authored and 15.8% last-authored by a woman, with only 6.5% with first and last authors being women. Conversely, 55.6% were first- and last-authored by men (Fig. 6B). The average percentage of women as co-authors was 17.7% in each study; however, the most common scenario was the absence of women in authorships (60.7% of studies, 215 out of 354).

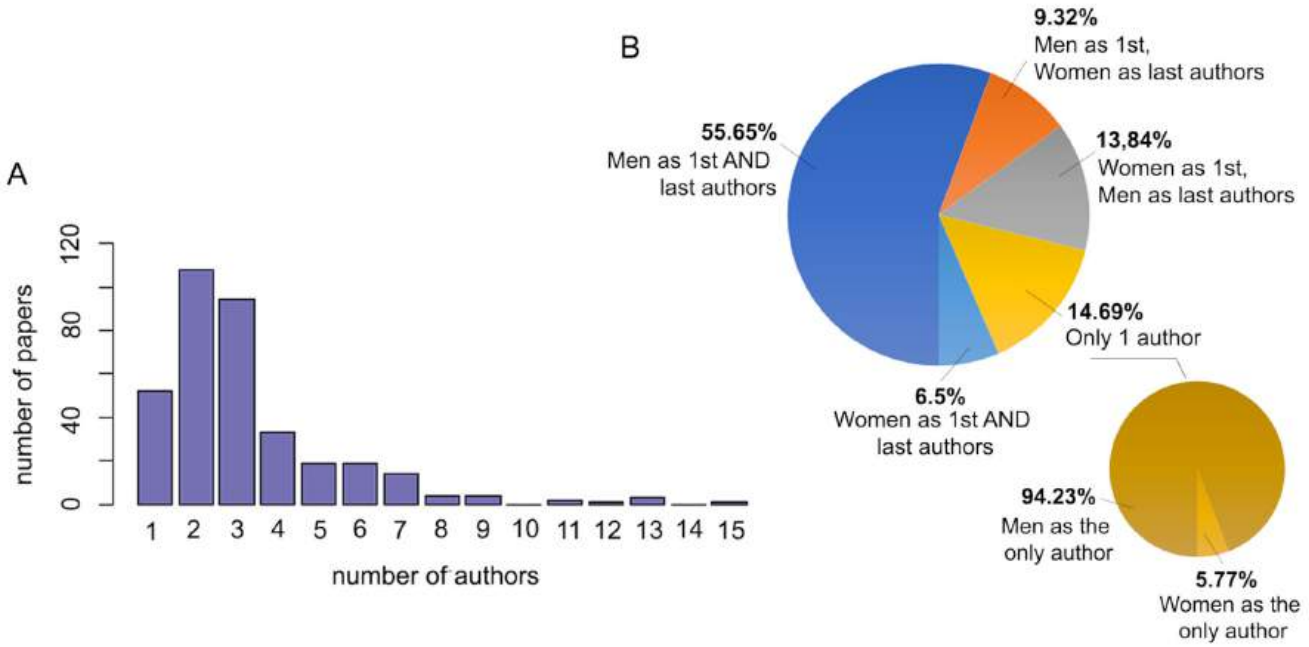

FIGURE 6 | **A.** Number of papers written by 1 to 15 authors; **B.** Percentage of publications authored by men and women as first and last authors.

DISCUSSION

Overall research trends in Brazil. Literature review of the 120-years period (1903–2023) revealed that scientific outputs within the Chondrichthyan Systematics in Brazil have constantly evolved. The number of publications has increased considerably since the Miranda-Ribeiro era. Least impactful studies were conducted during this first period, in which general species listings related to national diversity of fishes were the main study scope along with new species descriptions, with exception to the pioneer work of Batista (1944) concerning cranial anatomy. Sadowsky era mostly accompanied occurrence reports of wide-ranging species and remarkably the first taxonomic revisions of native species raised exponentially to over five times the total number of publications. Rosa-Gomes era kept the total number of publications rising notwithstanding comprising the shortest era within the Chondrichthyan Systematic history of the country and exhibited a publication average above the previous eras.

Substantial contributions to the field were noticed in the last 23 years, with the total number of studies and the publication average superseding earlier periods of research in Brazil altogether (Fig. 1). Brazil thus has contributed to exceptional inputs to the local and international knowledge, a protagonism that has never been experienced before in more than 120 years of Brazilian research on cartilaginous fishes. Heavy investments in research and higher education during this period were possibly the main determinant in the application of rapid taxonomic approaches such as molecular genetic data (see detailed explanation further below).

Modalities of research in Brazil have been disparate over time. Taxonomy stands out with 70.0% of the scientific productivity related to Chondrichthyes followed by morphology and phylogeny. Studies of taxonomic scope that involve revisions, species

descriptions, checklists and first/new records have been constantly implemented since the Miranda-Ribeiro era, remaining the main study field to date. Comparative anatomical investigations have been carried out since early 1990 throughout the Rosa-Gomes era till recently although the first descriptive morphological studies were conducted earlier during the 1940 and 1960's decades. Phylogenetic analyses, on the other hand, have been sporadically applied and thus it is underrepresented in the overall shark research trend.

Research knowledge gaps and challenges. Traditional Systematics dominates in studies related to the diversity and evolution of Brazilian sharks, batoids and chimeras. Most morphological-based studies have constantly provided high quality data of characters for species diagnosis and evolutionary support of higher clades within Chondrichthyes. Methods in traditional Systematics such as dissection, radiography and CT-scan, and clearing and staining are usually more time consuming for data gathering and analyses. Not surprisingly, the fields of phylogeny and morphology, that require detailed morphological characters, are less commonly employed than taxonomic studies. Within the latter field, low research effort is also applied for studies with scope on taxonomic revisions and descriptions of species. Thus, generic taxonomic studies such as checklists/lists and first records/new occurrences of species have superseded the scientific production in the country because it usually relies on rapid methodology for data acquisition such as literature compilation and/or superficial morphological investigations.

Modern Systematics is still evolving in Brazil, which is in contrast with the current global scenario related to Chondrichthyan research but in accordance with the South American trend as noticed in Awruch *et al*. (2019). Molecular taxonomy for species identification might undermine ichthyofaunistic listings (*e.g*., Brandão *et al*., 2016; Pereira *et al*., 2011), focus on forensics of target species in the fisheries industry (*e.g*., Bunholi *et al*., 2018) and specific taxa, such as sharpnose sharks in Mendonça *et al*. (2011) and Pinhal *et al*. (2011), guitarfishes in Mariguela *et al*. (2009) and De-Franco *et al*. (2010), angelsharks in Falcão *et al*. (2014), requiem sharks in Domingues *et al*. (2013), sawfishes in (Faria *et al*. (2013), guitarfishes in Cruz *et al*. (2023), and daggernose sharks in Nachtigall *et al*. (2017), to mention a few. Dasyatids have been well documented in this aspect whilst freshwater stingrays have been less investigated than marine species (*e.g*., Valentim *et al*., 2006; Toffoli *et al*., 2008; Cruz *et al*., 2015; Torres *et al*., 2022). Unexpected trends in research like these are unjustified as freshwater stingrays are abundant and commonly found in freshwater rivers of the country but still unexplored by the scientific community, as already shown by Soares, Petean (2023). However, disparity in research efforts of certain taxa may be related to other reasons such as shortage of permanent human resources (*e.g*., with shark molecular taxonomy qualifications), lack of equipment and facilities (*e.g*., molecular laboratories and supplies), and, more precisely, direct research funding to conduct costly genetic analyses.

Molecular phylogenetic studies are also in shortage and have been applied to a handful taxa that include only six families occurring in Brazil (out of 42 families): Aetobatidae (Sales *et al*., 2019), Arhynchobatidae (Coelho *et al*., 2020), Carcharhinidae (Mendonça *et al*., 2011; Rodrigues Filho *et al*., 2023), Dasyatidae (Vaz *et al*., 2006; Petean *et al*., 2020), Potamotrygonidae (Carvalho, Lovejoy, 2011; Fontenelle *et al*., 2021; Kolmann *et al*., 2022), and Sphyrnidae hammerheads in Cavalcanti (2007) and Gonzalez *et al*. (2021). More rarely phylogenetic studies that applied combined morphological and molecular

data have been represented to a minimum as seen in Carvalho, Lovejoy (2011) and Soares, Mathubara (2022). Genomic studies of phylogenetic inference are still exceptional (*e.g.*, Amaral *et al.*, 2018). Slow-growing trends of molecular Systematics in Brazil are also evident through examination of the online repositories of genetic sequences in which the availability of genetic information related to national and endemic species are scant.

Being a mega diverse country, it is expected that studies related to the taxonomy, phylogeny and morphology of Chondrichthyes in Brazil exhibit diversity of target taxa as well. Shark studies are more frequently conducted than batoids and, more rarely, chimeras, representing, respectively, 52.0%, 46.7% and 1.2% of the total number of studies produced during over 120-year period. Potamotrygonidae and Carcharhinidae consist of the two main study groups, representing over 10% each of the total number of studies. Dasyatids, hammerhead sharks, skates, catsharks and angelsharks represent, each, approximately 5.0% of the total studies. Availability and abundance of material in the wild, fish markets and scientific collections possibly have influenced the research outputs related to these taxa as freshwater stingrays, requiem sharks, dasyatids, skates, catsharks and hammerhead sharks are more easily spotted.

Remaining 26 families that occur in Brazil represent less than 30.0% of the total studies. Most of these taxa are pelagic species and demersal dwellers that inhabit deep-water realms such as cownose rays, thresher sharks, deep-water skates, lantern sharks which makes us infer that the lack of scientific expeditions and research funding in the Brazilian open ocean serve as drivers to the taxonomic impediment. Surprisingly, guitarfishes, electric rays, butterfly rays and smooth-hound sharks that are easily found in shallow coastlines and in artisanal fish markets have been scarcely investigated probably due its non-charismatic features even though these taxa represent one of the most problematic groups with guitarfishes being one of the most vulnerable taxa to extinction (Moore, 2017). Other taxa that have been listed to the country, including Ginglymostomatidae, Pseudocarcharhidae, Pseudotriakidae, Torpedinidae, and Rhinochimaeridae have not yet received any direct attention to Systematics research.

Future research perspectives and priorities. High susceptibility to environmental impacts such as overfishing and climate changes arises from the combining exposure to fishing mortality, life history and ecological traits of sharks, rays and chimeras (Dulvy *et al.*, 2014). Many species of sharks, batoids and chimeras are naturally vulnerable due to its *k*-selected (*e.g.*, slow growth rate, late maturity, long gestation periods, low fecundity) and ecological features (*e.g.*, habitat-specific, philopatry, limited dispersal) (Moore, 2017). It is estimated that 32% of the elasmobranch marine species are under extinction risk in Brazil (Rosa, Gadig, 2014; Reis *et al.*, 2016; ICMBio, 2018). Industrial and artisanal fisheries play a major influence over the resiliency of local populations and species together with habitat loss, degradation and coastal development as additional threats. Currently, Brazil represents the second in place for the global ranking of shark meat producer and fin exporter, especially of highly migratory and endangered species (Falcão *et al.*, 2014; Barreto *et al.*, 2017). Forensic investigations in the fishing industry have evidenced that shark meat is widely effective for consumption under mislabeled products in supermarkets and fish markets (*e.g.*, Bornatowski *et al.*, 2013; Feitosa *et al.*, 2018; Rodrigues Filho *et al.*, 2020). This scenario thus set the country in peril regarding shark sustainable fisheries as the fisheries sector has faced the worst management crises over the last decade (Di Dario *et al.*, 2015; Martins *et al.*, 2018).

Target or by-catch species are usually reported on fishing logbooks lacking accurate taxonomic identifications (*e.g.*, *Sphyrna* and *Carcharhinus*) and/or are barely assigned to general vernacular names such as "cação" or "raia". Fisheries statistics available for Brazil commonly list five species that are easily identifiable (*P. glauca*, *I. oxyrinchus*, *C. longimanus*, *C. falciformis*, and *A. superciliosus*; Barreto *et al*., 2017) while less charismatic and small-sized species that are still under fishing pressures are unreported. Inability to identify and apply species-name of sharks, rays and chimeras is a global tendency and not less locally Bornatowski *et al*. (2014) which hampers species-specific fisheries jurisdictions and conservation discharges. Knowledge gaps persist for a variety of taxa from Brazil that require taxonomic clarification regarding morphological and genetic characterization, application of synonyms, and type designation such as for guitarfishes *Pseudobatos*, stingrays *Hypanus*, skates *Rajella*, smooth-hound sharks *Mustelus*, and requiem sharks *Carcharhinus*.

Taxonomic impediment in Brazil obscures research development in Ichthyology. Absence of substantiate funding in STEM research that includes Systematics, limited research efforts through scientific expeditions in open ocean and remote freshwater regions, scarcity of permanent and full-time taxonomists in museums and universities, and reduced investment in education constitute its major drivers. Deficiency of scientific awareness on the sharks, rays and chimaeras diversity in the country also urges the impediment as it does not attract new students, research interests and public engagement. To gather Brazil within the worldwide framework in the modern Chondrichthyan Systematics it is imperative the implementation of strategic initiatives in research, education and infrastructure.

Modernization of zoological collections, such as digitalizing inventories of available specimens and tissues, will facilitate access to biodiversity data for the academic and general public. Currently, to know some collections' holdings, the manager should be inquired to send a list, since it is not freely available on an online database, hindering a fast access to data and progress of studies. Often, lists of elasmobranchs deposited in national museums carry misidentifications and/or outdated identifications, hampering the knowledge on taxa in need of review. For taxonomic and systematic research, it is of utmost importance for this transition toward digitalized collections to happen soon, so scientists can acknowledge taxa with distributional gaps that need higher sampling efforts to accomplish comprehensive studies. In this way, offering scholarships aimed at updating and digitalizing museum collection catalogs could represent a viable solution. In prevailing scenario, only those taxa easily accessed are studied, generating the bias we have noticed throughout this research.

Novel methodologies in Systematics research allied to evolutionary ecology and genomics which exemplify the so-called Integrative Systematics (*e.g.*, population genomics; eDNA; phylogenomics) will indeed uncover species delimitations and boost taxonomic and phylogenetic resolutions. Strengthening collaborative network among national and international shark experts, especially in Latin America, will further joint multi-lateral forces to minimize taxonomic confusions of taxa. Not less importantly, public outreach involvement in universities, institutions and museums by promoting educative programs and activities as well as publication of easy-to-learn identification guides will definitely raise the scientific awareness regarding the conservation and diversity of the group in Brazil.

As observed in our study, and in Soares, Petean (2023), Brazilian chondrichthyan research is very male dominated research field. More than half (60.7%) of analyzed papers were authored only by men, revealing a huge gender bias that still hampers women to participate as lead authors. It is mandatory the gender inclusion in future studies, research expeditions, regional book editions and other types of scientific outputs.

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AUTHORS' CONTRIBUTION

Sarah Viana: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing-original draft, Writing-review and editing.

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