Ocean and Coastal Research

Review
Special Article Collection
Sousa, Carreira and Fonseca (eds), Subsidies for ecosystem-based management in an offshore oil and gas exploration area, Santos Basin, Brazil
http://doi.org/10.1590/2675-2824071.22068fclv
ISSN 2675-2824

An overview of seabirds in the Santos Basin, Brazil: species, threats, and current trends in studies

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Abstract

The Santos Basin in eastern Brazil is adjacent to the largest human populations in the southwestern Atlantic Ocean, with several potential threats to marine vertebrates. In this study, we provided a systematic bibliographic review and integrated unpublished primary datasets to provide an overview on species, research topics and gaps, and threats to seabirds in the Santos Basin. Bibliographical sources were used for species recorded within the limits of the basin, while species census data were obtained through research and monitoring projects. We analyzed 156 studies from 1914 to 2021. An increase in the number of publications was observed from the 2000s onward (> 80%), with the state of Santa Catarina showing the highest number of publications (56%) on seabirds. Notes and Records (27%), Population and Community Structure (22%), and Fishing (11%) were the main subjects studied. Among the 76 seabird species reported in the Santos Basin (~2/3 of the species reported in Brazil), Procellariiformes was the most prevalent order (51%), including 14 species listed as threatened, either globally or nationally. Resident (28%) and long-distance migratory species, such as visitors from the Southern (39%) and Northern (17%) Hemispheres and Europe (12%), were widely recorded in the region, as well as vagrant species. The inclusion of different data sources allowed broadening the geographic cover used by species to consider both coastal (predominating in previous studies) and offshore areas. The association of seabird distribution with oceanographic and meteorological features should be addressed in future studies, as should studies on the impact of fishing and pollution on a range of common species.

Descriptors: At-sea distribution, Biodiversity, Ornithological records, Research priorities, Southeastern Brazil

INTRODUCTION

Seabirds are generally defined as species that depend on marine resources and that breed either on islands or coastal areas (Schreiber and Burger, 2001). However, this somewhat restrictive definition excludes most coastal birds, which are included in the definition proposed by Vooren and Brusque (1999), as birds that either feed on the beach or carry out kleptoparasitism on other birds, in addition to those that are strictly marine. As such, seabird species considered as marine may vary according to the criteria adopted by the author. According to Vooren and Brusque (1999), there are at least 148 species in Brazil, distributed between coastal and pelagic birds, although this includes many coastal birds excluded from most definitions. In a recent study, Nunes et al. (2023) mention 100 seabird species occurring in Brazil, based on the recent Brazilian bird species list (Pacheco et al., 2021). Among the species occurring in Brazil, many breed on coastal islands

Submitted: 31-May-2022
Approved: 01-Nov-2022

Associate Editor: Gustavo Fonseca

(e.g. Campos et al., 2004) and oceanic islands (Mancini et al., 2016), in addition to a number of migrants from both hemispheres (Somenzari et al., 2018), and some are vagrants, i.e., of occasional occurrence outside their regular distribution area (Dias et al., 2012). The Santos Basin is a vast area located across the south and southeast regions of Brazil, in a subtropical region close to a tropical area such that it receives migratory species from various latitudes and species that breed in the several adjacent coastal islands (Campos et al., 2004). This important area for resident and migratory seabirds is under a range of anthropogenic threats including contamination of the marine environment, fishing activities, and various impacts associated to coastal occupation.

Furthermore, seabirds are excellent indicators of the quality of the ocean (Furness and Camphuysen, 1997; Burger and Gochfeld, 2004) because they respond quickly to changes in the environment, making them key components in the marine ecosystem. They are top predators of the trophic chain, have long life spans, inhabit vast home ranges, and migrate long distances, in addition to occurring in areas ranging from coastal to pelagic waters, from tropical to polar regions (Schreiber and Burger, 2001; Spear et al., 2001; González-Solís et al., 2007). The use of seabirds as environmental indicators has some advantages, such as easy sampling during breeding periods when birds concentrate in colonies, and fidelity to breeding area (Schreiber and Burger, 2001; Petry et al., 2018). During non-breeding periods, birds may use different habitats, allowing them to assess different levels and compartments of the ecosystem throughout the year (e.g. Robuck et al., 2022).

Along the Atlantic coast of South America, cold currents from polar regions, such as the Malvinas Current, reach the southern coast of Brazil, providing great diversity of organisms and a high biomass of food resources for these top predators (Veit and Braun, 1984; Orgeira, 1995; Montalti and Orgeira, 1998). In turn, the Brazil Current, moving from the north, reaches southern Brazil with temperature and salinity above 20 °C and 36 PSU, respectively (Silveira et al., 2000). Therefore, migratory birds from the Southern and Northern Hemispheres are often observed either during their movement periods or while using the coast of Brazil as non-breeding areas (Vooren and Fernandes, 1989; Ramirez et al., 2013; Ramos et al., 2017). At this stage of their life cycle, seabirds are under anthropic threats from activities that occur in the region (Petry and Fonseca, 2002; Valls et al., 2015), which can result in substantial environmental changes and lead to ecological imbalance (Baum and Worm, 2009). An increasing number of studies have reported problems related to climate change, the exploitation of natural resources, and the release of pollutants into the ocean (e.g. Doney et al., 2012; Kühn et al., 2020; Hatje et al., 2021; Belhabib and Le Billon, 2022; Nunes et al., 2022), reinforcing the importance of detecting and monitoring their potential effects on marine ecosystems.

Anthropic activities such as pollution and longline, gillnet, and trawl fishing are high-impact threats to birds, causing mortality of different species (Wiese and Ryan, 2003; Branco et al., 2014; Dias et al., 2019; Nunes et al., 2022). Among others, metals, persistent organic pollutants, solid waste, and oil spills can affect seabirds, with effects ranging from lethal to chronic sublethal to individuals and population decline (Wiese and Robertson, 2004; Matcott et al., 2019; Wang et al., 2021; Lees et al., 2022).

Among pollutants of anthropic origin in marine ecosystems, oil is particularly problematic because it enters various compartments of the environment through daily human activities, such as sewage runoff, marine operations, drilling rigs, and pipeline spills (NRC, 2003; GESAMP, 2007). Though they begin as small amounts, daily oil discharges, known as chronic hydrocarbon pollution, can have greater negative consequences than large-scale oil spill disasters (Morandin and O'Hara, 2016). Oil pollution in marine ecosystems is a major threat to seabirds (García-Borboroglu et al., 2006; Camphuysen, 2010; Vollaard, 2017).

Despite existing in-depth knowledge on the effects of global changes on seabirds (Dias et al., 2019), Brazil lacks efforts to monitor the occurrence and distribution of several groups, especially pelagic birds. This is basic information to guide conservation efforts, required for fundamental

questions such as which species occur in which regions, which are common or abundant, and when they occur. Systematic data collection to profile the seabird community in detail, evaluate potential impacts, and understand species predominance in certain habitats and times of the year can provide crucial information for the management and development of conservation measures for pelagic birds, including migratory species that use the Brazilian coast and that are threatened to some degree with extinction (IUCN, 2020).

The Santos Basin is adjacent to the most densely populated area in Brazil, featuring the largest number of research institutions and universities with the highest level of knowledge of biodiversity (Calderón et al., 2014). Even so, information on coastal and pelagic seabirds is limited and mostly focused on the coast and coastal islands, where seabird breeding colonies are located (e.g. Branco, 2003). As such, the objective of this study was to conduct a systematic (i.e. based on predefined procedures) and integrative (i.e. coupled to primary data and online sources) review of the seabird community in the Santos Basin area. We also sought to highlight the main research themes and trends carried out and relationships with threats and conservation, in order to help identify gaps in knowledge and topics of importance for research and conservation.

METHODS

Study area

The Santos Basin is the largest offshore sedimentary basin and largest producer of oil and natural gas in Brazil (Souza and Sgarbi, 2019). The Santos Basin occupies approximately 350,000 km^2 of the southeastern-southern Brazilian coast, between 23° and 28°S, bordered to the north by the Campos Basin, marked by the Cabo Frio High off Cabo de São Tomé (22.1°S and 41°W), and to the south by the Pelotas Basin, marked by the Florianópolis High off Cabo de Santa Marta (28.55°S and 48.47°W) (Moreira et al., 2007; Gamboa et al., 2008). Thus, the four Brazilian states (Rio de Janeiro, São Paulo, Paraná, and Santa Catarina) and their offshore geopolitical boundaries were considered when assessing the occurrence of species (Figure 1). The region is

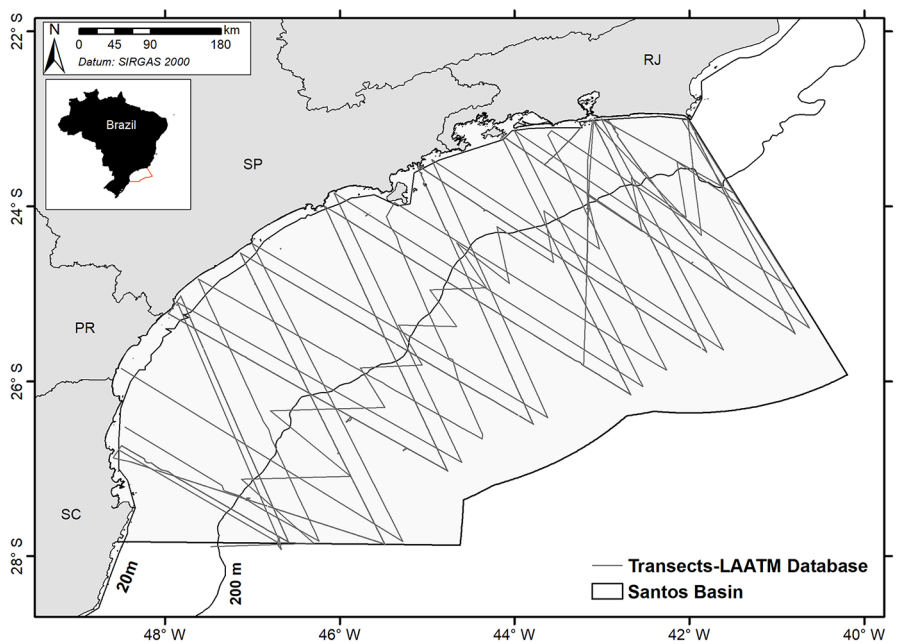

Figure 1. Map of the study area including the offshore geopolitical limits of the Santos Basin, Brazil, and the seabird sampling transects carried out from on-board platform observations (LAATM/FURG database). Bathymetric lines at 20 m and 200 m, and the limits of the Brazilian states that are part of the Santos Basin: Rio de Janeiro (RJ), São Paulo (SP), Paraná (PR) and Santa Catarina (SC).

also important for other socioeconomic activities such as steel mining, naval and port activities, fishing, tourism, civil construction, and commerce (Johnsson and Ikemoto, 2015; Viana and Marum, 2020).

Systematic review

The bibliographic survey on seabirds in the Santos Basin was carried out using the ISI Web of Science, Google Scholar, and Scielo databases, which provide a multitude of academic studies (undergraduate, master's, and doctoral theses, dissertations, and monographs) and publications in national and international journals. In the absence of other sources of information, abstracts from scientific events were used. Because the quality of the material gathered in different databases varies (see Gusenbauer and Haddaway, 2020), our analysis of content and information within each study was checked for further quantitative analyses, and critical discussion was provided when necessary.

The search for bibliography occurred from June 2019 to July 2021, using keywords separately and in combinations that were related to seabirds and marine birds (e.g. seabirds AND diet AND São Paulo). We used keywords in both English and Portuguese, such as bycatch, fisheries, fishing, occurrence, diet, foraging ecology, migration, southeastern Brazil, albatrosses, petrels, breeding population, threats, Santos Basin, Santa Catarina (SC), Paraná (PR), São Paulo (SP), Rio de Janeiro (RJ), Brazil, and Southeastern. The three orders (Charadriiformes, Procellariiformes, and Suliformes) that include occurrences of well-known species for the Santos Basin were also used as keywords. Specific genera such as *Sterna* spp., *Phaethon* spp., *Fregetta* spp., *Pelagodroma* spp., *Pterodroma* spp., *Pachyptila* spp., and *Morus* spp. were used as combined keywords in order to find new documentable records for species with either limited evidences or potential occurrence in the area. This strategy also sought to locate records of offshore distribution (e.g. migration) in the Santos Basin area.

Additionally, we conducted backward citation search by checking each mention of seabird species in the national list (Pacheco et al., 2021) and the state lists of SC and RJ (online lists), PR (Scherer-Neto et al., 2011), and SP (Silveira and Uezu, 2011) to identify bibliographic records for the Santos Basin region. The LAATM/FURG bibliographic database (1904–2013) was also checked. Finally, references cited in manuscripts were analyzed to locate occasional sources that did not appear through database searches.

The inclusion criteria for bibliographic sources considered references indicating the occurrence of species within the defined limits of the Santos Basin. Species living in the open sea and around oceanic islands that, therefore, use marine food resources and nest on islands were considered typical and constant components of the emerged coastal ecosystem. All species in the orders Phaethontiformes, Sphenisciformes, Procellariiformes, and Suliformes were considered seabirds, while for Charadriiformes species, only Chionidae, Stercorariidae, and Laridae (including gulls, terns, noddies, and skimmers) were included as marine. Consequently, shorebirds, or those predominantly terrestrial, from the limnetic zone of beach environments (e.g. waders, shorebirds, herons, ibises, oystercatcher), from the Charadriiformes and Pelecaniiformes orders, were not included.

After the bibliographic sources were included into the database, a systematic analysis was performed, which consisted of categorizing each publication according to: reference code; author(s); year of publication; title of the paper; species recorded in the paper; theme of the paper; Brazilian state(s) of occurrence; geographic position of the species recorded or place of coverage of the paper. Finally, we also discussed records with probable occurrence, nomenclatural changes, and identification issues regarding species cited for the area and with either unknown or lacking documentary evidence.

Integrative approach

In addition to publications found in online databases, other data sources were used to compose the list of seabird species occurring in the Santos Basin (Figure 1). We consolidated occurrence data (species presence) from three projects from the database of the *Laboratório*

de Aves Aquáticas e Tartarugas Marinhas from the Federal University of Rio Grande - LAATM/FURG: i) *Projeto de Caracterização Regional da Bacia de Santos* (PCR-BS) (the seabird survey was part of the Santos Project – The Santos Basin Regional Environmental Characterization (PCR-BS) – coordinated by PETROBRAS), carried out together with the *Projeto de Monitoramento de Cetáceos na Bacia de Santos* (PMC-BS) from 2019 to 2021; ii) *Projeto Talude*/FURG; and iii) Projeto *Pro-Trindade*/FURG. The latter two were both conducted between 2009–2015 (Figure 1). These projects contain data from systematic samplings (see sampling transects in Figure 1) conducted on vessels by on-board observers, covering areas in the Santos Basin. Thus, the database is standardized for the three research projects, and their results were obtained applying the following methods: ship followers, continuous counts, and snapshot counts with on-board observers (see Daudt et al., 2019).

In addition, the online lists published in the technical reports of the *Projeto de Monitoramento de Praias* (PMP-BS) (2015–2021) and *Monitoramento de Impactos de Plataformas e Embarcações sobre a Avifauna da Bacia de Santos* (PMAVE) (2014–2020) were also reviewed and included in the integrative approach. PMP data were obtained from the SIMBA (Aquatic Biota Monitoring Information System) data repository and PMAVE data were extracted from the Annual Reports, available on the project website. Both PMP and PMAVE are also results of environmental licensing processes of PETROBRAS activities in the Santos Basin, whose data are available for consultation in online reports.

To spatially visualize the coverage of records obtained from bibliographic sources and data on species occurrence (presence) from the systematic data of LAATM/FURG, all geographic positions (latitude/longitude) per species or region of coverage referred to in the studies were identified. The taxonomic order of species and occurrence status in Brazil were based on Pacheco et al. (2021), while the threat status of each species was classified under global (IUCN, 2020) and national (MMA, 2022) lists. Finally, we divided species into "coastal" and "pelagic" based on the criteria defined by Croxall et al. (2012).

RESULTS

Systematic review

Based on the criteria established for this study, a total of 156 studies were analyzed, including publications between 1914 and 2021, all with coverage areas in the Santos Basin. An increase in the number of publications was observed after 2000 (> 80% of studies compiled), with the greatest number published in 2010 (n = 14) (Figure 2). Santa Catarina (56%) was the state with the highest number of publications, while the states of São Paulo and Rio de Janeiro accounted for 40% and 37% of studies surveyed, respectively. The state of Paraná had only 28% of publications analyzed. Among the total number of publications, only six were categorized at the national level, i.e., without a specific state defined within the basin, but with an indication of species occurrence in the area of the Santos Basin (Table S1).

Regarding subjects studied, "Notes and records" (27%) and "Population and community structure" (22%) were the categories with the highest number of publications, while "Fishing" appeared in 11% of publications (Figure 3). Other anthropic impacts were recorded in only 7% of the references analyzed, including metal pollution, persistent organic pollutants, and marine litter. Other categories were recorded at < 6%, demonstrating that several areas of knowledge still lack research efforts, and several species remain without detailed studies within the Santos Basin. The majority of subjects covered were recorded in the four states, except for studies on breeding biology and health studies, which were addressed only in the states of Paraná and Santa Catarina.

The Santos Basin contains 76 seabird species (Table S1), which represents 76% of the seabird species recorded in Brazil, according to Nunes et al. (2023). Among these, Procellariiformes was the most representative order (51%) and includes 14 species categorized under some degree of threat, either globally or nationally. Among these,

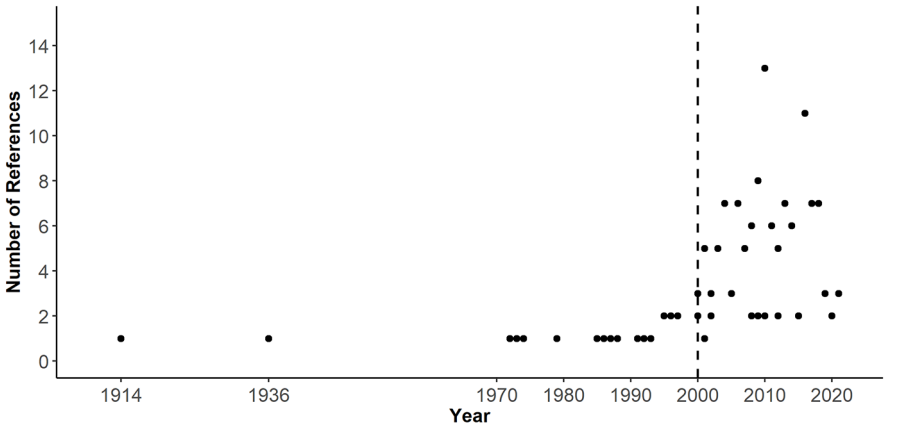

Figure 2. Number of publications over the last decades with records of seabirds in the Santos Basin area, Brazil.

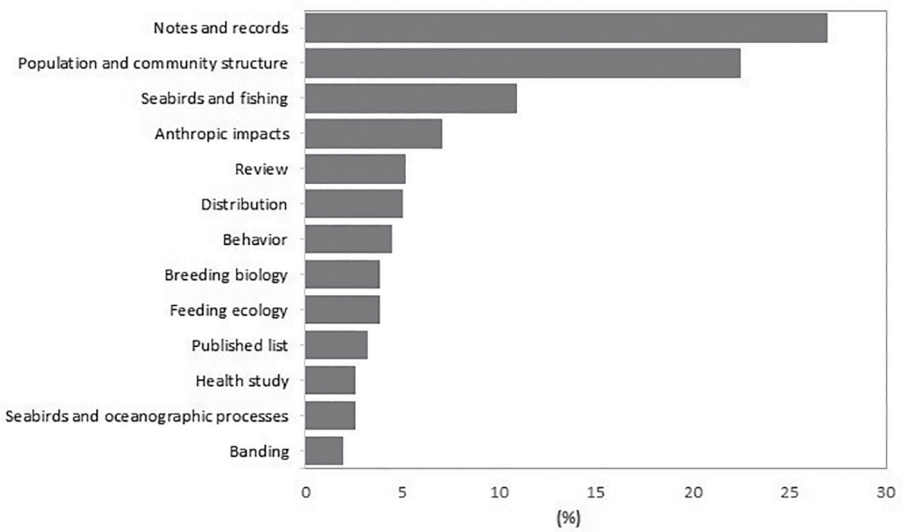

Figure 3. Proportion of researched topics involving seabirds, categorized based on the main objective of each publication analyzed.

Diomedea exulans, Pterodroma arminjoniana, and *Puffinus lherminieri* are classified as "critically endangered" at a national level, and *Diomedea dabbenena* is listed as "critically endangered" in both national (MMA, 2022) and global (IUCN, 2020) lists. For the Suliformes, of the five species recorded for the Santos Basin, only *Morus capensis* is classified as "endangered" at the international level (Table S1).

The highest number of species was recorded for the state of São Paulo (n = 61; 80%) and were predominantly pelagic (70%) (Table 1). The states of Rio de Janeiro and Santa Catarina had 56 (74%) and 57 (75%) species, respectively, also with a predominance of pelagic seabirds (Table 1). Paraná was the state with the lowest number of seabirds recorded in the bibliographic sources (66%) and the lowest number of coastal species (n = 9) (Table 1).

There are a few species with a single record in each state, such as *Aptenodytes patagonicus, Bulweria bulwerii*, *Chlidonias niger*, *Halobaena caerulea*, *Onychoprion fuscatus,* and *Phaethon aethereus* for the state of Rio de Janeiro; *Anous minutus*, *Lugensa brevirostris*, and *Phaetusa simplex* for the state of São Paulo; *Chionis albus* and *Thalassarche cauta* for Paraná; and *Larus atlanticus*, *Morus serrator*, and *Pterodroma lessonii* for Santa Catarina (Table S1). Some of these are considered vagrant species (e.g. *H.*

Table 1. Number of species extracted from the bibliography and seabirds' features by state bordering the Santos Basin. Classification into coastal and pelagic is based on Croxall et al. (2012). Status of occurrence are resident species, i.e. with breeding populations in Brazil or visitor/vagrant from Southern or Northern Hemispheres according with Pacheco et al. (2021). The features of each species are described in Table S1.

		Classification		Brazilian status of occurrence	
Santos Basin states	N of species	Coastal	Pelagic	Resident	Visitor/vagrant
Rio de Janeiro	56	14	42	13	43
São Paulo	61	18	43	18	43
Paraná	50	9	41	12	38
Santa Catarina	57	16	41	15	42

caerulea and *L. brevirostris*). The presence of migrants, including visitor and vagrant species, predominated in the four states of the Santos Basin (Table 1).

Southern visitors (39%), such as large skuas (*Stercorarius* spp.), albatrosses (e.g. *Thalassarche* spp.), and petrels/shearwaters (e.g. *Procellaria* spp., *Pterodroma* spp., and *Ardenna* spp.) are frequently found along the Brazilian coast and were widely recorded in the Santos Basin. In turn, species from the Northern Hemisphere, i.e. 'visitors' from the North (17%), and from Europe, i.e. visitors from Europe (12%), were reported in lower proportions but were also commonly recorded using the coast and pelagic regions of the Santos Basin (Table S1). Resident species, i.e. those breeding in Brazil (28%), such as *Larus dominicanus, Sula leucogaster,* and *Fregata magnificens*, were reported in the highest number of publications, with over 40 papers in the various study subjects (Table S1).

Integrative approach

While the literature review resulted in predominantly coastal or neritic studies, the integration of different databases - bibliographic and primary sources with unpublished data – allowed us to broaden the geographic cover of seabird species in the Santos Basin. Thus, a spatial cover toward offshore regions was verified. Through systematic monitoring conducted aboard vessels, it was possible to visualize the association of the most abundant species with certain habitats (Figure 4). The two most common albatross species *Thalassarche chlororhynchos* and *Thalassarche melanophris*, both migrants from the Southern Hemisphere (Figure 4), occur widely in the study region, but with marked differences in use of the region: while *T. chlororhynchos* is distributed across the study area, *T. melanophris* predominated in the southern areas of the Santos Basin, where waters are colder. This habitat segregation was also observed for *Procellaria aequinoctialis*, recorded frequently and in high numbers over the continental shelf and slope in the southern part of the basin, and *P. conspicillata*, which predominated in the shelf break/slope and pelagic areas, distributed across the study area (Figure 4). *Calonectris borealis* and *Ardenna gravis* (Figure 4), migrants from the Northern and Southern Hemisphere, respectively, were predominantly recorded in deep waters of the Santos Basin. In turn, resident seabirds (i.e. *F. magnificens* and *S. leucogaster*), which breed on Brazilian islands, were recorded both in the bibliographic sources and in the systematic censuses (LAATM/FURG) (Figure 4). Both species were registered on the continental shelf, including few records on the slope and pelagic region.

A total of 393 georeferenced locations were used from the publications analyzed (Figure 5), which covered most of the coastal areas of the four states belonging to the Santos Basin, with occasional records in the slope region. Besides these, 1,383 georeferenced occurrences were used from the LAATM/FURG dataset (Figure 5). A greater geographical cover of the basin was observed by pooling together these different sources.

Seven seabird species were recorded by PMAVE, which were sighted from the Maritime Units of oil and natural gas production, including *Anous stolidus*, a tropical species that breeds on Trindade Island (Mancini et al., 2016), the

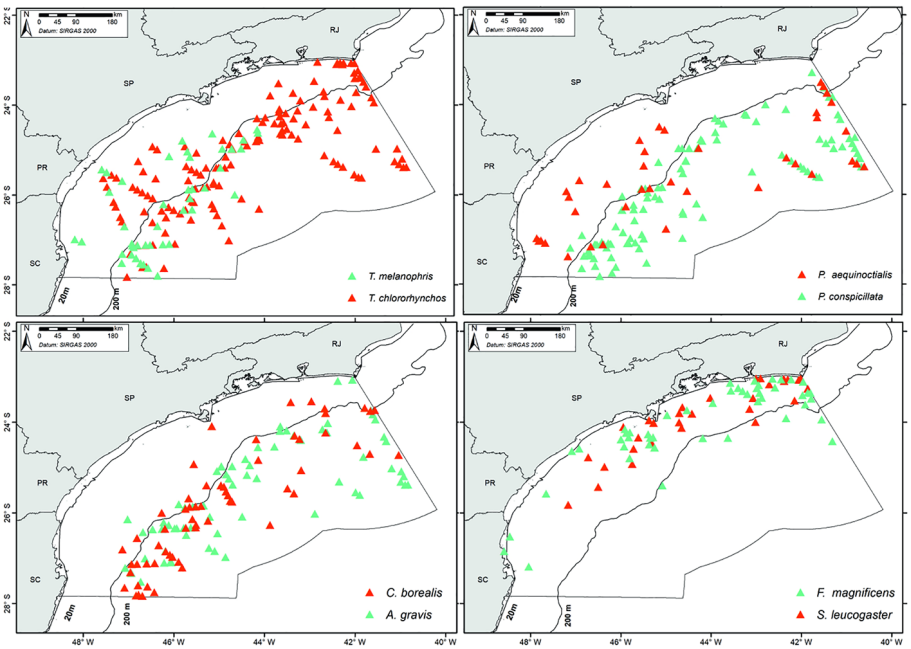

Figure 4. Occurrence (presence) of the most abundant species recorded from systematic monitoring onboard offshore vessels (LAATM/FURG database). Brazilian states: Rio de Janeiro (RJ), São Paulo (SP), Paraná (PR) and Santa Catarina (SC).

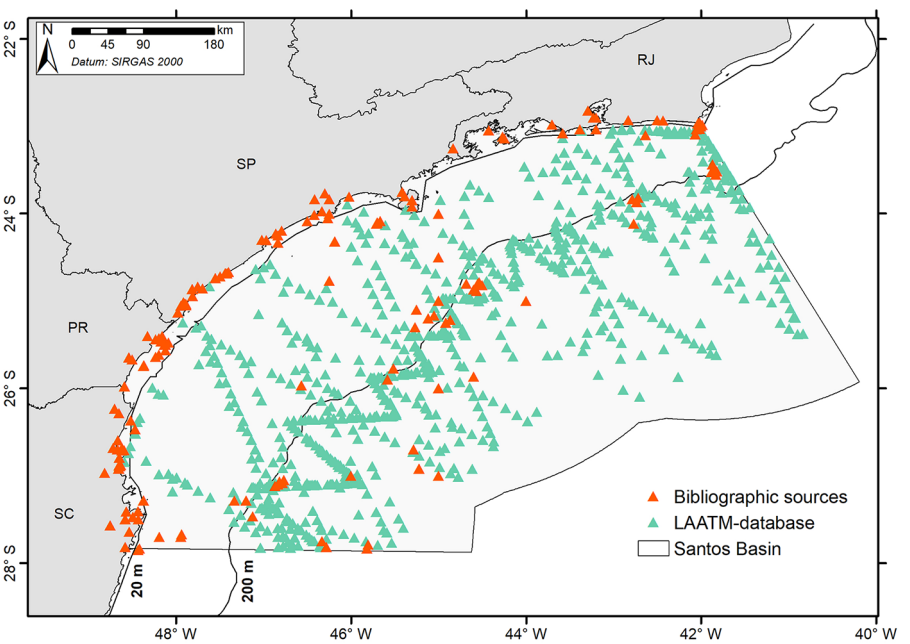

Figure 5. Spatial distribution of the bibliographic sources (orange triangles) and primary data (green triangles) obtained in standardized counts onboard vessels in the LAATM/FURG database. Brazilian states: Rio de Janeiro (RJ), São Paulo (SP), Paraná (PR) and Santa Catarina (SC).

southernmost breeding location in Brazil located eastward of the Santos Basin. Through the beach monitoring database (PMP-BS), 47 species were recorded, mostly dead specimens found on the beach and thus with uncertain oceanographic distribution (Table S1). These records obtained

through different techniques and from different areas of the Santos Basin allow for confirmation of the species in the region.

DISCUSSION

In this review, 156 publications on seabirds in the Santos Basin were identified, which resulted in the confirmation of the occurrence of 76 seabird species in the area. Other studies conducted on the Brazilian coast in the Campos (Lima et al., 2017) and Sergipe-Alagoas (Almeida et al., 2019) Basins recorded 43 and 37 seabird species, respectively. The Santos Basin is larger than these other basins, in addition to having been subject to systematic surveys at sea involving substantial sampling effort related to environmental licensing processes and research projects. In addition, an extensive list of previous studies explains the higher number of species recorded. However, different size of basins, sampling efforts, and methods allow for rudimentary comparisons, at best. Moreover, the Santos Basin is an important transition area for species from the Northern (e.g. *Sterna paradisaea*) and Southern (e.g. *Thalassarche* spp.) Hemispheres and migrants from Europe, Africa (e.g. *C. borealis*), and Oceania (e.g. *D. epomophora* and *T. cauta*) (Olmos et al., 1995; Olmos, 2002; Olmos and Bugoni, 2006; Egevang et al., 2010; Mestre et al., 2010; Silveira and Uezu, 2011; Dias et al., 2012). Many of these species occur in the area seasonally in search of food, or throughout the year, such as *T. chlororhynchos*, which has been recorded in all four states investigated and was the most studied albatross in the region (e.g. Harris and Hansen, 1974; Barbieri et al., 2019). On the other hand, the albatross *T. cauta*, from the Southern Hemisphere, is considered vagrant into the Brazilian territory (Costa et al., 2011; Scherer-Neto et al., 2011).

In general, large seabirds, particularly albatrosses and petrels (e.g. *Thalassarche* sp., *Diomedea* sp., and *Pterodroma* sp.), are increasingly threatened and rank among birds with the highest threat risk (Butchart et al., 2004; Dias et al., 2019). International recommendations include collecting additional information, particularly during juvenile and non-breeding periods, and analyzing threat patterns and trends (BirdLife International, 2004; Delord et al., 2008). In the present study, this group featured the highest number of species in the basin, including the most listed as threatened. Several studies in the area were associated with incidental capture (Bugoni et al., 2008a), contamination by plastics (Barbieri, 2009), and oil (Michels-Souza et al., 2010).

The annual trend of scientific production on seabirds in the Santos Basin has increased over the last few years, similar to what was observed by Moraes-Ornellas (2009). This seems to reflect a greater interest in seabird studies associated with the increase in number of graduate courses in the region and the increase in scientific production in general in the country, as observed in all areas of knowledge and by the high number of species found in the present study in each state of the Santos Basin.

Among topics covered in the publications analyzed, the notes and records of occurrences stand out. Publications of this nature are important ornithological observation records, such as the expeditions by Murphy (1914). Additionally, whenever a new seabird species is recorded, a note is published. Species such as *P. marina* (Soto et al., 2004) and *H. caerulea* (Teixeira et al., 1985), for example, were included in this survey due to a single note or record of occurrence. This highlights the importance of publishing records of seabirds of occasional occurrence, expanding knowledge of both the avifauna of the region studied and the distribution patterns of the species.

The second most commonly addressed topic in the region was population studies and bird community structures. Studies of this nature are frequent due to the presence of colonies on the coastal islands of the Santos Basin, particularly of *S. leucogaster* (Alves et al., 2004; Branco et al., 2010), *F. magnificens* (Nuss et al., 2016), *L. dominicanus* (Branco and Ebert, 2002; Barbieri, 2008; Yorio et al., 2016), and, to a lesser extent, Sternidae (Efe et al., 2007; Yorio and Efe, 2008). Much of the knowledge of seabirds in the Santos Basin is with respect to coastal areas and therefore focused on these species (e.g. *Spheniscus magellanicus*), which have been

extensively studied in relation to animal health (Martini et al., 2022).

Regarding species with questionable occurrence in the Santos Basin, *Puffinus assimilis* was recorded by PMP and by Costa et al. (2011) but is listed only in the Brazilian tertiary list, recently updated by Pacheco et al. (2021) and, given the absence of verifiable evidence, was not included in the species list here. Similarly, there are citations of *Pterodroma macroptera* for the area, which are questionable and possibly refer to confusion with similar species (see Bugoni, 2006; Valls et al., 2021 for an extensive discussion). Regarding *T. chrysostoma*, there are many records in the region off the southern and southeastern Brazilian coast (see Costa et al., 2011) and several individuals between the states of São Paulo and Santa Catarina (Sick, 1979; Rosário, 1996). However, these records could be attributed to *T. chlororhynchos* (see Bencke et al., 2010 for an extensive discussion of the confusion between these two species on the Brazilian waters). In turn, the numerous mentions of *C. diomedea* both in the Santos Basin and along the Brazilian coast are predominantly attributable to *C. borealis*, now considered a full species (see Oliveira et al., 2019 on the separation of species of the genus). Both *C. borealis* and *C. diomedea* surely occur in the Santos Basin. Regarding *T. cauta*, this species has also been separated into *T. steadi*, *T. salvini*, and *T. eremita* (Dellacasa et al., 2022), and possibly occur on Brazilian territory, but *T. cauta* and *T. steadi* are indistinguishable at sea and require genetic analysis for specific assignment (Pereira et al., 2016). Similarly, *P. deserta* had been included in the list due to unquestionable tracking data from Northern Hemisphere colonies (Ramos et al., 2017) and two specimens in southeastern Brazil, which are predicted to have crossed the studied area (Brusco et al., 2021). Other species of the *P. feae*-complex are expected in the area. Finally, *Xema sabini* was found by PMP (Prado et al., 2021), but the record occurred just south of the Santos Basin boundary; it was thus excluded from this review.

The relationship between fisheries and seabirds, either through the consumption of discards by birds (e.g. Branco, 2001; Carniel and Krul, 2012a,b), or by incidental capture (e.g. Bugoni et al., 2008a), is another important theme addressed in the publications analyzed. As visual predators, they often seek fishing vessels and/or feed on fish discarded from fishing operations. Thus, research that follows fishing fleets also allows for the identification of associated avifauna (e.g. Olmos, 1997). To some extent, seabirds benefit from fishing activity by gaining access to food resources that would otherwise be unavailable, such as demersal fish or offal of large fish (tuna, billfishes) and sharks. On the other hand, species can be captured by fishing gear; this interaction is one of the main causes of the threat levels of many species. Studies frequently investigate seabirds and their relationship to longline fishing and incidental species capture (Olmos and Bugoni, 2006; Olmos et al., 2006; Bugoni et al., 2008a; Bugoni et al., 2009; Canani et al., 2020). The Santos Basin is a region with intense fishing activity (e.g. Sales et al., 2008; Canani et al., 2020) that receives migratory species, some listed as "critically endangered" (e.g. *D. dabbenena*, *D. exulans*), which demonstrates the importance of studies addressing threats and conservation issues.

However, few studies addressed the relationship between seabirds and oceanographic processes in the Santos Basin, for example by using tracking (e.g. Bugoni et al., 2009) or bird counts at sea (e.g. Neves et al., 2006). Monitoring avifauna through systematic observation aboard vessels is costly and time-consuming but necessary to accurately establish abundance and distribution of bird species at sea. In turn, beach monitoring (e.g. PMP), which collects and studies carcasses of birds, allows us to identify species that occur in the region and sample tissues, as well as to study anthropic impacts (e.g. Michels-Souza et al., 2010; Moura et al., 2018), contamination by petroleum (e.g. Barbieri, 2009; Michels-Souza et al., 2010), and impacts to animal health (Niemeyer, 2014; Ebert et al., 2016; Fink et al., 2018; Vanhoni et al., 2018; Martini et al., 2022). However, studies on the

spatial distribution of seabirds along the Santos Basin are scarce, be they from at-sea counts or tracking data, and are restricted to few species and to the neritic region (< 20 m depth).

CONCLUSION

Although the area sampled is limited compared to the entire Brazilian territory (along 40 degrees of latitude and 7,000 km of coastline and adjacent waters), a large number of species uses the Santos Basin for breeding, foraging, and as a migratory corridor for trans-hemispheric or intra-hemispheric movements. The combination of unpublished data obtained in the framework of the Santos Basin project and other projects through observations on at-sea platforms has satisfactorily complemented spatial gaps in bird records, especially offshore where data were especially limited. A substantial number of studies on seabirds in the Santos Basin focused on a few subjects. The number and rarity of species is well-established, and additional species probably reach the area as vagrants. The integration of information and sampling methods improves the ecological understanding of seabird species, allowing for environmental impact assessments of the activities of the offshore oil and gas industry. However, efforts to establish the abundance and distribution of seabirds across the entire Santos Basin region (both coastal and pelagic) and to understand the relationship between birds and oceanographic and meteorological characteristics were found to be scarce. Similarly, many species have not yet been the subject of specific studies in the area, abundance notwithstanding. Additionally, impact studies on fishing, contamination by marine litter and organic and inorganic pollutants, and oceanographic processes on species are still scarce. Essential topics of focus to support conservation actions going forward include the relationship between species and threats, the importance of protected areas in the basin, and demographic studies addressing population viability, connectivity, and dynamics between populations and colonies. Given the complex environmental scenario, with various threats to seabird conservation already identified and others expected in the coming years such as off-shore wind farms (Bugoni et al., 2022) and global warming (Baum and Worm, 2009), the continued assessment of seabird populations in the Santos Basin and impact mitigation and prevention is necessary.

ACKNOWLEDGMENTS

We thank Petrobras for the possibility of collecting and analyzing material through the PD&I investment clauses of the *Agência Nacional do Petróleo, Gás Natural e Biocombustíveis* do Brasil (oil & gas regulatory agency, ANP) through the Santos Project – Santos Basin Environmental Characterization (PCR-BS). We also thank *Projeto de Monitoramento de Cetáceos na Bacia de Santos* - PMC-BS (Cetacean monitoring project in the Santos Basin), a program required by IBAMA (federal environmental agency) for environmental licensing of oil production and transport by Petrobras in the Santos Basin, run by *Socioambiental Consultores Associados* and *Fundação de Apoio à Universidade de São Paulo* (FUSP) as management partner (Proc. No. 2017/00686-0 and 3366). The authors are also grateful to *Projeto Talude* at FURG, coordinators, to seabird observers who provided substantial support for the sampling presented herein, and to anonymous reviewers whose suggestions helped improve and clarify this manuscript. F.C.L.V., P.L.C., and D.R.A. received a postdoctoral scholarship granted by FUSP Petrobras/CENPES, and L.B. is a research fellow of the *Conselho Nacional de Desenvolvimento Científico e Tecnológico* - CNPq (Proc. No. 311409/2018-0).

AUTHOR CONTRIBUTIONS

F.C.L.V.: Writing – original draft preparation, Formal analysis, Conceptualization, Investigation, Writing – review & editing.

P.L.C.: Formal analysis, Conceptualization, Investigation, Writing – review & editing.

D.R.A.: Writing – review & editing.

L.B.: Supervision, Resources, Conceptualization, Investigation, Writing – review & editing.

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