Lost in the Voidness of the Atlantic Ocean: a Synthesis of Publication Trends, Biological Diversity, and Conservation in Trindade Island

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ABSTRACT – Trindade is an oceanic island of volcanic origin in the South Atlantic. Although highly disturbed, the island hosts a rich biological diversity, serving as a *habitat* for many endemic species. Scientific research in Trindade has generated a vast amount of literature in the last 300 years. Nonetheless, an objective scientific synthesis summarizing the main research findings in the last century is still lacking, which prevents us to understand the knowledge gaps and to propose a way forward to better understand biodiversity and promote its conservation. Thus, this paper aims to present a synthesis of the research performed on Trindade Island, with emphasis on Biological Sciences studies. Therefore, an online search with specific strings on CrossRef, Google Scholar, and National Center for Biotechnology Information was performed, as well as a search on global extinction risk on the red list of the International Union for Conservation of Nature. Our search recovered 312 references, mainly from Biological, Health, and Agrarian Sciences research areas. More than 1000 species have occurrences reported on the island, most of them from oceanic environments. A total of 32 species occurring in Trindade are considered under threat of extinction. Animals and plants are the most studied organisms while the diversity of microorganisms is the main knowledge gap in the recognition of the island's biota. Data about the biological diversity of the island, conservation, and publication trends are shown and discussed. A list of all the reported species in the retrieved literature and their conservation status is also presented.

Keywords: Biodiversity; oceanic islands; island biogeography; species extinction.

Perdida em Meio à Vastidão do Oceano Atlântico: Síntese da Tendência de Publicações, Diversidade Biológica e Conservação na Ilha da Trindade

RESUMO – Trindade é uma ilha oceânica de origem vulcânica no Atlântico Sul. Embora tenha sofrido muitos impactos ambientais, a ilha abriga uma rica diversidade biológica, sendo *habitat* de várias espécies endêmicas. As pesquisas científicas nos últimos 300 anos geraram um grande volume de literatura especializada. No entanto, não existe uma síntese científica sumarizando os principais achados das pesquisas no último século na ilha, o que dificulta o entendimento das lacunas do conhecimento, bem como o reconhecimento da biodiversidade na ilha e como promover sua conservação. Essa revisão tem por objetivo apresentar uma síntese da pesquisa científica realizada na Ilha da Trindade, com ênfase na área de ciências biológicas. Para tanto, foi realizada uma busca online com palavras-chave no CrossRef, Google Scholar e NCBI, e pesquisa sobre a ameaça de extinção global na lista vermelha da União Internacional para a Conservação da Natureza. Foram recuperadas 312 referências, principalmente de pesquisas da área de Ciências Biológicas, da Saúde e Agrárias. Mais de 1000 espécies divididas em cinco reinos têm ocorrência relatada na ilha, a maioria em ambientes oceânicos. Trinta e duas espécies que ocorrem em Trindade estão ameaçadas de extinção. Animais e plantas são os organismos mais estudados, enquanto a diversidade de microrganismos é a principal lacuna de conhecimento no reconhecimento da biota da ilha. Dados sobre a diversidade biológica

da ilha, conservação e tendências de publicação são apresentados e discutidos. Uma lista de todas as espécies relatadas na literatura recuperada e seu estado de conservação também é apresentada.

Palavras-chave: Biodiversidade; ilhas oceânicas; biogeografia de ilhas; extinção de espécies.

Perdida en el Vacío del Océano Atlántico: una Síntesis de Tendencias de Publicación, Diversidad Biológica y Conservación en la Isla Trindade

RESUMEN – Trindade es una isla oceánica de origen volcánico en el Atlántico Sur. Aunque muy perturbada, la isla alberga una rica diversidad biológica, que sirve como *habitat* para muchas especies endémicas. La investigación científica en Trindade ha generado una gran cantidad de literatura en los últimos 300 años. Sin embargo, aún falta una síntesis científica objetiva que resuma los principales hallazgos de la investigación en el último siglo, lo que nos impide comprender los vacíos de conocimiento y proponer un camino a seguir para comprender su biodiversidad y promover su conservación. Por lo tanto, este artículo tiene como objetivo presentar una síntesis de la investigación realizada en la Isla, con énfasis en estudios de Ciencias Biológicas. Por lo tanto, se realizó una búsqueda en línea con palabras clave en CrossRef, Google Scholar y NCBI, y búsqueda de riesgo de extinción en la lista roja de la Unión Internacional para la Conservación de la Naturaleza. Nuestra búsqueda recuperó 312 referencias, principalmente de las áreas de Ciencias Biológicas, de la Salud y Agrarias. Más de 1000 especies tienen ocurrencias reportadas en la isla y 32 especies están en peligro de extinción. Los animales y las plantas son los organismos más estudiados mientras que la diversidad de microorganismos es el principal vacío de conocimiento en relación a la biota de la isla. Se muestran y discuten datos sobre la diversidad, conservación y tendencias de publicación. También se presenta una lista con todas las especies reportadas en la literatura recuperada y su estado de conservación.

Palabras clave: Biodiversidad; islas oceánicas; biogeografía insular; extinción de especies.

Introduction

Trindade Island is located in the South Atlantic, around 1,140 km from the nearest point in Brazil (Castro, 2010) and 4,200 km from Africa. The island originated from volcanic activities approximately 3 million years ago (Almeida, 1961; Greenwood, 1998; Monteiro et al., 2022) with an emerse area of ca. 13.5 Km^2, encompassing peaks of ca. 600 m high (Castro, 2010). Trindade is the most eastward point of the Brazilian territory and is part of the oceanic islands off the coast of eastern Brazil, within the Tropical Southwestern Atlantic world marine ecoregion (Spalding et al., 2007).

The human occupation of the island was initially disputed between Portugal and England, but, in the end, the island was attributed as a Brazilian territory in 1822, but its discovery is usually referred to the early XVI century (Marston, 1984). Because of human occupation, both intentional and unintentional introduction of domestic animals, such as goats, rats, cats, and dogs, among others, became a problem for the native biodiversity of the island, including the extinction of natural populations. One emblematic example is the tree *Colubrina glandulosa* Perkins (Rhamnaceae), which vastly covered the island in the past (Witovisk et al., 2018). The natural population was unfortunately extinct and remained as a mysterious dead forest reported during several explorations since 1783 (Eyde and Olson, 1983; Alves and Silva, 2016; Alves and Silva, 2017).

After the eradication of introduced alien animals in 2005, especially goats (which were the most pernicious ones), the terrestrial vegetation has gradually recovered (Silva and Alves, 2011). In addition, several new records of species on the island have been registered in recent expeditions (Alves et al., 2011; Silva et al., 2013; Alves and Silva, 2017). Nonetheless, the negative impact of the disturbances caused by human occupation and introduced species can still be observed due to the severity of disturbances (lack/delay of natural regeneration of vegetation due to grazing) caused by them on ecosystem functioning and composition (personal observation). As an example of the difficulties in the restoration of the island, an experimental reintroduction of *Colubrina glandulosa* was performed in the early 2000s, but most of the trees are currently dead or almost dead (Alves et al., 2011; Witovisk et al., 2018). This slow recovery or difficulty in restoration may be

an indication of either or both low resilience of the Trindade *habitat* or a severe impact on its natural *habitat*.

Trindade hosts a vast biological diversity in its marine and terrestrial ecosystems, including several endemic species, and, consequently, it has a great potential for the discovery of scientific novelties (Pereira-Filho et al., 2011; Cunha et al., 2015; Guimarães et al., 2010; Pinheiro et al., 2010). The island is known for being one of the most important sites for nesting of the endangered green turtle *Chelonia mydas* Linnaeus in the South Atlantic, as well as the largest area for the reproduction of seabirds in Brazil, including the endangered *Pterodroma arminjoniana* Giglioli & Salvadori (Moreira et al., 1995, 2017; Leal, 2017). Due to its biological relevance, since 2018, the island is part of two Brazilian conservation units, the "Área de Proteção Ambiental do Arquipélago de Trindade e Martim Vaz" and "Monumento Natural das Ilhas de Trindade, Martim Vaz e do Monte Columbia" (Brasil, 2018).

The geographic position of Trindade and its relatively recent volcanic origin is of special interest for scientific research due to the possibility to study long-distance colonization, migration, as well as other island biogeographical processes. Although discovered more than five centuries ago, scientific studies on the island practically started only two centuries later. Along the 300 years of scientific exploration, several naturalists, researchers, and pathfinders moored on the island. Famous names, such as the astronomer Edmond Halley (1700), captain James Cook (1775), and the botanist Joseph Dalton Hooker (1839) are among the contributors to the first half of scientific studies conducted on the island. Studies carried out by Brazilian naturalists were intensified only after the 1900s, mainly with researchers of the Brazilian National Museum, with a notorious contribution of the naturalist Johann Becker (1959-1965) (Alves and Silva, 2016).

A few conservation-related studies with plants were carried out on the island. These could be explained due to the historical damages to Trindade's Flora since the late 1700s (e.g. deforestation and introduced fauna), which resulted in extensive loss of native vegetation (Alves et al., 2011). Efforts were made by the Brazilian Navy and, by 2005, all the introduced animals that cause overgrazing, especially goats, were eradicated. This conservation initiative allowed the natural regeneration of the island vegetation (Silva and Alves, 2011).

Among the scientific publications based on research performed on the island, there is a thorough commented list of Trindade's Flora (Alves, 1998), a remarkable commented historical review of natural history studies performed on the island until 2010 (Alves and Silva, 2016), and a summary of ten years of research (2007-2017) under the PROTRINDADE project (PROTRINDADE, s.d.). Nevertheless, considering the strategic and biological importance of Trindade Island, an objective scientific synthesis summarizing the main research findings in the last three centuries is still lacking.

Thus, our study aimed at presenting a scientific synthesis of the knowledge related to Trindade Island, with a research emphasis on biological sciences. The main guiding questions for the study were: (i) which are the studies' research areas carried out on the island?; (ii) how are the studies distributed among the several *habitat* found on the island?; (iii) how are the studies distributed among the higher-level taxonomic groups?; (iv) how many species in Trindade are under extinction risk according to International Union for Conservation of Nature criteria?; (v) which are the greatest knowledge gaps for fully discovering Trindade's biota?

Material and Methods

We considered Crossref and Google Scholar indexing databases for our scientific synthesis. We applied a search strategy with the query string "Trindade Island" OR "Ilha da Trindade" OR "Ilha da Trindade'' occurring either in the title, abstract, or full text, and the publication period was set from 01/01/1700 to 10/08/2022. This search strategy was applied for the aforementioned indexing databases with Publish or Perish 7 software (Harzing, 2007) and downloaded to Microsoft Excel©. A secondary search was performed by searching for each reference (not retrieved in the primary search) cited in the following books: Alves (1998), Mohr et al. (2009), and Alves and Silva (2016). Only the studies that we could access in full were included in our study.

We extracted the following attributes relating to each selected study: year, publication type, research area – Biological, Health, and

Agrarian Sciences (Biodiversity / Biogeography / Bioremediation / Conservation / Ecology / Environmental monitoring / Forestry / Genomics / Population Genetics / Phylogeography / Reproductive biology / Taxonomy / Toxicology) / Human and Social Sciences / Technologies, Exact and Earth Sciences / Interdisciplinary, environment (oceanic, terrestrial, mixed, freshwater, and atmospheric).

Each literature in the Biological, Health, and Agrarian Sciences category was transformed into a text file with pdf2txt (Jasper, 2021) and automatically separated by the occurrence of the strings 'endemic', 'native', 'exotic' and their variations for posterior manual inspection to gather information about endemic, exotic, and native species occurrence in Trindade. Furthermore, we listed all the species cited in the selected literature. Only taxa identified to the species level were covered in this search, including direct and indirect (i.e. eDNA based) observation methods. The species names were corrected and checked for synonyms, and taxonomic information was gathered using the GBIF backbone (GBIF Secretariat, 2021) with GBIF's species matching online tool.

DNA and protein sequences from studies related to Trindade's biota were searched within the NBCI Nucleotide database through an API connection with the Entrez Molecular Sequence Database System. The terms "Trindade" and "Island" were used to fetch sequence identification numbers that were further treated with a personal Python script.

The retrieved species list was searched by individual species against the IUCN Red List Data (IUCN, 2021) with an API connection, recovering the conservation status of all globally evaluated species. All data treatment and manipulation were implemented in Python 3.8.6 (Van Rossum e Drake, 2009) and R 3.2.2 (R Core Team, 2020). Graph representations were performed in R 3.3.2 (R Core Team, 2020) using the ggplot2 package (Wickham, 2016) (https://cran.rproject.org).

Results

The primary literature search retrieved 221 entries while the secondary literature retrieved 91 entries, with a total of 312 references. Although the search was set from the 1700s, publications were recovered only after 1922. References not related to Trindade and unavailable online for download were excluded from the dataset used in all subsequent analyses, resulting in 212 entries kept from the primary search and 45 from the secondary one (Supplementary Table 1). The number of publications resulting from research performed on the island increased in the decade of 1950 but only reached its peak after 2000, especially from 2010 onwards (Fig. 2). These studies have been dominated by Biological, Health, and Agrarian Sciences research (especially on biodiversity and taxonomy) (Fig. 2). The vast majority of the literature recovered in the reference time for Trindade Island is published as scientific articles (n=173). Theses (undergraduate, master, doctoral), conference papers or presentations, books and book chapters, reports, and technical notes were also recovered, but at a lower abundance.

According to the revised literature, the most studied environment is the oceanic, followed by terrestrial, mixed (different environments in the same study), freshwater (ephemeral freshwater creeks), and atmospheric (Fig. 1).

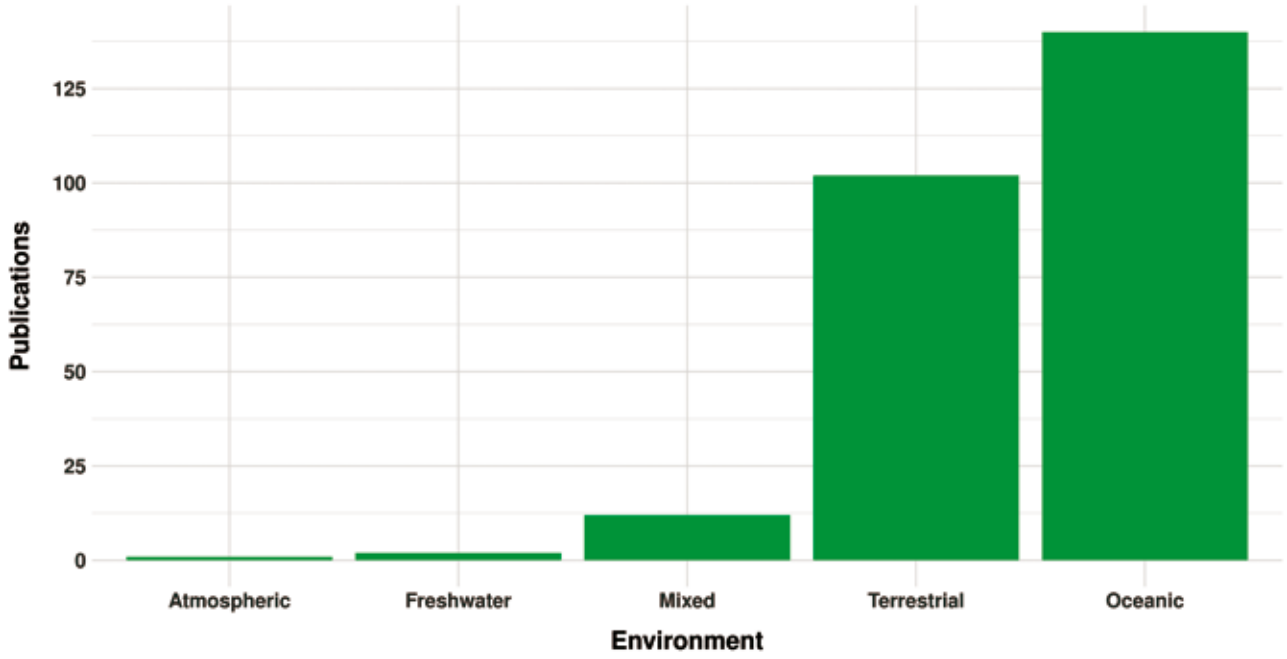

Figure 1 – Number of publications related to each defined environment.

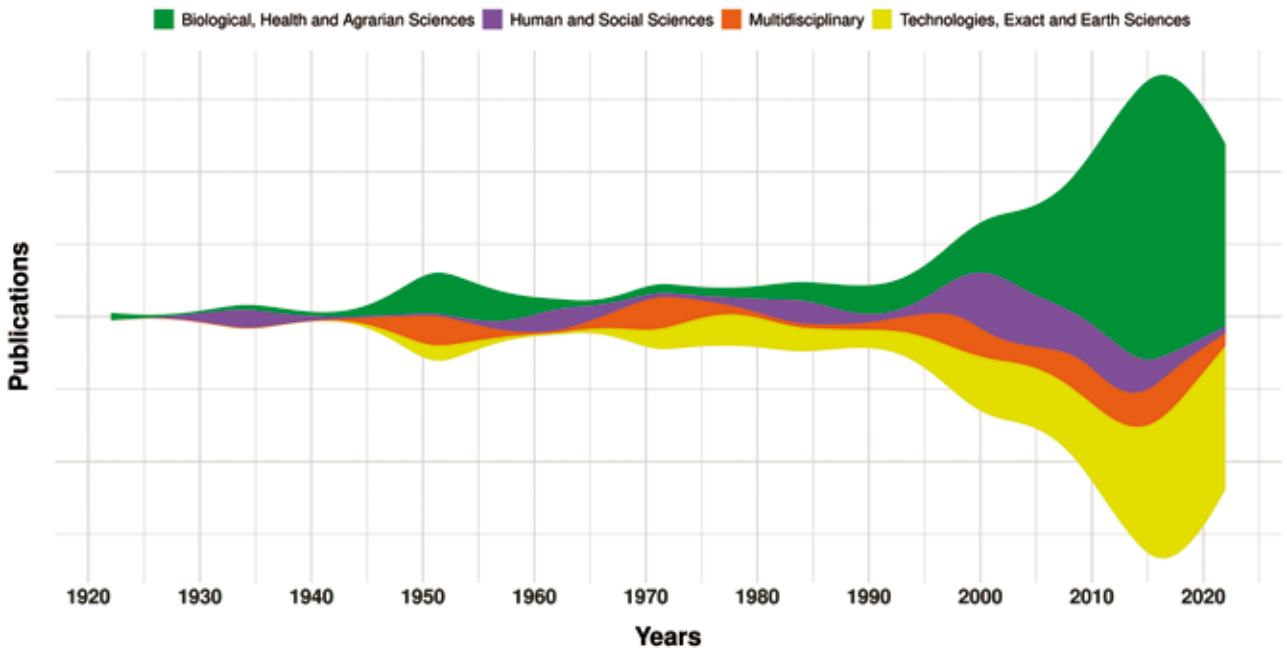

Figure 2 – Identified areas publication trends from 1920 to 2020.

A careful exam of each literature classified in Biological, Health, and Agrarian Sciences retrieved a list with 1076 accepted exotic and native species with occurrence reported for Trindade Island (Supplementary Table 1). The species are representative of both prokaryotic and eukaryotic lineages, distributed across Animalia, Bacteria, Chromista, Fungi, and Plantae in 28 phyla (Fig. 3). Among the retrieved kingdoms, Animalia and Plantae received the most efforts, encompassing 112 and 40 publications, leaving Chromista, Bacteria, Fungi and Protozoa as the major knowledge gaps in terms of biodiversity discovery for Trindade, which is reflected in the low number of publications related to these kingdoms (Fig. 4). Therefore, Animalia and Plantae comprise most of the species recorded. In total, 563 animals and 321 plants (including algae: Chlorophyta and Rhodophyta) species were recorded, followed by 132 fungal species. Around 30 species are reported for each of the other two kingdoms. Marine algae totalize 198 species retrieved in literature. These species are accommodated within Chromista (30 species), Chlorophyta (72), Rhodophyta (74), and Cyanobacteria (12). According to the retrieved literature, 35 species are endemic to the island (23 animals, 11 plants, and one fungus) while 38 are introduced (10 animals and 28 plants) (Supplementary Table 2).

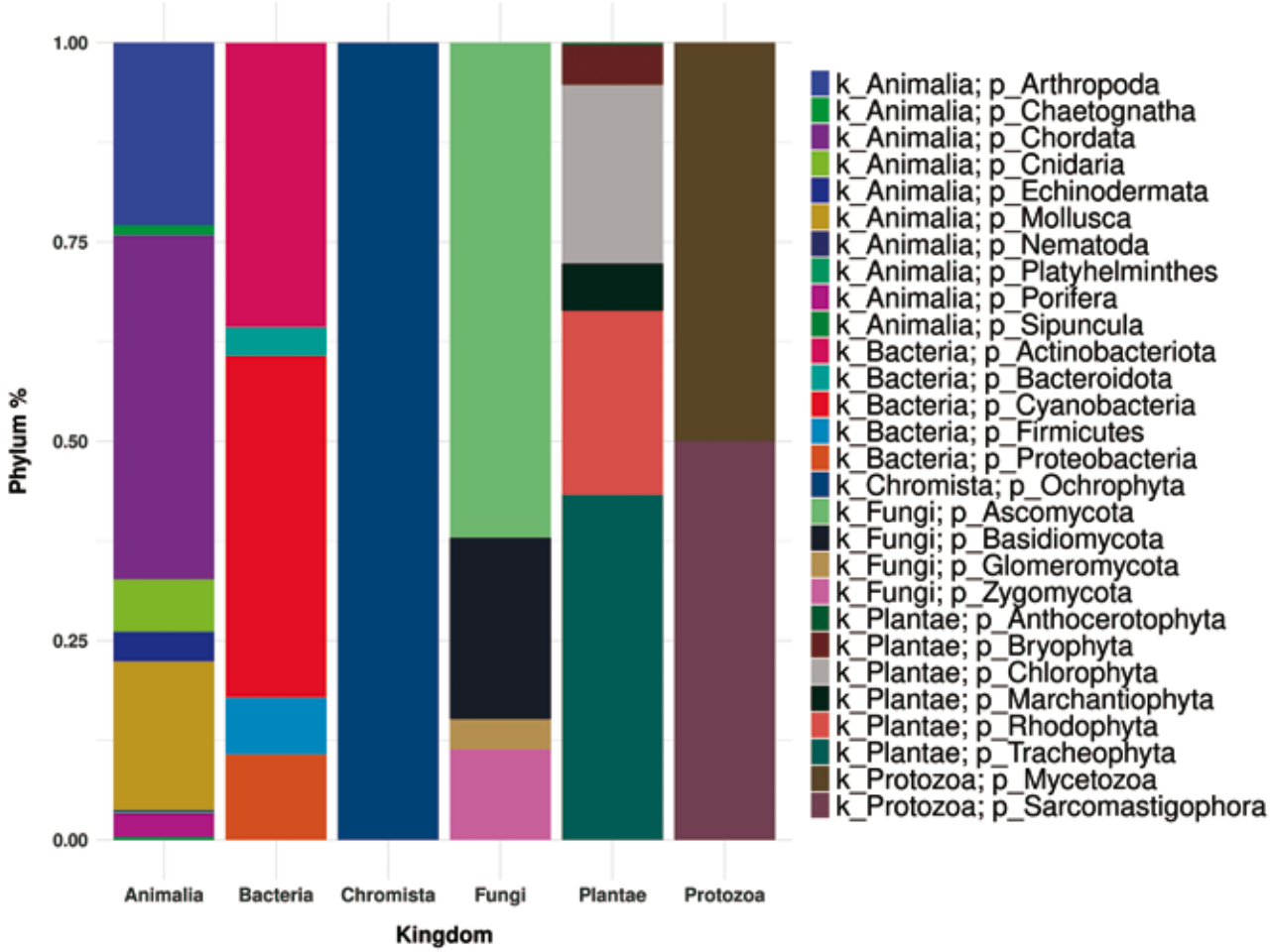

Figure 3 – Phyla percentage within retrieved Trindade's biota kingdoms.

The search at NCBI Nucleotide database retrieved 689 entries. The majority (564) of those entries correspond to sequences from draft genomes of three bacterial species: *Staphylococcus warneri* Kloos and Schleifer, *Nocardia farcinica* Trevisan, and *Rhodococcus rhodochrous* Zopf.

The remaining corresponds to amplicon sequences of species of *Campylopus* Brid. (68), *Peperomia* Ruiz & Pav. (26), *Bacillus* Berthold (14), *Exiguobacterium* Collins et al. (4), *Tistrella* Shi et al. (4), *Mycobacterium* Lehmann and Neumann (4), *Cellulosimicrobium* Schumann et al. (1), *Grapsus* Lamarck (1), *Nocardia* Trevisan (1), *Pempheris* Cuvier (1) and *Rhodococcus* Zopf (1). The NCBI Protein database includes 6848 entries, being 4823 of *Nocardia farcinicia* Trevisan, 2461 of *Staphylococcus warneri*, 45 of *Campylopus* spp., 17 of *Peperomia* spp. and one of *Pempheris gasparini* Pinheiro, Bernardi and Rocha.

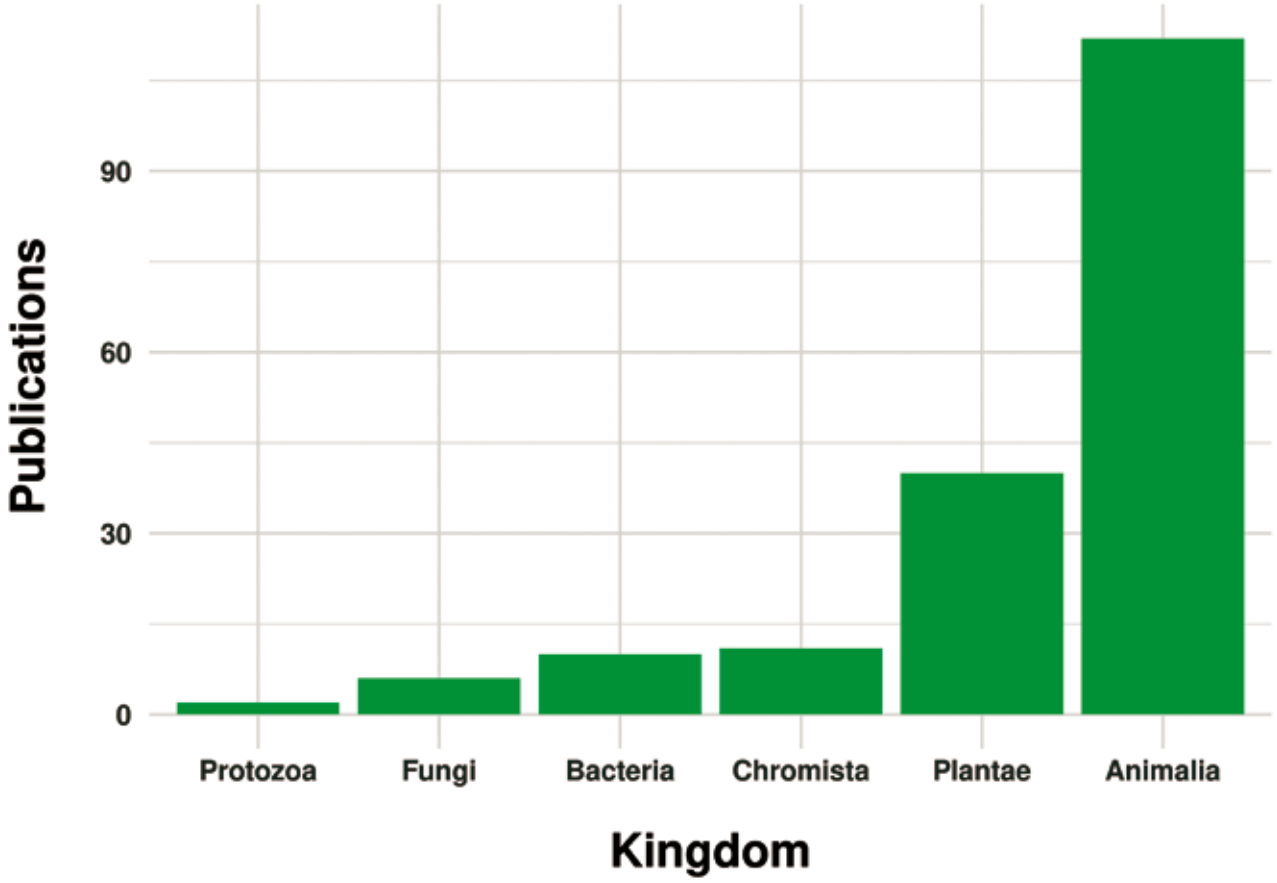

Figure 4 – Number of publications related to the retrieved Trindade's biota kingdoms.

The global conservation status of Trindade is unknown for 788 species (Not Evaluated) out of the 1076 species recovered. Amongst the 288 evaluated species, almost 80% are considered Least Concern, representing 226 species (Fig. 5). Thirty-two species are considered threatened to some degree, with four Critically Endangered, 10 Endangered, and 18 Vulnerable, accounting for 11% of Trindade Island's evaluated biota (Fig. 5). The threatened categories are dominated by marine animals, with just four plant and one fungal species (see discussion), which, among them, two were introduced on the island (*Araucaria angustifolia* (Bertol.) Kuntze and *Paubrasilia echinata* (Lam.) Gagnon, H.C.Lima & G.P.Lewis).

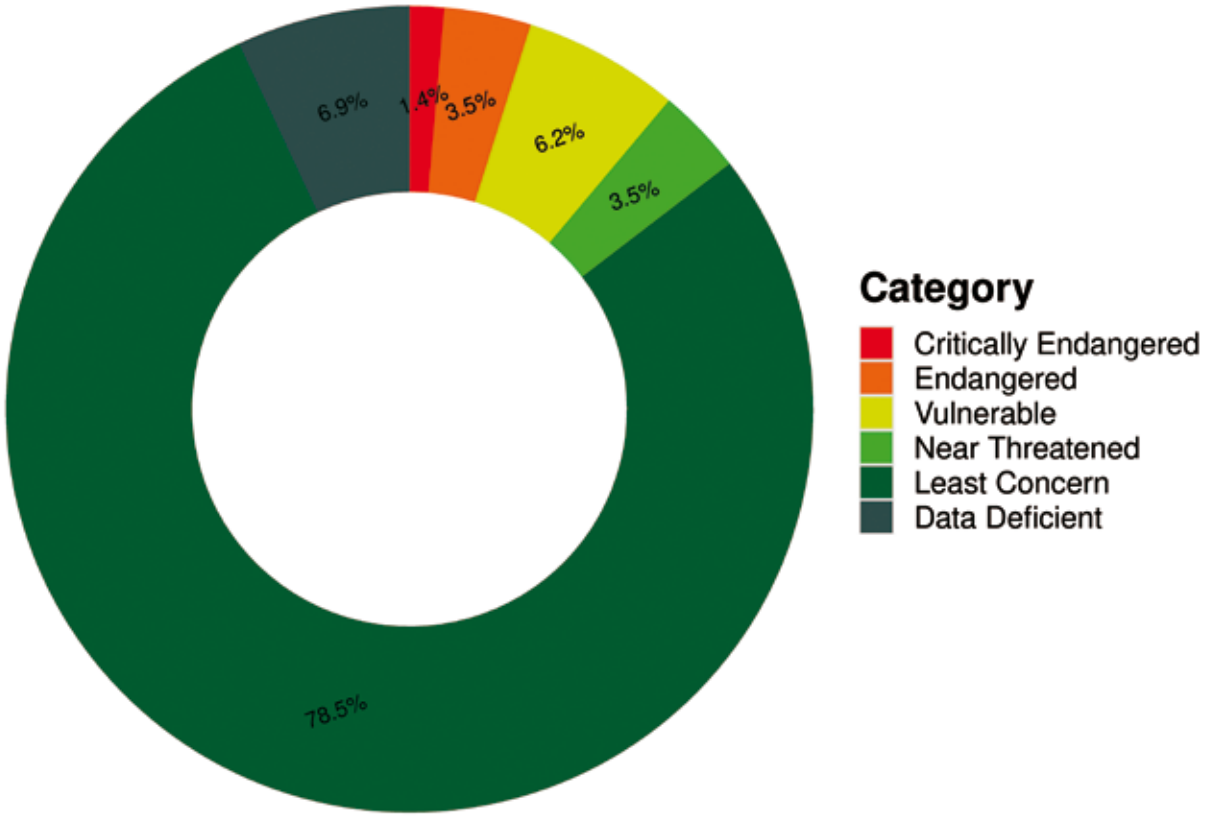

Figure 5 – Retrieved Trindade's evaluated biota IUCN categories.

Discussion

Even with a restricted geographic area, there is a vast bibliographic content associated with Trindade Island, especially within the last decade. Other "pulses" of expansion in scientific publication on the island are related to Brazil's independence (1822) and the expeditions of the Brazilian National Museum (1910', 1950') (Alves and Silva, 2016). The recent impulse came with an ongoing government program intended to provide funding for research at Trindade Island and Martin Vaz archipelago, called PROTRINDADE. The performed studies represent a broad framework of accumulated knowledge, including approaches to the island's history, with special emphasis on its colonization and disputes on territorial governance; a broad characterization of its physical aspects, especially related to the geology of both terrestrial and oceanic environments; as well as several studies for the recognition of the biodiversity that resides there. Since Trindade Island is an important extension of the Brazilian Exclusive Economic Zone, all this knowledge serves as a base for the maintenance of national sovereignty and also for the potential for sustainable exploitation of the region.

Oceanic Islands are models for the study of tectonic and volcanic events, as well as biogeography, species colonization, and evolution, conservation, and effects of species introduction (e.g., Paulay, 1994; Cowie and Holland, 2006; Caujapé-Castells et al., 2010; Gama et al., 2016; Heaney et al., 2018). Therefore, as expected, research in Trindade, in the last 100 years, is most represented by articles in the categories of Biological, Health, and Agrarian Sciences / Technologies, Exact, and Earth Sciences. However, as far as we could count, only 12 studies published about the island deal with biogeographical aspects, representing less than 10% of the studies, which could be unexpected as oceanic islands are interesting models for testing biogeographical hypotheses. A possible explanation for this finding could be that biogeographic studies usually rely on a solid base of biodiversity knowledge (taxonomy, occurrence, and distribution) (Ball, 1975). As the majority of the research on the island has been

relatively recent carried out, knowledge about biodiversity is probably still growing for most taxonomic groups, precluding or making it difficult to test for biogeographical hypotheses.

An examination of biological sciences retrieved literature shows that studies performed on the island followed the global trend of the "molecular era". Recent studies include the use of molecular phylogenies, metabarcoding, and genomics, representing that methodological strategy changed over time, moving from studies based mainly on morphological or structural attributes of organisms to DNA-based studies, which seems to be essential for biodiversity studies (especially for cryptic and unculturable organisms) (Ruppert et al., 2019).

The search employed herein retrieved 1076 accepted species with occurrences reported for Trindade Island, including species that no longer exist on the island or with current dubious occurrence. Most of the animal species recorded in Trindade Island are from oceanic environments. Fishes, mollusks, cnidarians, and crustaceans dominate the records, which was expected due to their taxa richness in this ecosystem (Costello et al., 2010). Several species are endemic to Trindade Islands (16 in total, Supplementary Table 2) or were shared only between Trindade and other South American oceanic islands or along the Vitoria-Trindade Seamount (Pinheiro et al., 2016; Andrades et al., 2017; Moraes and Muricy, 2017; Lima et al., 2019). The higher richness of oceanic species compared with terrestrial species *habitat* observed in Trindade Island is opposite to what has been observed in other oceanic islands, such as the Açores archipelago (Borges et al., 2010). We speculate that this may be another indication of the level of disturbances suffered by the terrestrial portion of Trindade Island during the occupation of exotic species.

Marine algae also represent an important portion of the known biodiversity of Trindade Island. With a relatively high diversity in comparison with other Brazilian oceanic islands (e.g. Fernando de Noronha Archipelago, Rocas Atoll, Abrolhos and São Pedro e São Paulo Archipelago), Trindade Island has been suggested to be a hotspot for seaweeds in the Southwestern Atlantic, being a transition zone with low endemism as result of complex connectivity relationships (Sissini et al., 2017; Pellizzari et al., 2020). In comparison with other oceanic archipelagos, the Açores has a more diverse algal diversity, with more than 400 species (Freitas et al., 2019).

As previously mentioned, the terrestrial fauna of Trindade has fewer species than the oceanic fauna. Only 72 species were retrieved in our compilation (including seabirds nesting or breeding grounds in Trindade Islands). Aves, Gastropoda, and Insecta are the most diverse classes, accounting for 30, 14, and 16 species, respectively. Compared with other oceanic islands, Corvo Island in the Açores Archipelago has a similar area to Trindade Island (17 km^2), originated from volcanic activity 0.7 Ma B.P., and is more than 2000 km far from the nearest mainland. Nonetheless, Corvo's terrestrial fauna presents 337 listed species, dominated by arthropods (Borges et al., 2010). Additionally, the Alegranza islet (~10 km^2), which is part of the Chinijo Archipelago also has a higher documented richness of terrestrial fauna than Trindade Island, with 175 animal species listed (Fernández-Palacios et al., 2018). Again, these results might be the result of the great disturbances caused by exotic species in the island environment. Alternatively, the proximity with other islands and islets/mainland (in Alegranza's case) might explain, at least in part, the difference in taxonomic richness. It is also important to highlight the low number of insects recorded for the island. Whether this is an attribute of Trindade Island or an artifact due to the lack of studies, needs further investigation.

Almost 200 plant species were retrieved in our search, represented by 139 Tracheophyta, 19 Marchantiophyta, and 16 Bryophyta species. Many of those species have been introduced (28 species), and among the native plants, 11 are endemic to Trindade Island (Supplementary Table 2) (Silva and Alves, 2017). Nevertheless, only 15 angiosperms and 14 ferns are reported in Brazil Flora Group (2021). In contrast to the observed terrestrial fauna, Trindade Island exhibits a higher richness of plant species (considering the total number of cited species in the last 100 years) than other oceanic islands, even considering larger territories (Borges et al., 2008, 2010). Remarkably, the most iconic plant species of the Island, the tree fern (*Cyathea copelandii* Kuhn & Luerss.) previously considered to be endemic, was proved to belong to the broadly distributed *C. delgadii* Sternb. (Faria et al., 2021).

The kingdom Fungi was represented by only 29 species based on specimen studies, of which only three are not lichens. *Cora trindadensis*

Lücking, M. Cáceres, N.G. Silva & R.J.V. Alves is a lichen species that is considered a putative endemic taxon for the island (Lucking et al., 2015). More recently, based on a metabarcoding approach, Câmara et al. (2022) pointed out the occurrence of five phyla that were not recorded before and the occurrence of 247 species (113 identified at the species level). This study represents an increase of almost 10-fold in the number of species registered to occur in the Trindade. However, fungi are known to be extremely diverse with highly heterogeneous communities even across close sampling sites. Thus, even with this increment of knowledge, fungal diversity likely remains one of the greatest knowledge gaps in the island. Also, fungal ecological functions in the Trindade ecosystem are still poorly known. Bacteria and Archaea domains are represented by 130 species in total. Considering that 30 grams of soil can harbor millions of bacterial species (Dykhuizen, 2005), they are also an important knowledge gap for the island.

The DNA and protein sequences generated so far for organisms from the island may be considered scarce when taking into account the diversity of species studied. Most of the entries recovered in our search are from studies of the biology of microorganisms (Rodrigues et al., 2015; Silva et al., 2015), genomics of microorganisms (Rodrigues et al., 2016; Rodrigues et al., 2017; Souza-Freitas et al., 2020), and taxonomic studies of plants (Gama et al., 2016; Dantas et al., 2017) and fishes (Pinheiro et al., 2016). Notably, no sequence obtained directly from fungal specimens was retrieved.

The unbalance in the known species in Trindade Island (much more plants and animals than Fungi, Bacteria, and protists) is probably the effect of a larger effort in studying animals and plants, which is commonly reported in science (Mora et al., 2011; Locey and Lennon, 2016; Antonelli et al., 2020; Cheek et al., 2020). Nonetheless, it is currently largely known that microorganisms, such as bacteria and fungi, remain mostly undescribed and are highly diverse (Locey and Lennon, 2016, Antonelli et al., 2020, Cheek et al., 2020). These organisms are essential for terrestrial ecosystem functioning, especially fungi, which participate in nutrient cycling as main decomposer agents. Moreover, fungi also form essential mutualistic relationships with plants and other symbiotic relationships with different groups (Alexopoulos et al., 1996; Webster and Weber, 2007; Bardgett and Van der Putten, 2014). Therefore, further sampling efforts for these organisms are necessary to better understand Trindade's life functioning, and also to aid in restoration initiatives.

The search against the IUCN database reveals that most of Trindade's species recovered in this checklist do not have their conservation status evaluated globally. As expected, most of the evaluated species are animals, reflecting the great efforts designated to these taxa. The bulk of evaluated species is not threatened, indicating that, overall, Trindade species are common and widely distributed, or at least, are not declining. Nevertheless, these numbers could be inflated due to introduced species (Supplementary Table 2). Four species recovered in this study are considered 'Critically Endangered': two fish species, one turtle species, and *Araucaria angustifolia*, an introduced tree species represented by two individuals on the island (Alves, 1998). However, none of the endemic plant species in Alves et al. (2011) has their status globally evaluated. *Asplenium beckeri* Brade, *Elaphoglossum beckeri* Brade, *Pleopeltis trindadensis* Brade, and *Amauropelta noveana* (Brade) Salino & T.E.Almeida (as *Thelypteris novaeana* (Brade) Ponce) are considered critically endangered and *Bulbostylis nesiotis* (Hemsl.) C.B.Clarke as vulnerable in the Brazilian Redlist of the Flora (Martinelli and Moraes, 2013).

Although historical and recent evidence has pointed towards the importance of including Fungi in global redlists (Mueller et al., 2022), just one fungal species reported to the island has been evaluated. *Gloioxanthomyces vitellinus* (Fr.) Lodge, Vizzini, Ercole & Boertm. was recovered in a recent soil metabarcoding study conducted in Trindade (Câmara et al., 2022), and it is considered Endangered (Jordal, 2019). Despite *G. vitellinus* being described as an oceanic species, its current distribution is restricted to the coast of European countries, and metabarcoding studies are known to have a considerable degree of bias from DNA extraction to bioinformatic treatment (Nilsson et al., 2019), which can undermine taxonomic classification. Nonetheless, the detection of long-dispersal spores deposits on the island can also be possible, as some fungal species can effectively disperse spores over long distances (Moncalvo and Buchanan, 2008). Therefore, more efforts should be put into investigating the presence of the species on the island, using eDNA-based sampling

methods as well as traditional fungal surveys, as the species produces macroscopic sporomes.

Studies addressing conservation in Trindade Island are still scarce, with the prevalence of oceanic taxa, such as fishes (Pinheiro and Gasparini, 2009; Pinheiro et al., 2010; Pinheiro et al., 2016), birds (Luigi et al., 2009), and algae (Pellizzari et al., 2020). Also, there are two reported extinctions of native species on the island: the red-footed booby (*Sula sula*), locally extinct, and *Peperomia beckeri* E. F. Guim. & R. J. V. Alves., globally extinct (Silva et al., 2013; Mancini et al., 2016). However, an occurrence of *S. sula* has been registered after 13 years after its last observation (Port and Fich, 2020).

Besides the already discussed obvious biodiversity knowledge gap for the microorganisms (fungi, bacteria, and protists) of the terrestrial portion of Trindade, marine life is probably far from being fully discovered. This thought is supported by evidence, such as, (i) the Brazilian shelf marine biodiversity is dominated, in order of magnitude, by crustaceans, mollusks, fishes, and polychaetes (Miloslavich et al., 2011), contrasting with the pattern observed so far for Trindade's marine biota, which is dominated by fishes, followed by mollusks. Thus, if Trindade follows the pattern of its vicinity, several species remain undescribed or with unknown occurrence in the island in groups, such as crustaceans and mollusks; (ii) most undiscovered species are likely to be found in the tropics, deep seas, and seas of the Southern Hemisphere (Costello et al., 2010) and species-description accumulation curves for South American marine species has not been stable yet in South America (Miloslavich et al., 2011); (iii) although the majority of the recovered literature from Trindade is from the oceanic environment, only around 70 research items deals with marine biodiversity and taxonomy, which might be a low number regarding the potential biodiversity of the region.

Conclusion

The literature recovered in our search is heavily dominated by research items of Biological, Health, and Agrarian Sciences, and Technologies, Exact and Earth Sciences and are deeply concentrated in the last decades and with a higher emphasis on the oceanic environment. As expected, the "macro" life forms dominate the records, with the diversity number strongly biased towards animals and plants. According to our analysis, no more than 300 species occurring on the island (both from terrestrial and oceanic environments) were evaluated under IUCN red listing criteria, with 32 threatened at some level. Although several research efforts have been historically performed on Trindade Island over the last century, there are still important biodiversity knowledge gaps to be elucidated, especially related to terrestrial microorganisms. Additionally, we discuss and present evidence that marine life is probably far from being completely recognized. Finally, we consider that with the amount of data generated so far, the historical use of Trindade Island may be used as a model for the understanding of biota restoration and resilience in oceanic islands, as well as colonization and recolonization processes, and biogeographical analyses.

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