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Assessment of land-based threats to Atlantic pelagic seabirds

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Abstract

Seabirds are exposed to numerous threats throughout their life-cycles, including land-based threats during their breeding season such as invasive species, diseases, or light pollution. Here we assess the timing, scope, and severity of land-based threats to populations of highly mobile petrels, albatrosses, storm-petrels, and alcids in the Atlantic Ocean, to guide priorities for their conservation across their mostly island-breeding areas. By combining our own field expertise of these species with a literature review, we built a dataset characterizing 18 threats for 49 species across 38 Large Marine Ecosystems. We analyze this dataset by highlighting the most impactful threats and the most impacted regions. Addressing invasive alien species on Tristan da Cunha & Gough and on the islands of the Canary Current are the interventions with the greatest potential to stimulate seabird population recovery across the Atlantic Ocean. Our results highlight priorities for targeted management actions that can support seabird conservation.

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KEYWORDS
Atlantic, climate change, conservation priorities, invasive alien species, island conservation, populations, seabird conservation, threat assessment

1 | INTRODUCTION

Seabirds, named "sentinels of the ocean" (Thibault et al., 2019), are considered good environmental indicators (Parsons et al., 2008). As marine top predators, their demography integrates changes across multiple levels of food webs (Hazen et al., 2019). For many species, data on demographic parameters (e.g., survival, fertility) and on population trends can be obtained relatively easily from colony monitoring (e.g., Parsons et al., 2008). And even if there are relatively few species (370), they occur across all oceans, with many breeding on islands (Mulder et al., 2011). Therefore, seabird population dynamics can thus provide valuable insights into changes in marine ecosystems (Parsons et al., 2008), their conservation status serving as a proxy measure of the health of marine environments (Phillips et al., 2023).

Seabirds are among the most threatened bird groups (Dias et al., 2019), with 30% of species classified as globally threatened with extinction (Critically Endangered, Endangered or Vulnerable) by the International Union for Conservation of Nature (IUCN) Red List (IUCN, 2023), plus 11% as Near Threatened, and with 57% of species experiencing population declines (BirdLife International, 2023). A global review of threats to seabirds (Dias et al., 2019) found that at sea, the main threat (in number of species as well as in cumulative impact) is bycatch from fisheries, affecting more than 100 species. Depletion of fish stocks through overfishing affects fewer species but is nearly as impactful. According to the same review, seabirds are mainly threatened on land by invasive species, particularly predation by introduced rats *Rattus* spp., mice *Mus musculus* and cats *Felis catus* (Phillips et al., 2023). The impacts of invasives are particularly felt on islands, most of which originally lacked native predators (Doherty et al., 2016), and which act today as crucial reservoirs of endemic species (Kier et al., 2009). Overabundant native species are also a threat to some seabirds, particularly as predators, but also as nest competitors (Anker-Nilssen et al., 2023; Dias et al., 2019; Rodriguez et al., 2022). Seabirds were historically overharvested in their breeding sites (leading notably to the extinction of the great auk, *Pinguinus impennis*; Hufthammer & Hufthammer, 2022), and for some species this remains a threat (Dias et al., 2019). Some threats occur both on land and at sea, with different effects. This is the case with climate change and severe weather conditions, an increasingly important driver of population declines (Grémillet & Boulinier, 2009; Sydeman et al., 2012). At sea, changes in oceanographic processes associated with climate change can result in reduced food availability around colonies (Hovinen et al., 2014), or increased at-sea mortality during more frequent storms (Clairbaux et al., 2021). On land, colonies may be affected by sea level rise (Von Holle et al., 2019) and extreme weather conditions (Descamps et al., 2015), and climate change may also increase the occurrence and virulence of avian pathogens (e.g., avian cholera; Phillips et al., 2016). Light pollution, and other forms of pollution, can also originate from—and affect birds in—both terrestrial and marine ecosystems (Dias et al., 2019). Many seabird species, particularly highly pelagic groups and island breeders, are exposed to multiple anthropogenic pressures (Dias et al., 2019). Seabird declines have broader impacts on the health of insular and marine ecosystems surrounding colonies, through the disruption of nutrient fluxes vectored by seabirds between their foraging and breeding areas (Benkwitt et al., 2022; Davis, 2013; Jones et al., 2016).

The global picture of threats faced by seabirds is now improved, with a characterization per species of each threat in terms of scope (i.e., the fraction of the global population affected) and of severity (i.e., the effects in terms of declines of an affected population) (Phillips et al., 2023). The magnitude of main marine threats such as bycatch, overfishing and plastics has been recently documented at global and regional scales, supporting marine management (Clark et al., 2023; Grémillet et al., 2018; Phillips et al., 2024; Ramirez et al., 2024; Votier et al., 2023). Such an approach—which compiles local-scale information across threats from an oceanic perspective to identify priorities for research and conservation—is still lacking for land-based threats but is of paramount importance given the fragile status of seabirds. Indeed, tackling land-based threats is not only fundamental in its own right to the conservation of many species (Dias et al., 2019), it is also often more immediately achievable when compared with the challenges of addressing marine threats. This is particularly so for species whose small and isolated island nesting areas (where targeted and effective actions are relatively easier to implement) contrast with very large at-sea distributions (including areas managed by multiple countries as well as international waters). Additionally, islands hold many endemic and threatened seabird species, thereby providing important conservation opportunities for seabirds (Spatz et al., 2014).

Here, we analyzed the ongoing land-based threats affecting seabird species in the Atlantic Ocean, an ocean whose islands and coastal zones host numerous seabird breeding populations (BirdLife International, 2023; O'Hanlon et al., 2023), experiencing a considerable cumulative impact of human activities (Halpern et al., 2019). We focused on highly mobile pelagic species belonging to five families: Alcidae (auks), Diomedeidae (albatrosses), Hydrobatidae (northern storm-petrels), Oceanitidae (southern storm-petrels), and Procellariidae (petrels and shearwaters). Exclusive island breeders in particular, such as albatrosses and petrels, are among the most threatened families of seabirds compared to coastal groups such as terns and gulls. We compiled a new dataset characterizing land-based threats across populations of these groups of seabirds within the Atlantic Ocean by reviewing information previously dispersed across the literature and by consulting experts with field experience of the focal species to obtain yet unpublished information. We make this dataset available as a contribution to supporting strategic planning for the conservation of seabirds in their breeding grounds.

We use this dataset to identify: (1) the land-based threats most impactful to highly mobile Atlantic seabirds, (2) the Atlantic regions that have suffered the strongest impacts, and (3) the land-based management actions with the strongest potential positive impact on species recovery.

2 | MATERIALS AND METHODS

2.1 | Study area

Our study area includes the archipelagos in, and coastal areas around, the Atlantic Ocean, from the Arctic to the Antarctic, including adjacent seas (herein: "Atlantic Ocean"; Figure S1). For analytical purposes, we split the breeding grounds of seabirds into 38 spatial units following Davies et al. (2021). Continental areas (including adjacent islands) were split following the boundaries of Large Marine Ecosystems (LMEs), which are large oceanic regions characterized by distinct bathymetry, hydrography, productivity, and trophically dependent populations (Sherman, 2001; Sherman & Alexander, 1986). LMEs do not cover all oceanic archipelagos, so in the case of the Canary Current LME we considered that it also included the nearby Canary Islands, Madeira (including Selvagens), and Cabo Verde. In addition, we added nine spatial units to cover other oceanic archipelagos in the study area: Azores, Bermuda, Trindade and Martim Vaz, Ascension Island, Saint Helena, Tristan da Cunha & Gough, South Orkney Islands, South Georgia and the South Sandwich Islands, and Bouvet Island. For simplicity, we refer throughout to all these spatial units as "LMEs" (Figure S1; Table S1).

2.2 | Species and populations

We focused on an initial set of 49 species of pelagic and highly mobile seabirds in families Alcidae, Diomedeidae, Hydrobatidae, Oceanitidae and Procellariidae with at least one breeding colony in the Atlantic (Supporting Methods 1; Table S2). We considered as highly mobile species those with evidence that individual birds undertake long-distance journeys over their life cycles (more than 2000 km away from their breeding colony; as determined based on tracking data and a literature review conducted under a parallel study; Rouyer, 2025).

We subdivided each species into populations, each population corresponding to the set of breeding colonies within a given LME, following Davies et al. (2021) and Frederiksen et al. (2012, 2016), resulting in 141 analyzed populations (Table S2). We obtained the current proportion (P_c) of the Atlantic population of each species S breeding in each LME L ($Pc_{S,L}$, Table S3) from an extensive literature review (Rouyer et al., 2025).

2.3 | Threats

We followed the IUCN (2023) definition of threat as "the proximate human activities or processes that have impacted, are impacting, or may impact the status of the taxon being assessed". We worked from the threat classification of Dias et al. (2019), who adapted the IUCN Red List Threats Classification Scheme to better represent threats to seabirds. We focused on land-based threats: invasive alien species; problematic native species; diseases; hunting/trapping; human intrusion and disturbance; pollution; light pollution; energy production and mining; residential and commercial development; agriculture; transportation and service corridors; natural systems modifications; logging and wood harvesting; geological events; and climate change and severe weather conditions (except when related to changes in oceanographic conditions). We divided the threat "invasive alien species" into cats, rats, mice, and other, which allows a more precise analysis of the most frequent seabird threat (Dias et al., 2019; Jones et al., 2008). This resulted in a total of 18 classes of land-based threats considered in this study (Table S4).

2.4 | Review of threats per population

We compiled a new dataset characterizing the timing, scope, and severity of each land-based threat to each seabird population studied by combining expert knowledge with a literature review.

We initially solicited expert knowledge through a questionnaire (Table S5, emailed in March 2023) sent to about 200 researchers or practitioners who had published tracking studies (reviewed by Bernard et al., 2021) or uploaded data to the seabird tracking database (Carneiro et al., 2024) on the populations included in this study. In this questionnaire, experts were asked to characterize land-based threats per population. More specifically, given a population and each of the 18 threats analyzed, experts were asked to indicate if one or more age groups are (or have been, or will likely be) affected by the threat, and if so to qualify:

- Timing of the threat: past; ongoing; future;
- Scope (the percentage of population in the LME affected by the threat): minority (0%–50%); majority (50%–90%); whole (90%–100%); unknown;
- Severity (the known or likely rate of population decline caused by the threat over three generations): no decline (0%); negligible declines (0%–5%); causing/could cause fluctuation (5%–20%); slow, significant declines (5%–20%); rapid declines (20%–30%); very rapid declines (30%–100%); unknown.

Experts were asked to provide data for as many populations as they were familiar with, and for any threats they had information on. We received information from 34 experts, all of whom became co-authors in this study.

In parallel, we carried out a detailed literature review of land-based threats affecting the studied populations. We started by reviewing relevant summary species accounts on existing databases (ACAP, 2023; BirdLife International, 2023; HBW Alive, 2023; IUCN, 2023) and in (Dias et al., 2019), who had reviewed information on threats for every seabird species up to 2017. We then searched recent (2017–2024) relevant scientific studies on each species, using its common and scientific name as search terms on the Web of Knowledge. We extracted information on the spatial occurrence of each threat (by attributing it to a specific LME/population), and estimated, when possible, timing, scope, and severity (recording the corresponding reasoning and references).

We combined the data collected through expert consultation and the literature review into an intermediate dataset, which included in many cases multiple entries for a given threat affecting a given population in a given LME. Whenever there were discrepancies, the co-authors with expertise on the corresponding species/population jointly revised the associated data entries to reach a consensus. The final dataset consists of a single entry per threat per population, indicating in each case the age group, timing, scope, severity and listing the data sources (Table S6).

2.5 | Characterizing the impacts of threats

We analyzed the dataset on threats per population (Table S6) to characterize the impact of ongoing threats per LME, per species, and per threat. For this purpose, we estimated a standardized unit of relative impact—variable $\Delta_{S,T,L}$—characterizing the extent to which a given threat T, occurring within a given LME L, impacts species S across its Atlantic-wide population.

We estimated values of $\Delta_{S,T,L}$ in three steps (described in Supporting Methods 2, Figure S2, Table S7). First, we obtained a measure of the relative impact of each threat on the current population size of each species within each LME, by combining the corresponding information on scope and severity (building on the "Impact Score" formula in Dias et al. 2019). Second, we calibrated these estimates using data on the proportion ($Pc_{S,L}$) of the Atlantic population of each species S breeding in each LME L (Table S3) to estimate the magnitude of impacts at the Atlantic-wide scale. Finally, we partitioned this Atlantic-wide impact across LMEs, and then across threats within each LME, to obtain the $\Delta_{S,T,L}$ values.

By aggregating values of $\Delta_{S,T,L}$ across threats, across species, and across LMEs, we obtained four indicators of impact (formulae in Supporting Methods 3):

1. Impact per threat. Combined impact of each threat T across the Atlantic, measured as the sum of $\Delta_{S,T,L}$ values across all species affected by the threat and all the LMEs where the threat is ongoing. We divided this by the total number of species analyzed to obtain a calibrated measure independent of species richness. From this indicator, we could identify the land-based threats most impactful to highly mobile Atlantic seabirds.
2. Impact of each threat per LME. We partitioned impact per threat θ_T across LMEs to obtain a $\theta_{T,L}$ value per threat and per LME, and then mapped the result. We inferred the land-based management actions with the strongest potential positive impact on species recovery across the Atlantic based on this indicator.
3. Cumulative impact in each LME. As an indicator of the total impact incurred in each LME, we summed $\Delta_{S,T,L}$ values across all species breeding in the LME,

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across all ongoing threats affecting them. From this indicator, we could identify the Atlantic regions that have suffered the strongest impacts.

4. Average impact per species in each LME. As an indicator of the relative impact incurred by the species of each LME, we divided the cumulative impact in each LME by the number of species in the LME for which we had quantifiable threat data.

3 | RESULTS

3.1 | Dataset on land-based threats

Our final dataset totals 985 entries, derived from data provided by the 34 experts who replied to the questionnaire and from the literature review, covering 141 populations, 49 species, 38 LMEs and 18 threats (Table S6). Of these, 55 entries correspond to populations for which we obtained no information on any past, ongoing, or future threats. The remaining 930 entries correspond to the characterization of one threat affecting one population.

The dataset contains 366 entries on the existence ("yes" or "probably yes") of ongoing threats, 347 for past threats and 305 for potential future threats. It includes a characterization of both threat scope and severity for 388 entries, and of the age group affected by the threat for 835 entries. Moreover, 402 entries include information on the presence or absence of management actions against the threat, and 233 specify the management actions in place. The dataset also contains information on the absence of threats at different times (classed as "no" or "probably not"): 272 entries for ongoing threats, 215 for past threats, and 230 for future threats.

When subsetting the dataset to include only assessments of ongoing (or probably ongoing) and knowingly absent (not ongoing or probably not ongoing or "age group affected: none") land-based threats, we obtained 796 entries, corresponding to 81 populations, across 44 seabird species (Table S2) breeding across 25 LMEs (Table S1). These assessments had a quantifiable impact and therefore were included in the analysis presented below.

3.2 | Impact across threats and LMEs

Our analysis indicates that the threat that has caused the greatest impact on the studied seabird species across the Atlantic over the past three generations is—by far—"invasive alien species" (Figure 1), predominantly mice, rats, and cats. Based on our current dataset, the impact of

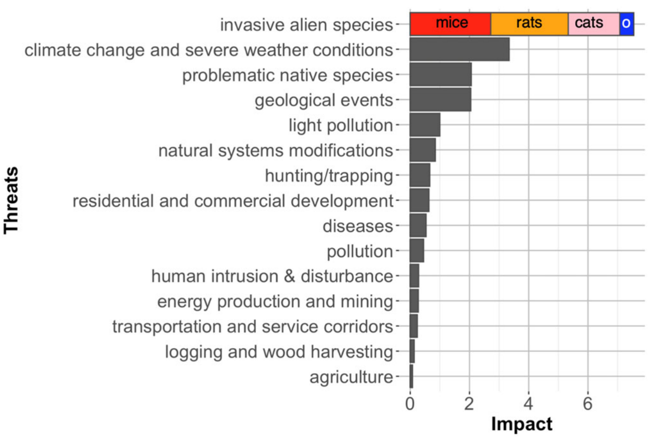

FIGURE 1 Impact per threat. For each threat, this corresponds to its cumulative impact (across species and across LMEs) on highly mobile seabirds across the Atlantic (calculated as the sum of $\Delta_{S,T,L}$ values across species and LMEs, divided by the number of species in this study for which we had data on threats). The threat "invasive alien species" is composed of impact by rats, mice, cats, and other species (o), and represented as such. Scale: One unit of impact is theoretically equivalent to, for example, a 100% decline in the Atlantic-wide population of a species, or a 50% decline in each of two species, or a 25% decline in each of four species, over the last three generations. Values should however be interpreted cautiously given the uncertainty associated with the data.

mice is particularly important in Tristan da Cunha & Gough, whereas rats are particularly problematic in the Canary Current, Bermuda, Mediterranean Sea, and Azores (Figure 2b), and cats in the Canary Current and the Mediterranean Sea (Figure 2c).

"Climate change and severe weather conditions" came out as the second most impactful threat (Figure 1), particularly affecting populations in the Canary Current, Bermuda and Azores (Figure 2d), followed by "geological events" and "problematic native species" impacting mostly seabird colonies in the Canary Current (Figure 2e,f).

The dominant threat varies among LMEs (Figure 3). "Invasive alien species" emerged as the most impactful threat in 44% of the LMEs, particularly those located in the northeastern Atlantic (including the Mediterranean) and in the remote archipelagos of Azores, Bermuda, Tristan da Cunha & Gough, and Trindade and Martim Vaz. "Climate change and severe weather conditions" appeared as equally impactful in Trindade and Martim Vaz, and as the most impactful threat in Antarctica and the subantarctic archipelagos of South Georgia and the South Sandwich Islands. Problematic native species stood out in the coastal northeastern and northwestern Atlantic, "natural system modifications" in the Caribbean Sea, "hunting/trapping" around Greenland, and "diseases" in the North Sea and Northeast U.S. Continental Shelf.

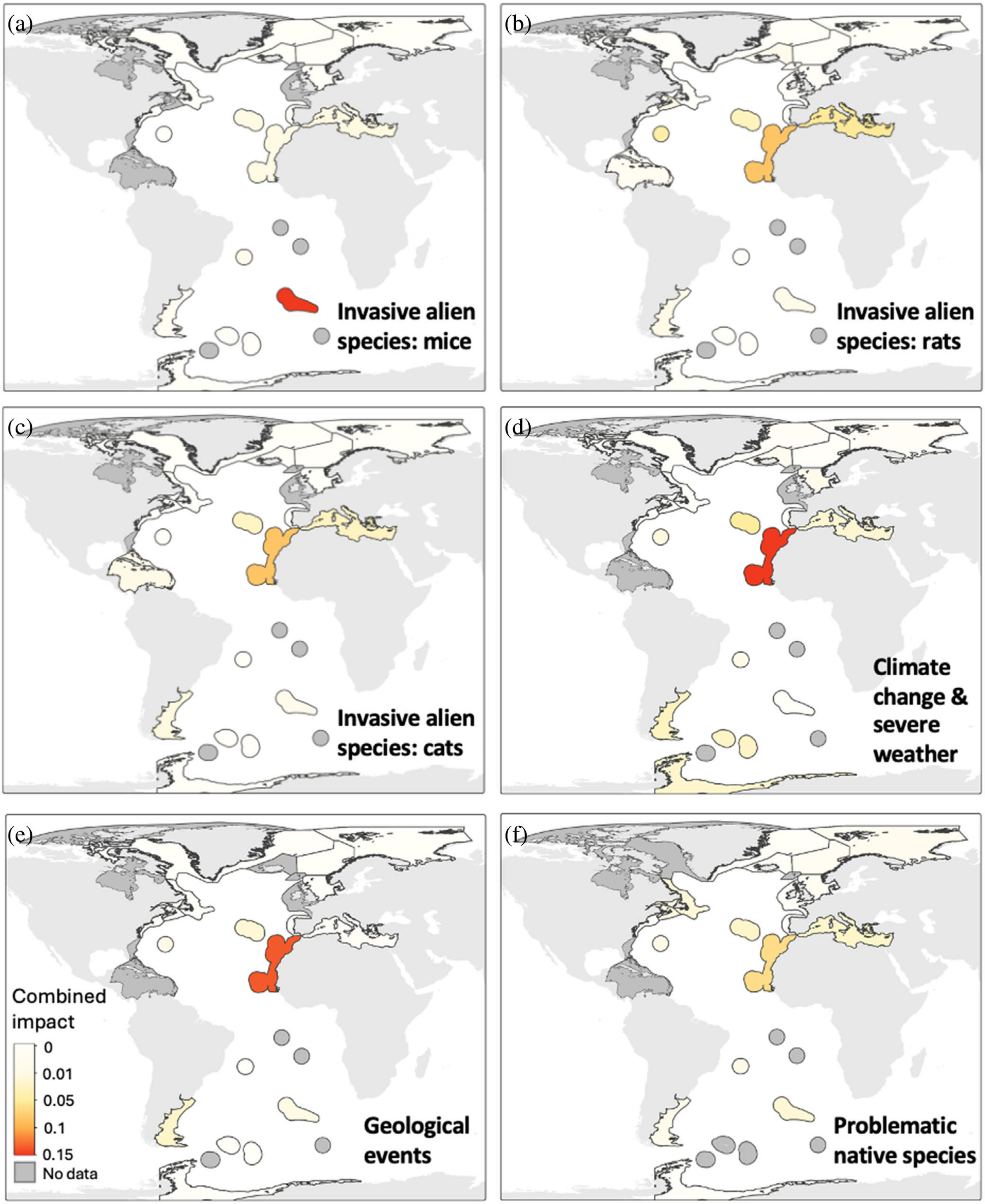

FIGURE 2 Combined impact of each of the top 4 land-based threats per LME, namely invasive alien species (a, mice; b, rats; c, cats), climate change and severe weather conditions (d), geological events (e) and problematic native species (f). Only LMEs with breeding populations are represented. LMEs with breeding populations but no data for the corresponding threat are colored in dark gray. Scale: A value of 0.1 is theoretically equivalent to the impact of a threat within an LME translating into the equivalent of a 10% Atlantic-wide decline of a species over the last three generations, or a 5% decline in two. Values should however be interpreted cautiously given the uncertainty associated with the data.

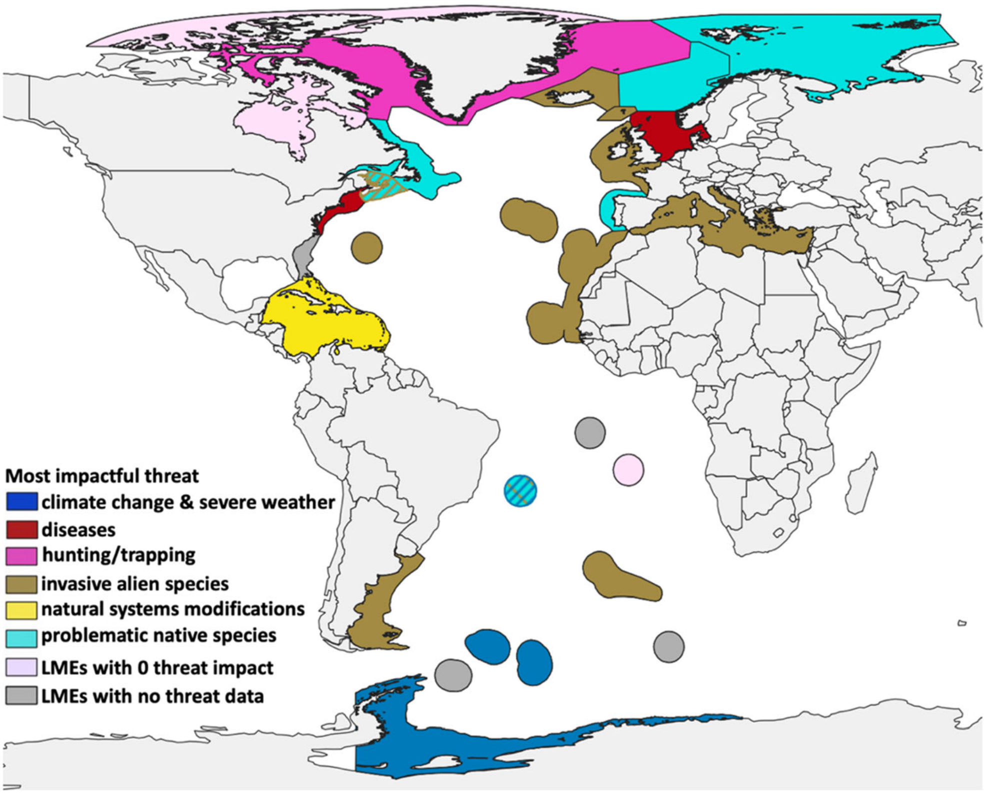

FIGURE 3 Most impactful land-based threat identified for each LME. In the Scotian Shelf there was equality between two threats (problematic native species + invasive alien species) while Trindade and Martim Vaz had equality between 3 threats (climate change and severe weather conditions + problematic native species + invasive alien species).

3.3 | Cumulative impact on species across LMEs

The Canary Current was the LME with the highest cumulative impact (290%), followed by Tristan da Cunha & Gough (118%), Azores (115%), Mediterranean Sea (99%) and Patagonian Shelf (99%) (Figures 4a and S3a).

3.4 | Average impact on species across LMEs

We found the highest average threat impact per species in Bermuda (34%), followed by the Canary Current (26%), the Mediterranean Sea (25%) and the Patagonian Shelf (25%), the Caribbean Sea (21%) and the Azores (19%). In contrast, LMEs in northern latitudes had lower values, below 10% (Figures 4b and S3b).

3.5 | Management priorities

Our results suggest that the management action that would have the greatest benefit in a single LME (i.e., the management action with the largest estimated Atlantic-wide benefits) would be eliminating the impacts of invasive alien species in Tristan da Cunha & Gough (Figure 5). Controlling this same threat in four other LMEs (Canary Current, Mediterranean Sea, Azores, Bermuda) would also bring substantial benefits, as would the mitigation of the impacts of climate change and severe weather conditions (Canary Current and Azores), of geological events (Canary Current), and problematic native species (Canary Current).

4 | DISCUSSION

4.1 | A new dataset on land-based threats to highly mobile Atlantic seabirds, and its limitations

We compiled a new Atlantic-wide dataset of land-based threats affecting highly mobile seabirds and illustrate how these data can be used to quantify the impact of ongoing threats across species, across regions (LMEs) and across threats, in order to highlight conservation priorities. Other possible applications of this dataset include evaluating historical and prospective threats.

The dataset is incomplete, and we hope it will be expanded in the future. There are multiple sources of missing information. First, we focused on a selection of highly mobile pelagic seabirds in the Atlantic. In the future, the dataset could be expanded to include all seabird species breeding in the Atlantic Ocean, and even all

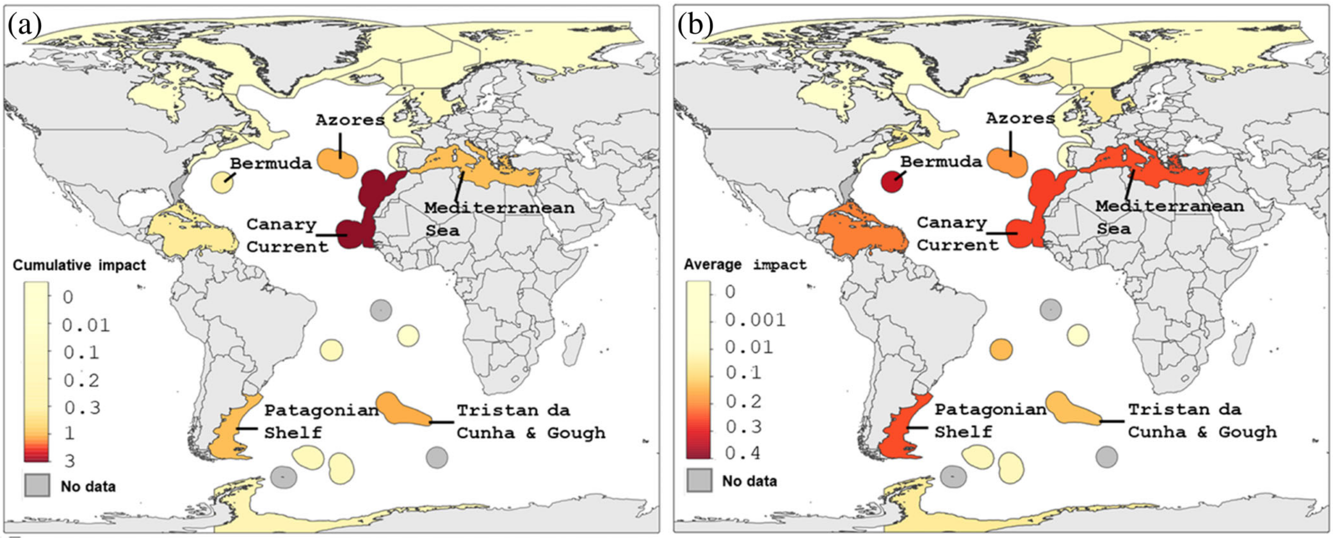

FIGURE 4 Impact of land-based threats across LMEs. (a) Cumulative impact. Scale: One unit of impact is theoretically equivalent to, for example, a 100% decline in the Atlantic-wide population of a species over the last three generations, or a 50% decline in each of two species, or a 25% decline in each of four species. (b) Average impact. A value of 0.1 means that, on average, for each species breeding in the LME, the threats it suffered in that LME translated into a 10% decline in its Atlantic-wide population. LMEs for which we did not find threat data are represented in dark gray.

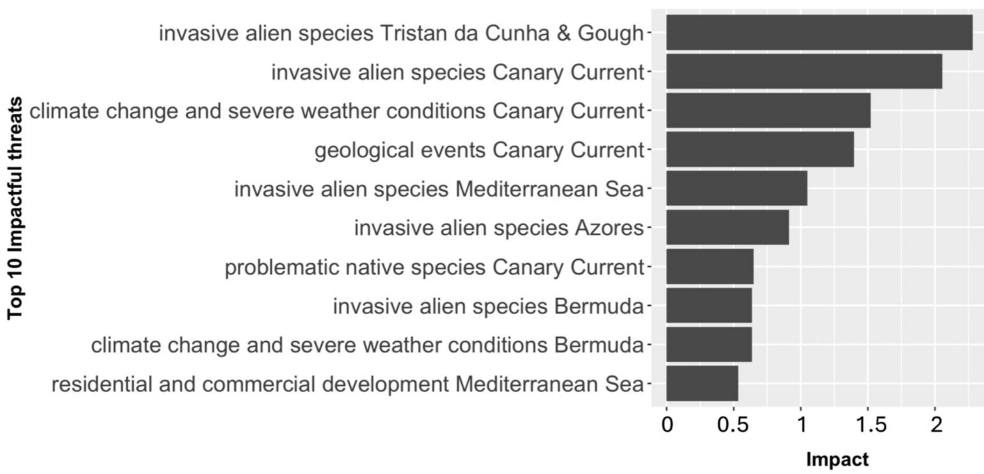

FIGURE 5 Top 10 threats in a given LME that have the highest impacts on highly mobile seabirds (causing the strongest declines across the Atlantic). Mitigating these (where possible) is thus the greatest management priority for highly mobile seabirds in the Atlantic. Scale: One unit of impact is theoretically equivalent to, for example, a 100% decline in the Atlantic-wide population over the last three generations of a species, or a 50% decline in each of two species, or a 25% decline in each of four species.

370 species worldwide. Second, we only focused on land-based threats. Quantifying exposure to marine-based threats would require analyzing the at-sea movements of seabirds in each population, to understand the extent to which they are exposed to pressures such as those associated with marine fisheries (bycatch, depletion of resources) or interactions with human infrastructure (windfarms, oil industry) (Davies, Carneiro, et al., 2021; Dias et al., 2019).

Third, there are many gaps in the dataset regarding the land-based threats affecting each population. Among the 49 species analyzed, there were five for which we found no information on ongoing threats (including assessments with unknown scope/severity) (Supporting Methods 1; Table S2). For 22 more species, we could not find information for at least one of the LMEs where they breed (corresponding in total to 60 populations with no data on ongoing threats). Additionally, out of the

81 populations analyzed in this study (with assessments of ongoing, or probably ongoing, and knowingly absent threats), we found information for all 18 threats for only 43 populations. The missing information may correspond to cases where populations are not impacted by the threats considered, or to gaps in knowledge. Expert information proved fundamental to fill gaps in the literature: 78% of the entries analyzed benefited from expert knowledge, adding information to 43 populations out of the 81, including nine for which we had no literature data (Table S1). Expert knowledge contributed substantially to reporting the absence of threats: 88% of the total entries with "no" or "probably no" ongoing threats, or "age group affected: none" were reported by experts. The resulting distribution of data inevitably reflects variation in scientific knowledge, with a higher concentration not only of database entries per population (Figure S4a) but also of unknown entries (Figure S4b) in the North Atlantic. Our results are therefore likely to underestimate the impact of threats on the less studied LMEs.

Fourth, it was not always possible to characterize the impact of ongoing threats, as for many species their biology and demography remain poorly known. Measuring severity was particularly challenging. We often relied on expert knowledge rather than quantitative data, which increases the risk of inconsistencies across species and LMEs (e.g., associated with misinterpretation, error, and observer bias). To account for uncertainty, we used large arithmetic intervals for scope and severity, yet they remained "unknown" for 14% and 20%, respectively, of the entries with existing ongoing threats.

Lastly, the dataset only considers extant colonies of the selected seabird species, and results must be interpreted accordingly. Indeed, even though many islands in the Atlantic suffered the local extirpation of entire seabird colonies or species (Hilton & Cuthbert, 2010; Hufthammer & Hufthammer, 2022; Olson, 1975), particularly because of invasive species and harvesting, these past threats are not considered in our dataset and assessment. For example, on both Ascension and Saint Helena, the only remnant breeding colonies of the species considered in our assessment are on inaccessible rock stacks that are free of invasive species, whereas the presence of invasive species has led to the disappearance of far larger colonies of the same species on the main islands (Olson, 1975; Ratcliffe et al., 2010). These historical colonies and threats are not accounted for in our dataset.

4.2 | Most impactful ongoing threats

In agreement with previous studies (Dias et al., 2019; Holmes et al., 2023), we found that invasive alien species are, by far, the land-based threat with the strongest impact, essentially invasive predators (mice, rats and cats; Figure 1). In our analysis, this is exacerbated by the fact that we focused on pelagic seabird species, which breed mainly on islands with no native mammalian predators (Blackburn et al., 2004). With some of these archipelagos harboring endemic species (e.g., Bermuda Petrel *Pterodroma cahow* in Bermuda; Zino's Petrel *Pterodroma madeira* and Desertas Petrel *Pterodroma deserta* in Madeira) and/or globally important populations of some species (e.g., Trindade Petrel *Pterodroma arminjoniana* in Trindade and Martim Vaz), local impacts can translate into global consequences for species' extinction risk. Indeed, the introduction of alien invasive predators to oceanic islands was the main driver of historical bird extinctions (Bellard et al., 2016; Szabo et al., 2012), including two petrel species from Saint Helena (Small Saint Helena Petrel *Bulweria bifax*; Large Saint Helena Petrel *Pterodroma rupinarum*) (IUCN, 2023).

The second most impactful land-based threat emerging from our analysis is climate change and severe weather conditions (Figure 1), affecting 19 LMEs (Figure 2d) and being the dominant threat in four LMEs (Figure 3). Expert knowledge highlighted storms (causing erosion and ultimately destroying nests and contributing to habitat loss), flooding (including from heavy rains, but also large swells that can destroy nests on low-lying islands), and temperature extremes (high temperatures decreasing survival and reproductive success; Mauck et al., 2018) as the main consequences of climate change affecting seabirds at their breeding grounds (Table S6). Whereas our study focuses on land-based threats, disentangling the impacts of climate change as a sea- versus a land-based threat is not always straightforward, because the effects of climate change on food availability (a sea-based threat) may express themselves as reduced productivity observed in the colonies (e.g., Hovinen et al., 2014) and may occur concomitantly. Already 27% of seabird species are considered globally threatened by climate change (Dias et al., 2019), and our results indicate that this emergent threat is becoming a significant driver of population losses, particularly in Antarctic and subantarctic regions and on some remote islands.

Problematic native species were the third most impactful threat (Figure 1), and a dominant one in some of the North Atlantic LMEs (Figure 3). In particular, experts highlighted that American Herring Gulls *Larus smithsonianus* as predators in the Scotian Shelf and Labrador-Newfoundland, including of Leach's Storm-petrel *Hydrobates leucorhous*, likely influenced by the availability of fishery discards (Bond et al., 2023). Problematic native species can also affect seabirds through other types of relationships, including nest competition (e.g., Oro et al., 2009).

Geological events appear as the fourth most impactful threat in our analysis (Figure 1), particularly to populations in the Canary Current (Figure 2e). Experts reported that volcanic eruptions, earthquakes landslides and rock falls (not linked to erosion events caused by invasive species or climate change) contribute to reduced reproduction due to habitat loss, which can be particularly problematic for burrow-nesting species (i.e., Rodríguez et al., 2019).

Hunting and trapping had historically very strong impacts on seabird populations across the Atlantic (Hufthammer & Hufthammer, 2022), but currently affect mostly coastal species (Dias et al., 2019) and did not come out as a major threat to pelagic species (Figure 1). Nonetheless, it still emerged in our results as the most impactful threat in regions around Greenland, where some species are still actively exploited, such as the Thick-billed Murre *Uria lomvia* and the Little Auk *Alle alle* (Merkel et al., 2016; Mosbech et al., 2018).

Diseases appear as a relatively minor threat in our analysis (Figure 1) but our data collection took place just before the devastating effects of the ongoing highly pathogenic avian influenza epidemic, which has already caused tens of thousands of seabird deaths across the world (Boulinier, 2023), including in the Atlantic (Avery-Gomm et al., 2024; Lane et al., 2024; McPhail et al., 2024). Both Alcidae and Procellariiformes have been affected by the epidemic (Couty et al., 2025), with potential conservation implications for some species such as the Sooty shearwater *Ardenna grisea* (Kuiken et al., 2025). In our database, disease appears as an ongoing threat ("yes," or "probably") for 11 species, with four more marked as "unsure." It is mentioned as a possible future threat for 21 species, but mostly with high uncertainty ("unsure" for 14 species), highlighting the challenges of making such predictions and the need for close monitoring in the face of rapidly evolving threats.

4.3 | Most impacted LMEs

The most impacted LMEs—both in terms of cumulative impact and of average impact per species—correspond to seabird colonies located mostly on islands (Figures 4 and S3). The Canary Current LME (including the archipelagos of Madeira, Canary Islands, and Cabo Verde) stands out as having the highest cumulative impact (Figure 4a) and as being second in terms of average impact per species (Figure 4b). It hosts numerous species among those considered in this study (13, Table S1), their abundant populations supported by the highly productive waters of the North-West Africa coastal upwelling, which find suitable breeding areas in the numerous islands and islets (Semedo et al., 2021). This LME has high endemism of seabird species (Alho et al., 2022; Semedo et al., 2021), including five of the species in our analysis (Cape Verde Storm-petrel *Hydrobates jabejabe*, Cape Verde Shearwater *Calonectris edwardsii*, Desertas Petrel, Cape Verde Petrel, and Zino's petrel), of which four are threatened or near-threatened. Many of these species were historically exploited and highly affected by invasive predators subsequent to the European colonization (Alho et al., 2022; Semedo et al., 2021), with predation by mice, rats and cats having caused multiple local extinctions (González-Solís et al., 2024; Semedo et al., 2021). Today, invasive alien species remain the main threat in this LME (Figures 2 and 3), compounded by climate change and geological events (Figure 5).

The LMEs that follow in terms of cumulative impact are Tristan da Cunha & Gough and the Azores (respectively, 8th and 6th in average impact per species). The former hosts some of the most important seabird colonies in the South Atlantic, with four endemic and threatened species: Tristan Albatross *Diomedea dabbenena*, Atlantic Yellow-nosed Albatross *Thalassarche chlororhynchos*, Spectacled Petrel *Procellaria conspicillata* and Atlantic Petrel *Pterodroma incerta*. Thirteen out of the 16 seabird populations from Gough included in our study are severely affected by invasive mice (Oppel et al., 2022), while on Tristan da Cunha the impact of predation by rats and cats is less understood and thus more difficult to quantify (Jones et al., 2021). The Azorean islands host an important community of seabirds, which suffered massive declines upon the arrival of the first human settlers (Monteiro et al., 1996). We considered in this study data from five Azorean seabird populations, including the endemic and Vulnerable Monteiro's Storm-petrel *Hydrobates monteiroi*, all of which are impacted by invasive alien species (particularly rats) and, to a lesser degree, by climate change.

The Mediterranean Sea LME (fourth in cumulative impact, third in average impact per species), which covers seabird colonies located in the Balearic, the Eolian and the Maltese Islands (among others), hosts breeding populations of four seabird species considered in this study, including the endemic and Critically Endangered Balearic Shearwater *Puffinus mauretanicus*, the most endangered European breeding seabird (Genovart et al., 2016). Seabirds that breed in the Mediterranean Sea are heavily affected by invasive alien species and their distribution is often limited to invasive species-free islands (Jones et al., 2008). They are also impacted by habitat loss associated with urbanization, coastal development and tourism infrastructures (Portolou et al., 2022).

The Patagonian Shelf (fifth in cumulative impact, fourth in impact per species), which covers the very large seabird colonies in the Falkland/Malvinas archipelagos, hosts four assessed species (Table S1), the most impacted being the Slender-billed Prion *Pachyptila belcheri* affected by invasive alien species and climate change, and the Black-browed albatross *Thalassarche melanophris*, affected by climate change (Table S6). Invasive alien species is the most impactful threat in this LME (Figure 3): cats predate three out of the four species (Table S6), despite past eradication efforts (IUCN, 2023). Climate change affects the breeding species through extreme weather events (Table S6), which have shown contrasting local-scale impacts on sympatric Black-browed albatross populations (Ventura et al., 2023), highlighting the difficulty of quantifying the demographic impacts of this threat.

Bermuda stands out when relative impact is averaged across species (Figures 4 and S3). It hosts only one of the seabird species we analyzed, the Bermuda Petrel. Listed as Endangered by the IUCN Red List (IUCN, 2023), it was thought to be extinct before its rediscovery in 1951 (Madeiros et al., 2012; Raine et al., 2021). Historically, the Bermuda petrel was highly threatened by hunting and trapping and by cat predation, but these threats have now ceased, with the breeding islets being highly protected through restricted visits and control of invasive predators (cats, mice and feral bees; Table S6). Rats however remain a main threat, compounded by the effects of climate change and severe weather conditions (Madeiros et al., 2012; Raine et al., 2021).

4.4 | Management priorities

The management interventions that we predict would have the greatest Atlantic-wide impact on seabirds would be eliminating invasive alien species in colonies located on islands, particularly on archipelagos hosting important populations of threatened species (Figure 5): Tristan da Cunha & Gough, and those located in the Canary Current. The eradication of invasive alien species from Gough Island would potentially allow for a global recovery of two endemic species: Atlantic petrel (Endangered) and Tristan Albatross (Critically Endangered) (Oppel et al., 2022; Wanless et al., 2012). Two other threatened species not covered by our analysis (Broad-billed Prion *Pachyptila vittata* and MacGillivrays Prion *P. macgillivrayi*) would also benefit from this action (Dawson et al., 2015; Jones et al., 2021). The conservation benefits of removing invasive mammals from islands are well documented (e.g., Jones et al., 2016), but eradication efforts still pose technical challenges and are not always successful (RSPB, 2023). Furthermore, although mice are currently the most impactful alien predator across this archipelago (Figure 2b), cats are also present on Tristan da Cunha island (Figure 2c), and they should be removed alongside rodents.

Addressing invasive alien species in the Canary Current LME would also have a strong positive impact (Figure 5), benefiting eight seabird species (Table S6). The most problematic invasive alien species in this LME are rats and cats (Figure 2a,c), and it would be beneficial to eradicate them simultaneously where they coexist (Rayner et al., 2007; Zavaleta et al., 2001). Cat trapping alongside rat and mouse eradication is ongoing at the main seabird breeding sites of this LME (Table S6). Given that the Canary Current is the second most impacted LME (Figure 4), addressing the threat posed by invasive alien species is of utmost importance, considering that the other main threats in this LME (climate change and geological events) are more challenging to address (Dias et al., 2019).

5 | CONCLUSION

This study provides a new dataset summarizing the results of an Atlantic-scale assessment of land-based threats affecting highly mobile pelagic seabirds. By using this dataset to characterize the impacts of threats at the level of species and of regions, we highlight management priorities that translate local actions not only into benefits for other seabird species from the same locality, but also into ocean-wide conservation benefits. Island systems stand out as strategic priorities from this assessment, stressing their key role in seabird conservation and recovery. Given uncertainties associated with the input datasets (on land-based threats, as well as on relative population sizes), our numerical results should not be interpreted at face value but rather as relative measures of impact.

AUTHOR CONTRIBUTIONS

Ioannis Kalaitzakis: Conceptualization; methodology; formal analysis; investigation; writing-original draft; writing—review and editing. **Marie-Morgane Rouyer**: Conceptualization; methodology; writing—review and editing; supervision; funding acquisition. **Ana S. L. Rodrigues**: Conceptualization; methodology; writing—review and editing; supervision; funding acquisition. **Maria P. Dias**: Conceptualization; methodology; writing—review and editing. **Tammy E. Davies**: Conceptualization; methodology; writing—review and editing. All authors contributed to the assessment of threats to seabirds and to the review of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare.

DATA AVAILABILITY STATEMENT

All data necessary to reproduce the results presented in this paper are available either as Supporting Information or through open datasets listed in the manuscript.

ETHICS STATEMENT

This work is based on a review of existing knowledge and does not require approval by an ethics committee.

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