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Highly Mobile Seabirds Reveal Areas of Conservation Importance Across the Atlantic Ocean

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ABSTRACT

Countries have committed to expanding the marine protected area (MPA) network to 30% of the world's ocean by 2030, more than tripling current coverage, and focusing on areas important for biodiversity. For such expansion to translate into effective conservation of marine biodiversity, it must rely on the best available knowledge. Here, we analyze tracking data on > 13,000 individuals (44 species, eight families) to map the distribution of highly mobile seabirds in the Atlantic Ocean and adjacent seas throughout the year. We identify regions important year-round or seasonally. The High Seas are as important as national waters for highly mobile seabirds but are even less protected. Current Atlantic MPAs hold < 14% of tracked species density, but their expansion to 30% of the ocean could protect up to two thirds. We share this new knowledge layer to support national and international efforts and policies to strategically expand the Atlantic MPA network.

1 | Introduction

Conserving marine ecosystems is challenging as many species are highly mobile, crossing entire ocean basins across and beyond countries' jurisdictions (Beal et al. 2021; Morten et al. 2025). Conservation measures may benefit from large-scale planning that considers dynamic distributions (Conners et al. 2022), yet data on species' distributions remain scarce (e.g., Townsend et al. 2014).

Marine protected areas (MPAs) are an important tool for halting marine biodiversity loss (Edgar et al. 2014). International biodiversity targets under the Convention on Biological Diversity (CBD) are driving their expansion, aiming to triple their current coverage of the ocean to reach 30% by 2030 (Kunming-Montreal Global Biodiversity Framework, CBD 2022; UNEP-WCMC and IUCN 2024). The recent Agreement on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction (BBNJ Agreement, UN General Assembly 2023) will further support the creation of MPAs in international waters. International targets clarify that MPAs should protect important areas for biodiversity (CBD 2022; Samarkand Strategic Plan for Migratory Species, CMS 2024), which can be identified through synthesizing available ecological data. Such synthesis can support conservation planning to place MPAs where they can be most effective rather than opportunistically in areas less valuable for human activities (Pressey et al. 1996, Devillers et al. 2015).

Seabirds are a well-studied group of marine species. As top predators integrating ecosystem processes across trophic levels, they are good indicators of marine ecosystems (Piatt et al. 2007) and have been used as umbrella species to inform conservation prioritization and MPA delineation, in both national and international waters (Ronconi et al. 2012; Davies et al. 2021). Among the most threatened birds—facing pressures on land and at sea (Dias et al. 2019; Kalaitzakis et al. 2026)—seabirds can benefit from focused conservation efforts such as MPAs, especially targeting seasonal aggregations (Oppel et al. 2018; Ronconi et al. 2023). Dynamic management can enhance protection, including through seasonal fishery closures around breeding seabirds' colonies, or MPA boundaries shifting with environmental conditions to protect foraging grounds (Tittensor et al. 2019; Handley et al. 2020).

Four decades of tracking studies revealed the long-distance movements undertaken by many seabird species (Carneiro et al. 2024). These highly mobile species face changing environments and management actions throughout their annual cycle, making their conservation rely on international collaborations over large scales (Harrison et al. 2018; Beal et al. 2021; Morten et al. 2025). Yet, tracking data are often collected for a single species or region, precluding the identification of important areas for multiple species at an ocean-basin scale and their translation into knowledge outputs that can inform management, marine spatial planning, and policy (McGowan et al. 2016; Hays et al.

2019). While syntheses exist for some species in some regions (e.g., Davies et al. 2021; Strøm et al. 2021; Trevail et al. 2023; Becker et al. 2024), no such study exists at an ocean-basin scale in the Atlantic, despite being heavily impacted by human activities (Halpern et al. 2019) and having the most seabird tracking data, with the fewest gaps in tracked species (Bernard et al. 2021).

Here, we compile and synthesize an important tracking dataset to reveal the spatio-temporal distribution of highly mobile seabirds across the Atlantic Ocean. We use the resulting maps to quantify the relative importance of national and international waters for highly mobile seabirds and to evaluate their current coverage by MPAs, which we compare with a maximum possible coverage with the same area and under a 30% MPA expansion.

2 | Methods

2.1 | Species Data

We defined Atlantic highly mobile seabirds as species that annually undertake long-distance journeys over the ocean (> 2000 km from their breeding colonies, Morten et al. 2025) and with at least one breeding colony in the Atlantic, including its adjacent seas (Supporting Information Methods S1, Figure S1). We identified 82 candidate species and compiled sufficient tracking data for 44 (Supporting Information Methods S2, Table S1).

We gathered tracking data from online databases (Seabird Tracking Database, Movebank), tracking programs (SEATRACK), and published and unpublished datasets. We followed standardized procedures to prepare these data (Supporting Information Methods S3, Figure S2), which came from light-level geolocation sensors (GLS), Platform Transmitter Terminal (PTT) and Global Positioning System (GPS) devices. We obtained a final tracking dataset totaling 3,560,488 locations from 13,060 individual birds (Figure S3, Table S2) across 31 years (1990–2021). The number of tracked individuals per species varied substantially (from five to 2308), with 37 species having > 20 individuals tracked (Figure S4). These seabirds bred in 206 colonies, spanning > 20 countries (Figure S5).

Following Davies et al. (2021), we defined a "population" as the individuals of a given species breeding in a large marine ecosystem (LME, adapted from Sherman and Alexander 1986, Figure S6) and assigned each breeding colony to an LME (Supporting Information Methods S4). We measured the demographic importance of a population as the fraction of a species' Atlantic population (number of individuals breeding in the Atlantic) breeding in an LME. To do so, we compiled population estimates by reviewing the published literature and databases, also including finer "subpopulation" estimates when available, such as different archipelagos or countries within an LME (Rouyer et al. 2025).

For each species, we evaluated the coverage of its Atlantic population by the tracking dataset, as the sum of the population sizes of those populations with tracking data divided by the species' Atlantic population size (Supporting Information Methods S4). Most species were very well covered: 37 had > 88% of their Atlantic population covered (Figure 1). Only five species had < 50% coverage, including three with < 5%.

2.2 | Mapping Species' Spatio-Temporal Distributions

We used a weighted kernel density estimation to map the density distribution of tracked highly mobile seabird species across the Atlantic in each year quarter, following four steps (detailed in Supporting Information Methods S5).

First, we mapped the density distribution of each population in each month, by summing subpopulation density distributions calculated with a kernel density estimation and weighted by their respective, proportional size (Rouyer et al. 2025).

Second, we summed these population rasters, weighted by their respective proportional size, to obtain species density maps per month. In the resulting species rasters, values add up to 1 for species with complete coverage (i.e., tracking data available for all populations, in that month) or < 1 otherwise (values adding to the fraction of the Atlantic population represented in the tracking data).

Third, we compiled species density maps per year quarter by averaging the corresponding monthly species rasters. We used year quarters to facilitate the uptake of our results into management and by stakeholders (e.g., Davies et al. 2021).

Fourth, we mapped the multi-species density per year quarter, by summing the corresponding species density rasters. Species with incomplete coverage (i.e., missing tracking data for some populations, Figure 1) contribute less to the multi-species maps. They are thus integrated in the analysis without assuming that their tracked populations represent all populations across the Atlantic.

Hereafter, we call this multi-species density "tracked species density." This metric reflects the intensity of use by the tracked species in each raster cell but not the abundance of individual birds (i.e., species that are more abundant are not represented more).

In addition, we mapped the core area used by each species in each year quarter, by identifying the smallest area containing 50% of a species' population with available tracking data. We then mapped the overlap between species' core areas, for each year quarter, to highlight areas in the Atlantic that are particularly important for multiple species throughout the year.

2.3 | Evaluating the Importance of National and International Waters and Their MPA Coverage

We quantified the importance of national (countries' Exclusive Economic Zones, EEZ, Supporting Information Methods S1) and international waters (High Seas) for highly mobile seabirds, as the percentage of tracked species density falling within each, in each year quarter.

We then evaluated the percentage of tracked species density within current MPAs (Figure S7, UNEP-WCMC and IUCN 2024), in both national and international waters, per year quarter (Supporting Information Methods S6). To put these values in context,

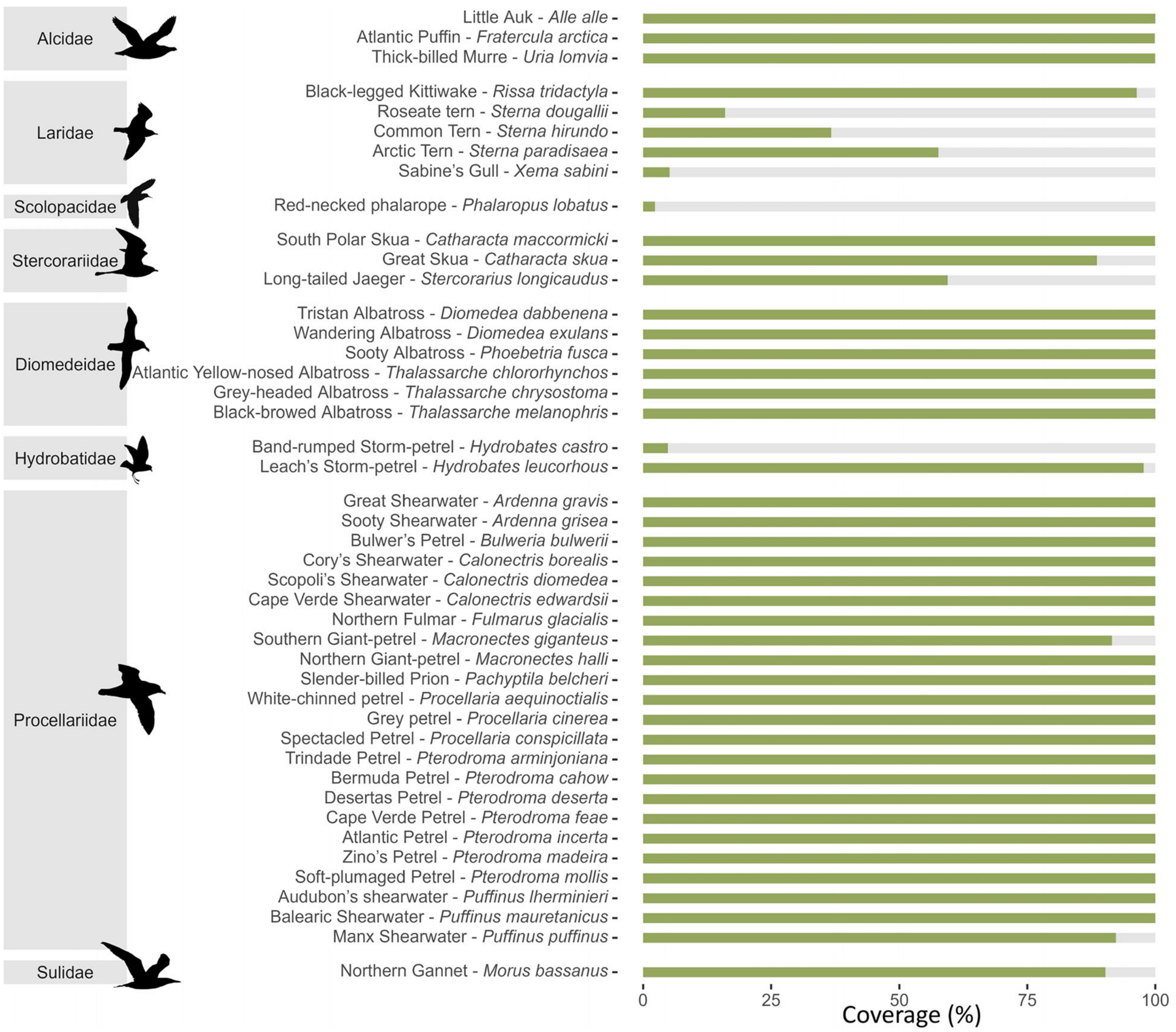

FIGURE 1 | Percentage of the Atlantic population of each species covered by the tracking dataset, for the 44 species included in this study. For each species, the coverage corresponds to the sum of the population sizes of those populations (i.e., individuals breeding within an LME) with available tracking data, divided by the size of the Atlantic population (i.e., number of individuals breeding in the Atlantic). Seabird silhouettes kindly provided by BirdLife International.

we calculated the maximum percentage of tracked species density that could be covered with: (a) the same MPA area as current, if MPAs had been placed where tracked species density is the highest in both national and international waters; (b) a theoretical MPA network covering 30% of national and 30% of international waters that include current MPAs and areas where tracked species density is the highest (Supporting Information Methods S7). For the latter, we considered two scenarios: a static network (same 30% of ocean area year-round) and a dynamic network (30% ocean area changing in each year quarter).

3 | Results

3.1 | Seasonal Distribution of Atlantic Highly Mobile Seabirds

Highly mobile seabirds use the whole Atlantic Ocean but concentrate in specific regions (Figure 2). Year-round, the Patagonian Shelf and waters around Tristan da Cunha (South Atlantic) and the Canary Current and the Grand Banks of Newfoundland (North Atlantic) hold high tracked species density and multiple species (Figure 3).

During the northern hemisphere's spring and summer (April–September, Figure 2b,c), tracked seabirds occur in high density in the North Atlantic, particularly around Macaronesia, the British Isles, the Mediterranean, off the Southeastern United States, and in some Arctic regions (e.g., Baffin Bay). During the southern hemisphere's spring and summer (October–March, Figure 2a,d), tracked species density increases in the South Atlantic, particularly around South Georgia and the South Sandwich Islands, along the Benguela Current, off the Antarctic Peninsula, and in the Gulf of Guinea. Most regions are seasonally important for multiple species, while others (e.g., Western Mediterranean, Baffin Bay, Antarctic Peninsula) are for few species included in this study (Figure 3).

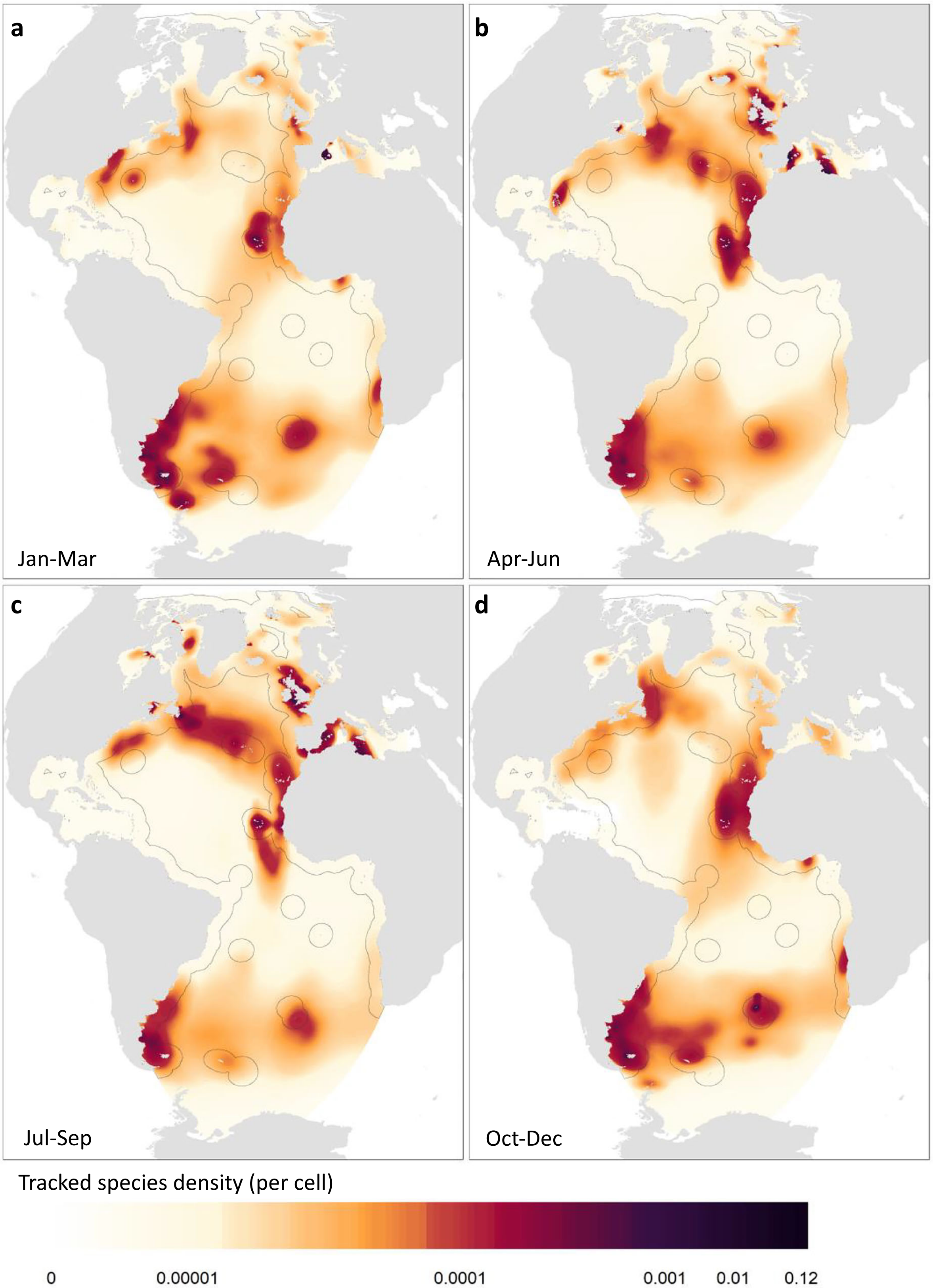

FIGURE 2 | Annual variation in tracked species density, for 44 Atlantic highly mobile seabird species. Each panel corresponds to a year quarter (a–d). The tracked species density value in each cell (0.1-degree resolution) is a multi-species density, corresponding to the sum of all individual species density rasters, themselves obtained through a kernel density estimation weighted by population sizes. The tracked species density reflects the intensity of use by the tracked species of each cell rather than numbers of birds per cell (i.e., species contribute equally to the density value, rather than proportionally to their abundance). Black lines show the boundary between national waters (EEZ) and international waters (High Seas).

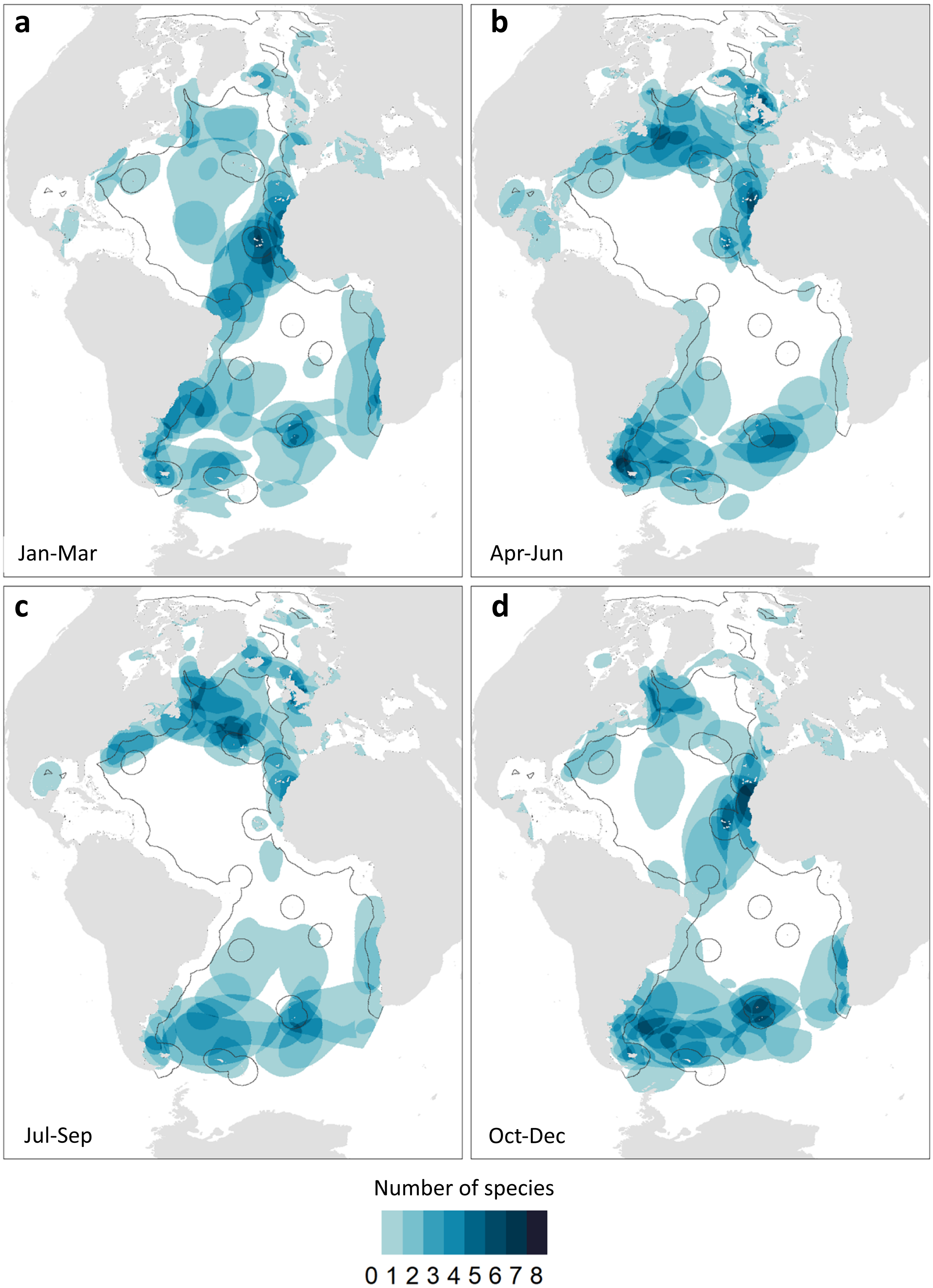

FIGURE 3 | Spatial distribution and overlap of the core areas of 44 species of Atlantic highly mobile seabirds, per year quarter (panels a to d). For each species, its core area corresponds to the minimum area used by 50% of its tracked population. Color intensity reflects increased number of species whose core areas overlap. Black lines show the boundary between national waters (EEZ) and international waters (High Seas).

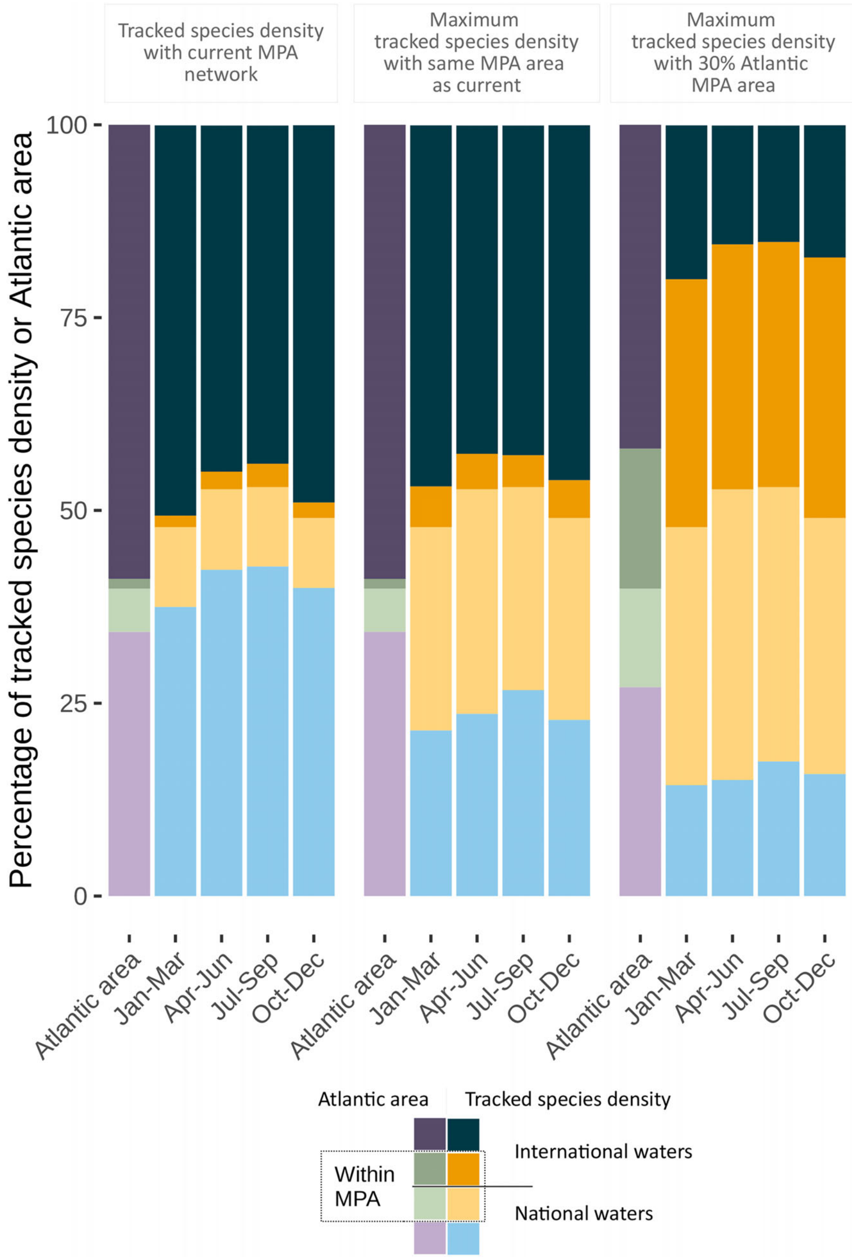

FIGURE 4 | Percentage of tracked species density and of Atlantic area, in national versus international waters, and in versus outside marine protected areas (MPAs). Values are shown in Table S3. The first bar in each plot indicates the percentage of Atlantic area within versus outside MPAs (green vs. purple) and in international versus national waters (dark vs. light shades). The other bars, corresponding each to a year quarter, indicate the percentage of tracked species density falling within versus outside MPAs (orange vs. blue) and in international versus national waters (dark vs. light shades). The three panels correspond to: (a) the current MPA network; (b) an MPA network with the same area as the current one but placed to maximize the coverage of tracked species density (i.e., where tracked species density is highest); (c) a static MPA network extending the current network to cover 30% of national and 30% of international waters and placed to maximize the coverage of tracked species density.

3.2 | Importance of National and International Waters

Waters within national jurisdictions comprise 40% of the Atlantic area and support 47%–53% of tracked species density throughout the year. Conversely, the High Seas cover 60% of the Atlantic Ocean and 46%–52% of tracked species density, with highest values from October to March (Figure 4, Table S3).

3.3 | MPA Coverage of Highly Mobile Seabirds

The Atlantic MPA network includes > 12,800 MPAs, covering 6.9% of the Atlantic area (Figure S7). Nearly all fall within national waters (5.6% of the Atlantic area) and only nine in the High Seas (1.3%; Figure 4, Table S3).

The current MPA network holds 11.1%–13.3% of tracked species density (maximum in July–September; Figure 4, Figure S8). It would have been possible to cover over twice that density (30.4%–33.7%) with the same area, if MPAs had been placed where tracked species density is the greatest (Table S3).

The majority (77%) of the tracked species density covered by current MPAs is found within national waters, with coverage relatively consistent throughout the year (9%–10.4%, lowest in October–December). In contrast, High Seas MPAs cover little tracked species density, but coverage doubles between January–March (1.5%) and July–September (3%) (Figure 4, Table S3).

Expanding the current Atlantic MPA network toward areas where tracked species density is the greatest and until it covers 30% of national and international waters could substantially increase the coverage of highly mobile seabirds: up to 65.6%–69.5% of tracked species density in a static network and slightly more (69.3%–71.5%) in a dynamic network (Figure 4, Table S3).

4 | Discussion

We present the first ocean-basin maps of the seasonal distribution of Atlantic highly mobile seabirds, based on the most comprehensive Atlantic tracking dataset to date: 13,060 individuals, 44 species, most with a very good coverage of their different populations (Figure 1). These species represent > 100 million adult seabirds in the Atlantic (Rouyer et al. 2025). This basin-scale overview identifies important regions, both within national and international waters, which would benefit from dedicated conservation planning that includes highly mobile species. Importantly, the maps' coarse resolution is not suited for a fine-scale (10s–100 km) understanding of seabird space use.

Our dataset has other limitations that should be considered when using these results. Only adults are included, and species are unevenly represented: some are absent (e.g., family Oceanitidae), others have few individuals (Figure S4) or populations (e.g., terns with a wide breeding range, Figure 1) tracked. Poorly tracked species (Table S1) may be prioritized in future tracking programs. Data accuracy also varies across species, as geolocators are less accurate during equinoxes and at high latitudes around solstices, potentially underestimating the importance of certain regions (e.g., polar areas).

4.1 | Concentration of Highly Mobile Seabirds Throughout the Year

We reveal the most important regions for highly mobile seabirds across the Atlantic Ocean (Figure 2). Year-round, multi-species concentrations of seabirds occur in productive regions and currents, namely, the Falkland/Malvinas, Canary, and Labrador currents and around Tristan da Cunha, all known seabird hotspots (Grecian et al. 2016; Dias et al. 2017; Baylis et al. 2019; Davies et al. 2021). Seasonal concentrations in the North and South Atlantic reflect migratory movements (Morten et al. 2025) and the locations of important breeding and non-breeding grounds.

These regions are globally important marine biodiversity hotspots, supporting zooplankton, mesopelagic fish, and foraging grounds for marine megafauna (e.g., CBD 2019; IUCN-MMPATF 2024). We provide evidence of their significance for seabirds. Their importance is recognized by international frameworks, including Ecologically or Biologically Significant Areas (e.g., parts of the Labrador Sea), Important Marine Mammal Areas (e.g., Patagonian Shelf), and Key Biodiversity Areas (e.g., Canary Current), making them priority areas for MPA establishment (Visalli et al. 2020), especially in regions where biodiversity is at risk across taxa (e.g., Patagonian Shelf, Mediterranean Sea; O'Hara et al. 2019).

4.2 | Importance of National and International Waters

Productive waters are often coastal (Fermepin et al. 2024), providing foraging grounds especially critical during the breeding season when seabirds are spatially constrained to waters surrounding their colonies. Accordingly, national waters hold a high proportion of tracked species density (47%–53%, in 40% of the Atlantic), particularly from April to September, when most tracked species are breeding.

Nonetheless, the Atlantic High Seas are equally important, holding approximately half of the tracked species density (supporting findings from other ocean basins; e.g., Harrison et al. 2018). Productive features such as fronts and eddies, especially at higher latitudes (Fermepin et al. 2024), offer foraging opportunities, notably during the non-breeding season.

Our results underscore the need to integrate national and international waters in conservation planning. Important regions extend across both (e.g., Northwestern Atlantic, Patagonian Shelf, Figure 2), and seabirds rely on and connect distant oceanic regions and jurisdictions (Beal et al. 2021; Morten et al. 2025), requiring effective international cooperation (e.g., under the Convention on Migratory Species; CMS).

4.3 | Insufficient MPA Coverage

The Atlantic MPA network is insufficient to protect highly mobile seabirds, covering only 11.1%–13.3% of tracked species density and 7% of the Atlantic area (below the 10% global target to be reached by 2020, CBD 2010). As a comparison, an MPA network located where tracked seabird density is the highest could have nearly tripled coverage (30.4%–33.7%) with the same area (Figure 4, Table S3). While current coverage is rather low, many MPAs were not designated specifically for highly mobile seabirds and remain important for marine biodiversity, including other seabirds (e.g., Yorio 2009).

MPA coverage is particularly poor in the High Seas (1.2%), even though half of the responsibility to conserve highly mobile seabirds falls outside of national jurisdictions. Filling the gaps in the Atlantic MPA network requires clarifying responsibilities among governance actors (e.g., countries, Regional Seas Conventions), which would support the implementation of the BBNJ Agreement. The NACES MPA, designated under the OSPAR Convention, exemplifies effective international cooperation. Identified through seabird tracking data (Davies et al. 2021), it covers alone around half of the tracked species density recorded in High Seas MPAs (Supporting Information Results).

4.4 | Opportunity to Expand the Atlantic MPA Network

Meeting the 30% target in the Atlantic will require doubling the MPA network in national waters and expanding it 15-fold in international waters while targeting areas of importance for biodiversity. Expanding the current network to protect productive regions where highly mobile seabirds aggregate (Figure 2) could cover nearly two thirds of the tracked species density (Figure 4) and benefit other marine taxa (see above).

Our study supports efforts to strategically expand the Atlantic MPA network, by providing biodiversity layers for highly mobile seabirds that can feed into Atlantic-scale or regional spatial planning and by identifying important regions that deserve finer-scale assessments. Providing these new knowledge layers can also improve the integration of highly mobile seabirds into national marine spatial plans and MPA planning (e.g., Sink et al. 2023). Additional layers, both ecological (e.g., distribution of other species, including resident and short-distance migratory seabirds) and socioeconomic (e.g., economic, political, and social constraints and benefits of conservation actions), are essential to support decision-making (Brown et al. 2015).

Ensuring that MPA expansion delivers on positive outcomes for biodiversity requires targeting important areas and ensuring that MPAs are sufficiently large, effectively managed, sufficiently resourced, and well-connected between them (Conners et al. 2022; Gardner et al. 2024; Pike et al. 2024). We show that if focusing only on the most important regions for highly mobile seabirds, static MPAs—easier to implement than dynamic ones—would be nearly as valuable. However, as climate change may shift productive ocean regions, MPAs should be climate-smart, with boundaries adjusting to changing environmental conditions (Tittensor et al. 2019).

Our results confirm the need for complementary management measures beyond MPAs (Oppel et al. 2018), as even if the MPA network was expanded to 30% by maximizing coverage of highly mobile seabirds, it would still leave out one third of the tracked species density. Deploying threat-mitigation measures over large scales (e.g., bycatch reduction devices) remains essential, especially where seabirds and human activities (e.g., fisheries) overlap greatly. The layers complemented by local-scale studies (e.g., Garthe et al. 2023) can also guide avoidance of critical habitats, such as migratory corridors or foraging areas, in offshore wind or other development.

The layers and data we provide can also support policy processes, including revising or describing CBD Ecologically or Biologically Significant marine Areas and identifying Key Biodiversity Areas (KBAs)—indicators to monitor the 30% target (CBD 2022)—at a species, country, or regional level (e.g., Handley et al. 2023; Becker et al. 2024). These can inform the implementation of the BBNJ Agreement by identifying areas suitable for area-based management tools, including MPAs (Carneiro et al. 2024). Our findings furthermore contribute to the implementation of the Samarkand Strategic Plan for Migratory Species (Convention on Migratory Species 2024), which directs countries to identify and effectively protect or manage all important habitats for CMS-listed migratory species by 2029.

In conclusion, we synthesized the best available ecological data to uncover the spatio-temporal distribution of Atlantic highly mobile seabirds, highlighting key regions that represent conservation opportunities. We provide a knowledge layer to support the strategic expansion of the Atlantic MPA network and international collaboration efforts to achieve biodiversity targets.

Author Contributions

M.-M.R., A.S.L.R, M.P.D., T.E.D., N.B. conceived the study. A.S.L.R., M.-M.R. and M.P.D. obtained funding. M.-M.R. A.S.L.R, M.P.D., T.E.D., N.B., B.L.C., A.P.B.C., J.L.G. designed or improved the methods. M.-M.R., B.L.C., E.J.P., M.P.D. processed the tracking data and compiled population numbers. M.-M.R. analyzed the data, produced the figures and tables, and wrote the first draft of the manuscript with support from A.S.L.R., M.P.D., T.E.D., N.B., B.L.C., A.P.B.C., J.L.G in obtaining advanced versions. All other authors provided data and feedback to improve the manuscript.

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Ethics Statement

Animal ethics were managed by each organization as appropriate.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The tracked species density rasters for each quarter are available at https://doi.org/10.57745/ULKJVD. Data are made available under a CC BY-NC-SA 4.0 International license. The underlying tracking data are available under restricted access as the data were collected for other purposes by their respective owners, and revealing the exact locations of sensitive species may put them at risk. Access can be obtained by making a request to the owners of each dataset (see Table S2). Most of the tracking data are deposited on BirdLife International's Seabird Tracking Database (https://www.seabirdtracking.org/), in SEATRACK (https://seatrack.net/) or Movebank (https://www.movebank.org/) and can be requested on these respective data portals. A summary of the tracking data used with their respective identifiers and descriptions is available in Table S2.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.

Supporting Information: conl70075-sup-0001-SuppMat.pdf **Supporting Information Table**: conl70075-sup-0002-TableS2.xlsx