

Supplementary information

Highly mobile seabirds reveal areas of conservation
importance across the Atlantic Ocean

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Supplementary methods

Supplementary methods 1 – Atlantic geographic limits

We focused on the Atlantic Ocean, including its adjacent seas (Figure S1). To delineate its geographic limits, we used official ocean boundaries from the International Hydrographic Organization (1953; shapefiles from Flanders Marine Institute 2018). We included the South and North Atlantic, their adjacent seas, the Atlantic part of the Arctic (from the western limit of the Northwestern Passages to the eastern limit of the Barents Sea, and until 90°N) and of the Southern Ocean (up to the Antarctic continent, between the meridians of Cape Horn and Cape Agulhas; Figure S1).

To keep only ocean area in the Atlantic spatial layer (i.e., excluding islands), we used the version 2.3.7 (2017) of the Global Self-consistent, Hierarchical, High-resolution Geography Database (Wessel & Smith 1996), offering a high-resolution shoreline commonly used in other marine GIS studies (e.g., Visconti et al. 2013; Thomas et al. 2014).

We subdivided the Atlantic into national waters, corresponding to Exclusive Economic Zones (EEZs, Flanders Marine Institute 2023) which are under the jurisdiction of adjacent coastal countries (usually extending until 200 nautical miles), and international waters (the High Seas), corresponding to areas beyond countries' jurisdictions. We rasterized EEZ and High Seas vector layers for faster computations at a resolution of 0.1 degree, in the WGS84 geographic coordinate reference system.



Figure S1 – Geographic limits of the Atlantic (in blue). It includes the South and North Atlantic, extended until the North Pole and the Antarctic continent, and all adjacent seas.

Supplementary methods 2 – Identification of Atlantic highly mobile seabird species

Our study focuses on Atlantic highly mobile seabird species, for which sufficient tracking data exist. First, to identify species with breeding colonies in the Atlantic and wide oceanic ranges, we visually checked the ranges of all 364 extant seabird species (BirdLife International and Handbook of the Birds of the World 2020), excluding non-flying seabirds (penguins; n=18) which have a distinctive ecology. We obtained a preliminary list of 82 potential Atlantic highly mobile species (Table S1). Second, we checked whether tracking data were available for these species in the Atlantic, either in tracking databases (Seabird Tracking Database, Movebank) or in the published literature until 2020, mostly from tracking datasets identified in Bernard et al. (2021). Then, we inspected these tracking data to clarify for each species if it met the definition of a highly mobile species, which annually undertakes long-distance journeys (>2,000 km from their breeding colony) over the ocean. This excluded species whose long-distance movements are mostly over land, such as some gull species (e.g., Lesser Black-backed Gull *Larus fuscus*). Two thousand kilometers is an arbitrary threshold that allows to distinguish species traveling very long distances and aligns with the definition used by Morten et al. (2025). Two thousands kilometers roughly correspond to the narrowest width of the Atlantic (~2,800 km between Brazil and Liberia), a quarter of the Atlantic' widest width (~8,000 km between Mexico and Western Africa) and a quarter of the North Atlantic or South Atlantic (~8,000 km in length each) (Google Earth, 2025). We measured the 2,000 km threshold as the median travel distance from the breeding colony of the top 10% furthest positions of a species' population (see Supplementary methods 4 for a definition). If at least one population of a species met this threshold for more than a month, then the species was included. Finally, we only kept species for which we had sufficient tracking data to include in the analysis, i.e. at least five adult birds tracked for at least 6 months, spanning at least 3 out of 4 year quarters. This resulted in our final list of 44 species (Table S1).

Overall, out of the 82 initial candidate species, we excluded 23 species for which it was not possible to determine the magnitude of their movements in the Atlantic (e.g. no or not enough existing tracking data); 8 species known to be highly mobile from other sources (e.g. ringing studies) but for which tracking data were also lacking. Therefore, we highlight 31 species as tracking-data deficient in the Atlantic (Table S1). Out of the 49 Atlantic highly mobile species with sufficient existing tracking data to be included in this study, we were able to compile data for 44 species (Table S2).

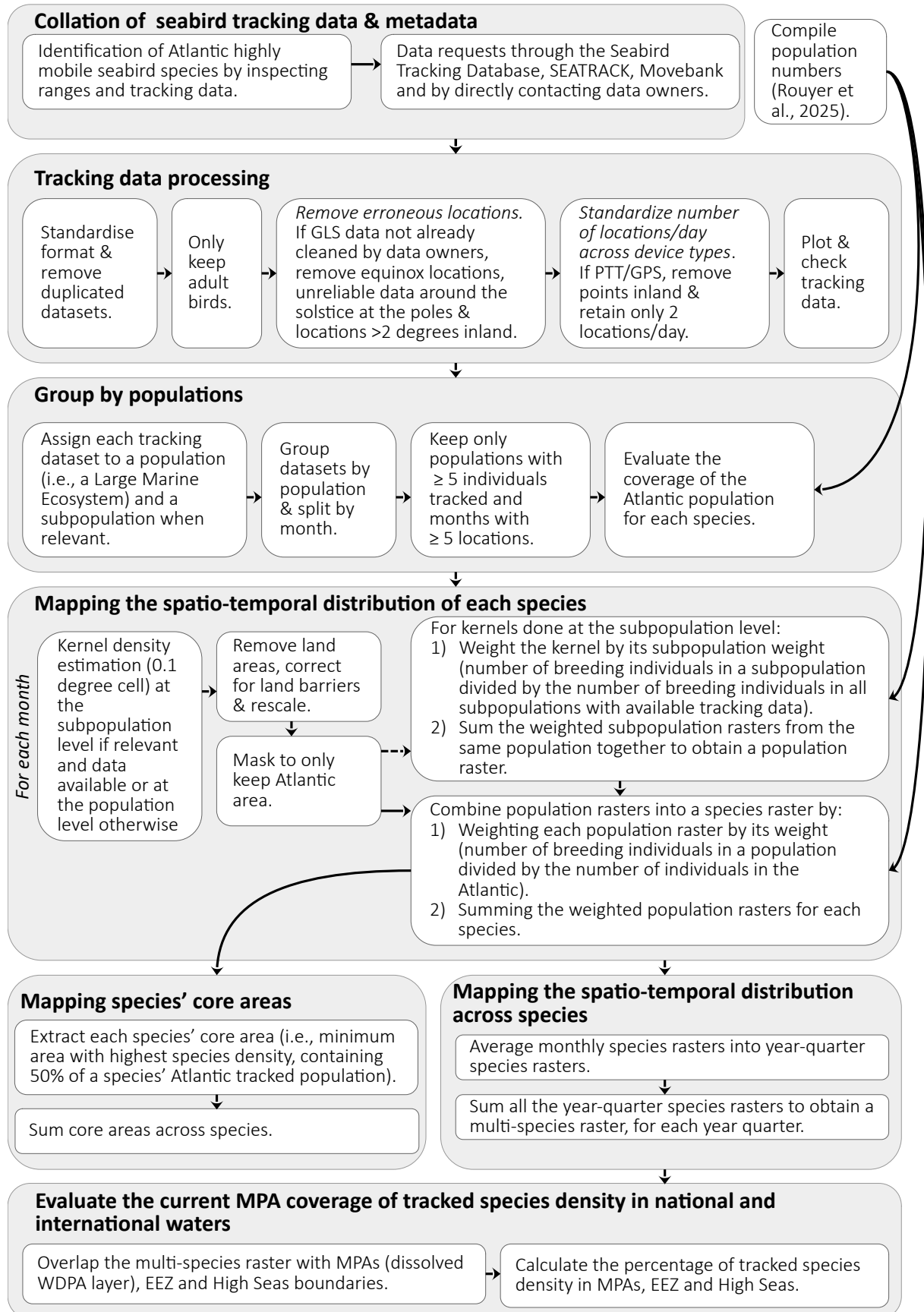
Table S1 – List of species considered in this study. Only Atlantic species classified as highly mobile species or potential ones are shown. Species included in the analyses, which scientific names are shown in bold, are those for which we compiled sufficient tracking data (i.e., at least five adult birds tracked for at least 6 months, spanning at least 3 out of 4 year quarters).

Family	scientific name	common name	Atlantic highly mobile species	Year-round tracking data	≥ 5 birds tracked
Diomedidae	<i>Diomedea dabbenena</i>	Tristan Albatross	yes	yes	yes
	<i>Diomedea exulans</i>	Wandering Albatross	yes	yes	yes
	<i>Phoebastria fusca</i>	Sooty Albatross	yes	yes	yes

	<i>Phoebastria palpebrata</i>	Light-mantled albatross	potential	no	no
	<i>Thalassarche chlororhynchos</i>	Atlantic Yellow-nosed Albatross	yes	yes	yes
	<i>Thalassarche chrysostoma</i>	Grey-headed Albatross	yes	yes	yes
	<i>Thalassarche melanophris</i>	Black-browed Albatross	yes	yes	yes
<i>Hydrobatidae</i>	<i>Hydrobates castro</i>	Band-rumped Storm-petrel	yes	yes	yes
	<i>Hydrobates jabejabe</i>	Cape Verde Storm-Petrel	potential	no	no
	<i>Hydrobates leucorhous</i>	Leach's Storm-petrel	yes	yes	yes
	<i>Hydrobates montei</i>	Monteiro's Storm-petrel	yes	no	yes
	<i>Hydrobates pelagicus</i>	European Storm-petrel	yes	no	yes
<i>Oceanitidae</i>	<i>Fregetta grallaria</i>	White-bellied Storm-petrel	potential	no	no
	<i>Fregetta tropica</i>	Black-bellied Storm-petrel	potential	no	no
	<i>Garrodia nereis</i>	Grey-backed Storm-petrel	potential	no	no
	<i>Oceanites oceanicus</i>	Wilson's Storm-petrel	potential	no	maybe
	<i>Pelagodroma marina</i>	White-faced Storm-petrel	potential	no	maybe
<i>Procellariidae</i>	<i>Aphrodroma brevirostris</i>	Kerguelen Petrel	potential	no	no
	<i>Ardenna gravis</i>	Great Shearwater	yes	yes	yes
	<i>Ardenna grisea</i>	Sooty Shearwater	yes	yes	yes
	<i>Bulweria bulwerii</i>	Bulwer's Petrel	yes	yes	yes
	<i>Calonectris borealis</i>	Cory's Shearwater	yes	yes	yes
	<i>Calonectris diomedea</i>	Scopoli's Shearwater	yes	yes	yes
	<i>Calonectris edwardsii</i>	Cape Verde Shearwater	yes	yes	yes
	<i>Daption capense</i>	Cape Petrel	potential	no	no
	<i>Fulmarus glacialis</i>	Northern Fulmar	yes	yes	yes
	<i>Fulmarus glacialisoides</i>	Southern Fulmar	potential	no	no
	<i>Macronectes giganteus</i>	Southern Giant-petrel	yes	yes	yes
	<i>Macronectes halli</i>	Northern Giant-petrel	yes	yes	yes
	<i>Pachyptila belcheri</i>	Slender-billed Prion	yes	yes	yes
	<i>Pachyptila macgillivrayi</i>	MacGillivray's Prion	yes	yes	yes

	<i>Pachyptila vittata</i>	Broad-billed Prion	yes	yes	yes
	<i>Pagodroma nivea</i>	Snow Petrel	potential	no	no
	<i>Procellaria aequinoctialis</i>	White-chinned petrel	yes	yes	yes
	<i>Procellaria cinerea</i>	Grey petrel	yes	yes	yes
	<i>Procellaria conspicillata</i>	Spectacled Petrel	yes	no	yes
	<i>Pterodroma arminjoniana</i>	Trindade Petrel	yes	yes	yes
	<i>Pterodroma cahow</i>	Bermuda Petrel	yes	yes	yes
	<i>Pterodroma deserta</i>	Desertas Petrel	yes	yes	yes
	<i>Pterodroma feae</i>	Cape Verde Petrel	yes	yes	yes
	<i>Pterodroma hasitata</i>	Black-capped Petrel	yes	no	yes
	<i>Pterodroma incerta</i>	Atlantic Petrel	yes	yes	yes
	<i>Pterodroma macroptera</i>	Great-winged Petrel	potential	no	no
	<i>Pterodroma madeira</i>	Zino's Petrel	yes	yes	yes
	<i>Pterodroma mollis</i>	Soft-plumaged Petrel	yes	yes	yes
	<i>Puffinus elegans</i>	Subantarctic Shearwater	potential	no	no
	<i>Puffinus lherminieri</i>	Audubon's shearwater	yes	yes	yes
	<i>Puffinus mauretanicus</i>	Balearic Shearwater	yes	no	yes
	<i>Puffinus puffinus</i>	Manx Shearwater	yes	yes	yes
	<i>Puffinus yelkouan</i>	Yelkouan Shearwater	occasional	yes	yes
	<i>Thalassoica antarctica</i>	Antarctic Petrel	yes	yes	yes
Alcidae	<i>Alle alle</i>	Little Auk	yes	yes	yes
	<i>Fratercula arctica</i>	Atlantic Puffin	yes	yes	yes
	<i>Uria lomvia</i>	Thick-billed Murre	yes	yes	yes
Laridae	<i>Anous minutus</i>	Black Noddy	potential	no	no
	<i>Anous stolidus</i>	Brown Noddy	potential	no	no
	<i>Chlidonias niger</i>	Black Tern	yes	unknown	unknown
	<i>Gelochelidon nilotica</i>	Gull-billed Tern	potential	no	no

	<i>Hydrocoloeus minutus</i>	Little Gull	potential	no	no
	<i>Larus audouinii</i>	Audouin's Gull	potential	no	no
	<i>Larus fuscus</i>	Lesser Black-backed Gull	no	yes	yes
	<i>Larus ridibundus</i>	Black-headed Gull	potential	no	no
	<i>Larus smithsonianus</i>	Arctic Herring Gull	potential	no	no
	<i>Onychoprion fuscatus</i>	Sooty Tern	potential	no	no
	<i>Pagophila eburnea</i>	Ivory Gull	yes	yes	yes
	<i>Rhodostethia rosea</i>	Ross's gull	potential	no	no
	<i>Rissa tridactyla</i>	Black-legged Kittiwake	yes	yes	yes
	<i>Sterna dougallii</i>	Roseate tern	yes	yes	yes
	<i>Sterna hirundo</i>	Common Tern	yes	yes	yes
	<i>Sterna paradisaea</i>	Arctic Tern	yes	yes	yes
	<i>Thalasseus maximus</i>	Royal Tern	yes	no	no
	<i>Thalasseus sandvicensis</i>	Sandwich tern	yes	no	no
	<i>Xema sabini</i>	Sabine's Gull	yes	yes	yes
Scolopacidae	<i>Phalaropus fulicarius</i>	Red phalarope (also called grey phalarope)	yes	yes	no
	<i>Phalaropus lobatus</i>	Red-necked phalarope	yes	yes	yes
Stercorariidae	<i>Catharacta maccormicki</i>	South Polar Skua	yes	yes	yes
	<i>Catharacta skua</i>	Great Skua	yes	yes	yes
	<i>Stercorarius longicaudus</i>	Long-tailed Jaeger	yes	yes	yes
	<i>Stercorarius parasiticus</i>	Arctic Jaeger	yes	yes	no
	<i>Stercorarius pomarinus</i>	Pomarine Jaeger	yes	no	no
Sulidae	<i>Morus bassanus</i>	Northern Gannet	yes	yes	yes
Anatidae	<i>Somateria spectabilis</i>	King Eider	potential	no	no



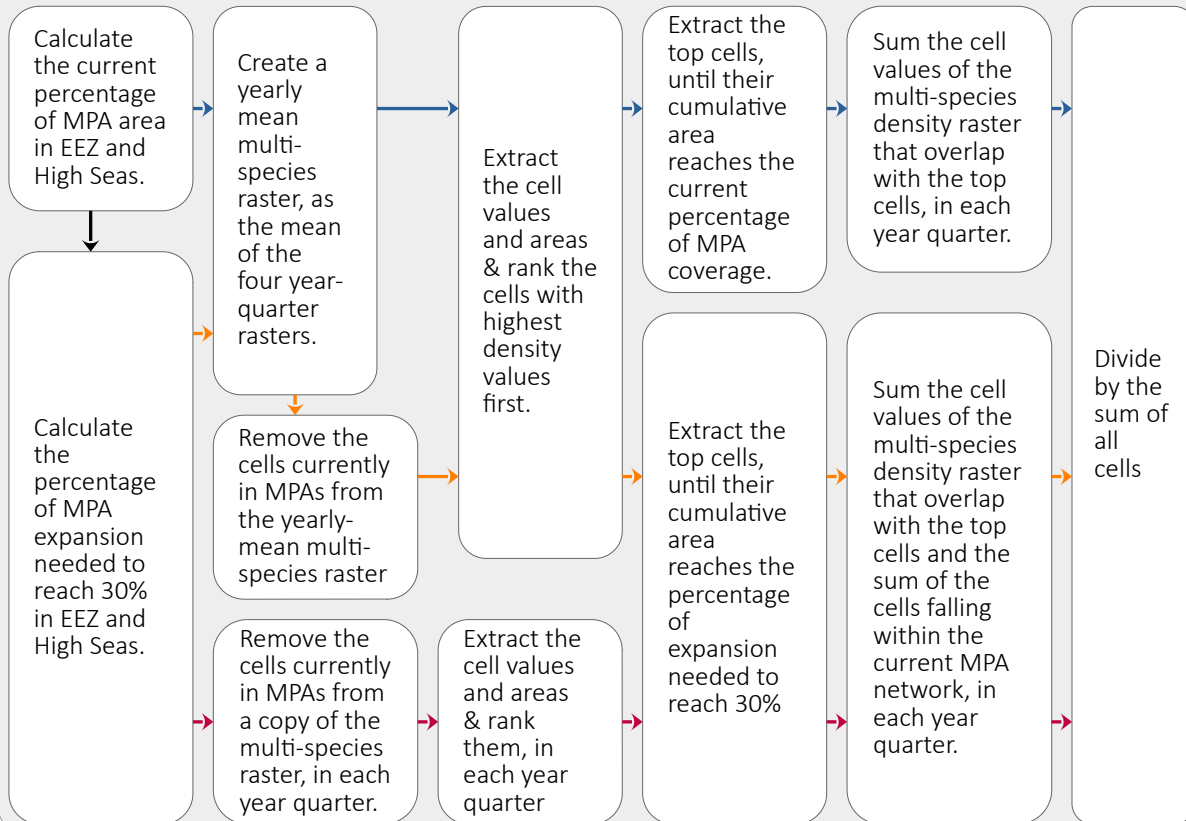
Evaluate the potential MPA coverage of tracked species density in national and international waters

→ Calculate the *maximum percentage* that could be covered with the same *MPA area as current*

Calculate the maximum percentage that could be covered by extending the current MPA network until it covers 30% of the High Seas and 30% of the EEZ area.

→ With a static MPA network

→ With a dynamic MPA network



89 Figure S2 – Schematic representation of the methods used to map the spatio-temporal distribution of
 90 Atlantic highly mobile seabirds from tracking data and measure their overlap with Marine Protected Areas.
 91 All analyses were conducted in R (version 4.3.1, R core team, 2023).

92 Supplementary methods 3 – Preparation of the tracking data

93 We performed several steps to clean, format and prepare the tracking data for analysis (Figure S2),
 94 following standardized procedures commonly used in tracking studies (e.g., Carneiro et al. 2020; Clark et
 95 al. 2023; Davies et al. 2021). We first removed duplicated tracking datasets (same data coming from
 96 different sources) and harmonized the formatting so that we could pool them together. The GLS data we
 97 compiled were already pre-processed by their respective owners to obtain two locations per day. We then
 98 pre-cleaned the data by removing location points with low accuracy scores, duplicated positions,

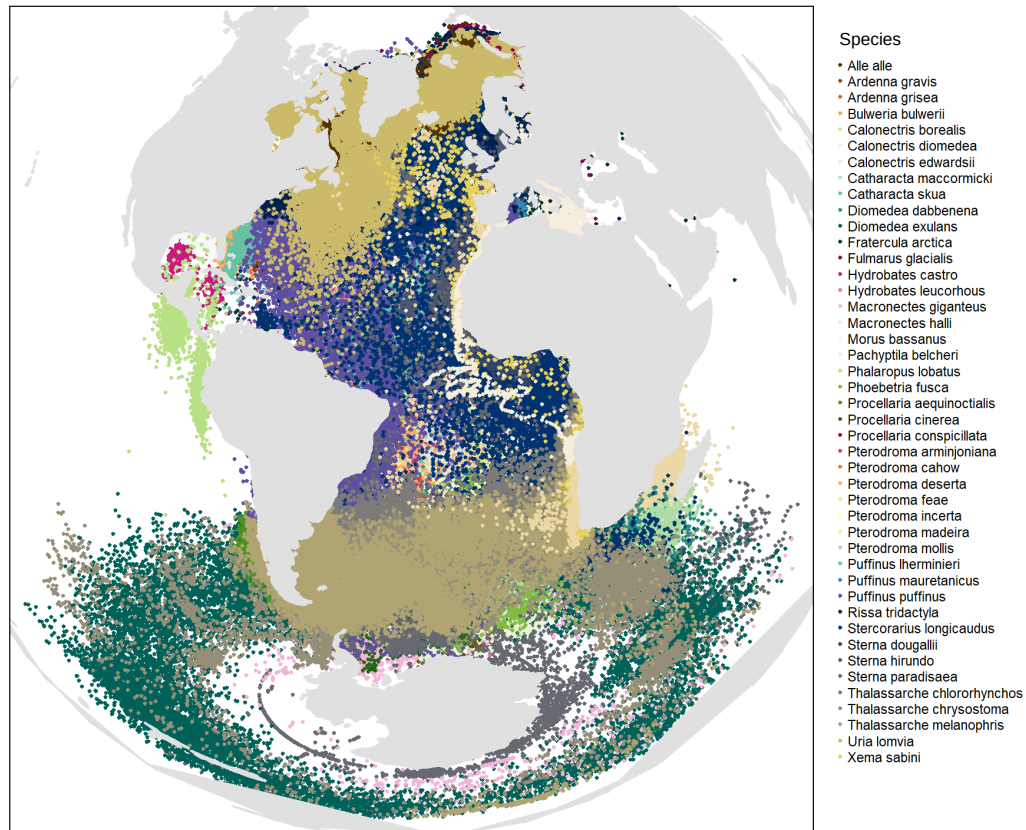
99 erroneous locations (e.g., by applying a McConnell speed filter to PTT data based on a maximum speed
 100 between two points of 90km/h, by removing obvious outliers), erroneous data entries, and ensuring that
 101 all points were associated with a unique date and time.

102 As we included different device types (Platform Transmitter Terminal, PTT; Global Positioning System,
 103 GPS; light-level geolocators, GLS) in this analysis, we aligned their temporal resolution to avoid location
 104 bias caused by device type, following (Clark et al. 2023). Indeed, PTT and GPS devices are often set with a
 105 higher temporal resolution, providing more points per day than GLS, but are rarely available for the full
 106 year. Hence, we kept only 2 points per day for PTT and GPS data (every 12 h), aligning their temporal
 107 resolution with that of the GLS data. To do so, we interpolated each bird's track using the `redisltraj`
 108 function of the `adehabitatLT` package in R (Calenge 2019). This selects the first point of each bird's track
 109 and then a point every 12h. For 18 datasets that had very large time gaps between consecutive points, we
 110 selected a point every 12 hours or the next point when the time gap was longer.

111 As we were interested in the importance of at-sea areas for seabirds, we removed all inland points from
 112 GPS and PTT devices by applying a high-resolution land mask, excluding all the islands (Wessel & Smith
 113 1996). We did not do it for GLS as the mean error is large (186 km, Phillips et al. 2004), leading to points
 114 commonly overlapping with land and removing them would lead to biasing locations away from the coast.
 115 However, for 10 datasets with numerous erroneous locations located far inland, we removed points that
 116 were more than 2 degrees inland, likely to fall beyond the mean error of the GLS.

117 As GLS locations are unreliable around the equinoxes, we applied an asymmetrical filter around equinox
 118 dates (Hill and Braun 2001) when needed (i.e., datasets not previously filtered), removing 21 days before
 119 until 7 days after the March equinox and 7 days before until 21 days after the September equinox (Beal et
 120 al. 2021). We visually inspected each dataset and remaining erroneous locations collected within a month
 121 around equinox periods were removed. High latitude GLS locations can also be unreliable around the
 122 solstices, as a result of a lack of twilight events during the polar night or the midnight sun. We removed
 123 unreliable data accordingly.

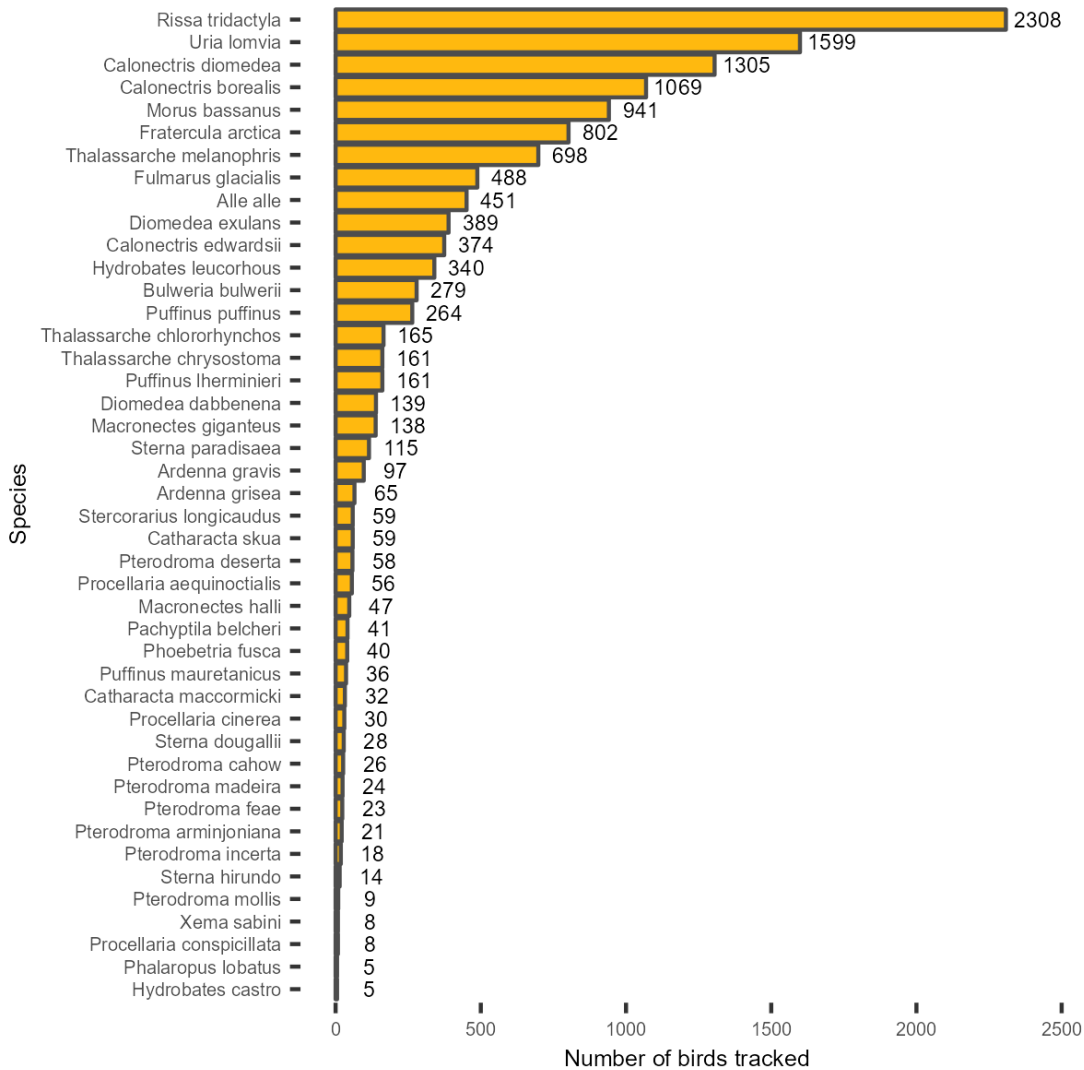
124 The final tracking dataset included 3,560,488 locations, of which 91.5% were from GLS, 7.6% from GPS
 125 and 0.9% from PTT.



126 Figure S3 – Tracking data of the 44 species of highly mobile seabirds included in the study. The data include
 127 3,560,488 location points from 13,060 individual birds. Each color represents a species. The projection used
 128 is an Atlantic-centred Lambert azimuthal equal-area projection.

129 Table S2 – Tracking data available for each species, population and subpopulation. For each, we provide the
 130 source of the tracking data (either from data owner, Seatrack project or the Seabird Tracking Database,
 131 STD), the devices used (GLS, GPS, PTT), the dataset IDs (numbers correspond to dataset ID in the STD), the
 132 years tracked and the primary data owner/contact.

133 Table S2 is provided as a separate excel document.



134 Figure S4 – Number of individual birds tracked per species. Species with fewer than 5 individuals tracked
 135 were excluded from the tracking dataset.

136 Supplementary methods 4 – Assigning the tracking dataset to populations and evaluating 137 the coverage of each species' Atlantic population in the tracking dataset

138 We assigned each individual bird of the tracking dataset to a population, and if relevant to a
 139 subpopulation, based on the location of its breeding colony (Figure S5). We defined a population as the
 140 individuals of a given species breeding in an LME (see Methods in main text, Figure S6). We grouped the
 141 different tracking datasets into a single dataset for each population, that we consequently split per month.
 142 We only kept populations with at least five birds tracked except for two populations that had more than
 143 5 bird tracked at the species level and small population sizes (<10% of the Atlantic population size, see

below), thereby excluding three populations from three species. We only kept months with at least five locations. There were in total 99 datasets (all populations of all species): 93% had GLS data, 55% GPS data and 24% PTT data.

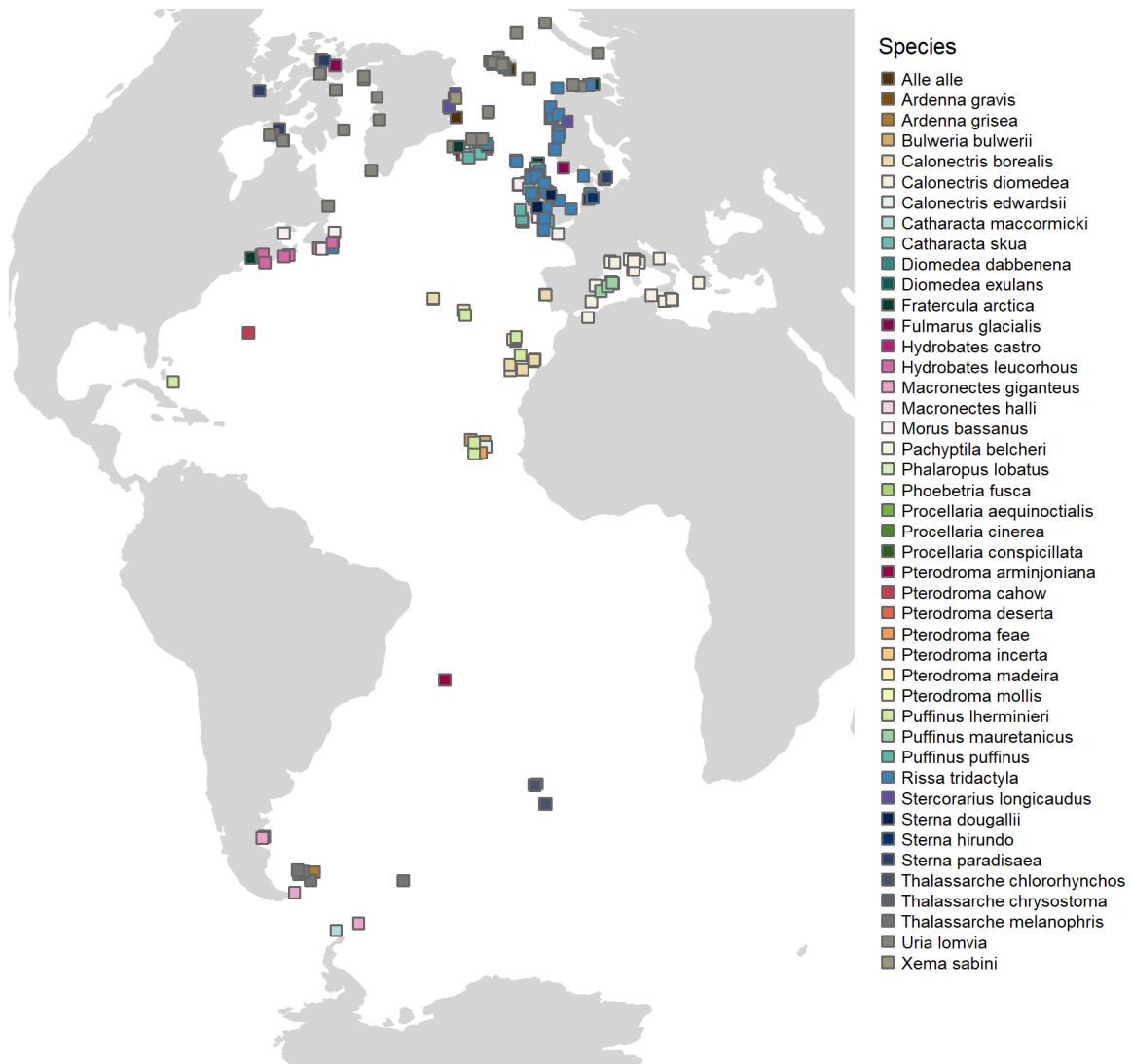
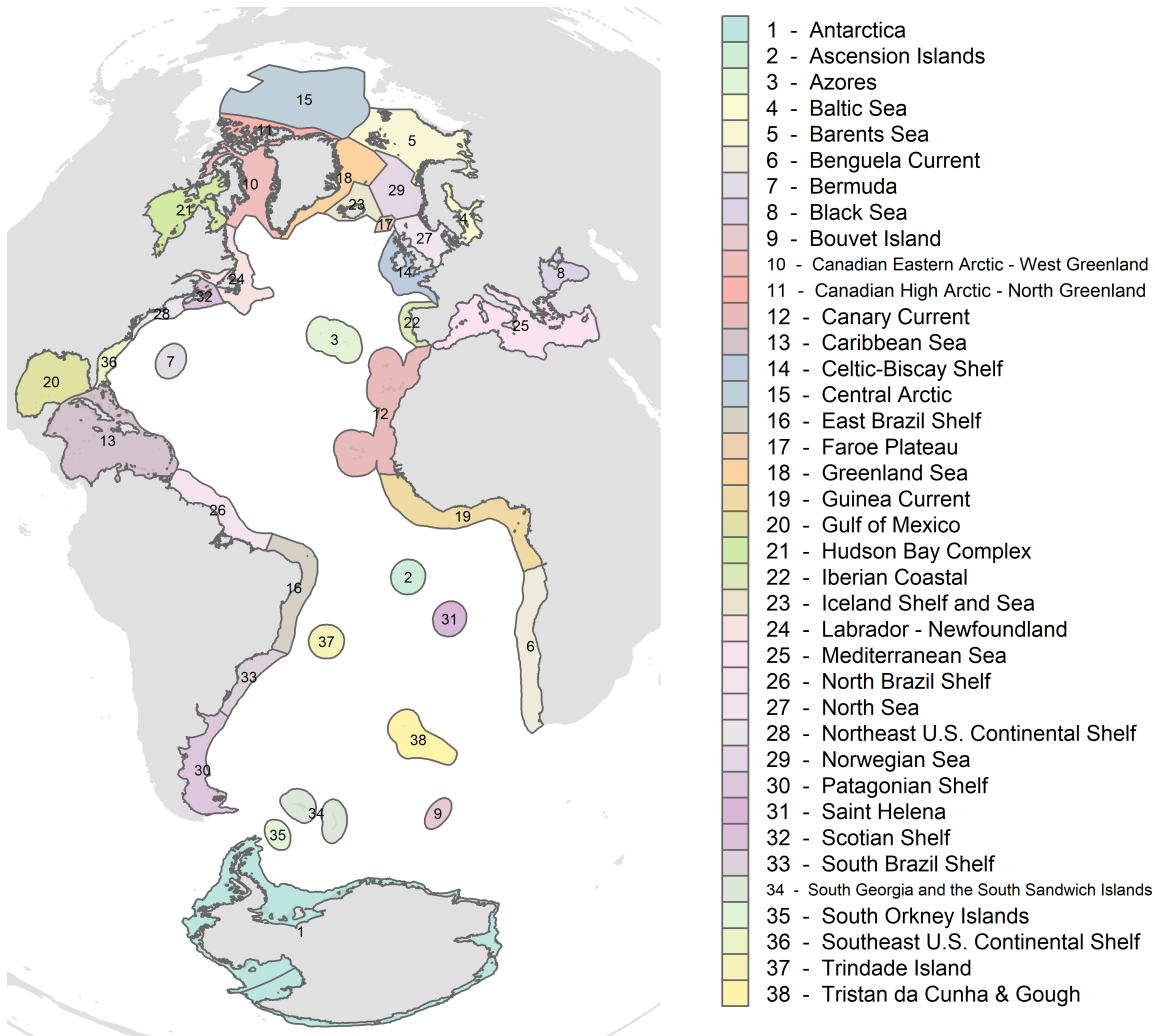


Figure S5 – Tracked colonies of highly mobile seabirds in the Atlantic included in the study. Each color represents a species.



149 *Figure S6 – Modified Large Marine Ecosystems used in the study, see Rouyer et al., (2025) for details.*

150 We then evaluated how well the overall tracking dataset (including all populations from all species, Table
 151 S2) covered the Atlantic population of each species (Figure 1) We measured this coverage as the sum of
 152 the population sizes of those populations with available tracking data, divided by the species' Atlantic
 153 population size. This assumes that the space use inferred from the tracking data available for a population
 154 (i.e., sample of tracked birds breeding in the same LME) represents well the space use of the entire
 155 population (i.e., all the birds breeding in the LME). Overall, the tracking dataset represents a large part of
 156 the Atlantic populations of highly mobile seabirds (Figure 1).

Supplementary methods 5 – Mapping species' spatio-temporal distribution

Generating density maps (utilization distribution) through kernel density estimation.

To map the probability density of each population of highly mobile seabird species in each month, we used a kernel density estimation.

We performed this analysis either at the subpopulation level, when we had tracking data available and were able to compile the size of the corresponding subpopulation (i.e. number of breeding individuals; Rouyer et al. 2025), or at the population (LME) level directly if no subpopulations existed, if no tracking data were available at the subpopulation level or if we could not obtain information on the size of the tracked subpopulations.

Given the distances covered by highly mobile seabirds and to avoid distortions created by projections, we calculated unprojected kernels (directly from longitude/latitude positions, 0.1 degree cell resolution) using the BRB_MKDE program (Benhamou 2018, version of August 2023), in R (version 4.3.1). We estimated the 95% fraction of the utilization distribution (UD, that considers both the density and the area of the cell) for each population (or subpopulation) in each month, using the following parameters:

- Classic Kernel Density Estimation (Tmax=0).
- A reference smoothing parameter, except for three datasets with very small reference smoothing parameters (<4 km), for which the program did not work. For these, we used instead the smallest values above the reference smoothing parameter for which the program could give an output (all below 6 km).
- A length threshold set to 1 km and a length flag set to 1 (to pinpoint small movements more likely to be due to GPS noise and filter out segments assumed to involve immobility of the animal)
- All other possible parameters of the program set to 0.

To be able to compare each UD raster across species and seasons, we divided each UD raster by the sum of its cells, so that the sum of the cells would add to 1 (instead of 0.95, corresponding to the 95% fraction of the utilization distribution).

To focus the analysis on at-sea areas, we removed land areas from the UD rasters, using a high-resolution shoreline layer (Wessel & Smith 1996). As UD rasters did not account for barriers to seabird movements like landmasses, we corrected them manually, when appropriate. To do so, we visually checked all maps to see if kernels were impacted by land masses (e.g. Italy separating the Tyrrhenian and Adriatic seas). In case they were impacted (i.e., no tracking data point on the other side of the land mass but kernel extending there), we masked out the area beyond the land mass. To ensure comparable UD rasters, we rescaled one more time by dividing by the sum of the cells of the land-masked UD rasters.

We then masked all UD rasters to the boundaries of the Atlantic Ocean (Supplementary methods 1). This means that seabirds leaving the Atlantic in a month would not count in the UD raster of this month once outside of the Atlantic.

Only for plotting purposes (final figures shown in the manuscript), we projected the UD rasters in an Atlantic-centred Lambert azimuthal equal-area projection.

Combining subpopulation density maps into population density maps, for each month

For those populations for which we had tracking data and population size estimates at the subpopulation level, we combined the density maps (UD rasters) of the subpopulations per month into a single density map of the population per month. We did so by firstly, weighting each subpopulation density map by its corresponding subpopulation weight, and secondly, summing all weighted subpopulation density maps together, hence giving more weight to larger subpopulations.

Subpopulation weights were calculated by dividing each subpopulation size (number of breeding individuals) by the sum of all subpopulation sizes belonging to the same population/LME for which we had tracking data available (Rouyer et al., 2025). This approach assumes that tracked subpopulations are representative of other untracked subpopulations within the same LME.

In addition, since not all subpopulations had tracking data for all months, we adjusted the subpopulation weights so that their sum would equal one. We divided each subpopulation weight by the sum of the weights of all subpopulations (within the same population) with available tracking data in a given month. That is, if we had tracking data for all subpopulations in a month, then the weight remained the same, but if we were missing some subpopulation(s) in a month, then we increased the weight of those subpopulations with tracking data available in that month, so that the sum of the subpopulation weights would equal one, making population density comparable across months. This assumes that for any given month with incomplete tracking data, tracked subpopulations are representative (in terms of space use) of untracked subpopulations within the same population (LME).

For those populations for which we did not have finer information at the subpopulation level, the population density maps per month were obtained directly through a kernel density estimation of the corresponding tracking data (see previous section).

This approach allowed us to make the best use of the available tracking data within each population, despite the variability in spatial resolution (some populations with finer-scale subpopulation data, others not) and in temporal resolution (some subpopulations with data for all months, others not).

Combining population density maps into species maps, for each month and per year quarter

We obtained species density maps per month by first, weighting each population density map by its corresponding population weight and second, summing all weighted population density maps together. Hence, the contribution of each population to the species density map is directly proportional to its size (number of breeding individuals). Population weights correspond to the population size divided by the Atlantic population size of each species (Rouyer et al. 2025).

For each species, we then combined the monthly species density maps into year quarter maps (January-March, April-June, July-September and October-December). For each year quarter, we summed the corresponding monthly species density maps and divided the resulting output by the number of months with data within that quarter. This assumes that the distribution of a species in a month without tracking data can be represented by the distribution of the same species in the other months of the same year quarter.

231 The resulting maps are such that the sum of values across all cells is equal to the sum of the populations'
232 weights (1 for species with tracking data available for all their populations, <1 for species with incomplete
233 tracking data coverage).

234 Given that for most species we had good coverage of their different populations (Figure 1), we expect
235 these species maps to be representative of the Atlantic-wide distribution of species throughout the year.

236 **Combining species density maps into multi-species density maps, per year quarter**

237 We obtained multi-species density maps by summing all the species density maps, per year quarter.

238 Species with complete tracking data (i.e. covering all populations) contribute equally (=1) to these final
239 maps, while species with incomplete tracking data contribute less, in the proportion of the fraction of the
240 Atlantic population tracked. This has two consequences: first, species with complete tracking data
241 contribute equally to the multi-species density map, regardless of their Atlantic-wide population, ensuring
242 that the density-map is not dominated by very abundant species. Second, species with incomplete
243 tracking data contribute less to the final multi-species map than species with complete tracking data,
244 ensuring that we do not assume that the tracked populations represent all populations across the Atlantic.

245 **Identifying areas holding 50% of each species' tracked population (species' core areas)**

246 We identified for each species its 'core area', defined as the minimum area with the highest density of the
247 species, containing 50% of its Atlantic tracked population (i.e., the part of the species' Atlantic population
248 with available tracking data). To do so, we extracted the cell values of each species' raster, in each year
249 quarter. We ranked the cells with the highest values first and calculated their cumulative sum. We kept
250 only the cells holding the top 50% of each species' tracked population. We transformed the resulting
251 raster into a binary raster, with values of 1 corresponding to cells used by 50% of a species' tracked
252 population.

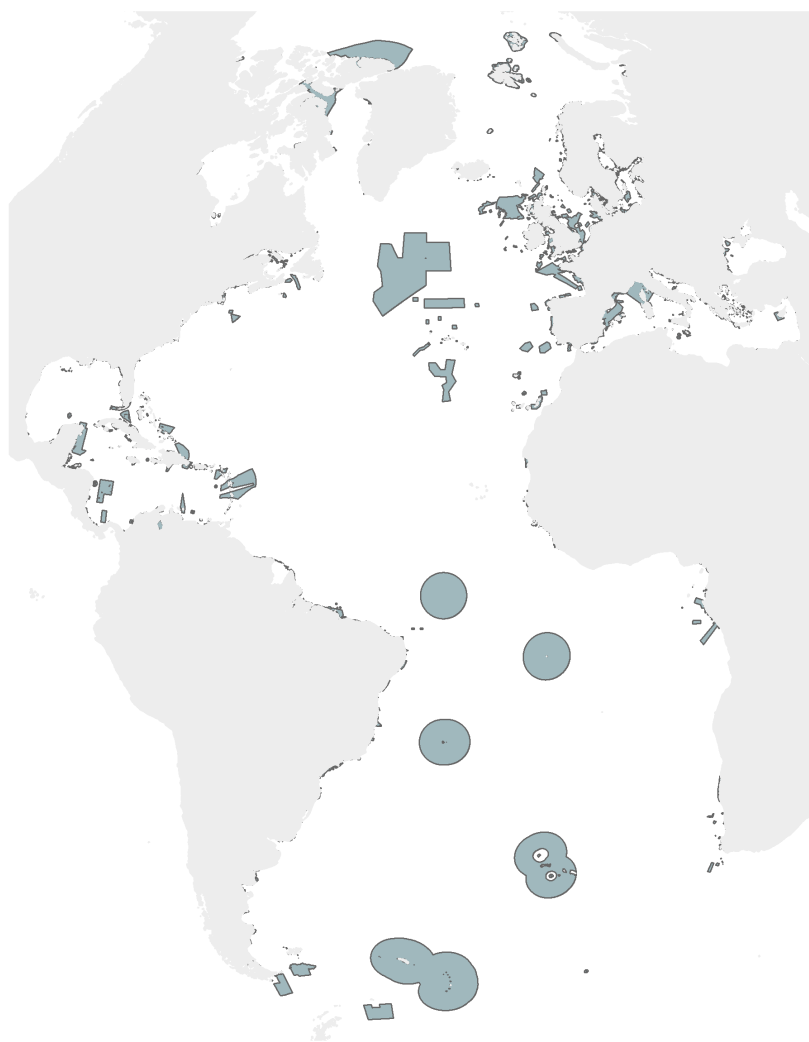
253 We summed these core areas across species to identify areas used by the majority of birds from multiple
254 species. This differs from a species richness map as it highlights areas that are particularly important (i.e.,
255 used by the majority of a species) for multiple species (as opposed to areas where multiple species are
256 simply present).

257 [Supplementary methods 6 – Preparing the Marine Protected Areas \(MPAs\) data for](#) 258 [analysis and calculating MPA coverage](#)

259 We followed standard procedure to prepare a layer of Atlantic MPAs, using the April 2024 version of the
260 World Database on Protected Areas (WDPA, UNEP-WCMC and IUCN 2024). We only kept marine and
261 coastal protected areas located in the Atlantic that had defined geographic boundaries (i.e. excluding
262 MPAs mapped as points, Figure S78). Following WDPA guidelines for calculating protected area coverage
263 (UNEP-WCMC 2024), we excluded MPAs that were only proposed and UNESCO Man and Biosphere
264 Reserves as they include buffer and transition zones that are not protected areas in many cases. We did
265 not include Other Effective Conservation Measures (OECM) in this analysis as most countries have not yet
266 designated them. We dissolved the layer of MPA polygons into a single MPA layer (to eliminate overlaps

267 between designations and to avoid double counting), which we then used to evaluate MPA coverage of
268 the Atlantic and of the tracked seabird density.

269 We calculated the percentage of tracked species density in MPAs by dividing the tracked species density
270 in MPAs by the total tracked species density in the Atlantic, for each year quarter and in both EEZ and the
271 High Seas.



272 *Figure S7 - Atlantic Marine Protected Areas, as of April 2024.*

Supplementary methods 7 – Evaluating the potential MPA coverage of tracked species density

First, we calculated the maximum percentage of tracked species density that could have been covered with the same percentage of MPA area as current (i.e., if MPAs had been placed in the most important places for highly mobile seabirds), in both the High Seas and EEZ (Figure S2). To do so, we first calculated the percentage of MPA coverage of the High Seas and EEZ. We then calculated the yearly mean of the tracked species density raster (mean cell value of the four year-quarter rasters). We extracted each cell value (i.e., mean seabird density) and area from the yearly-mean tracked species density raster. We ranked the cells top down and calculated the cumulative sum of the cell areas. We extracted the top cells until reaching the same percentage of coverage as current in the High Seas and EEZ, respectively. Taken together, these cells represent an “optimum” MPA network that could have covered the highest tracked species density with the same percentage of MPA area as current. We calculated the maximum percentage of tracked species density that could have been covered by this “optimum” network, by summing the cell values of the multi-species density raster that fell within this network and dividing them by the sum of the cells in the Atlantic, in each year quarter.

Second, we quantified the maximum percentage of tracked species density that could be covered by extending the current MPA network until it covers 30% of the High Seas and 30% of the EEZ area. We considered two scenarios: a static network (same 30% of ocean area year-round) and a dynamic network (30% ocean area changing in each season). We first calculated the percentage of MPA expansion needed by subtracting the current MPA coverage to 30%, in both the High Seas and EEZ, respectively.

For the static network scenario, we removed cells currently covered by the MPA network from the *yearly-mean* multi-species density raster to avoid selecting these cells. We then extracted each cell value (i.e., *mean* tracked species density) and area from the resulting raster. We ranked the cells top down and calculated the cumulative sum of the cell areas. We extracted the top cells until reaching the percentage of MPA expansion needed to reach 30%, in the High Seas and EEZ respectively. Taken together, these cells represent an “optimum” expansion of the current MPA network that could cover the highest tracked species density. We calculated the maximum percentage of tracked species density that could be covered by this “optimum” network, by summing the cell values of the multi-species density raster that fell within this network and the sum of the cells falling within the current MPA network, and dividing them by the sum of the cells in the Atlantic, in each year quarter.

For the dynamic network scenario, we repeated the same steps as for the static scenario but using the multi-species density raster (by year quarter) to create the “optimum” network instead of the yearly-mean multi-species density raster. By doing so, we allowed the “optimum” cells selected to change in each year quarter.

Supplementary results

Table S3 – Percentage of tracked species density in EEZ, High Seas and MPAs. Percentages are shown for (1) the current MPA network, (2) a potential network with the same MPA area as the current one but that would have covered places of highest tracked species density, and (3) a network that would expand the current one until covering 30% of EEZ and 30% of High Seas, by prioritizing areas with highest tracked species density. The Atlantic area covered by EEZ, High Seas and the MPA networks is also shown.

Tracked species density in (%)		Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Atlantic area (%)
(1) Current MPA network	EEZ	47.83	52.74	53.03	49.03	39.9
	High Seas	52.08	47.17	46.88	50.92	60.1
	MPA in EEZ	10.36	10.44	10.31	9.08	5.6
	MPA in High Seas	1.49	2.29	3.03	2.01	1.3
	MPA total	11.86	12.77	13.36	11.10	6.9
(2) Top possible MPA network with same MPA area as current	MPA in EEZ	26.37	29.12	26.33	26.20	5.6
	MPA in High Seas	5.28	4.60	4.14	4.91	1.3
	MPA total	31.65	33.72	30.47	31.10	6.9
(3) Top possible expansion of current network until 30% of Atlantic area	MPA in EEZ	33.46	37.70	35.58	33.22	12.8
	MPA in High Seas	32.14	31.76	31.78	33.77	18.1
	MPA total	65.60	69.46	67.37	66.99	30.9

Figure S8 – Yearly mean tracked species density, for 44 Atlantic highly mobile seabird species. Values in each cell (0.1-degree resolution) correspond to the sum of each species' density, averaged across year quarters (Figure 1). Dark lines represent MPA boundaries.

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