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LETTER

Multispecies tracking reveals a major seabird hotspot in the North Atlantic

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Abstract

The conservation of migratory marine species, including pelagic seabirds, is challenging because their movements span vast distances frequently beyond national jurisdictions. Here, we aim to identify important aggregations of seabirds in the North Atlantic to inform ongoing regional conservation efforts. Using tracking, phenology, and population data, we mapped the abundance and diversity of 21 seabird species. This revealed a major hotspot associated with a discrete area of the subpolar frontal zone, used annually by 2.9–5 million seabirds from ≥56 colonies in the Atlantic: the first time this magnitude of seabird concentrations has been documented in the high seas. The hotspot is temporally stable and amenable to site-based conservation and is under consideration as a marine protected area by the OSPAR Commission. Protection could help mitigate current and future threats facing species in the area. Overall, our approach provides an exemplar data-driven pathway for future conservation efforts on the high seas.

KEYWORDS
area beyond national jurisdiction, Atlantic, biologging, conservation, high seas, marine protected area, regional seas convention

1 | INTRODUCTION

Many seabird species are wide-ranging, traveling thousands of kilometers across jurisdictional and international waters, only returning to land to breed (Harrison et al., 2018). Such migratory species are increasingly exposed to the expanding cumulative human impacts in the oceans (Halpern et al., 2019). Consequently, seabirds are one of the most threatened groups of vertebrates, with almost half of all species (47%) experiencing population declines (Dias et al., 2019).

As higher predators, seabirds play key roles in marine ecosystems making their conservation critical (Grémillet et al., 2018). However, their high mobility makes this challenging, particularly because seabirds rely on multiple, often geographically distant ecosystems, all of which need some form of protection for successful conservation (Dunn et al., 2019). For highly pelagic species, this is further complicated by the lack of an effective governance mechanism for areas beyond national jurisdictions (De Santo et al., 2019), and often incomplete knowledge of their distribution throughout all life-history stages (Carneiro et al., 2020).

Identifying important areas at-sea has been facilitated through advances in biologging technology (Lascelles et al., 2016). Individual-based tracking, using animal-attached devices, is becoming an indispensable tool for guiding conservation efforts through the identification of areas of high species diversity and abundance (hereafter, "hotspots") that are critical for species survival (e.g., molting or foraging areas) (Hays et al., 2019). Recent animal tracking studies have demonstrated that many pelagic seabird species consistently occur at predictable times and places at the macroscale (Frederiksen et al., 2016), often in association with particular habitats or migratory corridors (Dias et al., 2013). This presents an opportunity for area-based conservation for migratory species, particularly because many oceanic hotspots (i.e., areas beyond continental shelves) are often associated with persistent features, such as major frontal and upwelling systems (Block et al., 2011).

The North Atlantic is a priority area for seabird conservation because over the last decade many species in this region have experienced pronounced population declines, including Atlantic Puffin (*Fratercula arctica*), Black-legged Kittiwake (*Rissa tridactyla*), Common Guillemot (*Uria aalge*), and Northern Fulmar (*Fulmarus glacialis*) (Dias et al., 2019). While colonies in the Northeast Atlantic are generally afforded good protection, their foraging areas remain poorly known and protected (Ramirez et al., 2017). Moreover, many seabird species in the North Atlantic, such as shearwaters and auks, are impacted by marine-based threats (e.g., bycatch, pollution, and overfishing; Dias et al., 2019), indicating an urgent need to identify and protect important marine areas to address the recent declines of threatened seabird species.

The Oslo-Paris-Convention on the protection of the North-East Atlantic (OSPAR) is one of two regional seas

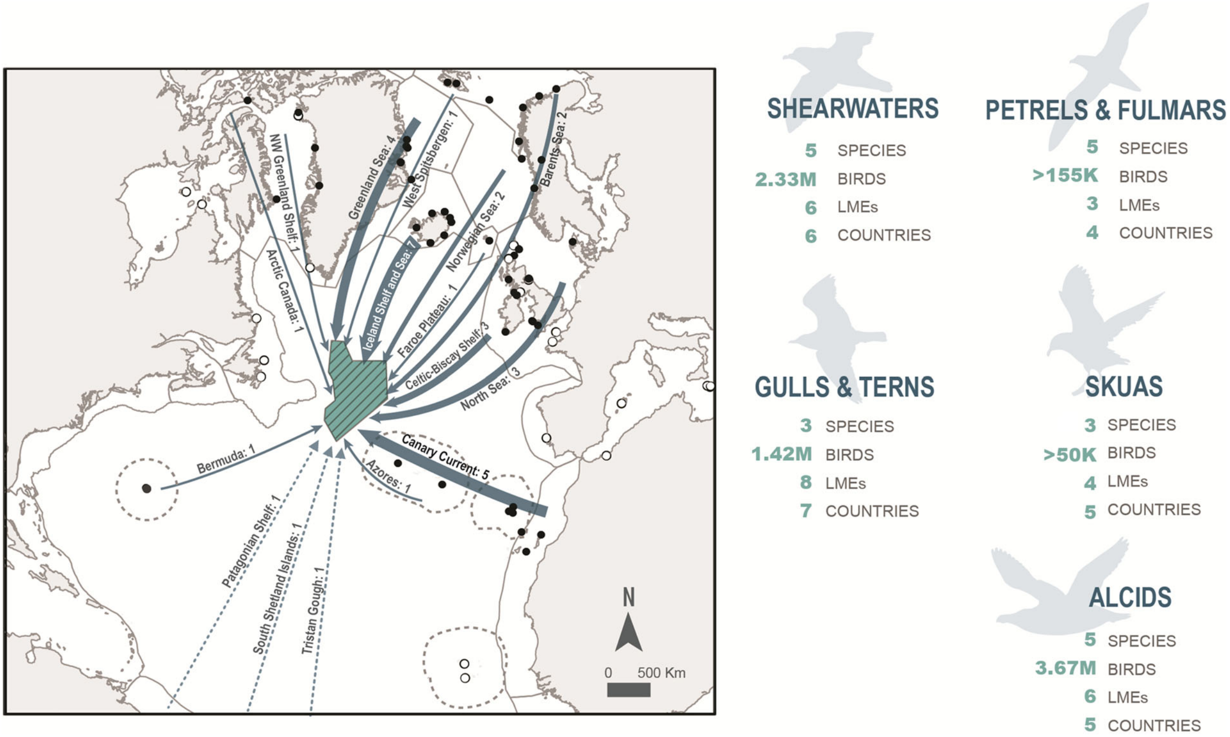

FIGURE 1 Location of identified hotspot in the middle of North Atlantic (green) and summary information of species groups at the site. Arrows indicate the LMEs the birds are traveling from to the site, labeled with LME name and number of species. Dashed arrows are from LMEs in the South Atlantic (not visible on the map). LMEs are shown by a solid gray line, with a dashed gray line for adapted LMEs (Azores, Bermuda, Cabo Verde, Madeira; the latter analyzed with the Canary Current LME). Colonies are shown in circles (black = data used in analysis, white = data considered but not included in final analysis). Figure prepared by Terra Communications

conventions (the other being the Commission for the Conservation of Antarctic Marine Living Resources) that have initiated actions within their remit in Areas Beyond National Jurisdiction (ABNJ), providing a unique opportunity for conservation action in ABNJ. OSPAR have established a number of marine protected areas (MPAs) in ABNJ and are working toward improving the ecological coherence of this network––including addressing an identified gap for seabirds, alongside achieving 10% protection of the OSPAR Maritime Area (Aichi Target 11) (Johnson et al., 2014; OSPAR, 2019). At-sea surveys (Bennison & Jessopp, 2015; Boertmann, 2011) and single species tracking studies (e.g., Dias et al., 2012; Egevang et al., 2010; Fayet et al., 2017) indicate that important seabird concentrations may occur around the Mid-Atlantic Ridge (MAR), and suggesting a community-level assessment of available tracking data is needed, and could help guide current policy and practice.

Here, we combine tracking, phenology, and population data on 21 Atlantic seabird species to quantify their distribution, density, and diversity in the ABNJ of OSPAR Region V. We reveal an important hotspot of unexpected extent and temporal stability. We suggest how our findings could guide conservation management, and provide an exemplar for the use of multispecies tracking to identify sites suitable for protection in ABNJ.

2 | METHODS

2.1 | Study area

Our study area is defined as ABNJ within OSPAR Region V (www.ospar.org/convention/the-north-east-atlantic). This encompasses the deeper waters of the North Atlantic, between 35 and 62°N and from 10 to 42°W west of Iberia/France and west of the 200 m depth contour off the British Isles (Figure 1).

2.2 | Tracking data

We downloaded all available seabird tracking data that overlapped OSPAR Region V from the BirdLife Seabird Tracking Database (www.seabirdtracking.org) in 2016. These data comprised 2188 tracks of 23 species, from 105 colonies within 16 countries and 25 large marine ecosystems (LME), located in both the North and South Atlantic

(Figure S1). We excluded all tracks from colonies that had less than 2% overlap with the study area, unless other colonies in the same LME had higher overlap. The final analyses included 1524 tracked birds of 21 species, from 56 colonies, across 17 LMEs and 16 countries/jurisdictions (Table 1). Phenology and population data for each species and colony were obtained from the literature and verified by experts (Table S1, Figure S2). Following advice from the scientific community, and in line with other studies (e.g., Frederiksen et al., 2016; Frederiksen et al., 2012), colonies of the same species located in the same LME were combined and considered to represent unique populations. Our data were representative of the species distributions in the Atlantic (Table S2).

2.3 | Identification of marine Important Bird and Biodiversity Areas

We analyzed tracking data in combination with objective site selection criteria following the method developed to delineate marine Important Bird and Biodiversity Areas (IBAs) (Lascelles et al., 2016) and Key Biodiversity Areas ("track2kba" R package; Beal et al., 2020). This is a well-established, standardized approach to identify important hotspots for foraging seabirds based on kernel density analysis of tracking data, in combination with abundance estimates of the colonies of origin. The hotspots identified through this method are key sites for the persistence of species by regularly holding important numbers of a globally threatened species, or supporting $> 1\%$ of the global or biogeographic population (Lascelles et al., 2016). This method has been applied in all oceans, with many resultant sites informing conservation action (e.g., Hays et al., 2019; Waliczky et al., 2018). We checked tracked birds of nonthreatened species against the IBA criteria: 1% threshold (i.e., LME represents $\geq 1\%$ of the global [for species breeding outside Europe] or biogeographic population [EU number of individuals for European species]). Population sizes refer to the number of mature individuals.

We conducted all analyses in R, as detailed in the Supporting Methods. In brief, we first grouped tracking data by species, LME, and breeding stage (i.e., breeding, nonbreeding, migration, e.g., Black-legged Kittiwake, Iceland Shelf and Sea LME, nonbreeding; Figure S3). We followed the Lascelles et al. (2016) methodology for each group. We estimated the "core use area" of each bird in each group, defined by the 50% utilization distribution contour. We then calculated the proportion of core use areas occurring in each cell in a 0.2×0.2 degree grid (Lascelles et al., 2016). We then estimated the number of birds in each cell by multiplying the proportion of the tracked population in each grid cell by the size of the LME population (Table S1) to generate one *density map/group*.

2.4 | Species richness and abundance hotspot identification

To identify areas that are important for multiple species at the same time of year, we aggregated the density maps in calendar seasons (Supporting Methods), defined as: Q1: January–March, Q2: April–June, Q3: July–September, and Q4: October–December. We weighted each *density map/group* by the average number of half months in each season spent in each breeding stage, based on the species' phenology (Carneiro et al., 2020) to generate one *density map/species-LME-season*.

We combined all *density maps/species-LME-season* to produce: (1) *density maps/species-season*; (2) *density maps for all species combined/season*; and (3) *overall density map* (all species and seasons) (Figure S3). We also estimated species richness by binary coding presence/absence raster density maps and summing across species for each season. Finally, we combined the richness and density maps and used the 15% highest values to delimit the most important hotspot within the study area. We then excluded areas within extended shelf claims to facilitate the uptake of conservation measures (Ramirez et al., 2017), so the final area is located solely within ABNJ.

2.5 | Interannual consistency of area use

To assess the consistency in area use, we conducted additional analysis within groups with relatively large sample sizes (> 20 birds) in multiple years (Supporting Methods, Figure S4). We conducted an analysis of similarity (ANOSIM, a measure of relative within-group dissimilarity based on a bootstrap randomization; Oksanen et al., 2013) to test for differences in the distribution within and between-years using two metrics of distribution overlap (Bhattacharyya's affinity and HR indexes; Fieberg & Kochanny, 2005).

3 | RESULTS

Our analysis revealed an extensive (~595,000 km^2) hotspot of seabird diversity and abundance near the western boundary of OSPAR Region V (Figure 1), extending from ~41 to 53°N and 32 to 42°W. The area is bounded in the north by the Charlie–Gibbs Fracture Zone, to the west by the Flemish Cap and the Grand Banks of Newfoundland,

TABLE 1 Summary of the final seabird tracking data used in the analyses

Species	IUCN status	No. colonies	No. birds	Tracking years (*N*)	Locations of colonies birds tracked from	
					Large marine ecosystem	**Country/jurisdiction**
Cory's Shearwater, *Calonectris borealis*	LC	6	349	2002–2015 (14)	Azores	Spain, Portugal
					Canary Current	
Manx Shearwater, *Puffinus puffinus*	LC	6	181	1999–2014 (11)	Celtic-Biscay Shelf	United Kingdom, Iceland
					Iceland Shelf and Sea	
Audubon's Shearwater,*Puffinus lherminieri*	LC	2	23	2010–2014 (5)	Canary Current	Portugal
Great Shearwater, *Ardenna gravis*	LC	2	72	2006–2012 (6)	Tristan Gough*	Saint Helena, Ascension and Tristan da Cunha
Sooty Shearwater, *Ardenna grisea*	NT	1	18	2007–2009 (3)	Patagonian Shelf	Falkland Islands (Malvinas)
Northern Fulmar, *Fulmarus glacialis*	LC	1	72	2006–2013 (8)	North Sea	United Kingdom
Desertas Petrel, *Pterodroma deserta*	VU	1	39	2008–2013 (6)	Canary Current*	Portugal
Zino's Petrel, *Pterodroma madeira*	EN	1	12	2007–2010 (4)	Canary Current*	Portugal
Bermuda Petrel, *Pterodroma cahow*	EN	1	11	2009–2010 (2)	Bermuda*	Bermuda
Bulwer's Petrel, *Bulweria bulwerii*	LC	2	48	2009–2013 (5)	Canary Current	Portugal, Spain
Black-legged Kittiwake,*Rissa tridactyla*	VU	16	275	2007–2011 (5)	Barents Sea	Russian Federation, United Kingdom, Faroe Islands, Iceland, Denmark, Norway
					North Sea	
					Celtic-Biscay Shelf	
					Faroe Plateau	
					Iceland Shelf and Sea	
					Norwegian Sea	
					West Spitsbergen	
Sabine's Gull,*Xema sabini*	LC	1	8	2007–2008 (2)	Greenland Sea	Greenland
Arctic Tern, *Sterna paradisaea*	LC	1	9	2007–2008 (2)	Greenland Sea	Greenland
Great Skua, *Catharacta skua*	LC	1	11	2008–2009 (2)	Iceland Shelf and Sea	Iceland
South Polar Skua, *Catharacta maccormicki*	LC	1	32	2007–2010 (4)	South Shetland Islands	Antarctica
Long-tailed Jaeger, *Stercorarius longicaudus*	LC	6	42	2006–2015 (8)	Greenland Sea	Greenland, Norway, Sweden
Norwegian Sea + Barents Sea						

(Continues)

TABLE 1 (Continued)

Species	IUCN status	No. colonies	No. birds	Tracking years (*N*)	Locations of colonies birds tracked from	
					Large marine ecosystem	Country/jurisdiction
Atlantic Puffin, *Fratercula arctica*	VU	8	146	2007–2015 (9)	Celtic-Biscay Shelf	Ireland, Iceland,United Kingdom
					Iceland Shelf and Sea	
					North Sea	
Common Murre,*Uria aalge*	LC	3	20	2013–2014 (2)	Iceland Shelf and Sea	Iceland
Thick-billed Murre, *Uria lomvia*	LC	9	151	2007–2014 (7)	Arctic Canada	Canada, Greenland, Iceland
					NW Greenland Shelf	
					Iceland Shelf and Sea	
Razorbill,*Alca torda*	NT	3	20	2013–2015 (3)	Iceland Shelf and Sea	Iceland
Little Auk,*Alle alle*	LC	1	18	2010–2011 (2)	Greenland Sea	Greenland

Note: Tracking years show the overall year range, with the max number of years held per LME in brackets. * Species endemic to an LME. For further details on population (Table S1) and phenology (Figure S3).

to the east by the MAR and to the south by the Azores (Figure 1).

All 21 species used the identified hotspot, including five globally threatened species (endangered Bermuda Petrel [*Pterodroma cahow*], Zino's Petrel [*Pterodroma madeira*], and vulnerable Desertas Petrel [*Pterodroma deserta*], Black-legged Kittiwake and Atlantic Puffin; Table 1). We estimated that 2.9–5 million birds use the area throughout the year (Table 2) traveling from 56 colonies within 16 countries (Figure 1).

The highest abundance (ca. 4.4–5 million individuals) occurred during the boreal winter (October–March; Q4–Q1, Table 2). The highest number of species ($n = 21$) occurred in spring–summer (April–September), when ca. 2.9–3.3 million birds were present (Q2–Q3, Table 2). Consistency in area use was demonstrated for all nine species with multiyear data, with the ANOSIM index [R value] always lower than 0.12 (Supporting Methods, Figure S4).

The most abundant (2.3 million) species using the area was the Little Auk (*Alle alle*) during nonbreeding (January–March), followed by wintering Great Shearwater (*Ardenna gravis;* 1.8 million, July–September; Table 2), a migrant species breeding in Tristan da Cunha archipelago, South Atlantic. We found three species with more than 50% of their global population using the area as a winter or staging ground: South Polar Skua (*Catharacta maccormicki*; 64.8–68.4%, April–September), Long-tailed Jaeger (*Stercorarius longicaudus*; 63.3%, July–September), and Sooty Shearwater (*Ardenna grisea;* 61%, April–June; Figure 2). Almost 50% of the endangered Bermuda Petrel (45.8%) use the area during July–September.

Most seabirds used the area during their nonbreeding stage. This included three species of southern hemisphere breeders that winter in the area (Great Shearwater, Sooty Shearwater, and South Polar Skua), as well as Long-tailed Jaeger and Arctic Tern (*Sterna paradisaea*) that use the area as a staging ground for 1–4 weeks during their outward and return migrations. Seven species used the area throughout the year: Zino's Petrel, Great Skua (*Catharacta skua*; peak July–December), and the following species showing a peak in numbers October–March: Cory's Shearwater (*Calonectris borealis*), Northern Fulmar, Black-legged Kittiwake, Atlantic Puffin, and Thick-billed Murre (*Uria lomvia*). Four species also used the area while breeding (Manx Shearwater [*Puffinus puffinus*], Cory's Shearwater, Desertas Petrel, and Bulwer's Petrel [*Bulweria bulwerii*]).

4 | DISCUSSION

Our analysis revealed a major hotspot for foraging seabirds in the North Atlantic, used by 21 species totaling up to an

TABLE 2 Estimated maximum number of adults from tracked populations using the site per year quarter

Species name	Biogeographic population (max mature birds)	Q1 Jan–Mar (max ind)	Q2 Apr–Jun (max ind)	Q3 Jul–Sept (max ind)	Q4 Oct–Dec (max ind)
Cory's Shearwater	503,430	69,685	20,358	40,085	59,442
Manx Shearwater	982,510		71,827	167	
Audubon's Shearwater	4084		62	743	278
Great Shearwater	8,000,000		1,564,472	1,819,681	
Sooty Shearwater	600,000		368,627	338,562	
Northern Fulmar	756,210	154,024	70,506	86,893	154,024
Desertas Petrel	340		12	53	13
Zino's Petrel	160	15	21	21	15
Bermuda Petrel	142			65	22
Bulwer's Petrel	100,000			1418	
Black-legged Kittiwake	3,822,882	1,347,050	63,650	664,577	1,366,342
Sabine's Gull	3000		375		
Arctic Tern	165,000			65,529	
Great Skua	10,800	1964	1309	2618	2945
South Polar Skua	1542		999	1054	
Long-tailed Jaeger	72,856		34,765	46,131	
Atlantic Puffin	5,121,612	936,713	506,057	257,030	1,079,091
Common Murre	1,392,408		71,406	35,703	
Thick-billed Murre	2,589,888	161,184	50,625	13,619	144,309
Razorbill	626,944		26,123		
Little Auk	7,000,000	2,333,333	129,630		1,555,556
Total number of birds		5,003,968	2,980,824	3,373,949	4,362,037
Total number of species		8	18	18	11

FIGURE 2 Percentage of biogeographic population of each species estimated to be using the hotspot for each year quarter. Colors indicate if the species breeds in the northern or southern hemisphere

estimated 5 million adults. At-sea surveys previously indicated that relative abundance peaked in this area, but this is the first time that a seabird aggregation of this absolute abundance has been robustly quantified anywhere in the high seas. The hotspot qualifies as an IBA and can be considered the most important oceanic foraging grounds for the community of seabirds in the OSPAR maritime high seas area and one of the most important concentrations of migratory seabirds in the Atlantic. Seabirds using this hotspot originated from a minimum of 56 colonies in 16 different countries. Many of these species traveled great distances to use the area, with some using it year-round, suggesting that food availability in the area is consistently high. Boreal breeders, such as Arctic Terns, Long-tailed Jaegers, Sabine's Gulls, Manx Shearwaters, and Cory's Shearwaters, use the area as a staging area to fuel trans-equatorial migrations (Egevang et al., 2010; Guilford et al., 2009; Sittler et al., 2011), or to fuel the last migration leg to the breeding areas (Egevang et al., 2010; van Bemmelen et al., 2017) sometimes making detours of > 5000 km to do so (Dias et al., 2013). Southern Hemisphere breeders, such as South Polar Skuas, Sooty Shearwaters, and Great Shearwaters, migrate up to 13,000 km to spend some of the austral winter in the area (Hedd et al., 2012; Kopp et al., 2011).

Our analysis included tracking data from major colonies of each species in the Atlantic, including those that represent more than 90% of the global or Atlantic population for many species (e.g., Cory's Shearwater, Sooty Shearwater, Great Shearwater; all gadfly petrels, genus *Pterodroma*). We only used tracks of adults, because relatively few juvenile and immature birds have so far been tracked, which can have an influence on the overall distribution of seabirds (Carneiro et al., 2020). Indeed, a recent study also found the area to be used by immature Cory's Shearwaters (Campioni et al., 2020). Thus, our estimates should be considered a minimum. Population estimates for each colony are subject to natural variation and recording error, and the number of birds using the area should ideally be updated regularly.

4.1 | Biodiversity hotspot

Recent studies have found additional seabird species use the area, including Leach's Storm-Petrel (*Oceanodroma leucorhoa*) (Pollet et al., 2019), Wilson's Storm-Petrel (*Oceanites oceanicus*), Great Black-backed Gull (*Larus marinus*), Arctic Jaeger (*Stercorarius parasiticus*), Pomarine Jaeger (*S. pomarinus*), and Northern Gannet (*Morus bassanus*) (Boertmann, 2011; Wakefield, 2018). Tracking studies also demonstrate that the area is used by many nonavian, wide-ranging species, including Blue Shark (*Prionace glauca*), Shortfin Mako Shark (*Isurus oxyrinchus*) (Queiroz et al., 2016), Basking Shark (*Cetorhinus maximus*) (Gore et al., 2008), Atlantic Bluefin Tuna (*Thunnus thynnus*) (Walli et al., 2009), Sei Whale (*Balaenoptera borealis*) (Prieto *et al*. 2014), and Leatherback Turtle (*Dermochelys coriacea*) (Fossette et al., 2014). At-sea surveys in the area have also found many cetacean species, including Blue Whale (*Balaenoptera musculus*), various beaked whales, Common and Spotted dolphins (Wakefield, 2018). Further work is needed to understand how these species use and interact in the area, and the role of oceanographic drivers in the region.

4.2 | Potential drivers of abundance and diversity

The hotspot is located in an area of complex oceanography, dominated by the North-Atlantic Current (NAC) and the associated Subpolar Frontal system (Belkin & Levitus 1996). These oceanographic drivers are both more intense and spatially stable due to bathymetric steering by the continental slope/Grand Banks to the West and Charlie-Gibbs Fracture Zone in the East (Rossby, 1996). The associated mesoscale turbulence creates high rates of primary production (Longhurst, 2010), and it is likely the combination of high primary production and spatiotemporal predictability that allows the area to support large numbers of higher predators. Studies indicate that prey, such as zooplankton (e.g., calanoid copepods) and mesopelagic fish (e.g., myctophids; Fort et al., 2010; Hudson et al., 2014), are abundant in the area, with the availability to seabirds further enhanced through both mesoscale turbulence (McGillicuddy, 2016) and the diel vertical migration of mesopelagic prey (Dias et al., 2012). See Supporting Information—Oceanography.

4.3 | Conservation implications

Most seabirds used the multispecies hotspot during their nonbreeding stage––a period of their lifecycle that is currently poorly protected (Ramirez et al., 2017). Conditions during nonbreeding can directly affect subsequent breeding productivity via carryover effects (Fayet et al., 2017). This stage includes the mid-winter period, when adverse weather, food, and light conditions may account for the highest mortality of some Atlantic seabirds (Mesquita et al., 2015). Many of the studied seabird species use the hotspot while molting (Hedd et al., 2012; Wakefield, 2018). Molt is a critical time for seabirds because it is energetically demanding and can compromise flight efficiency, potentially increasing the susceptibility to natural and anthropogenic threats (Grissot et al., 2019).

We contend that the identified hotspot deserves year-round protection as an MPA, given the regular use by a large number of birds and spatiotemporal stability of the area (likely caused by stable physical drivers). Seventeen of the 21 species using the area are impacted by marine-based threats, including bycatch (65%), overfishing (29%), energy production and mining (18%), climate change (71%), pollution (including light pollution; 59%), and are undergoing population declines (Dias et al., 2019). Except for climate change, these threats can be reduced via area-based management (Game et al., 2009) and given that many breeding colonies are already protected, there is an urgent need for marine spatial protections. Although there is a debate about the utility of MPAs to protect migratory species (Game et al., 2009), there are an increasing number of studies showing their importance, particularly during spatially limited and vulnerable life-history stages (Péron et al., 2013; White et al., 2017; Young et al., 2015), and there have been demonstrated successes for seabirds when management measures have preserved their prey base (Croxall, 2008; Pichegru et al., 2010). MPAs can help reduce the likelihood of mortality, and even though the MPA may only represent a small portion of a seabirds' migratory range, they can serve a vital role in species conservation (Hooker et al., 2011; Péron et al., 2013). Given that many migratory species have limited protection at sea, even small reductions in mortality rates can have decisive demographic benefits, especially for rare and endangered species (Caswell et al., 1999; Péron et al., 2013).

The identified hotspot is currently being discussed by the OSPAR Commission as the North Atlantic Current and Evlanov Seamount (NACES) MPA. Protection of this proposed MPA would address an identified gap in the OSPAR MPA network for seabirds (Johnson et al., 2014), and improve the coverage of nonbreeding areas more broadly (Game et al., 2009; Ramirez et al., 2017). Present threats to seabirds in the area are not fully understood: shipping lanes are predominantly in the southern part of the area (risk of disturbance, oil, and light pollution), some, limited long-line fishing occurs (bycatch risk), and recent oil exploration west of the hotspot (oil pollution and light pollution) (Impact Assessment Agency of Canada, 2020). Understanding the threats in the area, alongside the relevant contribution of other threats––both at breeding sites and across the rest of their migratory journeys––that are driving population declines should be evaluated. Understanding the relative contributions of different threats, both terrestrial and marine, that are driving population trends could help direct conservation priorities. However, it is also important to consider protection of remote areas before they become heavily exploited (McCauley et al., 2013) and to mitigate against future threats, particularly because impacts are increasing across the high seas (Halpern et al., 2019; O'Leary et al., 2020). MPAs are not a panacea for conserving marine biodiversity, and their capacity to reduce threats differs depending on their management and level of enforcement (Zupan et al., 2018). However, MPAs can contribute to biodiversity conservation where effectively managed, and the proposed NACES MPA should include measures to mitigate current and prevent future threats to seabirds. A research and monitoring plan should be adopted alongside the managed MPA, to understand more about the features supporting seabirds and other taxa, to monitor the effectiveness of the MPA, and to inform additional management measures if required. There are also increasing opportunities for monitoring remote areas using satellite and biologging technologies that could be explored (Harcourt et al., 2019; Sutherland et al., 2016). The current ABNJ MPAs under OSPAR are managed through a "Collective Arrangement" (NEAFC & OSPAR, 2015), and a collaborative approach to management would also be needed for this proposed MPA.

Overall, our analysis has demonstrated that multispecies tracking data can identify important sites in ABNJ that are suitable for protection. The ongoing work of the OSPAR Commission presents a unique opportunity for this study to inform policy and practice to benefit seabird conservation on the high seas. Once the new UN Treaty for the high seas has been adopted, replicating this approach for different regions and taxa could provide a data-driven pathway for marine conservation in ABNJ.

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AUTHORS' CONTRIBUTIONS

Study conception: B.L., M.T., M.P. D., J.H., and B.C.; Methods workshop: M.T., A.P.B.C., M.P.D., B.C., C.H., J.H., H.A., J.D., E.D., M.F., J.P.G., T.G., E.S.H., B.M., V.H.P., Th.L.Th., and E.W.; Data collection/processing: T.A-N., R.T.B., M.B., L.B., T.B., P.C., F.R.C., O.C., S.C-D., M.C-F., J.D., F.D., M.P.D., C.E., A.I.F., A.L.F., J.F., M.F., R.W.F., O.G., J.G-S., J.P.G., D.G., T.G., E.S.H., S.A.H., M.P.H., A.H., N.P.H., M.J., Y.K., J.K., J.L., J.F.L., S-H.L., J.M., E.M., M.L.M., L.Mc.T., F.R.M., T.M., B.M., W.A.M., V.M-P., A.M., V.N., M.A.N., B.O., V.H.P., H-U.P., A.P., R.A.P., I.R., J.A.R., R.R., R.A.R., P.G.R., N.M.S., I.A.S., B.S., H.Ste., I.J.S., H.Str., G.H.R.S., P.T., Th.L.Th., R.S.A.Vb., S.W., and F.Z.; Data analysis; A.P.B.C. led the analysis, with support from M.P.D., T.E.D., M.T., and E.W.; Writing: T.E.D. led the writing of the manuscript with significant contributions from all coauthors. All authors reviewed and approved the final version for submission.

ETHICS STATEMENT

The authors adhered to all relevant laws, regulations, and protocols in conducting this research.

DATA ACCESSIBILITY STATEMENT

The data are deposited on BirdLife International's Seabird Tracking Database http://www.seabirdtracking.org/

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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