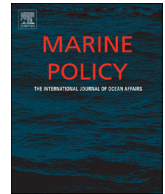




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Spatial scales of marine conservation management for breeding seabirds

Steffen Oppel^{a,*}, Mark Bolton^a, Ana P.B. Carneiro^b, Maria P. Dias^b, Jonathan A. Green^c, Juan F. Masello^d, Richard A. Phillips^r, Ellie Owen^a, Petra Quillfeldt^d, Annalea Beard^e, Sophie Bertrand^{f,g}, Jez Blackburn^h, P. Dee Boersmaⁱ, Alder Borges^j, Annette C. Broderick^k, Paulo Catry^l, Ian Cleasby^a, Elizabeth Clingham^e, Jeroen Creuwels^m, Sarah Croftsⁿ, Richard J. Cuthbert^a, Hanneke Dallmeijer^o, Delia Davies^p, Rachel Davies^q, Ben J. Dilley^p, Herculano Andrade Dinis^u, Justine Dossa^b, Michael J. Dunn^r, Marcio A. Efe^s, Annette L. Fayet^t, Leila Figueiredo^s, Adelcides Pereira Frederico^j, Carina Gjerdrum^v, Brendan J. Godley^k, José Pedro Granadeiro^x, Tim Guilford^t, Keith C. Hamer^y, Carolina Hazin^b, April Hedd^z, Leeann Henry^e, Marcos Hernández-Montero^{aa}, Jefferson Hinke^{ab}, Nobuo Kokubun^{ac}, Eliza Leat^{ad}, Laura McFarlane Tranquilla^{ae}, Benjamin Metzger^{ae}, Teresa Militão^w, Gilson Montrond^l, Wim Mullié^o, Oliver Padgett^t, Elizabeth J. Pearmain^b, Ingrid L. Pollet^{af}, Klemens Pütz^{ag}, Flavio Quintana^{ah}, Norman Ratcliffe^r, Robert A. Ronconi^v, Peter G. Ryan^p, Sarah Saldanha^w, Akiko Shoji^t, Jolene Sim^{ad}, Cleo Small^a, Louise Soanes^c, Akinori Takahashi^{ac}, Phil Trathan^r, Wayne Trivelpiece^{ab}, Jan Veen^o, Ewan Wakefield^{ai}, Nicola Weber^{ka,ad}, Sam Weber^{ka,ad}, Laura Zango^w, Jacob González-Solís^w, John Croxall^b

^a RSPB Centre for Conservation Science, Royal Society for the Protection of Birds, United Kingdom

^b BirdLife International, David Attenborough Building, Pembroke Street, Cambridge CB2 3QZ, United Kingdom

^c School of Environmental Sciences, University of Liverpool, Liverpool L69 3GP, United Kingdom

^d Department of Animal Ecology & Systematics, Justus Liebig University Giessen, Heinrich-Buff-Ring 26, D-35392 Giessen, Germany

^e Marine Section, Environmental and Natural Resources Directorate, St Helena Government, St Helena Island, South Atlantic Ocean

^f IRD, UMR Marbec (IRD, Ifremer, CNRS, U. Montpellier) – Centre de Recherche Halieutique, Avenue Jean Monnet, 34200 Sète, France

^g Universidade Federal Rural de Pernambuco, Rua Dom Manuel de Medeiros, s/n, Dois Irmãos, CEP: 52171-900 Recife, PE, Brazil

^h British Trust for Ornithology, The Nunnery, Thetford, Norfolk IP24 2PU, United Kingdom

ⁱ Center for Ecosystem Sentinels, University of Washington, 24 Kincaid Hall, Seattle, WA 98195-1800, USA

^j Projecto Vitó, Achada de São Filipe, São Filipe, Ilha do Fogo, Cabo Verde

^k Centre for Ecology and Conservation, University of Exeter, Cornwall Campus, TR10 9EZ, United Kingdom

^l MARE - Marine and Environmental Sciences Center, ISPA - Instituto Universitário, Portugal

^m Naturalis Biodiversity Center, P.O. Box 9517, 2300 RA Leiden, the Netherlands

ⁿ Falklands Conservation, Stanley FIQQ 1ZZ, Falkland Islands

^o Veda Consultancy, Wieselseweg 110 7345 CC Wenum Wiesel, the Netherlands

^p FitzPatrick Institute of African Ornithology, DST-NRF Centre of Excellence, University of Cape Town, Rondebosch 7701, South Africa

^q MARINElife, 1 Higher Street, Bradpole, Bridport West Dorset DT6 3JA, United Kingdom

^r British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 0ET, United Kingdom

^s Biocology and Conservation of Neotropical Birds Lab. – ICBS/UFAL, Av. Lourival Melo Mota, s/n, Tabuleiro dos Martins, CEP: 57072-900, Maceió, AL, Brazil

^t Department of Zoology, University of Oxford, Oxford, OX1 3PS, United Kingdom

^u Parque Natural do Fogo, Direção Nacional do Ambiente, Chã das Caldeiras Ilha do Fogo, Cabo Verde

^v Canadian Wildlife Service, Environment and Climate Change Canada, Dartmouth, NS, Canada B2Y 2N6

^w Institut de Recerca de la Biodiversitat (IRBio) and Department de Biologia Evolutiva, Ecologia i Ciències Ambientals (BEECA), Universitat de Barcelona, 08028 Barcelona, Spain

^x CESAM, Faculdade de Ciências, Universidade de Lisboa, 1749-016 Lisboa, Portugal

^y Faculty of Biological Sciences, University of Leeds, Irene Manton Building, Leeds LS2 9JT, United Kingdom

^z Wildlife Research Division, Science and Technology Branch, Environment and Climate Change Canada, Mount Pearl, NL, Canada A1N 4T3

^{aa} Projeto Biodiversidade, Santa Maria, Cabo Verde

^{ab} Antarctic Ecosystem Research Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, La Jolla, USA

^{ac} National Institute of Polar Research, Tachikawa, Tokyo 190-8518, Japan

^{ad} Conservation and Fisheries Department, Ascension Island Government, Ascension Island ASCN 1ZZ, South Atlantic Ocean

^{ae} BirdLife Malta, 57/28 Triq Abate Rigord, Ta'Xbiex XBX 1120, Malta

^{af} Bird Studies Canada, 17 Waterfowl Lane, Sackville, NB, Canada E4L 1G6

^{ag} Antarctic Research Trust, Am Oste-Hamme-Kanal 10, 27432 Bremervörde, Germany

^{ah} Instituto de Biología de Organismos Marinos (IBIOMAR), CONICET, Boulevard Brown 2915, U9120ACD Puerto Madryn, Chubut, Argentina

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ABSTRACT

Knowing the spatial scales at which effective management can be implemented is fundamental for conservation planning. This is especially important for mobile species, which can be exposed to threats across large areas, but the space use requirements of different species can vary to an extent that might render some management approaches inefficient. Here the space use patterns of seabirds were examined to provide guidance on whether conservation management approaches should be tailored for taxonomic groups with different movement characteristics. Seabird tracking data were synthesised from 5419 adult breeding individuals of 52 species in ten families that were collected in the Atlantic Ocean basin between 1998 and 2017. Two key aspects of spatial distribution were quantified, namely how far seabirds ranged from their colony, and to what extent individuals from the same colony used the same areas at sea. There was evidence for substantial differences in patterns of space-use among the ten studied seabird families, indicating that several alternative conservation management approaches are needed. Several species exhibited large foraging ranges and little aggregation at sea, indicating that area-based conservation solutions would have to be extremely large to adequately protect such species. The results highlight that short-ranging and aggregating species such as cormorants, auks, some penguins, and gulls would benefit from conservation approaches at relatively small spatial scales during their breeding season. However, improved regulation of fisheries, bycatch, pollution and other threats over large spatial scales will be needed for wide-ranging and dispersed species such as albatrosses, petrels, storm petrels and frigatebirds.

1. Introduction

Decision makers often have to select among a suite of management actions that might benefit a given species, and management options can range from small-scale solutions that protect a local area from outside disturbance or destruction, to large-scale or global actions that regulate human activities which are considered detrimental. In the marine realm, the unambiguous delineation of important areas for the protection of biodiversity is complicated by the lack of obvious habitat boundaries [1–3], and in many cases the spatial scale of marine protected areas is inadequate to fully protect the species of interest [4,5]. Selecting the most appropriate conservation management option will therefore benefit from accurate knowledge about the spatial scale at which management is required to protect highly mobile species [6].

Seabirds are distributed across all of the world's oceans and adjacent coastlines and islands [7,8]. They face multiple threats on land and at sea, and are more threatened than other groups of birds [9–11]. Because many seabirds feed on fish and are near the apex of the marine food chain, they are useful indicator species for the health of the marine environment and for marine spatial planning [12–14]. To protect seabirds at sea it is essential to understand their spatial distribution and potential exposure to anthropogenic threats. During the breeding season, seabirds are constrained to marine areas which they can reach from their nest while maintaining parental duties of incubating eggs or feeding chicks. The areas exploited during the breeding season are therefore important for the persistence of populations, and may be more feasible to manage than areas used during other life stages. However, some seabird species can travel thousands of kilometres even during the breeding season [e.g. 8,15,16], and the spatial scale of appropriate management may therefore vary.

Currently available approaches for seabird conservation at sea can be implemented across a range of spatial scales and within a variety of regulatory frameworks [5,17]. Area-based management approaches such as marine protected areas can be based on a broad variety of management frameworks that range from complete protection from all extractive and destructive activities ('marine reserves') to multiple use areas that permit and regulate economic activity [18–20]. For seabirds, area-based measures range from the protection of breeding colonies at the very local scale, to marine foraging areas around colonies and

further offshore where significant seabird concentrations occur [21–23]. At larger spatial scales, additional conservation management options exist for seabirds that are not based on the protection of a specific area [17]. For example, regulations that reduce or eliminate the incidental mortality (bycatch) of seabirds in industrial or artisanal fishing operations [11,24,25], or regulations that limit the extraction of food resources [26,27], can be implemented across all spatial scales and may therefore mitigate key threats to widely dispersed species [28–30]. Deciding which of these policy instruments may be most appropriate for a given seabird species of conservation concern can be informed by a better understanding of the species' broad spatial distribution and aggregation patterns.

The distribution of seabird species was often inferred from observations at sea, until the development of small tracking devices in recent decades [31–33]. By 2017, more than 100 of the 360 species of seabirds had been equipped with tracking devices [34]; hence, sufficient seabird tracking data exist on the spatial scales of foraging to inform effective management at a broad taxonomic level [6,35,36]. To synthesize the existing information for management planning, two complementary aspects of seabird distribution patterns are particularly important, albeit not entirely independent: (1) the distance a species travels and the size of the marine area that birds of a given colony exploit; and (2) to what extent individuals of the same colony use the same areas at sea, which is referred to as 'spatial aggregation'. Even very mobile species can show high spatial aggregation at sea, and areas in which they congregate may be in national or international waters depending on the distance the birds travel from the colony [37,38]. Here, seabird space-use with respect to these two aspects is quantified to indicate appropriate spatial scales for conservation management of breeding seabirds at the family level.

Existing tracking data from 52 species of ten different families collected in the Atlantic Ocean basin over the past two decades were used. These data were analysed with previously established methods [1,39,40] to quantify the broad space-use requirements and spatial aggregation patterns of adult seabirds during the breeding season, and variation among families was tested. This approach allowed an assessment of whether the patterns of taxonomically coherent groups of species are sufficiently consistent to provide guidance for marine management.

* Corresponding author.

E-mail address: steffen.oppel@rspb.org.uk (S. Oppel).

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