IDENTIFICATION OF MARINE IMPORTANT CONSERVATION AREAS FOR MEDITERRANEAN STORM PETRELS *HYDROBATES PELAGICUS MELITENSIS* BREEDING IN SARDINIA, ITALY

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ABSTRACT

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Marine predators are an important component of marine trophic webs, and their decline has important consequences on whole ecosystem dynamics. Understanding their movements and habits is vital for conservation, yet extremely challenging. Tracking technologies, coupled with a robust, reproducible, and quantitative analytical framework, are being used to successfully identify Important Conservation Areas (ICAs) for seabirds, which are wide-ranging and declining marine predators. However, the identification of such areas is skewed towards large-bodied seabird species, and there are few marine ICAs for small-bodied birds like storm petrels. We GPS-tracked Mediterranean Storm Petrels *Hydrobates pelagicus melitensis* breeding in northwestern Sardinia over three consecutive breeding seasons (2019–2021), and we applied a recently proposed analytical framework for the assessment of ICAs using GPS data. We identified an area of 40 638 km^2 in the central Mediterranean Sea that spans three different national marine jurisdictions and partially falls within the Pelagos Sanctuary for Mediterranean Marine Mammals. In these ICAs, a range of human activities take place (e.g., fishing activities, maritime traffic, tanker maritime routes), particularly in the neritic zones. Despite the relatively low human presence in the area, the human impact on the Mediterranean Sea is predicted to increase in future years, with important consequences for conservation. International cooperation to identify ICAs at the basin scale is needed, given the trans-national nature of storm petrel movements. Here, we describe the polygon of the identified ICAs for the Italian population of Mediterranean Storm Petrel we studied (available for download) to help inform marine spatial planning and target the conservation and protection of the species.

Key words: seabird, conservation, European Storm Petrel, marine spatial planning, human impact

INTRODUCTION

Seas and oceans are experiencing human-driven changes at an alarming rate worldwide (Halpern *et al.* 2008). Direct human activities and their indirect consequences affect marine habitats and species, thereby dramatically altering population processes (Hutchings & Reynolds 2004, Halpern *et al.* 2008). Large marine vertebrates are particularly affected by human activities, and their ongoing and drastic decline has far-reaching consequences that influence the dynamics of whole ecosystems (Heithaus *et al.* 2008, Ferretti *et al.* 2010). Since they are often difficult to study and highly mobile, routinely moving across trans-national boundaries, the protection of such species and the implementation of effective conservation measures are challenging.

For seabirds, which are wide-ranging and declining marine predators (Dias *et al.* 2019), individual biotelemetry has become a key tool for assessing their at-sea habits (Péron *et al.* 2013, Lascelles *et al.* 2016, Davies *et al.* 2021) and informing science-based policy processes (Fraser *et al.* 2018). Tracking data are extremely valuable for site-based conservation, as they can be used to select candidate sites for formal protection and management (Lascelles *et al.* 2016); these sites can then be taken into account for maritime spatial planning operations. Alongside advances in tracking technologies, a data-based analytical framework that allows for a robust and standardized assessment of these Important Conservation Areas (ICAs) is emerging (Lascelles *et al.* 2016). This quantitative and consistent framework has been used by BirdLife International for the identification of candidate marine Important Bird and Biodiversity Areas (IBAs; Lascelles *et al.* 2016, Dias *et al.* 2017, Donald *et al.* 2019), and it has been recently generalized for usage in the identification of Key Biodiversity Areas (KBA; Beal *et al.* 2021). However, ICAs based on seabird tracking data are often biased towards large-bodied seabirds, owing to the technical limits of GPS devices. This has caused difficulties in implementing effective conservation strategies for the poorly known light-bodied species such as storm petrels (Lascelles *et al.* 2016, Oppel *et al.* 2018, Rodríguez *et al.* 2019).

Mediterranean Storm Petrels *Hydrobates pelagicus melitensis* (hereafter "storm petrels") are a subspecies of European Storm Petrel *Hydrobates pelagicus*. Mediterranean Storm Petrels are small (~28 g) planktivorous pelagic seabirds inhabiting almost year-round the Mediterranean Sea (Lago *et al.* 2019, Martínez *et al.* 2019), one of the most degraded marine areas worldwide (Claudet & Fraschetti 2010, Lebreton *et al.* 2012). The storm petrel is a threatened species in Europe (CEU 2009), and the conservation status of genetically and phenotypically distinct Mediterranean populations is unclear (Cagnon *et al.* 2004). Moreover, only a limited number of colonies in the Mediterranean is known (Keller *et al.* 2020), and they are at risk due to introduced predatory species, nesting habitat loss, and resource depletion (Massa & Sultana 1991, Soldatini *et al.* 2015). Storm petrels are particularly susceptible to plastic ingestion (De Pascalis *et al*. 2022) and oil spills, which can have both direct and indirect detrimental effects on individuals and populations (Azkona *et al.* 2006, Zabala *et al.* 2011). Breeding and wintering movements of storm petrels from Malta, Scotland, and Spain have been previously uncovered (Lago *et al.* 2019, Bolton 2020, Rotger *et al.* 2020), resulting in the identification of ICAs for the species. This represents a first step towards the conservation of this sensitive seabird. However, there is a lack of knowledge of potential marine ICAs for storm petrels in the central Mediterranean Sea.

In this study, we GPS-tracked storm petrels breeding in northwestern Sardinia, Italy, over three breeding seasons. We then identified ICAs for the species, using a framework created by Lascelles *et al.* (2016) and later generalized by Beal *et al.* (2021). This study represents the first quantitative assessment of marine important areas for Mediterranean Storm Petrels in Italy. Our results can be used to inform marine spatial planning, conservation actions, and management plans targeting this sensitive and secretive species.

MATERIALS AND METHODS

Data collection

We deployed GPS devices on storm petrels breeding in the Capo Caccia colony (northwestern Sardinia, Italy; 40°35′18.2″N, 008°10′23.7″E) during three consecutive breeding seasons. Chick rearing occurred in July–August 2019, and incubation occurred in July–August 2020 and 2021. Over the three-year study period, we estimated the colony to host approximately 300–600 breeding pairs. Adults arrived at the colony in March, laid eggs from May until July, and chicks fledged from September until the end of October. We used PathTrack (Otley, UK) nanoFIX® GEO-MINI GPS loggers (*ca*. 0.9 g, < 4% bird body mass) set to record one fix per hour during incubation and one fix per 20 minutes during chick rearing. Further details on GPS tracking activity and controls for possible detrimental effects are available in De Pascalis *et al.* (2021). Overall, we obtained 36 foraging trips from 32 individuals (7 in 2019, 12 in 2020, and 13 in 2021). Capture, handling, and tagging procedures were carried out under the supervision of the Italian Institute for Environmental Protection and Research (ISPRA) following the prescriptions of Law 157/1992 [Art.4(1) and Art 7(5)], which regulates research on wild bird species. Field work was also conducted with the permission of Parco Naturale Regionale di Porto Conte. The tracking data set is available upon request from the BirdLife Seabird Tracking Database (http://www.seabirdtracking.org/).

Data analysis

All analyses were performed using R software (v. 4.0.5; R Core Team 2018). We inspected the raw data and removed spatio-temporal duplicates as well as fixes with unrealistic ground speed using the "SDLfilter" package (Shimada *et al*. 2012). To homogenize sampling interval and account for irregular sampling rate, we linearly interpolated and re-sampled the data set at one-hour intervals for both incubation and chick-rearing data using the "adehabitatLT" package (Calenge 2006). We then applied the workflow proposed by Beal *et al.* (2021) and implemented in the "track2KBA" package. Specifically, we first identified foraging trips using the *tripSplit* function and tested for individual site fidelity using the *indEffectTest* function, since fidelity to a foraging site could lead to autocorrelation among subsequent foraging trips of the same individual. We then computed the 50% kernel utilization distribution (UDs) using the *estSpaceUse* function (based on the "adehabitatLT" package; Calenge 2006), pooling together foraging trips from all years (2019–2021). Although this approach can lead to smaller ICAs (Morinay *et al.* 2022), we adopted it to ensure that data were representative of the foraging distributions of the population. Representativeness of the sample was tested using the bootstrapping approach described by Lascelles *et al.* (2016) via the *repAssess* function. To ensure that the kernels were not under- or over-smoothed, we selected the appropriate h-value (smoothing parameter) using the *findScale* function (h = 33.83). Finally, we used the obtained UDs, the representativeness estimate (92.2%), and the minimum estimated population size (n = 600 individuals) as inputs to the *findSite* function, which identifies the areas used by ≥ 10% of the population (this default value is applied when representativeness > 90%).

To visually assess the human impacts in the area, we overlaid the ICAs obtained with a range of human activities using QGIS software (QGIS Development Team 2009). We then calculated mean and standard deviation (SD) in the ICA for each activity using the *extract* function (exact=T) from the "raster" package (Hijmans 2018). Specifically, the three impacts we assessed were fishing effort, shipping density, and tanker density. For the fishing effort, we used data from Global Fishing Watch (GFW, https://globalfishingwatch.org/), which provides daily fishing effort data (in hours) from vessels participating in the Automatic Identification System on a grid of 0.01°. We computed the mean fishing effort for the years 2019–2020. For the shipping density and the tanker density, we used data from the EMODnet human activity layer (EC 2022). The shipping density included data from cargo ships, dredging & underwater operations, high speed craft, fishing vessels, military & law enforcement vessels, passenger & pleasure craft, sailboats, service tugs & towing boats, tankers, and unknown vessels; tanker density considered tankers only. Data were provided in hours per km^2 per month, and we computed the mean for 2019–2020. GFW and EMODnet data for the year 2021 were not available at the time of writing.

RESULTS

We identified a large area of important conservation relevance for the studied population, located in the central Mediterranean Sea. It is composed of two large, one medium, and two small polygons and is available for download at https://figshare.com/articles/online_resource/ICA_H_pelagicus_melitensis_Italy_gpkg/20037179. The whole area has a surface area of 40 638 km^2 and includes portions of the Italian (41%), French (58%), and Monégasque (1%) Exclusive Economic Zones (Fig. 1). Of the identified area, 51% overlaps with the Pelagos Sanctuary for Mediterranean Marine Mammals (Fig. 2A), a Marine Protected Area in the northwestern Mediterranean Sea characterized by a dynamic oceanographic regime with localized upwelling and a permanent frontal system (Notarbartolo-di-Sciara *et al.* 2008). Overall, fishing activity in the area is relatively low (mean ± SD: 0.03 ± 0.15 h) and concentrated in a region within the ICAs on the northwestern Sardinian coast (Fig. 2B). Similarly, the vessel density (2.36 ± 88.73 h/km^2/month) seems lower than in the surrounding region and is mainly concentrated in the ICAs along the French and Sardinian coasts (Fig. 2C). Tanker density in the area is low overall (0.03 ± 0.54 h/km^2/month), but it is present in the identified ICAs (Fig. 2D).

DISCUSSION

We provide here the first quantitative assessment of marine ICAs for storm petrels breeding in Italy to help inform marine spatial planning, along with conservation and management actions. This could be a useful tool to assist national and regional public entities, non-governmental organizations, conservation agencies, and parks in evaluating the conservation importance of specific marine sectors. It would also help leaders consider the impact of maritime economic activities and future developmental plans in the area, such as the establishment of offshore platforms or maritime tanker routes.

As expected from the at-sea behaviour of the species (De Pascalis *et al.* 2021), the areas we have identified are extremely large, located mainly in a pelagic zone and spread across three national

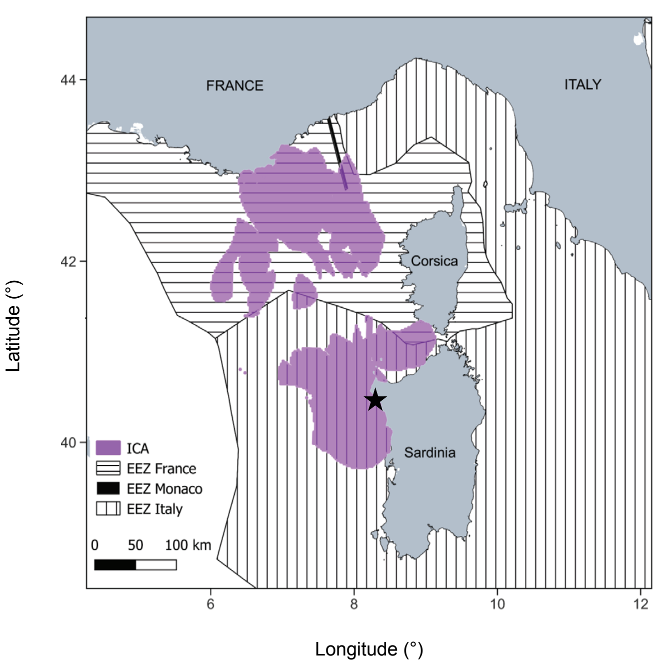

Fig. 1. Important Conservation Area (ICA) identified for an Italian population of the Mediterranean Storm Petrel *Hydrobates pelagicus melitensis* through GPS tracking of 32 individuals (2019–2021 breeding seasons), overlapped with Italian (horizontal lines), French (vertical lines), and Monégasque (solid black) Exclusive Economic Zones (EEZ). The colony location is shown with a star.

jurisdictions. However, some coastal areas of Sardinia, Corsica, and mainland France are included in the identified ICAs as well, highlighting that such habitats are nevertheless important for the species. Indeed, storm petrels could use neritic areas for transiting, resting, or even foraging in particular situations (e.g., fish farms, localized upwelling zones, opportunistic food sources). Moreover, it has been suggested that storm petrels could forage closer to coast during the night (D'Elbée & Hémery 1998, Albores-Barajas *et al.* 2011).

The human impact in the ICAs seems relatively low, and this is probably because storm petrels are truly pelagic foragers that exploit deep and oceanic areas (De Pascalis *et al.* 2021) less suited for many human activities. It follows that the impact of human activities is potentially higher close to the coastlines. Particularly, in the Gulf of Asinara (northern Sardinia) and around western Sardinia, fishing effort is higher than in the surrounding areas. Despite the lack of information about storm petrel bycatch, which could be also due to their small size and low detectability, it is known that they are attracted to fishing vessels and can be susceptible to entanglement in different gear types (Bugoni *et al.* 2008, Pott & Wiedenfeld 2017). The presence of tanker routes through the ICAs, particularly in their offshore sectors, is more alarming. An oil spill in the area could severely affect the species by impacting foraging individuals and reaching the colony and its surrounding waters. Moreover, the complex circulation patterns of the Liguro-Provençal-Catalan Current could bring oil towards other colonies in the region (e.g., Corsica, France, Balearic Islands), with a potentially dramatic impact on a large proportion of the Mediterranean population of this sensitive taxon. Our tracking data cover only a minimal fraction of the storm petrel breeding season, and we sampled a small but representative number of individuals. Therefore, it is likely that throughout the annual cycle, individuals use different areas, resulting in a different risk of exposure to threats. However, considering the low at-sea detectability of storm petrels and the large scale of their movements, GPS tracking is the most effective tool for assessing their exposure to specific threats, compared to traditional vessel-based surveys.

Considering the predicted increase in human activities in the Mediterranean Sea (Micheli *et al.* 2013), it is likely that human presence in the identified ICAs is going to increase, with potential relevant consequences on conservation. For example, an offshore windfarm expansion and/or gas exploitation plan is likely, with potential detrimental consequences on the species if not planned carefully. Indeed, storm petrels have been evaluated as the species with the highest sensitivity index to adverse windfarm impacts among the 30 seabird species considered (Certain *et al.* 2015), and they could be attracted by the light of offshore platforms resulting in incineration in flares from oil and gas platforms (Bolton 2020).

There are few marine ICAs and protected areas for storm petrels in the Mediterranean Sea. These are located in the Western Mediterranean (Rotger *et al.* 2020) and around Malta, where there are four marine Special Protection Areas (SPAs) for which storm petrels are trigger species (i.e., a species that triggers the implementation of conservation measures; ERA 2022). Given the low number of protected areas and the high movement capability of the species, a comprehensive assessment of important marine regions based on tracking data from multiple colonies at the basin scale is a key conservation goal. However, the identification of ICAs is a preliminary step towards the conservation of the species.

Indeed, the identified areas need to be recognised as marine IBAs or SPAs and subjected to effective protection measures and regulations. Ideally, this would mitigate major direct and indirect current and future anthropogenic threats.

The trans-national and trans-jurisdictional nature of storm petrel movements makes *in situ* at-sea conservation actions particularly challenging to achieve without international cooperation. The identification of IBAs or SPAs and the implementation of conservation measures could have important effects on the whole marine system, since the areas exploited by storm petrels are used by a range of apex predators of different taxa. Half of the area we identified overlaps with the Pelagos Sanctuary, an important area regularly exploited by several species of cetaceans, turtles, seabirds, and large pelagic fish. The Pelagos Sanctuary is currently the only pelagic marine area we have

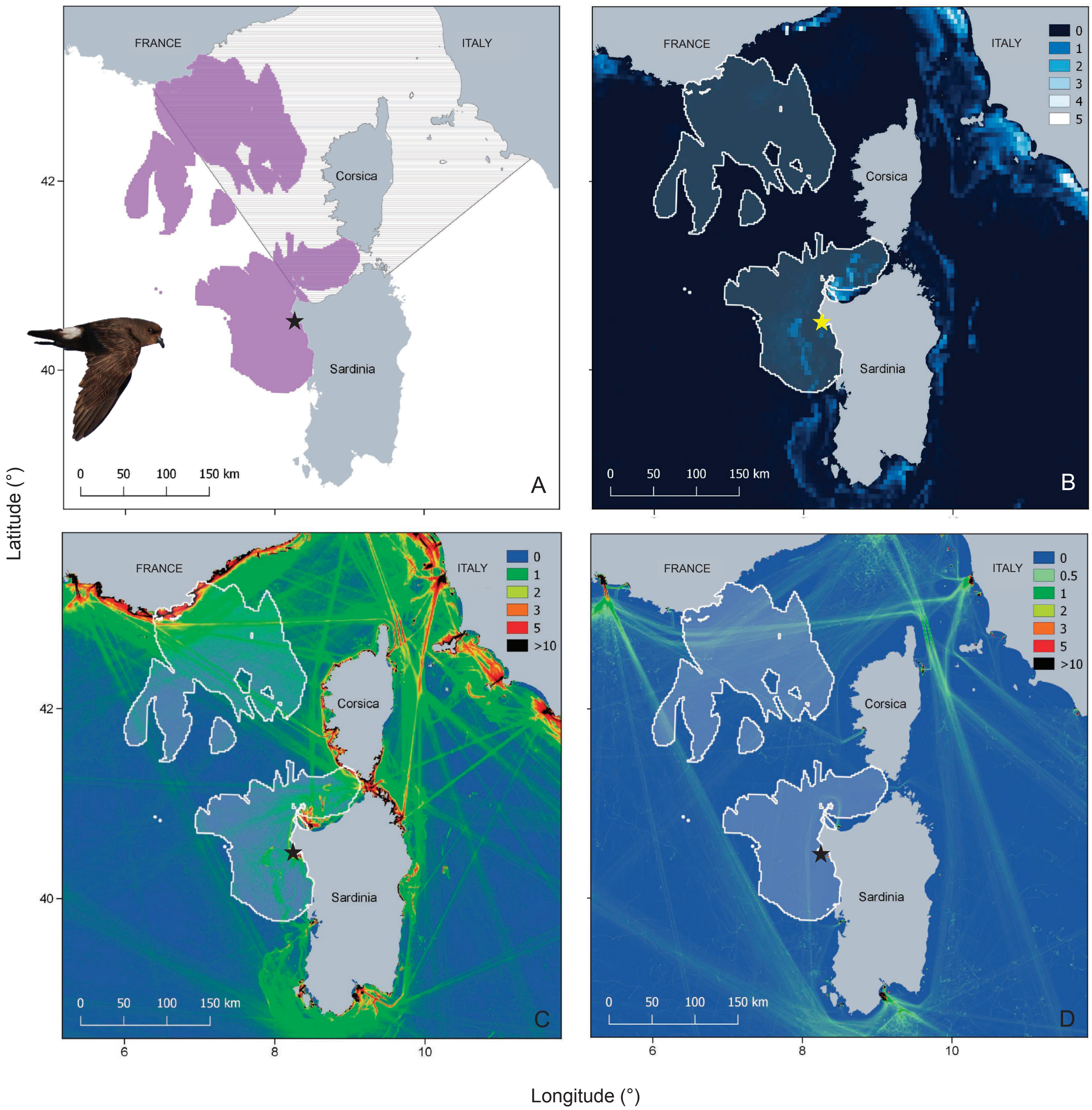

Fig. 2. Important Conservation Area (ICA) identified for an Italian population of the Mediterranean Storm Petrel *Hydrobates pelagicus melitensis* through GPS tracking of 32 individuals (2019–2021 breeding seasons). Panel A shows the overlap of the ICA with the Pelagos Sanctuary for Mediterranean Marine Mammals (dashed lines). Panel B shows the overlap of the ICA with mean fishing effort (hours) for 2019–2020. Panels C and D show the overlap with mean vessel density (all vessel types) and tanker density for 2019–2020 (hours/km^2/month). The colony location is shown with a star.

identified that has some level of regulation overlapping with the ICAs (MedPAN 2022). The aim of the sanctuary is to identify threats posed to cetaceans and to regulate them through appropriate measures applied by the signatory countries. Storm petrels indirectly benefit from this protection status, since they share some human-related threats with cetaceans, such as bycatch and chemical pollution. However, seabirds frequenting the area could benefit from more specific management measures, such as mitigation measures on fishery activities that could help reduce the impact of bycatch.

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