Insights into fin whale movements and foraging behaviour around Elephant Island, Antarctica

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ABSTRACT

Following near-extinction from 20th-Century industrial whaling, fin whales are now reappearing in growing numbers in Antarctic waters. Shipboard and aerial surveys have documented their return to ancestral feeding grounds along the Western Antarctic Peninsula. Using behavioural analyses based on satellite telemetry data, this study aims to complement existing knowledge on the ecology of fin whales, with insights into movement patterns and behaviour at feeding grounds that support some of the largest aggregations of baleen whales ever observed. In the austral autumn (March and April) of 2021 and 2023, four and nine fin whales, respectively, were equipped with satellite transmitters at their foraging grounds off Elephant Island. Their movements were tracked for durations ranging from 4 to 39 days (SD = 9 days). Behavioural analyses employing a two-state Hidden-Markov model (HMM) were conducted to assess the whales' activity states. The HMM revealed that fin whales dedicated almost 80% of their time to area-restricted search, a behaviour commonly associated with foraging. Most individuals (n = 8) exhibited a notable site fidelity to the waters off the Northern coast of Elephant Island. Three whales moved away from the tagging location in different directions: south-west into the Bransfield Strait, east towards the South Orkneys, and south towards the Weddell Sea, where they again engaged in area-restricted search. The concentration of foraging behaviour around Elephant Island, the South Orkneys and the Northern region of the Weddell Sea highlights known and potentially novel core feeding grounds within the Western Antarctic Peninsula and Islands IMMA (Important Marine Mammal Area). The identification of these foraging areas within an IMMA strengthens the urgent need for special protection to ensure the continued recovery of this species and preserve core feeding habitats.

KEYWORDS: SATELLITE TELEMETRY; FIN WHALES (*BALAENOPTERA PHYSALUS QUOYI*); FORAGING; BEHAVIOUR; IMPORTANT MARINE MAMMAL AREAS (IMMAS); WESTERN ANTARCTIC PENINSULA

INTRODUCTION

Southern Hemisphere fin whales (*Balaenoptera physalus quoyi*) were heavily exploited during the era of industrial whaling, with over 723,000 individuals killed prior to the end of their commercial exploitation in the mid-1970s (Rocha *et al.*, 2015; Clapham & Baker, 2018). These operations largely targeted (sub) Antarctic feeding grounds, particularly around South Georgia and the Antarctic Peninsula, where fin whales aggregated in large numbers during the austral summers (Kemp & Bennett, 1932; Mackintosh, 1966). Historical whaling records underline

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the importance of these areas for fin whales; their population was reduced to an estimated 1–2% of its pre-whaling size of approximately 325,000 individuals (Rocha *et al*., 2015; Clapham & Baker, 2018; Tulloch *et al*., 2018). By the end of the whaling era, few fin whales were left in the Southern Hemisphere, and sightings in historical feeding grounds remained scarce for decades.

In the 2000s, reports of fin whale sightings began increasing, particularly around the Northern Antarctic Peninsula. Hotspots of occurrence were identified near Elephant Island, based on data collected during repeated krill (Santora *et al*., 2014) and vessel surveys (Burkhard & Lanfredi, 2012; Joiris & Dochy, 2013). More recent surveys have reported high densities of fin whales in these areas, with a ship-based helicopter survey in March 2013 estimating a minimum abundance of 4,898 (95% CI: 2,221–7,575) individuals around the South Shetland Islands (Herr *et al*., 2016). In February 2016, additional surveys reported high densities in the continental shelf waters around Elephant Island and the South Orkney Islands (Viquerat & Herr, 2017). Large feeding aggregations, including groups of up to 300 individuals (Herr *et al*., 2022a), have been observed, suggesting at least some level of population recovery and a return to ancestral feeding grounds (Herr *et al*., 2022b). Recently, a large-scale synoptic krill survey carried out by three vessels simultaneously provided an updated estimate of 50,837 (95% CI: 38,966–66,324) fin whales in the Scotia Sea, ultimately confirming an area-wide increase (Biuw *et al*., 2024).

The waters around the Western and Northern Antarctic Peninsula and surrounding areas, including the South Orkney and South Shetland Islands, have been identified as an Important Marine Mammal Area (IMMA) by the IUCN SSC/WCPA Marine Mammal Protected Areas Task Force in 2019 (Tetley *et al*., 2022), with fin whales recognised as a qualifying species for the following criteria: 'population vulnerability', 'aggregations' and 'feeding areas'. This region, characterised by complex bathymetry and oceanic currents supporting high biological productivity, is known for its high biomass of Antarctic krill (*Euphausia superba*), providing critical feeding grounds for baleen whales (Santora *et al*., 2010, 2014). Some of the highest rates of warming in Antarctica have been recorded in this region (Vaughan *et al*., 2003; IPCC, 2007), although recent analyses indicate a slowdown or partial reversal of that warming in the 21st century (Turner *et al*., 2016; Oliva *et al*., 2017). Such climate variability has been associated with changes in winter sea-ice duration and extent (e.g., Stammerjohn *et al*., 2012), which affects primary productivity and causes fluctuations in the abundance of krill (Loeb *et al*., 1997; Brierley *et al*., 1999, 2002).

Furthermore, following the depletion of whales, a large fishery for krill has developed in the Southern Ocean, which is now in direct competition with baleen whales. The krill fishery has focused its operations on areas and times known to be critical for baleen whale feeding. A spatio-temporal overlap between humpback whales and the krill fishery has already been demonstrated (Weinstein *et al*., 2017; Reisinger *et al*., 2022). A growing concern is the current lack of comparable data for fin and blue whales, which historically were the largest and most abundant consumers of krill (Savoca *et al*., 2021). Significant data gaps remain regarding individual, local and population-level consumption rates, which critically depend on robust information about site fidelity and the duration of stay at feeding grounds during the feeding season (Trathan *et al*., 2024).

Here, we analyse the meso-scale movement of fin whales at these feeding grounds for the first time using satellite telemetry. We employ a continuous-time state-space model and a two-state switching-state Hidden-Markov model to analyse the tracking data and provide insights into the movement patterns and behaviours of fin whales around Elephant Island. The results contribute to understanding ecological drivers of distribution, informing conservation strategies and highlighting the importance of these historical feeding grounds as critical habitats for a recovering population.

MATERIALS & METHODS

Study area

The study area encompassed inshore and offshore waters of the Northern Antarctic Peninsula and the South Orkney and South Shetland Islands, within the recently identified Western Antarctic Peninsula and Islands IMMA. The Western Antarctic Peninsula ecosystem is influenced by the Antarctic Circumpolar Current, especially by intrusions of warm and nutrient-rich upper circumpolar deep water over the continental shelf, which increases biological productivity (Hofmann & Murphy, 2004). The complex bathymetry associated with the shelf break around islands and the continent, as well as embayments and troughs, result in dynamic circulation features, including oceanic gyres and the interaction between Weddell Sea water with inshore currents from the Gerlache and Bransfield Straits. Such characteristics create a rich foraging environment of extremely high krill biomass, supporting high densities of marine mammals (Nicol *et al*., 2000; Ducklow *et al*., 2007; Orgeira *et al*., 2015).

The South Shetland Islands also support a large diversity of marine mammals and other large predator populations that feed on the abundant krill in this region and use the area as resting sites during migration. These islands mark an important transition zone between Antarctic and Subantarctic habitats. The presence of an efficient krill fishery that operates within the foraging range of marine mammals makes this a critical site for ecosystem monitoring.

Data collection

Data collection took place in March and April 2021 and 2023, off the Northern coast of Elephant Island (61°S, 55°W), Antarctica. In 2021, tagging operations occurred during a five-week expedition aboard the 23 m sailing vessel *Australis* (for details on the data collection see Herr *et al*., 2022b). In 2023, tagging operations were conducted during the research voyage MSM115_FINWAP (Herr *et al*., 2023) on the German research vessel *Maria S. Merian*. Satellite transmitters were deployed on an opportunistic basis, when fin whale groups were approachable and small boat work feasible (i.e., depending on weather conditions), using rigid-keeled inflatable boats. Four SPLASH10-333 or SPLASH10-F-333 GPS Fastloc® transmitters of the Low-Impact Minimally Percutaneous External Electronic (LIMPET) configuration (Wildlife Computers Inc., Redmond, WA) were deployed in 2021 and seven in 2023. Furthermore, in 2023, two consolidated transdermal (Type C, Wildlife Computers Model 372A) tags were deployed following best practice guidelines (Andrews *et al*., 2019). Telemetry data were transmitted exclusively via the Argos satellite system for the Type C tags, and via Argos satellites and Geographical Positioning System (GPS) for the LIMPET tags. All tags were duty cycled to prioritise long-range movement analysis; more details can be found in Herr *et al*. (2022b).

Tag settings in 2023 matched those used in 2021, with tags programmed to transmit up to 14 hours each day, with a maximum of 300 transmissions during that period, with a 1–5 hours transmission interval. The Type C implantable tags were programmed to transmit during the following hours (UTC): 00h through 15h, and 21h through 23h. They were programmed not to transmit from 16h through 20h (UTC) due to low satellite availability. The Type C implantable tags were programmed to relay data to the Argos satellites until they reached 20 uplinks per hour for every hour they were programmed to transmit.

Data analysis

Behavioural estimation

After downloading data from the Wildlife Computers portal, the aniMotum package from R Studio (Jonsen *et al.*, 2023; R Core Team, 2025) was used to filter and run a state-space model (SSM) on fin whale telemetry data. The locations were visually inspected and outliers removed according to unrealistic distances from other position points. The mean time between transmissions was calculated at 3.8 hours and two state-space models with 3 and 4-hour time-steps were run. A correlated random walk was fit to all tracked individuals, and the models were run to account for apparent bias in the error ellipses of the Argos Kalman Filtering algorithm using a fixed or non-fixed 'psi' factor (Jonsen *et al*., 2020). After running the four models (3-hour model with and without fixed 'psi' factor; 4-hour model with and without fixed 'psi' factor), corrected Akaike Information Criterion (AICc) values and negative log-likelihoods were compared to assess the best model fit. Here, the model with a time step of 3 hours and a non-fixed 'psi' factor performed slightly better in both model validations. The regularised locations were then further analysed with a two-state Hidden-Markov Model (HMM) to infer behavioural states from observed movements through a maximum-likelihood estimation analysis using the R package momentuHMM (McClintock *et al*., 2018), following the approach described in Panigada *et al*. (2024). State 1 was characterised by shorter step lengths and higher turning angles, indicative of tortuous movements consistent with area-restricted search (ARS) behaviour, typically associated with foraging. State 2 exhibited longer step lengths and lower turning angles, reflecting more directed movements consistent with transiting behaviour. State classification was based on the most likely sequence of hidden states (via the Viterbi algorithm).

Home ranges

Home ranges, or realised habitats, were assessed by calculating Kernel Utilisation Distributions (UD), adopting the methodology described in Panigada *et al*. (2024). UDs describe the probability density of an animal's occurrence across space, effectively identifying the areas most frequently used during the data collection period. UDs were computed using the kernelUD function in the adehabitatHR R package (Calenge, 2006), applied to the regularised tracks generated by the state-space model. A bivariate normal kernel with the reference bandwidth was used for smoothing, and a grid resolution of 10 × 10 km was chosen to assess the minimum extent of the animals' ranges and to measure the spatial intensity of use. A spatial grid of 10 × 10 km cells was adopted for the calculation of UDs considering both statistical and biological reference. This grid resolution is sufficiently large to smooth short-term positional noise while remaining fine enough to preserve meaningful spatial structure and reflect the characteristic scale of movement exhibited by the tracked animals. Descriptive movement statistics were computed for each individual and across all whales, including mean and median step lengths, associated standard deviations, and corresponding travel speeds. The mean displacement per 3-hour interval averaged approximately 9 km, with standard deviations typically between 4–10 km. In agreement with the literature (Worton, 1989, 1995), we defined core and home ranges as the 50% and 95% UD isopleths, respectively. Because the input locations were regularised in time, the resulting UDs provide a time-weighted representation of space use, highlighting areas where animals spent the majority of their time during tracking.

RESULTS

Thirteen fin whales (n = 4 in 2021, n = 9 in 2023) were equipped with satellite transmitters, with transmission periods ranging from 4 to 39 days (mean = 20; SD = 9 days; Table 1). Data from one satellite tag were excluded from analyses (PTT 198916), as transmission duration lasted less than 10 hours, bringing the total of individual tracks analysed here to 12. Two of the 2021 whales (PTT 198915 and PTT 198905) were partially tracked making their northward migration across the Drake Passage, into the Pacific Ocean and up the west coast of South America in offshore waters (see Herr *et al*. [2022b] for detailed movement tracks) (Fig. 1).

Of the nine whales tagged in 2023, no directed northward migration movements were recorded, but departures from the Elephant Island tagging site were documented. Three animals made clear movements away from Elephant Island, one animal (PTT 198912 'Charlie') moved to the south-west into the Bransfield Strait, another (PTT 239576 'India') moved east to the South Orkneys, where transmissions ended. PTT 239577 'Juliet' left Elephant Island and moved south into the northern region of the Weddell Sea (Fig. 1).

Table 1
Summary of satellite telemetry data from fin whales tracked off Elephant Island, West Antarctic Peninsula, in 2021 (n=4) and 2023 (n=9). One deployment marked with * was excluded from the analyses, as the data collection period was less than 10 hours (PTT 198916). 2021 deployments are highlighted in grey.

PTT	Deploy ID	Decoded as	Transmission type	First uplink date	Last uplink date	Duration (days)	Number of raw locations	Movements
198904	NA	Mk10	Argos	2021/03/28	2021/03/31	4	54	Elephant Island
198905	NA	MK10	Argos	2021/04/03	2021/05/01	29	715	Chile coast
198909	NA	MK10	Argos	2021/04/10	2021/04/22	13	256	Elephant Island
198915	NA	MK10	GPS/Argos	2021/04/10	2021/04/25	16	411	Chile coast
198910	*Alpha*	MK10	Argos	2023/03/17	2023/03/31	15	169	Elephant Island
198911	*Bravo*	MK10	Argos	2023/03/17	2023/04/06	21	290	Elephant Island
198912	*Charlie*	MK10	Argos	2023/03/19	2023/04/13	26	424	Bransfield Strait
198913	*Delta*	MK10	Argos	2023/03/19	2023/04/11	24	352	Elephant Island
212923	*Echo*	MK10	Argos	2023/03/19	2023/04/04	17	220	Elephant Island
198916*	*Foxtrot*	MK10	GPS/Argos	2023/03/19	2023/03/20	1	46	Elephant Island
198906	*Golf*	MK10	Argos	2023/03/20	2023/03/27	8	43	Elephant Island
239576	*India*	Type C: SPOT6	Argos	2023/03/22	2023/04/19	29	663	S. Orkney
239577	*Juliet*	Type C: SPOT6	Argos	2023/03/21	2023/04/25	36	1,093	Weddell Sea

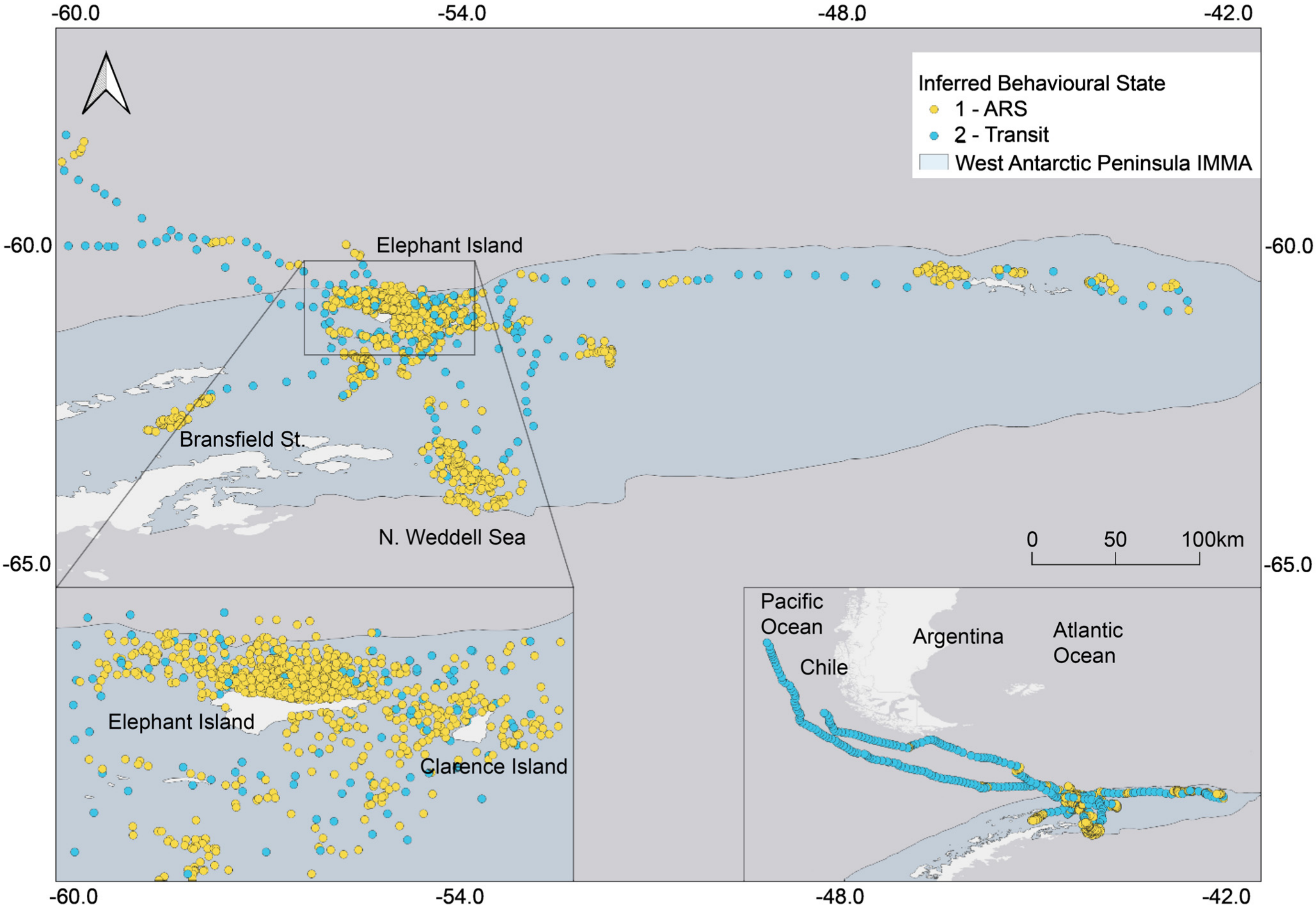

Figure 1. Location estimates of 12 fin whales tagged off the northern coast of Elephant Island in 2021 (n = 4) and 2023 (n = 9). A behavioural state was assigned to each location estimate using output from both a state-space and Hidden-Markov model, assigning behaviour to either: (1) area-restricted search (ARS; yellow circles); or (2) transit behaviour (blue circles). The main map frame indicates movements from the tagging site around Elephant Island, east to the South Orkney Islands, south into the Weddell Sea, west into the Bransfield Strait, and northwest towards the Pacific Ocean. The left inset image shows a close-up of Elephant (centre) and Clarence Islands (to the right) and the abundance of ARS activity in close proximity to the northern shores of both islands. The right inset map depicts the extent of the northwest migration of two animals into the Pacific Ocean until tag transmissions ceased in 2021 (see Herr *et al.*, 2022b). The boundary of the West Antarctic Peninsula Important Marine Mammal Area (IMMA) is indicated by the pale blue region of each map.

Behavioural estimation

The output of the HMM revealed that the tracked individuals spent an average of 80% (79.2%) of their time engaging in area-restricted search (ARS) behaviour (median = 85%) (Fig. 2). The spatial distribution of ARS locations was consistent around Elephant Island across 2021 and 2023, with previously unknown potential feeding hotspots revealed around South Orkney, the northern Weddell Sea and the Bransfield Strait (Fig. 1).

Overlap with the IMMA

The home ranges calculated on ARS locations overlapped with the IMMA by 64.3% for the core (50th percentile) and 71.3% for the home (95% percentile) ranges (Fig. 3). Aside from the northwest migration, the observed fin whale 'local' movements and foraging activity largely occurred within the IMMA, with their distribution closely aligned to the IMMA boundaries, terminating along the slope edge, and thereby strongly validating the current delineation of the IMMA as it relates to fin whale needs.

DISCUSSION

The results of this study provide the first insights into the meso-scale movement and behavioural ecology of fin whales at their feeding grounds around Elephant Island. The high proportion of time spent in ARS behaviour

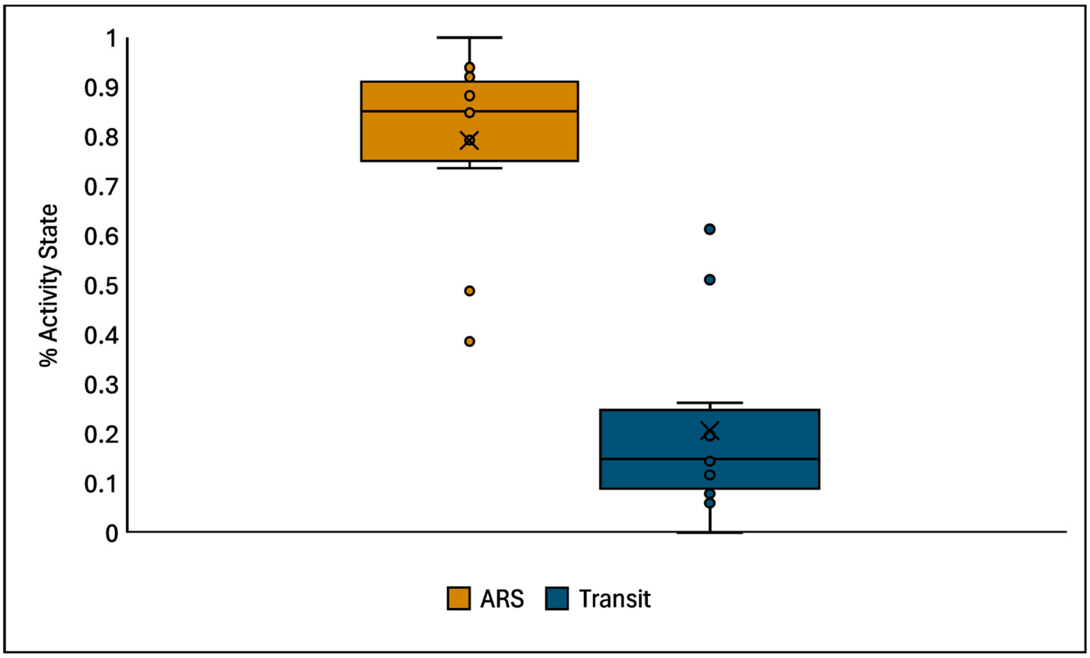

Figure 2. Boxplots of activity states for two behaviours: area-restricted search (ARS), and transit, determined using both a state-space and a two-state Hidden-Markov model for 12 fin whales equipped with satellite tags around Elephant Island. Boxes display the inter-quartile ranges; horizontal lines are medians, and vertical lines display the inter whisker range and fill the extent of the distributions. Outliers fall outside the quartile boxes.

(> 75%) suggests that the whales regularly engaged in intensive foraging-related activities, although ARS alone cannot conclusively confirm feeding. This pattern nonetheless supports previous studies identifying the waters surrounding Elephant Island as important feeding grounds for fin whales in the Antarctic (Santora *et al.*, 2010; Herr *et al.*, 2022a, b).

Drone-based video footage from the same area (Herr *et al.*, 2022a, 2023) support a high degree of surface activity, with fin whales engaging in repeated lunge manoeuvres and displaying synchronised group feeding at the surface (Rychwalski & Herr, 2024). It has been suggested that, if prey patches at depth are denser and larger compared to smaller and less dense prey patches at the surface, North Pacific fin whales maximise foraging performance and food intake by increasing feeding rates at depth (Friedlaender *et al.*, 2019). On the other hand, humpback whales *(Megaptera novaeangliae)* in the Antarctic preferentially feed on less dense prey aggregations at the surface, as opposed to denser patches at depth (Friedlaender *et al.*, 2016). In rorquals, prey density is considered a primary factor affecting behavioural adaptations during foraging, and energetically costly acrobatic side-lunge manoeuvres are usually found to be more frequent when feeding on less dense krill patches (Goldbogen *et al.*, 2015; Cade *et al.*, 2016; Shadwick *et al.*, 2019). The combination of large numbers of shallow dives, a high rate of observed side-lunge behaviour during surface feeding events (Rychwalski & Herr, 2024), and the reported high percentage of ARS throughout the area, characterised by high fin whale density, suggest fin whales at the Elephant Island feeding grounds forage on a reliable occurrence of a prey resource in the upper surface layers.

The fin whales tagged in this study were observed as part of large feeding aggregations around Elephant Island (Herr *et al.*, in press). During the survey period, fin whale abundance in the area was estimated at approximately 4,126 ± 1,344 animals (CV 0.33; 95% CI 2,130–7,990), with consistently high densities recorded throughout (Herr *et al.*, in press). Despite the relatively small sample size (n = 12), the movement patterns of the tagged individuals are likely representative of a larger population that exhibits similar site fidelity and reliance on these productive feeding grounds.

The evidence of site fidelity reported among most individuals equipped with satellite transmitters in both 2021 and 2023 further underlines the ecological importance of this region for fin whales. These waters offer

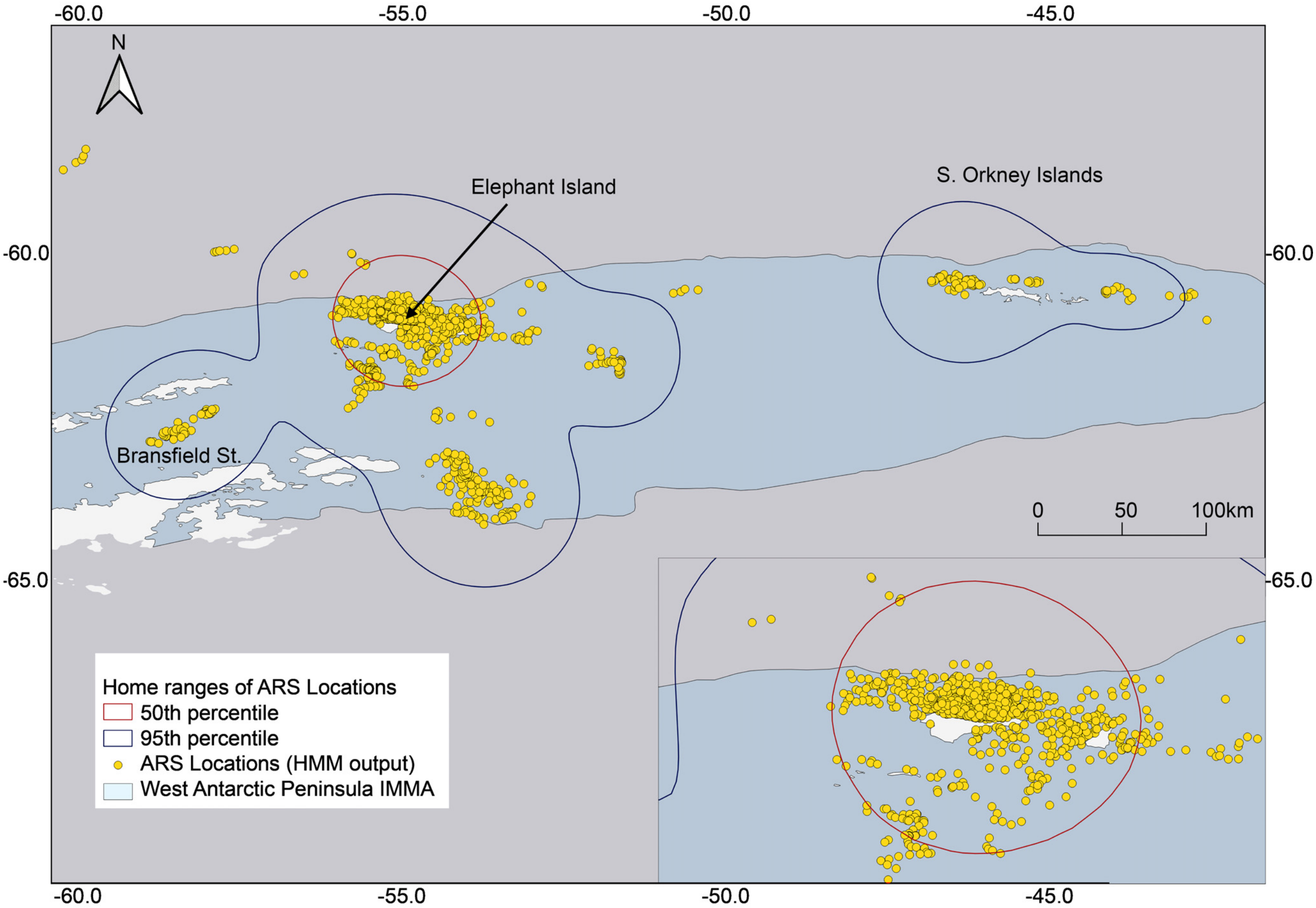

Figure 3. Location estimates of 12 fin whales tagged off the northern coast of Elephant Island in 2021 (n = 4) and 2023 (n = 9), where the behavioural state was assigned as area-restricted search (ARS) (yellow circles) using the output from the 2-state Hidden-Markov model. The main map frame displays home range estimates of the 50th (red outlined area) and 95th percentiles (blue outlined areas) for the transmission period, centred around Elephant Island in the South Shetland Islands and Coronation Island in the South Orkney Islands. The inset map on the bottom right shows a close-up of Elephant (centre) and Clarence Islands (to the right) and the abundance of ARS activity in close proximity to the northern shores of both islands. The boundary of the West Antarctic Peninsula Important Marine Mammal Area (IMMA) is indicated by the pale blue region of each map.

predictable and abundant prey resources, likely Antarctic krill, allowing large fin whale aggregations around Elephant Island during the austral summer and early autumn (Nowacek *et al*., 2011; Herr *et al*. 2022a).

It is important to note that the strong apparent reliance of the tagged fin whales in the waters around Elephant Island likely reflects, at least in part, the tagging location itself. Whales were chosen to be tagged in this region because of the highly productive feeding grounds in these waters. Some degree of site fidelity to local feeding grounds is therefore inherent in the study design. However, both opportunistic observations and recent systematic surveys indicate that high densities and large aggregations of fin whales also occur further east, particularly around the South Orkney Islands (Ryan *et al*., 2023) and in the Bransfield Strait (Biuw *et al*., 2024). Our data show that fin whales transit between these locations, with ARS behaviour at both feeding grounds and none in between. Based on a small sample size, it is difficult to estimate the rates of transition between the feeding grounds, and whether there is a temporal component in choice of feeding grounds, or whether specific fin whale groups predominantly prefer one or the other feeding ground, or perhaps even belong to distinct breeding populations connected to specific feeding grounds.

The further movements of three individuals away from Elephant Island – towards the Bransfield Strait, South Orkneys and Weddell Sea – indicate a broader use of the area in search of additional foraging sites. This behaviour is relatively common in fin whales, which demonstrate the ability to exploit ephemeral prey patches over large spatial scales, not only in the Antarctic waters but also in the Mediterranean Sea (Joiris, 1991; Panigada *et al*., 2017, 2024).

The presence of foraging grounds in the Weddell Sea and near the South Orkney Islands may also reflect broader regional productivity patterns or interannual shifts in prey availability, which can be influenced by climatic and oceanographic variability (Atkinson *et al*., 2008). These results on the fine-scale habitat use of fin whales further demonstrate the dynamic nature of krill-dependent predator-prey interactions in the region and the importance of multi-year data to better understand how baleen whales could respond to changing environmental conditions. The north coast of Elephant Island is considered an important recruitment area for Antarctic krill, featuring particularly high densities of juvenile krill (Siegel *et al*., 2002; Loeb *et al*., 2009). However, declines in krill abundance around Elephant Island since the end of the 20th Century have been observed, with decreased juvenile survival suggested as a potential cause (Panasiuk *et al*., in review). Increasing salp (*Salpa thompsoni*) dominance in the area, as a result of changing environmental conditions, may have cascading effects on the food web (Pietzsch *et al*., 2023). These changes highlight the vulnerability of the feeding grounds that sustain the recovering population of fin whales.

The identification of core foraging areas within the boundaries of the Western Antarctic Peninsula and Islands IMMA, identified by the Marine Mammal Protected Areas Task Force, within the framework of the IUCN's SSC and WCPA (Tetley *et al*., 2022), further strengthens the need for enhanced conservation and mitigation measures in these regions. Overall, 96.2% of ARS behaviour of tagged whales around Elephant Island, South Orkney and the Bransfield Strait fell within the Western Antarctic Peninsula and Islands IMMA, an area with the potential to be managed for conservation. It is important to note, however, that this area currently carries no formal mandatory protection measures. A proposal for the protection of Western Antarctica was submitted to CCAMLR in 2018 (CCAMLR, 2018), an MPA comprising three zones: the General Protection Zone (GPZ), the Krill Fisheries Research Zone (KFRZ), and the Special Fisheries Management Zone (SFMZ). The Elephant Island area and its surrounding waters are part of the proposed GPZ, designed to protect key life-history stages of various species, including under climate change scenarios (Sylvester & Brooks, 2020). As such, commercial fishing would be prohibited within the GPZ (Sylvester & Brooks, 2020), largely protecting fin whales from competition with the krill fishery at this important feeding ground. However, progress towards establishing this MPA has been blocked by a number of CCAMLR member states, preventing the adoption of new marine protected areas in the region (see Brooks *et al*., 2016; Sylvester & Brooks, 2020).

Despite the recent signs of recovery, fin whales in the Southern Ocean remain vulnerable to a suite of anthropogenic threats that could negatively affect their population status and structure. One of the most immediate concerns is the increasing presence of large vessels along the Western Antarctic Peninsula, including krill fishing fleets and tourism ships, which elevates the risk of vessel strikes, most likely the main cause of mortality for large whales globally (Laist *et al*., 2001; Panigada *et al*., 2006; van Waerebeek *et al*., 2007; Nisi *et al*., 2024). The overlap between high-density whale aggregations and vessel traffic near Elephant Island presents significant risks, particularly during peak foraging periods, when whales tend to spend extended time near the surface. The growth of the Antarctic krill fishery also poses a substantial threat. While current catch levels remain below regulatory thresholds, localised depletion can reduce prey availability for krill-dependent predators, including fin whales, especially in regions identified as ecological hotspots (Nicol *et al*., 2008; Hinke *et al*., 2017). Health impacts on individuals with population-level consequences, such as decreased body condition and reduced reproductive rates, may arise from local depletion of prey (Pallin *et al*., 2023), prey field disturbance, and repeated disturbance during foraging that increases whale energetic costs (Guilpin *et al*., 2020). There is observational evidence that krill fishing is carried out amid fin whale feeding aggregations (Ryan *et al*., 2023). Distributional overlap between whales and fisheries on feeding/fishing grounds represents a major conservation concern, with individual whales not only at direct mortality risk from ship strikes, but also from entanglement and bycatch. In 2021 and 2022, four humpback whales were bycaught in krill trawls (CCAMLR, 2023).

Furthermore, climate change is contributing to long-term declines in sea ice and altering krill recruitment and distribution, potentially enhancing the effects of fisheries and reducing the resilience of marine food webs (Flores *et al*., 2012). Addressing these pressures through spatial management measures within the IMMA waters (e.g., seasonal vessel slow-down zones, dynamic no-fishing areas, and expansion of marine protected areas) is crucial to support the continuous recovery of fin whale populations. As of 2019, the International Association of

Antarctica Tour Operators (IAATO) have committed to a 10 kn speed restriction in designated geo-fenced areas at specific times of the year (IAATO, 2019). The Elephant Island area has been added on a voluntary basis for the 2023/24 and 2024/25 seasons, before becoming mandatory for the current 2025/26 season (IAATO, 2025). The proposed geo-referenced area occurs in the immediate proximity of Elephant and Clarence islands, in agreement with the fin whale tracks presented in this study. For a more generous buffer area, we recommend extending the geo-referenced boundaries further offshore, to encompass all inferred foraging behaviour associated with the Elephant Island grounds.

In conclusion, this study supports the role of the Western Antarctic Peninsula and Islands IMMA as a key area for fin whales in Antarctic waters. Future studies integrating longer-duration satellite tracking for population identity purposes, combined with shorter-duration, higher-resolution tracking to obtain more precise information on 3D movements, as well as prey field mapping and environmental variables, will allow a more comprehensive understanding of habitat use, better underlining the conservation needs of this recovering species.

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REFERENCES

Andrews, R., Baird, R., Calambokidis, J., Goertz, C., Gulland, F., Heide-Jørgensen, M.P., Hooker, S., Johnson, M., Mate, B., Mitani, Y., Nowacek, D., Owen, K., Quakenbush, L., Raverty, S., Robbins, J., Schorr, G., Shpak, O.F., Jr., Uhart, M., & Zerbini, A. (2019). Best practice guidelines for cetacean tagging. *J. Cetacean Res. Manage*. 20: 27–66. [Available at: *https://doi.org/10.47536/jcrm.v20i1.237*]

Atkinson, A., Siegel, V., Pakhomov, E.A., Rothery, P., Loeb, V., Ross, R.M., Quetin, L.B., Schmidt, K., Fretwell, P., Murphy, E.J., Tarling, G.A., & Fleming, A.H. (2008). Oceanic circumpolar habitats of Antarctic krill. *Mar. Ecol. Prog. Ser.* 362: 1–23. [Available at: *https://doi.org/10.3354/meps07498*]

Biuw, M., Lindstrøm, U., Jackson, J.A., Baines, M., Kelly, N., McCallum, G., Skaret, G., Krafft, B.A. (2024). Estimated Summer Abundance and Krill Consumption of Fin Whales throughout the Scotia Sea during the 2018/2019 Summer Season. *Sci. Rep.* 14(1): 7493. [Available at: *https://doi.org/10.1038/s41598-024-57378-3*]

Branch, T.A., & Butterworth, D.S. (2001). Estimates of abundance south of 60°S for cetacean species sighted frequently on the 1978/79 to 1997/98 IWC/IDCR-SOWER sighting surveys. *J. Cetacean Res. Manage.* 3(3): 251–270. [Available at: *https://doi.org/10.47536/jcrm.v3i3.877*]

Brierley, A.S., Watkins, J.L., Goss, C., Wilkinson, M.T., & Everson, I. (1999). Acoustic Estimates of Krill Density at South Georgia, 1981 to 1998. *CCAMLR Science* 6: 47–57.

Brierley, A.S., Fernandes, P.G., Brandon, M.A., Armstrong, F., Millard, N.W., McPail, S.D., Stevenson, P., Pebody, M., Perret, J., Squires, M., Bone, D.G., & Griffiths, G. (2002). Antarctic Krill Under Sea Ice: Elevated Abundance in a Narrow Band just South of Ice Edge. *Science* 295: 1890–1892. [Available at: *https://doi.org/10.1126/science.1068574*]

Brooks, C.M., Crowder, L.B., Curran, L.M., Dunbar, R.B., Ainley, D.G., Dodds, K.J., Gjerde, K.M., & Sumaila, U.R. (2016). Science-based management in decline in the Southern Ocean. *Science* 354(6309): 185–187. [Available at: *https://doi.org/10.1126/science.aah4119*]

Cade, D.E., Friedlaender, A.S., Calambokidis, J., & Goldbogen, J.A. (2016). Kinematic Diversity in Rorqual Whale Feeding Mechanisms. *Curr. Biol.* 26(19): 2617–2624. [Available at: *https://doi.org/10.1016/j.cub.2016.07.037*]

Calenge, C. (2006). The package 'adehabitat' for the R software: A tool for the analysis of space and habitat use by animals. *Ecol. Model*. 197: 516–519. [Available at: *https://doi.org/10.1016/j.ecolmodel.2006.03.017*]

Clapham, P.J., & Baker, C.S. (2018). Modern whaling. In: W. F. Perrin, B. Würsig, J.G.M. Thewissen (eds.) *Encyclopedia of Marine Mammals* (3rd ed., pp.1070–1074). New York, NY: Academic Press. [Available at: *https://doi.org/10.1016/b978-0-12-804327-1.00272-7*]

Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) (2018). *Report of the Thirty-Seventh Meeting of the Scientific Committee (SC-CCAMLR-37).* Hobart, Australia.

Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) (2023). *Report of the Forty-Second Meeting of the Commission (CCAMLR-42).* Hobart, Australia.

Ducklow, H.W., Baker, K., Fraser, W.R., Martinson, D.G., Quetin, L.B., Ross, R.M., Smith, R.C., Stammerjohn, S., & Vernet, M. (2007). Marine Pelagic Ecosystems: the West Antarctic Peninsula. *Phil. Trans. R. Soc. B* 362: 67–94. [Available at: *https://doi.org/10.1098/rstb.2006.1955*]

Flores, H., Atkinson, A., Kawaguchi, S., Krafft, B. A., Milinevsky, G., Nicol, S., & Werner, R. (2012). Impact of climate change on Antarctic krill. *Mar. Ecol. Prog. Ser.* 458: 1–19. [Available at: *https://doi.org/10.3354/meps09831*]

Friedlaender, A.S., Johnston, D.W., Tyson, R.B., Kaltenberg, A., Goldbogen, J.A., Stimpert, A.K., Nowacek, D.P. (2016). Multiple-stage decisions in a marine central-place forager. *R. Soc. Open Sci*. 3: 160043. [Available at: *https://doi.org/10.1098/rsos.160043*]

Friedlaender, A.S., Bowers, M.T., Cade, D., Hazen, E.L., Stimpert, A.K., Allen, A.N., Calambokidis, J., Fahlbusch, J., Segre, P., Visser, F., Southall, B.L., Goldbogen, J.A., & Crocker, D. (2019). The advantages of diving deep: Fin whales quadruple their energy intake when targeting deep krill patches. *Funct. Ecol*. 34(2): 497–506. [Available at: *https://doi.org/10.1111/1365-2435.13471*]

Goldbogen J.A., Shadwick R.E., Lillie M.A., Piscitelli M.A., Potvin J., Pyenson N.D., & Vogl A.W. (2015). Using morphology to infer physiology: case studies on rorqual whales (Balaenopteridae). *Can. J. Zool*. 93(9): 687–700. [Available at: *https://doi.org/10.1139/cjz-2014-031*1]

Grant, S.M., Hill, S.L., Trathan, P.N., & Murphy, E.J. (2013). Ecosystem services of the Southern Ocean: trade-offs in decision-making. *Antarct. Sci*. 25(5) : 603–617. [Available at: *https://doi.org/10.1017/S0954102013000308*]

Guilpin, M., Lesage, V., McQuinn, I., Brosset, P., Doniol-Valcroze, T., Jeanniard-du-Dot, T., & Winkler, G. (2020). Repeated Vessel Interactions and Climate- or Fishery-Driven Changes in Prey Density Limit Energy Acquisition by Foraging Blue Whales. *Front. Mar. Sci.* 7. [Available at: *https://doi.org/10.3389/fmars.2020.00626*]

Herr, H., Viquerat, S., Siegel, V., Kock, K.H., Dorschel, B., Huneke, W.G.C., Bracher, A., Schröder, M., & Gutt, J. (2016). Horizontal Niche Partitioning of Humpback and Fin Whales Around the West Antarctic Peninsula: Evidence from a Concurrent Whale and Krill Survey. *Polar Biol*. 39: 799–818. [Available at: *https://doi.org/10.1007/s00300-016-1927-9*]

Herr, H., Viquerat, S., Devas, F., Lees, A., Wells, L., Gregory, B., Giffords, T., Beecham, D., & Meyer, B. (2022a). Return of large fin whale feeding aggregations to historical whaling grounds in the Southern Ocean. *Sci. Rep*. 12: 9458. [Available at: *https://doi.org/10.1038/s41598-022-13798-7*]

Herr, H., Hickmott, L., Viquerat, S., Panigada, S. (2022b). First evidence for fin whale migration into the Pacific from Antarctic feeding grounds at Elephant Island. *R. Soc. Open Sci*. 9: 220721. [Available at: *https://doi.org/10.1098/rsos.220721*]

Herr, H., Groenewoud, Z., Gunning, H., Hickmott, L., Kennedy, A., Kirchner, T., Panasiuk, A., Panigada, S., Viquerat, S., & Vortkamp, M. (2023). Comprehensive assessment of a fin whale high density area along the western Antarctic Peninsula, Cruise No. MSM115, 25.02.2023–30.03.2023, Punta Arenas (Chile) – Montevideo (Uruguay) (MSM115). MARIA S. MERIAN-Reports. [Available at: *https://doi.org/10.48433/cr_msm115*]

Herr, H., Viquerat, S., Vortkamp, M., Panasiuk, A. (in press). Canyon-effects structure fin whale feeding aggregations at Southern Ocean feeding grounds. *Ecosphere*.

Hinke, J.T., Cossio, A.M., Goebel, M.E., Reiss, C.S., Trivelpiece, W.Z., & Watters, G.M. (2017). Identifying Risk: Concurrent Overlap of the Antarctic Krill Fishery with Krill-Dependent Predators in the Scotia Sea. *PLoS ONE* 12(1): e0170132. [Available at: *https://doi.org/10.1371/journal.pone.0170132*]

Hofmann, E.E., & Murphy, E.J. (2004). Advection, Krill, and Antarctic Marine Ecosystems. *Antarct. Sci*. 16(4): 487–499. [Available at: *https://doi.org/10.1017/s0954102004002275*]

International Association of Antarctica Tour Operators (2019). *Geofenced whale areas and speed restrictions: Field operations manual*. [Available at: *https://iaato.org/system/files?file=2025-01/ATCM46_ip106_e_IAATO-Field-Operations-Manual-FOM.pdf*]

International Association of Antarctica Tour Operators (2025). *IAATO members mandate acoustic mitigation measures to protect whales in Antarctic waters*. [Available at: *https://iaato.org/iaato-members-mandate-acoustic-mitigation-measures-protect-whales-antarctic-waters*]

Intergovernmental Panel on Climate Change (IPCC) (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Joiris, C.R. (1991). Spring distribution and ecological role of seabirds and marine mammals in the Weddell Sea, Antarctica. *Polar Biol.* 11: 415–424. [Available at: *https://doi.org/10.1007/BF00233076*]

Joiris, C.R., & Dochy, O. (2013). A major autumn feeding ground for fin whales, southern fulmars and grey-headed albatrosses around the South Shetland Islands, Antarctica. *Polar Biol*. 36: 1649–1658. [Available at: *https://doi.org/10.1007/s00300-013-1383-8*]

Jonsen, I.D., Patterson, T.A., Costa, D.P., Doherty, P.D., Godley, B.J., Grecian, W.J., & McMahon, C.R. (2020). A continuous-time state-space model for rapid quality-control of Argos locations from animal-borne tags. *Mov. Ecol*. 8: 31. [Available at: *https://doi.org/10.1186/s40462-020-00217-7*]

Jonsen, I.D., Grecian, W.J., Phillips, L., Carroll, G., McMahon, C., Harcourt, R.G., Hindell, M.A., & Patterson, T.A. (2023). aniMotum, an R package for animal movement data: Rapid quality control, behavioural estimation and simulation. *Methods Ecol. Evol*. 14: 806–816. [Available at: *https://doi.org/10.1111/2041-210X.14060*]

Kemp, S., Bennett, A.G. (1932). On the distribution and movements of whales on the South Georgia and South Shetland whaling grounds. *Discovery Rep*. 6: 165–190.
Laist, D.W., Knowlton, A.R., Mead, J.G., Collet, A.S., & Podesta, M. (2001). Collisions between ships and whales. *Mar. Mammal Sci*. 17(1): 35–75.
Lee, J.F., Friedlaender, A.S., Oliver, M.J., & DeLiberty, T.L. (2017). Behavior of satellite-tracked Antarctic minke whales (*Balaenoptera bonaerensis*) in relation to environmental factors around the western Antarctic Peninsula. *Anim. Biotelemetry* 5: 23. [Available at: *https://doi.org/10.1186/s40317-017-0138-7*]
Loeb, V., Siegel, V., Holm-Hansen, O., Hewitt, R., Fraser, W., Trivelpiece, W., & Trivelpiece, S. (1997). Effects of Sea-ice Extent and Krill or SalpDominance on the Antarctic Food Web. *Nature* 387: 897–900.
Loeb, V.J., Hofmann, E.E., Klinck, J.M., Holm-Hansen, O., & White, W.B. (2009). ENSO and variability of the Antarctic Peninsula pelagic marine ecosystem. *Antarct. Sci.* 21: 135–148.
Mackintosh, N.A. (1966). The distribution of southern blue and fin whales. In: K.S. Norris (ed.) *Whales, Dolphins and Porpoises* (pp.125–144). Berkeley, CA: University of California Press.
McClintock, B.T., & Michelot, T. (2018). momentuHMM: R package for generalized hidden Markov models of animal movement. *Methods Ecol. Evol*. 9: 1518–1530. [Available at: *https://doi.org/10.1111/2041-210X.12995*]
Nicol, S., Constable, A.J., & Pauly, T. (2000). Estimates of Circumpolar Abundance of Antarctic Krill Based on Recent Acoustic Density Measurements. *CCAMLR Science* 7: 87–99.
Nicol, S., Worby, A., Leaper, R. (2008). Changes in the Antarctic sea ice ecosystem: potential effects on krill and baleen whales. *Mar. Freshw. Res.* 59: 361–382. [Available at: *https://doi.org/10.1071/MF07161*]
Nisi, A.C., Welch, H., Brodie, S., Leiphardt, C., Rhodes, R., Hazen, E.L., Redfern, J.V., Branch, T.A., Barreto, A.S., Calambokidis, J., Clavelle, T., Dares, L., De Vos, A., Gero, S., Jackson, J.A., Kenney, R.D., Kroodsma, D., Leaper, R., McCauley, D.J., Moore, S.E., Ovsyanikova, E., Panigada, S., Robinson, C.V., White, T., Wilson, J., & Abrahms, B. (2024). Ship Collision Risk Threatens Whales across the World's Oceans. *Science* 386(6724): 870–875. [Available at: *https://doi.org/10.1126/science.adp195*0]
Nowacek D.P., Friedlaender, A.S., Halpin, P.N., Hazen, E.L., Johnston, D.W., & Read, A.J. (2011) Super-Aggregations of Krill and Humpback Whales in Wilhelmina Bay, Antarctic Peninsula. *PLoS ONE* 6(4): e19173. [Available at: *https://doi.org/10.1371/journal.pone.0019173*]
Oliva, M., Navarro, F., Hrbáček, F., Hernández, A., Nývlt, D., Pereira, P., Ruiz-Fernández, J., & Trigo, R. (2017). Recent Regional Climate Cooling on the Antarctic Peninsula and Associated Impacts on the Cryosphere. *Sci. Total Environ.* 580: 210–223. [Available at: *https://doi.org/10.1016/j.scitotenv.2016.12.030*]
Orgeira, J.L., Alderete, M.C., Jiménez, Y.G., & González, J.C. (2015). Long-Term Study of At-Sea Distribution of Seabirds and Marine Mammals in the Scotia Sea, Antartica. *Advances Polar Sci*. 26: 158–167.
Pallin, L.J., Kellar, N.M., Steel, D., Botero-Acosta, N., Baker, C.S., Conroy, J.A., Costa, D.P., Johnson, C.M., Johnston, D.W., Nichols, R.C., Nowacek, D.P., Read, A.J., Savenko, O., Schofield, O.M., Stammerjohn, S.E., Steinberg, D.K., Friedlaender, A.S. (2023). A Surplus No More? Variation in Krill Availability Impacts Reproductive Rates of Antarctic Baleen Whales. *Glob. Change Bio.* 29(8): 2108–2121. [Available at: *https://doi.org/10.1111/gcb.16559*]
Panigada, S., Pesante, G., Zanardelli, M., Capoulade, F., Gannier, A., Weinrich, M.T. (2006). Mediterranean fin whales at risk from fatal ship strikes. *Mar. Pollut. Bull*. 52: 1287–1298. [Available at: *https://doi.org/10.1016/j.marpolbul.2006.03.014*]
Panigada, S., Donovan, G.P., Druon, J-N., Lauriano, G., Pierantonio, N., Pirotta, E., Zanardelli, M., Zerbini, A.N., & Notarbartolo di Sciara, G.N. (2017). Satellite tagging of Mediterranean fin whales: working towards the identification of critical habitats and the focussing of mitigation measures. *Sci. Rep*. 7: 3365. [Available at: *https://doi.org/10.1038/s41598-017-03560-9*]
Panigada, V., Bodey, T.W., Friedlaender, A., Druon, J-N., Huckstädt, L.A., Pierantonio, N., Degollada, E., Tort, B., & Panigada, S. (2024). Targeting fin whale conservation in the North-Western Mediterranean Sea: insights on movements and behaviour from biologging and habitat modelling. *R. Soc. Open Sci*. 11: 231783. [Available at: *https://doi.org/10.1098/rsos.231783*]
Pietzsch, B.W., Schmidt, A., Groeneveld, J. (2023). The impact of salps (*Salpa thompsoni*) on the Antarctic krill population (*Euphausia superba*): an individual-based modelling study. *Ecol Process* 12: 50. [Available at: *https://doi.org/10.1186/s13717-023-00462-9*]
R Core Team (2025). R: A language and environment for statistical computing.
Reisinger, R.R., Trathan, P.N., Johnson, C.M., Joyce, T.W., Durban, J.W., Pitman, R.L., & Friedlaender, A.S. (2022). Spatiotemporal Overlap of Baleen Whales and Krill Fisheries in the Western Antarctic Peninsula Region. *Front. Mar. Sci*. 9. [Available at: *https://doi.org/10.3389/fmars.2022.914726*]
Rocha, J., Clapham, P., Ivashchenko, Y. (2015). Emptying the Oceans: A Summary of Industrial Whaling Catches in the 20th Century. *Mar. Fish. Rev.* 76: 37–48.
Ryan, C., Santangelo, M., Stephenson, B., Branch, T.A., Wilson, E.A., & Savoca, M.S. (2023). Commercial krill fishing within a foraging supergroup of fin whales in the Southern Ocean. *Ecology* 104(4): e4002. [Available at: *https://doi.org/10.1002/ecy.4002*]
Rychwalski, A.N., & Herr, H. (2024). Lateralised lunge feeding behaviour in Southern Hemisphere fin whales at Antarctic feeding grounds. *J. Cetacean Res. Manage.* 25: 23–29. [Available at: *https://doi.org/10.47536/jcrm.v25i1.947*]
Santora, J.A., Reiss, C.S., Loeb, V.J., & Veit, R.R. (2010). Spatial association between hotspots of baleen whales and demographic patterns of Antarctic krill (*Euphausia superba*) suggests size-dependent predation. *Mar. Ecol. Prog. Ser.* 405: 255–269. [Available at: *https://doi.org/10.3354/meps08513*]
Santora, J.A., Schroeder, I.D., & Loeb, V.J. (2014). Spatial assessment of fin whale hotspots and their association with krill within an important Antarctic feeding and fishing ground. *Mar. Biol*. 161: 2293–2305. [Available at: *https://doi.org/10.1007/s00227-014-2506-7*]
Savoca, M.S., Czapanskiy, M.F., Kahane-Rapport, S.R., Gough, W.T., Fahlbusch, J.A., Bierlich, K.C., Segre, P.S., Di Clemente, J., Penry, G.S., Wiley, D.N., Calambokidis, J., Nowacek, D.P., Johnston, D.W., Pyenson, N.D., Friedlaender, A.S., Hazen, E.L., & Goldbogen, J.A. (2021). Baleen Whale Prey Consumption Based on High-Resolution Foraging Measurements. *Nature* 599 (7883): 85–90. [Available at: *https://doi.org/10.1038/s41586-021-03991-5*]

Siegel, V., Bergström, B., Mühlenhardt-Siegel, U., & Thomasson, M. (2002). Demography of krill in the Elephant Island area during summer 2001 and its significance for stock recruitment. *Antarct Sci* 14: 162–170. [Available at: *https://doi.org/10.1017/S095410200200072X*]

Shadwick, R.E., Potvin, J., & Goldbogen, J.A. (2019). Lunge feeding in rorqual whales. *Physiology* 34(6): 409–418. [Available at: *https://doi.org/10.1152/physiol.00010.2019*]

Stammerjohn, S., Massom, R., Rind, D., & Martinson, D. (2012). Regions of Rapid Sea Ice Change: An Inter-Hemispheric Seasonal Comparison. *Geophys. Res. Lett*. 39: L06501. [Available at: *https://doi.org/10.1029/2012GL050874*]

Sylvester, Z.T., & Brooks, C.M. (2020). Protecting Antarctica through Co-production of actionable science: Lessons from the CCAMLR marine protected area process. *Mar. Pol*. 111. [Available at: *https://doi.org/10.1016/j.marpol.2019.103720*]

Tetley, M.J., Braulik, G.T., Lanfredi, C., Minton, G., Panigada, S., Politi, E., Zanardelli, M., Notarbartolo di Sciara, G., & Hoyt, E. (2022). The Important Marine Mammal Area Network: A Tool for Systematic Spatial Planning in Response to the Marine Mammal Habitat Conservation Crisis. *Front. Mar. Sci*. 9: 841789. [Available at: *https://doi.org/10.3389/fmars.2022.841789*]

Trathan, P.N., Savoca, M.S., Friedlaender, A., Baines, M., Burkhardt, E., Cheeseman, T., Dalla Rosa, L., Herr, H., Secchi, E. R., Zerbini, A.N., & Reisinger, R.R. (2024). Integrating the needs of recovering populations of baleen whales into the revised management framework for the commercial fishery for Antarctic krill. *Front. Mar. Sci*. 11. [Available at: *https://doi.org/10.3389/fmars.2024.1458042*]

Tulloch, V.J.D., Plagányi, É.E., Matear, R., Brown, C.J., & Richardson, A.J. (2018). Ecosystem modelling to quantify the impact of historical whaling on Southern Hemisphere baleen whales. *Fish Fish*. 19: 117–137. [Available at: *https://doi.org/10.1111/faf.12241*]

Turner, J., Lu, H., White, I., King, J., Phillips, T., Hosking, J., Bracegirdle, T., Marshall, G., Mulvaney, R., & Deb, P. (2016). Absence of 21st century warming on Antarctic Peninsula consistent with natural variability. *Nature* 535: 411–415. [Available at: *https://doi.org/10.1038/nature18645*]

Van Waerebeek, K., Baker, A.N., Félix, F., Gedamke, J., Iñiguez, M., Sanino, G.P., Secchi, E., Sutaria, D., van Helden, A., & Wang, Y. (2007). Vessel collisions with small cetaceans worldwide and with large whales in the Southern Hemisphere, an initial assessment. *Lat. Am. J. Aquat. Mamm.* 6(1): 43–69. [Available at: *https://doi.org/10.5597/lajam0010*9]

Vaughan, D.G., Marshall, G.J., Connolley, W.M., Parkinson, C., Mulvaney, R., Hodgson, D.A., King, J.C., Pudsey, C.J., & Turner, J. (2003). Recent rapid regional climate warming on the Antarctic Peninsula. *Climatic Change* 60(3): 243–274. [Available at: *https://doi.org/10.1023/A:1026021217991*]

Viquerat, S., & Herr, H. (2017). Mid-summer abundance estimates of fin whales Balaenoptera physalus around the South Orkney Islands and Elephant Island. *Endang. Species Res*. 32: 515–524. [Available at: *https://doi.org/10.3354/esr00832*]

Weinstein, B.G., & Friedlaender, A.S. (2017). Dynamic Foraging of a Top Predator in a Seasonal Polar Marine Environment. *Oecologia* 185(3): 427–435. [Available at: *https://doi.org/10.1007/s00442-017-3949-6*]

Worton, B.J. (1989). Kernel methods for estimating the utilization distribution in home-range studies. *Ecology* 70: 164–168. [Available at: *https://doi.org/10.2307/1938423*]

Worton, B.J. (1995). A convex hull-based estimator of home-range size. *Biometrics* 51: 1206. [Available at: *https://doi.org/10.2307/2533254*]