Received: 14 August 2022 | Accepted: 2 May 2023

DOI: 10.1111/mms.13033

NOTE

Marine Mammal Science

The most southerly occurrence of humpback whales in the western Weddell Sea

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Globally, warming oceans are causing marine species to shift poleward (Melbourne-Thomas et al., 2022). The Antarctic Peninsula is a global hotspot for human-induced warming (Jones et al., 2019; Turner et al., 2020), evidenced by lessening sea ice conditions (Kumar et al., 2021), warming oceans, and the collapse of ice shelves (Etourneau et al., 2019). Warming is influencing the spatiotemporal occurrence of prey species such as Antarctic krill (*Euphausia superba*; Kawaguchi & Nicol, 2020), which is, in turn, influencing the foraging behaviors and demographic success of some Southern Ocean predators, e.g., crabeater seals (*Erignathus barbatus*; Hückstädt et al., 2020). For highly mobile marine predators, such as baleen whales, which are free from range restrictions faced by central place foragers (Orians, 1979), foraging is thought to be directly dictated by finding and accessing profitable prey patches, likely driven by the underlying environmental conditions (e.g., sea ice and chlorophyll concentrations; Bedriñana-Romano et al., 2022; Meynecke et al., 2021; Reisinger et al., 2021). There is some recent evidence that humpback whale (*Megaptera novaeangliae*) foraging activities have shifted southward in response to record lows in sea-ice extent and presumably spatial shifts in krill populations (Atkinson et al., 2019; Bedriñana-Romano et al., 2022; Mori et al., 2019).

Southern Ocean foraging humpback whales occur in high densities in coastal regions north of and/or in proximity (10s of km) of the ice edge (15% sea ice concentration), as well as select regions adjacent to sub-Antarctic islands (e.g., South Georgia; Baines et al., 2021; Bamford et al., 2022; Bedriñana-Romano et al., 2022; Herr et al., 2016;

Reisinger et al., 2021; Riekkola et al., 2018; Thiele et al., 2004). The exception is in the Ross Sea (south of ≈70°S) where humpback whales are rarely sighted even in ice-free areas, despite supporting high densities of Antarctic minke whales (*Balaenoptera bonaerensis*; Ainley et al., 2017, 2020; Branch, 2011; Constantine et al., 2014; Murase et al., 2013; Riekkola et al., 2018). Given the similarity between the Ross and the Weddell Seas (Drucker et al., 2011), it could be assumed that humpback whales would also be excluded from the western Weddell Sea (WS) due to the cooler water temperatures and higher sea ice concentrations encountered there (Branch, 2011; Herr et al., 2019). Many records exist of humpback whale sightings in the northwestern WS dating back to the 1970s (Branch, 2011; Herr et al., 2016). However, deep penetration of humpback whales into the western WS, south of James Ross Island (64.32°S, 57.88°W) has to our knowledge never been reported.

Here, we detail two new record-breaking sightings of humpback whales in the western WS. Both sightings were made from ice-breaker class tourist vessels, which were able to access southerly regions of the western WS during a summer with a new record low in sea ice extent (February 23, 2022; Raphael & Handcock, 2022) and the now regular breakup of the Larsen A & B ice shelves (Wang et al., 2022). During survey efforts, a single trained observer surveyed one side of the ship's track from 0° to 90° (from bow to starboard beam), while a second trained observer/data logger recorded sighting information, effort type, and environmental conditions, following a distance sampling methodology (Buckland et al., 2015). Alternative use of a two-person team was considered but observing a single 90° quadrant was deemed optimal (Henderson et al., 2023). Sightings were recorded by trained observers from an observation station on the bridge. Opportunistic sightings made by observers from the bridge were also documented. Opportunistic sightings are those recorded outside on the observational quadrat (one side of the ship's track from 0° to 90°), and/or outside of "on-effort" survey periods (e.g., when sighting conditions were poor, defined as, "when observers were unable to readily detect a minke whale at 1.5 nmi [2.8 km]"). The location of the sightings and survey effort data were plotted on a satellite image corresponding to the day the sightings were made to illustrate where data was collected and under what sea ice conditions (Figure 1). Satellite images were accessed at https://earthdata.nasa.gov/labs/worldview/. All data analysis and plotting were conducted in the scientific programming language R (R Core Team, 2021), using packages "tidyverse" (Wickham et al., 2019), "sf" (Pebesma, 2018), "ggplot2" (Wickham, 2011), "terrainr" (Mahoney et al., 2022), and "raadtools" (Sumner, 2023).

The novel humpback whale sightings were made on December 8 at 1230 UTC (ship's position: 64.83°S, 59.15°W) and on January 26 at 0944 UTC (ship's position: 65.31°S, 58.98°W) 30 and 90 nmi (56 and 167 km) further south than any previously reported humpback whale sighting in the western WS (Figure 1). The December 8 (2021) sighting was made by a tour participant, while observers were not conducting survey effort (with photographic evidence; Figure S1), and the January 26, 2022, sighting was made by trained observers from the observation station before commencing active effort, at an estimated distance of approximately 1.1 nmi (2 km) from the observer to the whale. Observers recorded wind speed registering 1 on the Beaufort scale, "very good" observation conditions, and small to medium ice floes in the observation field. Slow-speed maneuvering around and ramming of sea ice prevented the commencement of active effort. Figure 1 details the sea ice conditions on the day each of these sightings was made, which also document the now regular breakup of the former Larsen A & B ice shelves (compare Figure 1a and b).

Humpback whales respond to dynamic environmental features (Thiele et al., 2004) which likely drive preferred prey aggregations (Herr et al., 2016; Santora et al., 2010) and thus will likely be able to continue to respond to new extremes in sea ice conditions like the more regular opening of the western WS (Jena et al., 2022). Modeling of humpback whale habitat in the 2000s (Williams et al., 2006) and 1970–2010 (Reisinger et al., 2021) suggested very low densities of whales in the western WS, while habitat suitability models from a more recent humpback whale data sets (2005–2011) indicate favorable habitat conditions for humpback whales may exist in open waters in the western WS, south of those recorded here (Bombosch et al., 2014). In the Northern Hemisphere, humpback whales are responding to dramatic changes in Arctic sea ice conditions by accessing new and profitable foraging regions (Brower et al., 2018; Moore, 2016). While for other species (such as the bowhead whale (*Balaena mysticetus*) that

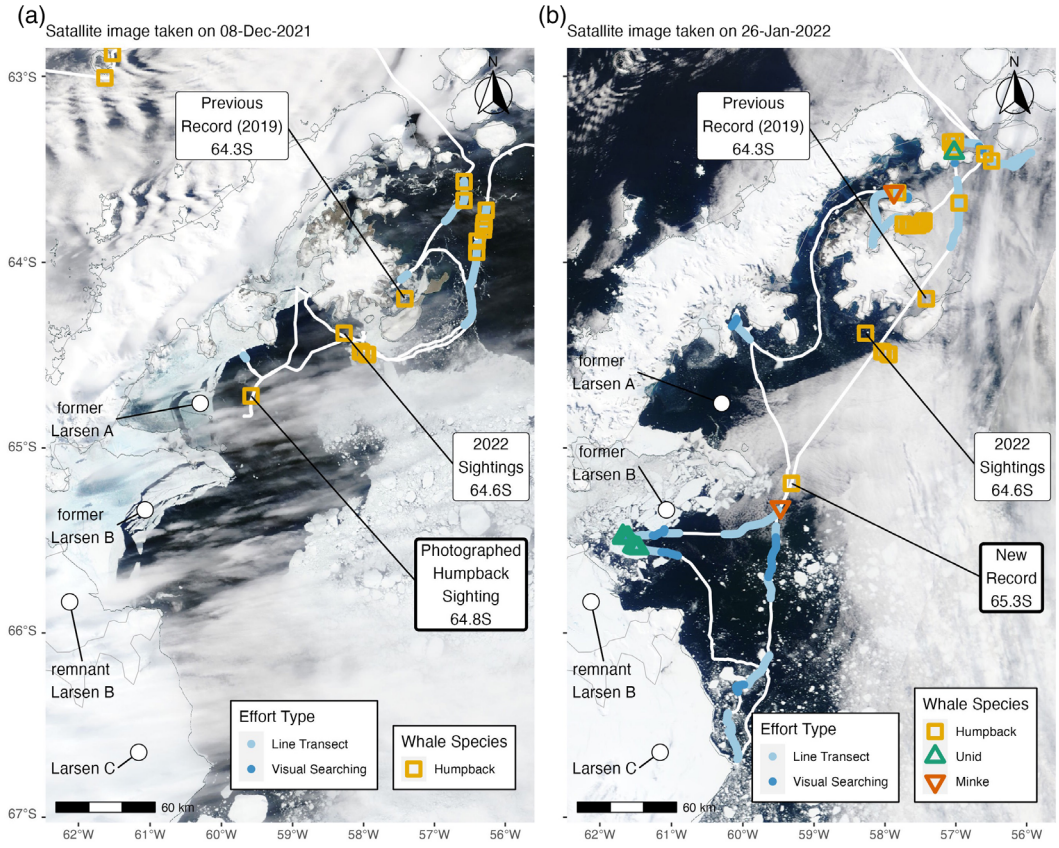

FIGURE 1 Plots of the most southerly reported humpback whale sightings in the western WS region. The photographed sighting (a) and the new most southerly reported humpback whale sighting to date (b). The background image was taken from a NASA satellite (accessed at https://earthdata.nasa.gov/labs/worldview/), taken on the same day as each sighting was made. The white line is the route taken by the tourist ship from which the observations were made, and the thicker pale blue lines depicted active survey effort. Whale sightings by color and shape.

depend on cool, ice-filled waters), the retraction of sea ice is potentially restricting profitable foraging regions (Chambault et al., 2018; Kovacs et al., 2020).

Southern Hemisphere humpback whales continue to recover at a relatively high rates (Bortolotto et al., 2021; Zerbini et al., 2019) and now dominate sightings from scientific surveys of the southwest Atlantic (Baines et al., 2021). Successful foraging is likely a key driver of the recovery of Southern Hemisphere humpback whales, which may be aided by the poleward expansion of their foraging grounds as previously exclusive habitats (regions of the ocean that remain ice covered) become accessible. In contrast, the possible reduction in profitable sea ice habitat for Antarctic minke whales has been linked to a probable population decline in the Southern Ocean (Branch, 2006; Filun et al., 2020; Friedlaender et al., 2014).

The western WS receives little survey effort from scientific research vessels, and consequently, the lack of recorded humpback whale sightings may be a product of a lack of survey effort rather than the species not being present. The Alfred Wegener Institute and other Polarstern-based voyages have completed helicopter- and ship-based sighting surveys in the western WS; however, these surveys only reported detections of Antarctic minke whales in this region (Herr et al., 2014, 2016, 2019; Kock et al., 2010; Scheidat et al., 2011). Few others have surveyed the western WS for the occurrence of cetaceans, noting the region's absence from broad-scale IWC-led

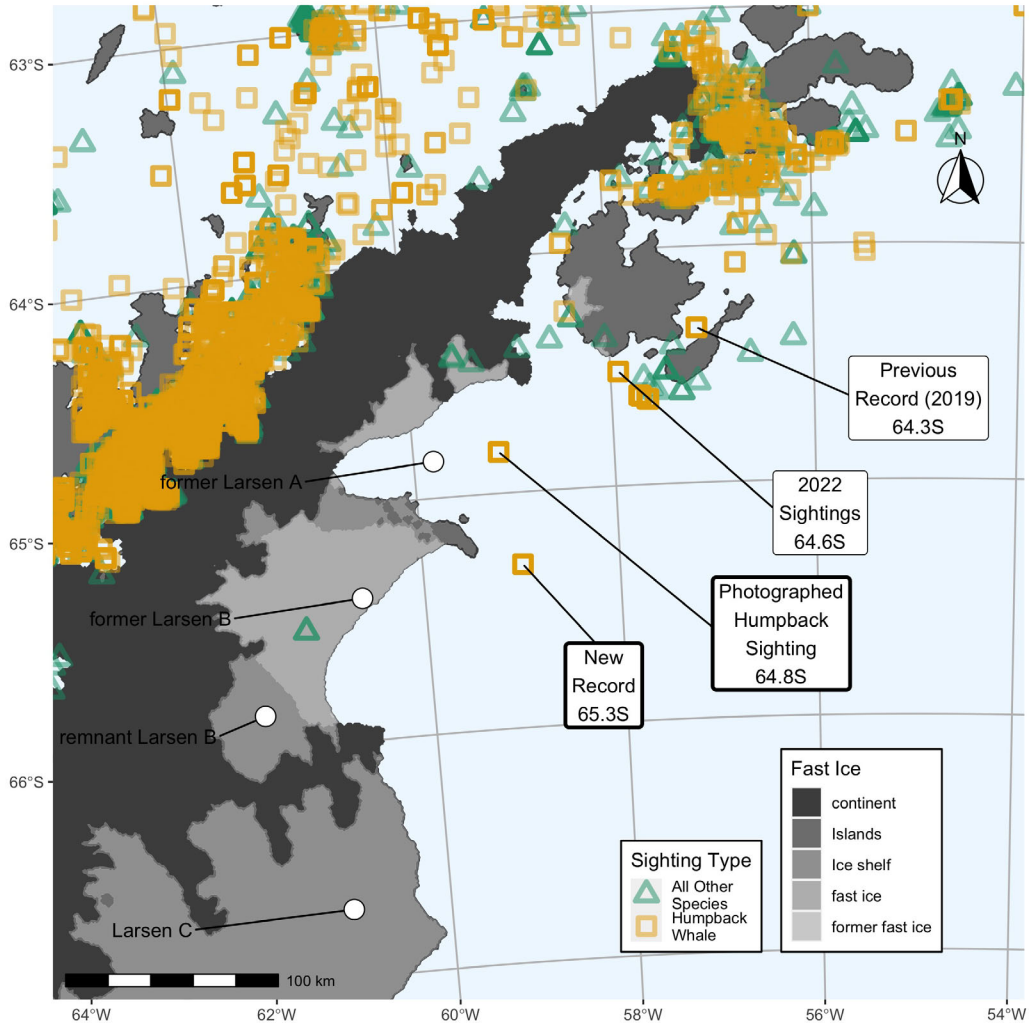

FIGURE 2 Sightings reported to Happywhale in the Antarctic Peninsula region. This plot characterizes the extent of sightings reported by engaged citizen scientists in the Antarctic Peninsula region. Humpback sightings dominate reported sightings while all other species (triangles) illustrate where some level of citizen science "survey effort" has occurred. 2018 fast ice conditions are plotted. Data from 53°–65°S, 63–67°W.

Southern Ocean surveys of the 1970s, 1980s, 1990s, and early 2000s (Branch, 2011; Branch & Butterworth, 2001). Whaling records suggest very few humpback whales were caught in the western WS (Reisinger et al., 2021), potentially due to prohibitive sea-ice conditions and/or the vessel's ice-class (Ackley et al., 2003). However, the western WS is becoming a popular tourist destination, and citizen scientists onboard Antarctic tourist expedition vessels are increasingly reporting whale sightings in this region (Figure 2 and S2).

The reporting of animal sightings of various species via online platforms by citizen scientists, guides, and scientists is a useful tool for tracking range shifts in marine species (Earp & Liconti, 2020). The western Antarctic Peninsula is a hotspot of sightings reported via the research collaboration and citizen science web platform, Happywhale.com (Cheeseman et al., 2021), with the rate of reported sightings (sightings reported/year) is increasing each year to a peak of 3,193 in 2020, including 2,585 humpback whale reports alone (Figure S2). Sighting rates have reduced significantly in this region during the COVID-19 pandemic (heavily impacted seasons, 2020/2021 and 2021/2022) but are

likely to return to pre-pandemic levels in the coming years with tourist traffic returning (International Association of Antarctic Tour Operators, 2021). Most sightings reported to Happywhale were of humpback whales in the Bransfield and Gerlache Strait regions (Figure 2). The most southerly sighting previously reported to Happywhale in the western WS region was from the prepandemic 2019/2020 season, with several additional humpback whale sightings further south in 2022 (Figure 1). Tourists have reported sightings of other species farther south than the previous record for humpback whales, suggesting some level of "observer effort" by citizen scientists aboard tourist vessels in the western WS region.

Whether these two new sightings are an example of a species extending south in response to a changing climate or due to a lack of survey effort masking a previously unknown foraging region for humpback whales is unclear. However, this work does highlight the potential for novel biological findings from tourist vessel-based cetacean surveys and engaged citizen scientists. Tourist platforms, especially when outfitted for structured survey effort, offer great potential for establishing baseline biological data in remote, highly data-limited marine regions (Henderson et al., 2023). Further work in the western WS is needed to uncover the response of key Southern Ocean predators to a changing climate as they continue to recover from past exploitation.

ACKNOWLEDGMENTS

We thank Ponant Expeditions and the crew and staff aboard M/V *Le Commandant Charcot* for their gracious support of this project. We are grateful to cruise participant Pascal Ronde for their opportunistic effort and permission to use the image in Figure S1, and to all citizen scientists contributing data to Happywhale. We acknowledge the use of imagery from the NASA Worldview application (https://worldview.earthdata.nasa.gov/), part of the NASA Earth Observing System Data and Information System (EOSDIS). This research was conducted with the approval of the University of Tasmania Animal Ethics Committee (project: 24745).

AUTHOR CONTRIBUTIONS

Angus F. Henderson: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; software; validation; visualization; writing – original draft. **Ted Cheeseman:** Conceptualization; methodology; project administration; resources; writing – review and editing. **Olive Andrews:** Conceptualization; investigation; methodology; project administration; resources; writing – review and editing. **Nadia S. Curcio:** Conceptualization; data curation; investigation; methodology; project administration; resources; writing – review and editing. **Maria L. Marcías:** Conceptualization; data curation; methodology; project administration; resources; writing – review and editing. **Mary-Anne Lea:** Conceptualization; investigation; methodology; project administration; supervision; writing – review and editing.

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REFERENCES

Ackley, S., Wadhams, P., Comiso, J. C., & Worby, A. P. (2003). Decadal decrease of Antarctic sea ice extent inferred from whaling records revisited on the basis of historical and modern sea ice records. *Polar Research*, *22*(1), 19–25. https://doi.org/10.1111/j.1751-8369.2003.tb00091.x

Ainley, D. G., Joyce, T. W., Saenz, B., Pitman, R. L., Durban, J. W., Ballard, G., Daly, K., & Kim, S. (2020). Foraging patterns of Antarctic minke whales in McMurdo Sound, Ross Sea. *Antarctic Science*, *32*(6), 454–465. https://doi.org/10.1017/S0954102020000310

Ainley, D. G., Lindke, K., Ballard, G., Lyver, P. O., Jennings, S., Toniolo, V., Pennycook, J., Massaro, M., & Santora, J. A. (2017). Spatio-temporal occurrence patterns of cetaceans near Ross Island, Antarctica, 2002–2015: Implications for food web dynamics. *Polar Biology*, *40*(9), 1761–1775. https://doi.org/10.1007/s00300-017-2100-9

Atkinson, A., Hill, S. L., Pakhomov, E. A., Siegel, V., Reiss, C. S., Loeb, V. J., Steinberg, D. K., Schmidt, K., Tarling, G. A., Gerrish, L., & Sailley, S. F. (2019). Krill (*Euphausia superba*) distribution contracts southward during rapid regional warming. *Nature Climate Change*, *9*(2), Article 2. https://doi.org/10.1038/s41558-018-0370-z

Baines, M., Kelly, N., Reichelt, M., Lacey, C., Pinder, S., Fielding, S., Murphy, E., Trathan, P., Biuw, M., Lindstrøm, U., Krafft, B., & Jackson, J. (2021). Population abundance of recovering humpback whales *Megaptera novaeangliae* and other baleen whales in the Scotia Arc, South Atlantic. *Marine Ecology Progress Series*, *676*, 77–94. https://doi.org/10.3354/meps13849

Bamford, C. C. G., Jackson, J. A., Kennedy, A. K., Trathan, P. N., Staniland, I. J., Andriolo, A., Bedriñana-Romano, L., Carroll, E. L., Martin, S., & Zerbini, A. N. (2022). Humpback whale (*Megaptera novaeangliae*) distribution and movements in the vicinity of South Georgia and the South Sandwich Islands Marine Protected Area. *Deep Sea Research Part II: Topical Studies in Oceanography*, *198*, Article 105074. https://doi.org/10.1016/j.dsr2.2022.105074

Bedriñana-Romano, L., Zerbini, A. N., Andriolo, A., Danilewicz, D., & Sucunza, F. (2022). Individual and joint estimation of humpback whale migratory patterns and their environmental drivers in the Southwest Atlantic Ocean. *Scientific Reports*, *12*(1), Article 7487. https://doi.org/10.1038/s41598-022-11536-7

Bombosch, A., Zitterbart, D. P., Van Opzeeland, I., Frickenhaus, S., Burkhardt, E., Wisz, M. S., & Boebel, O. (2014). Predictive habitat modelling of humpback (*Megaptera novaeangliae*) and Antarctic minke (*Balaenoptera bonaerensis*) whales in the Southern Ocean as a planning tool for seismic surveys. *Deep Sea Research Part I: Oceanographic Research Papers*, *91*, 101–114. https://doi.org/10.1016/j.dsr.2014.05.017

Bortolotto, G. A., Thomas, L., Hammond, P., & Zerbini, A. N. (2021). Alternative method for assessment of southwestern Atlantic humpback whale population status. *PLoS ONE*, *16*(11), Article e0259541. https://doi.org/10.1371/journal.pone.0259541

Branch, T. A. (2006). *Abundance estimates for Antarctic minke whales from three completed circumpolar sets of surveys, 1978/79 to 2003/04*. Paper SC/58/IA18 presented to the Scientific Committee of the International Whaling Commission.

Branch, T. A. (2011). Humpback whale abundance south of 60°S from three complete circumpolar sets of surveys. *Journal of Cetacean Research and Management*, *Special Issue 3*, 53–69. https://doi.org/10.47536/jcrm.vi.305

Branch, T. A., & Butterworth, D. S. (2001). Southern Hemisphere minke whales: Standardised abundance estimates from the 1978/79 to 1997/98 IDCR-SOWER surveys. *Journal of Cetacean Research and Management*, *3*, 143–174.

Brower, A. A., Clarke, J. T., & Ferguson, M. C. (2018). Increased sightings of subArctic cetaceans in the eastern Chukchi Sea, 2008–2016: Population recovery, response to climate change, or increased survey effort? *Polar Biology*, *41*(5), 1033–1039. https://doi.org/10.1007/s00300-018-2257-x

Buckland, S. T., Rexstad, E. A., Marques, T. A., & Oedekoven, C. S. (2015). *Distance sampling: Methods and applications*. Springer.

Chambault, P., Albertsen, C. M., Patterson, T. A., Hansen, R. G., Tervo, O., Laidre, K. L., & Heide-Jørgensen, M. P. (2018). Sea surface temperature predicts the movements of an Arctic cetacean: The bowhead whale. *Scientific Reports*, *8*(1), Article 1. https://doi.org/10.1038/s41598-018-27966-1

Cheeseman, T., Southerland, K., Park, J., Olio, M., Flynn, K., Calambokidis, J., Jones, L., Garrigue, C., Frisch Jordán, A., & Howard, A. (2021). Advanced image recognition: A fully automated, high-accuracy photo-identification matching system for humpback whales. *Mammalian Biology*, *102*, 915–929. https://doi.org/10.1007/s42991-021-00180-9

Constantine, R., Steel, D., Allen, J., Anderson, M., Andrews, O., Baker, C. S., Beeman, P., Burns, D., Charrassin, J.-B., & Childerhouse, S. (2014). Remote Antarctic feeding ground important for east Australian humpback whales. *Marine Biology*, *161*(5), 1087–1093. https://doi.org/10.1007/s00227-014-2401-2

Drucker, R., Martin, S., & Kwok, R. (2011). Sea ice production and export from coastal polynyas in the Weddell and Ross Seas. *Geophysical Research Letters*, *38*(17), Article L17502. https://doi.org/10.1029/2011GL048668

Earp, H. S., & Liconti, A. (2020). Science for the future: The use of citizen science in marine research and conservation. In S. Jungblut, V. Liebich, & M. Bode-Dalby (Eds.), *YOUMARES 9—The Oceans: Our Research, Our Future: Proceedings of the 2018 conference for YOUng MArine RESearcher in Oldenburg, Germany* (pp. 1–19). Springer International Publishing. https://doi.org/10.1007/978-3-030-20389-4_1

Etourneau, J., Sgubin, G., Crosta, X., Swingedouw, D., Willmott, V., Barbara, L., Houssais, M.-N., Schouten, S., Damsté, J. S. S., Goosse, H., Escutia, C., Crespin, J., Massé, G., & Kim, J.-H. (2019). Ocean temperature impact on ice shelf extent in the eastern Antarctic Peninsula. *Nature Communications*, *10*(1), Article 1. https://doi.org/10.1038/s41467-018-08195-6

Filun, D., Thomisch, K., Boebel, O., Brey, T., Širović, A., Spiesecke, S., & Van Opzeeland, I. (2020). Frozen verses: Antarctic minke whales (*Balaenoptera bonaerensis*) call predominantly during austral winter. *Royal Society Open Science*, *7*(10), Article 192112. https://doi.org/10.1098/rsos.192112

Friedlaender, A. S., Goldbogen, J. A., Nowacek, D. P., Read, A. J., Johnston, D., & Gales, N. (2014). Feeding rates and under-ice foraging strategies of the smallest lunge filter feeder, the Antarctic minke whale (*Balaenoptera bonaerensis*). *Journal of Experimental Biology*, *217*(16), 2851–2854. https://doi.org/10.1242/jeb.106682

Henderson, A. F., Hindell, M. A., Wotherspoon, S., Biuw, M., Lea, M.-A., Kelly, N., & Lowther, A. D. (2023). Assessing the viability of estimating baleen whale abundance from tourist vessels. *Frontiers in Marine Science*, *10*. https://doi.org/10.3389/fmars.2023.1048869

Herr, H., Kelly, N., Dorschel, B., Huntemann, M., Kock, K.-H., Lehnert, L. S., Siebert, U., Viquerat, S., Williams, R., & Scheidat, M. (2019). Aerial surveys for Antarctic minke whales (*Balaenoptera bonaerensis*) reveal sea ice dependent distribution patterns. *Ecology and Evolution*, *9*(10), 5664–5682. https://doi.org/10.1002/ece3.5149

Herr, H., Kelly, N., Viquerat, S., Kock, K.-H., Williams, R., Scheidat, M., Lehnert, L. S., & Siebert, U. (2014). *Overview of five German helicopter surveys provide insight into spatio-temporal variability of minke whale densities in ice*. Paper SC/65-b/IA16 presented to the Scientific Committee of the International Whaling Commission.

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 Biology*, *39*(5), 799–818. https://doi.org/10.1007/s00300-016-1927-9

Hückstädt, L. A., Piñones, A., Palacios, D. M., McDonald, B. I., Dinniman, M. S., Hofmann, E. E., Burns, J. M., Crocker, D. E., & Costa, D. P. (2020). Projected shifts in the foraging habitat of crabeater seals along the Antarctic Peninsula. *Nature Climate Change*, *10*(5), 472–477. https://doi.org/10.1038/s41558-020-0745-9

International Association of Antarctic Tour Operators. (2021, June). *Overview of Antarctic tourism: A historical review of growth, the 2020–21 season, and preliminary estimates for 2021–22* (Information paper 110). XLIII[e] Réunion Consultative du Traité sur l'Antarctique, Paris, France. https://iaato.org/wp-content/uploads/2021/07/ATCM43_ip110_e.docx

Jena, B., Bajish, C. C., Turner, J., Ravichandran, M., Anilkumar, N., & Kshitija, S. (2022). Record low sea ice extent in the Weddell Sea, Antarctica in April/May 2019 driven by intense and explosive polar cyclones. *npj Climate and Atmospheric Science*, *5*(1), Article 1. https://doi.org/10.1038/s41612-022-00243-9

Jones, M. E., Bromwich, D. H., Nicolas, J. P., Carrasco, J., Plavcová, E., Zou, X., & Wang, S.-H. (2019). Sixty years of widespread warming in the southern middle and high latitudes (1957–2016). *Journal of Climate*, *32*(20), 6875–6898. https://doi.org/10.1175/JCLI-D-18-0565.1

Kawaguchi, S., & Nicol, S. (2020). Krill fishery. In G. Lovrich & M. Thiel (Eds.), *Fisheries and aquaculture* (pp. 137–158). Oxford University Press.

Kock, K.-H., Herr, H., Scheidat, M., Bräger, S., Lehnert, K., Lehnert, L. S., Verdaat, H., Williams, R., Siebert, U., & Boebel, O. (2010). *Sighting surveys from a ship and a helicopter in the Weddell Sea in 2006/07 and 2008/09*. Paper SC/62/015 presented to the Scientific Committee of the International Whaling Commission.

Kovacs, K. M., Lydersen, C., Vacquiè-Garcia, J., Shpak, O., Glazov, D., & Heide-Jørgensen, M. P. (2020). The endangered Spitsbergen bowhead whales' secrets revealed after hundreds of years in hiding. *Biology Letters*, *16*(6), Article 20200148. https://doi.org/10.1098/rsbl.2020.0148

Kumar, A., Yadav, J., & Mohan, R. (2021). Seasonal sea-ice variability and its trend in the Weddell Sea sector of West Antarctica. *Environmental Research Letters*, *16*(2), Article 024046. https://doi.org/10.1088/1748-9326/abdc88

Mahoney, M. J., Beier, C. M., & Ackerman, A. (2022). terrainr: An R package for creating immersive virtual environments. *Journal of Open Source Software*, *7*(69), Article 4060. https://doi.org/10.21105/joss.04060

Melbourne-Thomas, J., Audzijonyte, A., Brasier, M. J., Cresswell, K. A., Fogarty, H. E., Haward, M., Hobday, A. J., Hunt, H. L., Ling, S. D., McCormack, P. C., Mustonen, T., Mustonen, K., Nye, J. A., Oellermann, M., Trebilco, R., van Putten, I., Villanueva, C., Watson, R. A., & Pecl, G. T. (2022). Poleward bound: Adapting to climate-driven species redistribution. *Reviews in Fish Biology and Fisheries*, *32*(1), 231–251. https://doi.org/10.1007/s11160-021-09641-3

Meynecke, J.-O., de Bie, J., Barraqueta, J.-L. M., Seyboth, E., Dey, S. P., Lee, S. B., Samanta, S., Vichi, M., Findlay, K., Roychoudhury, A., & Mackey, B. (2021). The role of environmental drivers in humpback whale distribution, movement and behavior: A review. *Frontiers in Marine Science*, *8*, Article 720774. https://doi.org/10.3389/fmars.2021.720774

Moore, S. E. (2016). Is it 'boom times' for baleen whales in the Pacific Arctic region? *Biology Letters*, *12*(9), Article 20160251. https://doi.org/10.1098/rsbl.2016.0251

Mori, M., Corney, S. P., Melbourne-Thomas, J., Klocker, A., Kawaguchi, S., Constable, A., & Sumner, M. (2019). Modelling dispersal of juvenile krill released from the Antarctic ice edge: Ecosystem implications of ocean movement. *Journal of Marine Systems*, *189*, 50–61. https://doi.org/10.1016/j.jmarsys.2018.09.005

Murase, H., Kitakado, T., Hakamada, T., Matsuoka, K., Nishiwaki, S., & Naganobu, M. (2013). Spatial distribution of Antarctic minke whales (*Balaenoptera bonaerensis*) in relation to spatial distributions of krill in the Ross Sea, Antarctica. *Fisheries Oceanography*, *22*(3), 154–173. https://doi.org/10.1111/fog.12011

Orians, G. H. (1979). On the theory of central place foraging. *Analysis of Ecological Systems*, 157–177.

Pebesma, E. J. (2018). Simple features for R: standardized support for spatial vector data. *R Journal*, *10*(1), 439–446. https://doi.org/10.32614/RJ-2018-009

Raphael, M. N., & Handcock, M. S. (2022). A new record minimum for Antarctic sea ice. *Nature Reviews Earth & Environment*, *3*(4), Article 4. https://doi.org/10.1038/s43017-022-00281-0

R Core Team. (2021). *R: A language and environment for statistical computing* [Computer software]. R Foundation for Statistical Computing.

Reisinger, R. R., Friedlaender, A. S., Zerbini, A. N., Palacios, D. M., Andrews-Goff, V., Dalla Rosa, L., Double, M., Findlay, K., Garrigue, C., & How, J. (2021). Combining regional habitat selection models for large-scale prediction: Circumpolar habitat selection of Southern Ocean humpback whales. *Remote Sensing*, *13*(11), Article 2074. https://doi.org/10.3390/rs13112074

Riekkola, L., Zerbini, A. N., Andrews, O., Andrews-Goff, V., Baker, C. S., Chandler, D., Childerhouse, S., Clapham, P., Dodémont, R., Donnelly, D., Friedlaender, A., Gallego, R., Garrigue, C., Ivashchenko, Y., Jarman, S., Lindsay, R., Pallin, L., Robbins, J., Steel, D., … Constantine, R. (2018). Application of a multi-disciplinary approach to reveal population structure and Southern Ocean feeding grounds of humpback whales. *Ecological Indicators*, *89*, 455–465. https://doi.org/10.1016/j.ecolind.2018.02.030

Santora, J., Reiss, C., Loeb, V., & Veit, R. (2010). Spatial association between hotspots of baleen whales and demographic patterns of Antarctic krill *Euphausia superba* suggests size-dependent predation. *Marine Ecology Progress Series*, *405*, 255–269. https://doi.org/10.3354/meps08513

Scheidat, M., Friedlaender, A., Kock, K.-H., Lehnert, L., Boebel, O., Roberts, J., & Williams, R. (2011). Cetacean surveys in the Southern Ocean using icebreaker-supported helicopters. *Polar Biology*, *34*(10), 1513–1522. https://doi.org/10.1007/s00300-011-1010-5

Sumner, M. D. (2023). *raadtools: Tools for synoptic environmental spatial data* (R package version 0.6.0.9029) [Computer software]. https://github.com/AustralianAntarcticDivision/raadtools

Thiele, D., Chester, E. T., Moore, S. E., Širovic, A., Hildebrand, J. A., & Friedlaender, A. S. (2004). Seasonal variability in whale encounters in the Western Antarctic Peninsula. *Deep Sea Research Part II: Topical Studies in Oceanography*, *51*(17–19), 2311–2325. https://doi.org/10.1016/j.dsr2.2004.07.007

Turner, J., Marshall, G. J., Clem, K., Colwell, S., Phillips, T., & Lu, H. (2020). Antarctic temperature variability and change from station data. *International Journal of Climatology*, *40*(6), 2986–3007. https://doi.org/10.1002/joc.6378

Wang, S., Liu, H., Jezek, K., Alley, R. B., Wang, L., Alexander, P., & Huang, Y. (2022). Controls on Larsen C Ice Shelf retreat from a 60-year satellite data record. *Journal of Geophysical Research: Earth Surface*, *127*(3), Article e2021JF006346. https://doi.org/10.1029/2021JF006346

Wickham, H. (2011). Ggplot2. *Wiley Interdisciplinary Reviews: Computational Statistics*, *3*(2), 180–185. https://doi.org/10.1002/wics.147

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L. D., François, R., Grolemund, G., Hayes, A., Henry, L., & Hester, J., Kuhn, M., Pedersen, T. L., Miller, E., Bache, S. M., Müller, K., Ooms, J., Robinson, D., Seidel, D. P., Spinu, V., … Yutani, H. (2019). Welcome to the Tidyverse. *Journal of Open Source Software*, *4*(43), Article 1686. https://doi.org/10.21105/joss.01686

Williams, R., Hedley, S. L., & Hammond, P. S. (2006). Modeling distribution and abundance of Antarctic baleen whales using ships of opportunity. *Ecology and Society*, *11*(1), Article 1. https://doi.org/10.5751/ES-01534-110101

Zerbini, A. N., Adams, G., Best, J., Clapham, P. J., Jackson, J. A., & Punt, A. E. (2019). Assessing the recovery of an Antarctic predator from historical exploitation. *Royal Society Open Science*, *6*(10), Article 190368. https://doi.org/10.1098/rsos.190368

SUPPORTING INFORMATION

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

How to cite this article: Henderson, A. F., Cheeseman, T., Curcio, N., Marcías, M. L., Andrews, O., & Lea, M.-A. (2023). The most southerly occurrence of humpback whales in the western Weddell Sea. *Marine Mammal Science*, 1–8. https://doi.org/10.1111/mms.13033