New / updated information of krill and predator for harmonising the D1MPA and the fishery in Domain 1

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Tracking data for each species was given a seasonality attributing it to a 3-month period: October, November and December (OND), January, February and March (JFM), April May and June (AMJ), July August and September (JAS); from that data, 10km x 10km spatial grids were generated to calculate occurrence through the different periods. Each of those grids for each of the species were considered a layer. For instance, Antarctic Fur Seal Distribution has 4 layers, one for each 3-month period. Non-dynamic layers, that is, those not based on tracking data, were considered as a single layer, independently of the temporality of it. For instance, chinstrap penguin colonies are active prominently from October to March, therefore, they would represent OND and JFM periods. However, it counts as one layer as its location did not change between both periods.

Krill

Since 2019 CCAMLR scientists have been reviewing the management strategy for krill fishing, and during the process, it became clear the need for the establishment of a Krill Stock Hypothesis. The SCAR Krill Expert Group (SKEG) was then organised together with external scientists outside CCAMLR in order to achieve a design through collective knowledge of krill experts around the world added to evidence published from literature (Ryabov et al., 2017; Atkinson et al., 2019; Perry et al., 2019; Ichii et al., 2020). A first view of the krill stock structure and dynamic was then proposed (Meyer et al., 2023), identifying the most likely spawning grounds, juvenile recruitment and paths of dispersal and retention.

Information on the distribution of spawning grounds and recruitment hotspots were used separated by sectors, as it is important to have a balanced coverage throughout the area in order to guarantee that important areas are not fished entirely, which, in years of low productivity could have impacts over krill populations (Meyer et al., 2020), predators (Watters, Hinke & Reiss, 2020; Krüger et al., 2021; Ratcliffe et al., 2021) and the fishery itself (Santa Cruz, Krüger & Cárdenas, 2022). Evidences in literature point out that maintaining a percentage of important breeding grounds for exploited species can even boost fishing in adjacent waters (Goñi et al., 2008; Di Lorenzo, Claudet & Guidetti, 2016; Marshall et al., 2019; Di Lorenzo et al., 2020; Lenihan et al., 2021; Ziegler et al., 2022); whilst that has been tested for Antarctic Krill only in modelling exercises (Dahood, de Mutsert & Watters, 2020), in lack of further evidence the precautionary approach adopted by CCAMLR should consider this measure as an important aspect of the krill fishing management (Garcia, 1994; Hanchet et al., 2014; Lauck et al., 2014; Hill et al., 2016). Therefore, a percentage of those areas should receive no-take area status.

Krill predators

Predators that depend on krill as its main diet during a part of their breeding cycle with openly available data were included in the evaluation (Table 1): Humpback whales *Megaptera novaengliae*, Antarctic minke whale *Eubalaena bonariensis*, Fin Whale *Eubalaena physalus* (Santora et al., 2010; Viquerat & Herr, 2017; Friedlaender et al., 2021; Reisinger et al., 2021; Seyboth et al., 2021; Herr et al., 2022), Antarctic fur seal *Arctocephalus gazella* including adults and juvenile tracking data from Cape Shirreff breeding colony (Boveng et al., 1998; Casaux et al., 2003; Osman et al., 2004; Waluda, Gregory & Dunn, 2010; Harrington et al., 2017; Hinke et al., 2017; Ropert-Coudert et al., 2020; Krause et al., 2022), Crabeater seal *Lobodon carcinophaga* (Hückstädt et al., 2012, 2020; Southwell et al., 2012; Botta et al., 2018; Ropert-Coudert et al., 2020), Southern elephant seal *Mirounga leonina* (Walters et al., 2014; Ropert-Coudert et al., 2020), Adelie *Pygoscelis adeliae*, chinstrap *P. antarcticus* and gentoo *P. papua* penguins (Lynnes, Reid & Croxall, 2004; Hinke et al., 2017, 2020; Humphries et al., 2017; Juáres et al., 2018; Ropert-Coudert et al., 2020; Handley et al., 2021; Korczak-Abshire et al., 2021; Wawrzynek-Borejko et al., 2022; Lynch et al., 2024) and Emperor penguin *Atenodytes forsteri* (Ratcliffe & Trathan, 2012; Humphries et al., 2017; Fretwell & Trathan, 2020; Handley et al., 2021; Jafari et al., 2021; Lynch et al., 2024; Trathan et al., 2024).

Table 1. Conservation objects and description of layers, updated (2024) and used for PACs generation in the previous D1MPA design (2023).

		2024			2023		
Group	Object	Description	Periodicity	N layers	Description	Periodicity	N layers
Cetacea	Humpback whale distribution	Argos tracking	JFM, AMJ	2	Argos tracking	Jan to Jun	1
	Humpback and Fin whale aggregations	Sightings of whale aggregations onboard research vessels	JFM	1	-	-	0
	Minke Whale distribution	Argos tracking	JFM, AMJ	2	Argos tracking	Jan to Jun	1
Pinniped	Antarctic Fur Seal distribution	Argos tracking	Year-round	4	Argos tracking	Year-round	1
	Antarctic Fur Seal breeding sites	40km from known breeding sites	OND, JFM	1	Buffer around known breeding sites	OND, JFM	1
	Crabeater Seal distribution	Argos tracking	AMJ, JAS, OND	3	-	-	0
	Southern Elephant Seal distribution	Argos tracking	Year-round	4	Argos tracking	Year-round	1
Penguins	Adelie penguin migration	Tracking of animals from three breeding colonies	JFM, AMJ	1	Tracking of animals from three breeding colonies	JFM, AMJ	1
	Adelie penguin breeding sites	Biologically important areas for penguins	OND-JFM	1	Buffer around known penguin colonies	October to March	1
	Chinstrap Penguin pos-breeding dispersal	Tracking of animals from three breeding colonies	AMJ, JAS	2	Tracking of animals from three breeding colonies	April to September	1
	Chinstrap Penguin breeding sites	Biologically important areas for penguins	OND-JFM	1	Buffer around known penguin colonies	October to March	1
	Gentoo Penguin non-breeding distribution	Tracking of animals from seven breeding colonies	JFM, AMJ	2	Tracking of animals from three breeding colonies	JFM, AMJ	1
	Gentoo Penguin breeding sites	Biologically important areas for penguins	OND-JFM	1	Buffer around known penguin colonies	October to March	1
	Emperor Penguin breeding sites	100 kms from 3 breeding colonies with land as barrier	April to December	1	100 kms buffer around two breeding colonies	April to December	1

Fish	Adult habitats	Based on known vertical distribution of species	October to March	1	Based on known vertical distribution of species	October to March	1
	Larvae habitats	Based on known vertical distribution of species	October to March	1	Based on known vertical distribution of species	October to March	1
Krill	Spawning grounds	Krill stock from SKEG report	JFM	1	-	-	0
	Juvenile recruitment areas	Krill stock from SKEG report	JFM	1	-	-	0
	Krill density	Krillbase data	Year-round	1	Krillbase data	Year-round	1
			N object	19		N objects	15
			N layers	31		N layers	15

Penguin breeding distribution

Handley et al. (2021) applied the Birdlife International concept of Important Bird and Biodiversity Areas (IBA) to identify significant hotspots for *Pygoscelis* and Emperor penguins throughout Antarctica, taking into account population size, at-sea distribution and species phenology. Areas identified as important for the 3 Pygoscelis penguin species were used as separated layers, which, considering the breeding phenology of the species (Handley et al., 2021), would be used by penguins in breeding activity between October to March. Handley et al. (2021) only identified one important area for Emperor Penguins in Domain 1, however, other two breeding sites are known (Fretwell & Trathan, 2020). Given the likely vulnerability of the Emperor penguins to the Climate Change and extreme climatic events (Jenouvrier et al., 2021) we consider it important to use all the 3 breeding sites as relevant for the domain 1 area. Based on tracking data of Emperor Penguin from colonies outside Domain 1 (Andrews, Pitman & Ballance, 2008; Houstin et al., 2022) and from Rothschild Island (Trathan et al., 2024) it is expected that a radius of 100 km around the colony is important during breeding activities, Therefore, importance was calculated considering a 100km radius and calculating the Euclidean distance from the last known colony position using land as a barrier. Recent publications have shown that colonies can shift position several tens of kms from the previous position in case of sea ice retraction (Fretwell & Trathan, 2020; Krüger et al., 2023).

Whale aggregations

Aggregations of large groups of foraging baleen whales have been recorded in recent years, indicating important foraging grounds for fin and humpback whales (Viquerat & Herr, 2017; Herr et al., 2022).

Antarctic fur seal Breeding Sites

Antarctic fur seal breeding sites with unavailable tracking data was collated from different sources: Seal Islands, Stinker Point (Elephant Island), and King George Island (Boveng et al., 1998; Waluda, Gregory & Dunn, 2010; Krause et al., 2022). Based on tracking data for the Cape Shirreff (Livingston Island) breeding site, a 40 kms radius (see tracking data section) using continents as barriers was generated in ArcMap to identify the most likely area used by breeding Antarctic fur seals.

Tracking data

Tracking data for 8 species was collated from different sources (table 2). Representativeness of the tracking data was also considered, by evaluation of the number of individuals tracked throughout time

(Table 2). For instance, the best available tracking data for Weddell Seals in Domain 1 (Ropert-Coudert et al., 2020) only had data for two individuals in the WAP, therefore it was not used. So the evaluation includes further data for 6 of the 8 tracked species.

Processing of tracking data

ARGOS geographical fixes with low quality were removed from the tracking data, and a posterior distance filter was applied to eliminate unlikely locations. Data was aggregated over 3-months periods, or year quarters, as 1-JFM, 2-AMJ, 3-JAS and 4-OND. Importance of an area was calculated as area usage through cumulative time residency using the 'trip' R package. Trip R-packageand uses a Bayesian approach to regularise tracking data and calculate time-residency per individual. A sum of individual time-residency values was used. All layers were rescaled to the maximum value, in order to vary from 0 to 1, and posteriorly binarized using the higher 5% quantile of the values to identify the more important areas from each species per period.

Identification of important areas for krill and predators

Layers used to generate the PACs in the previous designs of D1MPA were binarized and also used to quantify important areas for krill and predators. All binarized layers were summed in order to identify sites that were used consistently throughout the year for several conservation objectives.

References

Andrews, R.D., Pitman, R.L. & Ballance, L.T. (2008). Satellite tracking reveals distinct movement patterns for Type B and Type C killer whales in the southern Ross Sea, Antarctica. *Polar Biology*, 31(12), 1461–1468. https://doi.org/10.1007/s00300-008-0487-z

Atkinson, A., Hill, S.L., Pakhomov, E.A., Siegel, V., Reiss, C.S., Loeb, V.J., et al. (2019). Krill (Euphausia superba) distribution contracts southward during rapid regional warming. *Nature Climate Change*, 9(2), 142–147. https://doi.org/10.1038/s41558-018-0370-z

Botta, S., Secchi, E.R., Rogers, T.L., Prado, J.H.F., de Lima, R.C., Carlini, P., et al. (2018). Isotopic niche overlap and partition among three Antarctic seals from the Western Antarctic Peninsula. *Deep-Sea Research Part II: Topical Studies in Oceanography*, 149(November 2017), 240–249. https://doi.org/10.1016/j.dsr2.2017.11.005

Boveng, P.L., Hiruki, L.M., Schwartz, M.K. & Bengtson, J.L. (1998). Population growth of antarctic fur seals: Limitation by a top predator, the leopard seal? *Ecology*, 79(8), 2863–2877. https://doi.org/10.1890/0012-9658(1998)079[2863:PGOAFS]2.0.CO;2

Casaux, R., Baroni, A., Arrighetti, F., Ramón, A. & Carlini, A. (2003). Geographical variation in the diet of the Antarctic fur seal Arctocephalus gazella. *Polar Biology*, 26(12), 753–758. https://doi.org/10.1007/s00300-003-0554-4

Dahood, A., de Mutsert, K. & Watters, G.M. (2020). Evaluating Antarctic marine protected area scenarios using a dynamic food web model. *Biological Conservation*, 251(August), 108766. https://doi.org/10.1016/j.biocon.2020.108766

Fretwell, P.T. & Trathan, P.N. (2020). Discovery of new colonies by Sentinel2 reveals good and bad news for emperor penguins. K Scales and P Bouchet, Eds. *Remote Sensing in Ecology and Conservation*, rse2.176. https://doi.org/10.1002/rse2.176

Friedlaender, A.S., Joyce, T., Johnston, D.W., Read, A.J., Nowacek, D.P., Goldbogen, J.A., et al. (2021). Sympatry and resource partitioning between the largest krill consumers around the Antarctic Peninsula. *Marine Ecology Progress Series*, 669, 1–16. https://doi.org/10.3354/meps13771

Garcia, S.M. (1994). The Precautionary Principle: its implications in capture fisheries management. *Ocean and Coastal Management*, 22(2), 99–125. https://doi.org/10.1016/0964-5691(94)90014-0

Goñi, R., Adlerstein, S., Alvarez-Berastegui, D., Forcada, A., Reñones, O., Criquet, G., et al. (2008). Spillover from six western Mediterranean marine protected areas: Evidence from artisanal fisheries. *Marine Ecology Progress Series*, 366, 159–174. https://doi.org/10.3354/meps07532

Hanchet, S., Sainsbury, K., Butterworth, D., Darby, C., Bizikov, V., Rune Godø, O., et al. (2014). CCAMLR's precautionary approach to management focusing on Ross Sea toothfish fishery. *Antarctic Science*, 27(4), 333–340. https://doi.org/10.1017/S095410201400087X

Handley, J., Rouyer, M., Pearmain, E.J., Warwick-Evans, V., Teschke, K., Hinke, J.T., et al. (2021). Marine Important Bird and Biodiversity Areas for Penguins in Antarctica, Targets for Conservation Action. *Frontiers in Marine Science*, 7(January). https://doi.org/10.3389/fmars.2020.602972

Harrington, A., Daneri, G.A., Carlini, A.R., Reygert, D.S. & Corbalán, A. (2017). Seasonal variation in the diet of Antarctic fur seals, Arctocephalus gazella, at 25 de Mayo/King George Island, South Shetland Islands, Antarctica. *Polar Biology*, 40(2), 471–475. https://doi.org/10.1007/s00300-016-1959-1

Herr, H., Viquerat, S., Devas, F., Lees, A., Wells, L., Gregory, B., et al. (2022). Return of large fin whale feeding aggregations to historical whaling grounds in the Southern Ocean. *Scientific Reports*, 12(1), 1–15. https://doi.org/10.1038/s41598-022-13798-7

Hill, S.L., Atkinson, A., Darby, C., Fielding, S., Krafft, B.A., Godø, O.R., et al. (2016). Is current management of the antarctic krill fishery in the atlantic sector of the southern ocean precautionary? *CCAMLR Science*, 23, 31–51.

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. https://doi.org/10.1371/journal.pone.0170132

Hinke, J.T., Watters, G.M., Reiss, C.S., Santora, J.A. & Santos, M.M. (2020). Acute bottlenecks to the survival of juvenile Pygoscelis penguins occur immediately after fledging: Acute bottleneck to fledgling survival. *Biology Letters*, 16(12), 0–5. https://doi.org/10.1098/rsbl.2020.0645

Houstin, A., Zitterbart, D.P., Heerah, K., Eisen, O., Planas-Bielsa, V., Fabry, B., et al. (2022). Juvenile emperor penguin range calls for extended conservation measures in the Southern Ocean. *Royal Society Open Science*, 9(8), 2021.04.06.438390. https://doi.org/10.1098/rsos.211708

Hückstädt, L.A., Burns, J.M., Koch, P.L., McDonald, B.I., Crocker, D.E. & Costa, D.P. (2012). Diet of a specialist in a changing environment: the crabeater seal along the western Antarctic Peninsula. *Marine Ecology Progress Series*, 455, 287–301. https://doi.org/10.3354/meps09601

Hückstädt, L.A., Piñones, A., Palacios, D.M., McDonald, B.I., Dinniman, M.S., Hofmann, E.E., et al. (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

Humphries, G.R.W., Naveen, R., Schwaller, M., Che-Castaldo, C., McDowall, P., Schrimpf, M., et al. (2017). Mapping Application for Penguin Populations and Projected Dynamics (MAPPPD): data and tools for dynamic management and decision support. *Polar Record*, 53(2), 160–166. https://doi.org/10.1017/S0032247417000055

Ichii, T., Mori, Y., Mahapatra, K., Trathan, P., Okazaki, M., Hayashi, T., et al. (2020). Body length-dependent diel vertical migration of Antarctic krill in relation to food availability and predator avoidance in winter at South Georgia. *Marine Ecology Progress Series*, 654, 53–

66. https://doi.org/10.3354/meps13508
Jafari, V., Maccapan, D., Careddu, G., Sporta Caputi, S., Calizza, E., Rossi, L., et al. (2021). Spatial and temporal diet variability of Adélie (Pygoscelis adeliae) and Emperor (Aptenodytes forsteri) Penguin: a multi tissue stable isotope analysis. *Polar Biology*, 44(9), 1869–1881. https://doi.org/10.1007/s00300-021-02925-1
Jenouvrier, S., Judy, C., Wolf, S., Holland, M., Labrousse, S., LaRue, M., et al. (2021). The call of the emperor penguin: Legal responses to species threatened by climate change. *Global Change Biology*, (July), gcb.15806. https://doi.org/10.1111/gcb.15806
Juáres, M.A., Casaux, R., Corbalán, A., Blanco, G., Pereira, G.A., Perchivale, P.J., et al. (2018). Diet of Adélie penguins (Pygoscelis adeliae) at Stranger Point (25 de Mayo/King George Island, Antarctica) over a 13-year period (2003–2015). *Polar Biology*, 41(2), 303–311. https://doi.org/10.1007/s00300-017-2191-3
Korczak-Abshire, M., Hinke, J.T., Milinevsky, G., Juáres, M.A. & Watters, G.M. (2021). Coastal regions of the northern Antarctic Peninsula are key for gentoo populations: Winter movements of gentoo penguins. *Biology Letters*, 17(1), 0–5. https://doi.org/10.1098/rsbl.2020.0708
Krause, D.J., Bonin, C.A., Goebel, M.E., Reiss, C.S. & Watters, G.M. (2022). The Rapid Population Collapse of a Key Marine Predator in the Northern Antarctic Peninsula Endangers Genetic Diversity and Resilience to Climate Change. *Frontiers in Marine Science*, 8(January). https://doi.org/10.3389/fmars.2021.796488
Krüger, L., Huerta, M.F., Santa Cruz, F. & Cárdenas, C.A. (2021). Antarctic krill fishery effects over penguin populations under adverse climate conditions: Implications for the management of fishing practices. *Ambio*, 50(3), 560–571. https://doi.org/10.1007/s13280-020-01386-w
Krüger, L., Vianna, J., Bohec, C. Le & Cárdenas, C. (2023). A tipping point in West Antarctica in 2023's circumpolar 5-sigma event? a glimpse from the emperor penguin's perspective. *bioRxiv*, preprint. https://doi.org/10.1101/2023.09.28.559910
Lauck, T., Clark, C.W., Mangel, M., Munro, G.R., Applications, S.E. & Ecosystem, S. (2014). Implementing the Precautionary Principle in Fisheries Management Through Marine Reserves. *Ecological Society of America*, 8(1), 72–78. https://doi.org/10.1890/1051-0761(1998)8[S72:ITPPIF]2.0.CO;2
Lenihan, H.S., Gallagher, J.P., Peters, J.R., Stier, A.C., Hofmeister, J.K.K. & Reed, D.C. (2021). Evidence that spillover from Marine Protected Areas benefits the spiny lobster (Panulirus interruptus) fishery in southern California. *Scientific Reports*, 11(1), 1–9. https://doi.org/10.1038/s41598-021-82371-5
Di Lorenzo, M., Claudet, J. & Guidetti, P. (2016). Spillover from marine protected areas to adjacent fisheries has an ecological and a fishery component. *Journal for Nature Conservation*, 32, 62–66. https://doi.org/10.1016/j.jnc.2016.04.004
Di Lorenzo, M., Guidetti, P., Di Franco, A., Calò, A. & Claudet, J. (2020). Assessing spillover from marine protected areas and its drivers: A meta-analytical approach. *Fish and Fisheries*, (May), faf.12469. https://doi.org/10.1111/faf.12469
Lynch, H., Che-Castaldo, C., Humphries, G. & Naveen, R. (2024). MAPPPD (Mapping Application for Penguin Populations and Projected Dynamics). Available at: https://www.penguinmap.com/ [Accessed 23 August 2022]
Lynnes, A.S., Reid, K. & Croxall, J.P. (2004). Diet and reproductive success of Adélie and chinstrap penguins: Linking response of predators to prey population dynamics. *Polar Biology*, 27(9), 544–554. https://doi.org/10.1007/s00300-004-0617-1
Marshall, D.J., Gaines, S., Warner, R., Barneche, D.R. & Bode, M. (2019). Underestimating the benefits of marine protected areas for the replenishment of fished populations. *Frontiers in Ecology and the Environment*, 17(7), 407–413. https://doi.org/10.1002/fee.2075
Meyer, B., Arata, J.A., Sylvester, Z., Bransome, N. & Kirkham, N. (2023). Development of a Krill

stock hypothesis (KSH) for CCAMLR area 48 REPORT of the online workshop of the SCAR Krill Expert Group. (March), 20–24.
Meyer, B., Atkinson, A., Bernard, K.S., Brierley, A.S., Driscoll, R., Hill, S.L., et al. (2020). Successful ecosystem-based management of Antarctic krill should address uncertainties in krill recruitment, behaviour and ecological adaptation. *Communications Earth & Environment*, 1(1), 28. https://doi.org/10.1038/s43247-020-00026-1
Osman, L.P., Hucke-Gaete, R., Moreno, C.A. & Torres, D. (2004). Feeding ecology of Antarctic fur seals at Cape Shirreff, South Shetlands, Antarctica. *Polar Biology*, 27(2), 92–98. https://doi.org/10.1007/s00300-003-0555-3
Perry, F.A., Atkinson, A., Sailley, S.F., Tarling, G.A., Hill, S.L., Lucas, C.H., et al. (2019). Habitat partitioning in Antarctic krill: Spawning hotspots and nursery areas. E V. Thuesen, Ed. *PLOS ONE*, 14(7), e0219325. https://doi.org/10.1371/journal.pone.0219325
Ratcliffe, N. & Trathan, P. (2012). A review of the diet and at-sea distribution of penguins breeding within the CAMLR convention area. *CCAMLR Science*, 19, 1–40.
Ratcliffe, N., Deagle, B., Love, K., Polanowski, A., Fielding, S., Wood, A.G., et al. (2021). Changes in prey fields increase the potential for spatial overlap between gentoo penguins and a krill fishery within a marine protected area. *Diversity and Distributions*, (November 2020), 1–12. https://doi.org/10.1111/ddi.13216
Reisinger, R.R., Friedlaender, A.S., Zerbini, A.N., Palacios, D.M., Andrews-Goff, V., Dalla Rosa, L., et al. (2021). Combining regional habitat selection models for large-scale prediction: Circumpolar habitat selection of southern ocean humpback whales. *Remote Sensing*, 13(11). https://doi.org/10.3390/rs13112074
Ropert-Coudert, Y., Van de Putte, A.P., Reisinger, R.R., Bornemann, H., Charrassin, J.B., Costa, D.P., et al. (2020). The retrospective analysis of Antarctic tracking data project. *Scientific Data*, 7(1), 1–11. https://doi.org/10.1038/s41597-020-0406-x
Ryabov, A.B., de Roos, A.M., Meyer, B., Kawaguchi, S. & Blasius, B. (2017). Competition-induced starvation drives large-scale population cycles in Antarctic krill. *Nature Ecology & Evolution*, 1(7), 1–8. https://doi.org/10.1038/s41559-017-0177
Santa Cruz, F., Krüger, L. & Cárdenas, C.A. (2022). Spatial and temporal catch concentrations for Antarctic krill: Implications for fishing performance and precautionary management in the Southern Ocean. *Ocean & Coastal Management*, 223(September 2021), 106146. https://doi.org/10.1016/j.ocecoaman.2022.106146
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. *Marine Ecology Progress Series*, 405, 255–269. https://doi.org/10.3354/meps08513
Seyboth, E., Félix, F., Lea, M.A., Dalla Rosa, L., Watters, G.M., Reid, K., et al. (2021). Influence of krill (Euphausia superba) availability on humpback whale (Megaptera novaeangliae) reproductive rate. *Marine Mammal Science*, 37(4), 1498–1506. https://doi.org/10.1111/mms.12805
Southwell, C., Bengtson, J., Bester, M., Schytte Blix, A., Bornemann, H., Boveng, P., et al. (2012). A review of data on abundance, trends in abundance, habitat use and diet of ice-breeding seals in the Southern Ocean. *CCAMLR Science*, 19, 1–26.
Trathan, P.N., Wienecke, B., Fleming, A. & Ireland, L. (2024). Using telemetry data and the sea ice satellite record to identify vulnerabilities in critical moult habitat for emperor penguins in West Antarctica. *Polar Biology*, (1986). https://doi.org/10.1007/s00300-024-03252-x
Viquerat, S. & Herr, H. (2017). Mid-summer abundance estimates of fin whales Balaenoptera physalus around the South Orkney Islands and Elephant Island. *Endangered Species Research*, 32(June 2017), 515–524. https://doi.org/10.3354/ESR00832
Walters, A., Lea, M.A., Van Den Hoff, J., Field, I.C., Virtue, P., Sokolov, S., et al. (2014). Spatially explicit estimates of prey consumption reveal a new krill predator in the Southern

Ocean. *PLoS ONE*, 9(1), 1–17. https://doi.org/10.1371/journal.pone.0086452
Waluda, C.M., Gregory, S. & Dunn, M.J. (2010). Long-term variability in the abundance of Antarctic fur seals Arctocephalus gazella at Signy Island, South Orkneys. *Polar Biology*, 33(3), 305–312. https://doi.org/10.1007/s00300-009-0706-2
Watters, G.M., Hinke, J.T. & Reiss, C.S. (2020). Long-term observations from Antarctica demonstrate that mismatched scales of fisheries management and predator-prey interaction lead to erroneous conclusions about precaution. *Scientific Reports*, 10(1), 2314. https://doi.org/10.1038/s41598-020-59223-9
Wawrzynek-Borejko, J., Panasiuk, A., Hinke, J.T. & Korczak-Abshire, M. (2022). Are the diets of sympatric Pygoscelid penguins more similar than previously thought? *Polar Biology*, 45(10), 1559–1569. https://doi.org/10.1007/s00300-022-03090-9
Ziegler, S.L., Brooks, R.O., Hamilton, S.L., Ruttenberg, B.I., Chiu, J.A., Fields, R.T., et al. (2022). External fishing effort regulates positive effects of no-take marine protected areas. *Biological Conservation*, 269(December 2021), 109546. https://doi.org/10.1016/j.biocon.2022.109546