### Title

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Synoptic weekly counts of Southern Ocean phocid haul-out during the austral summer at Cape Shirreff

### Authors

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### Abstract

*Maximum 170 words recommended*

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### Background & Summary

The Antarctic Peninsula (AP) is one of the most rapidly warming regions in the world (Vaughan et al. 2003, Turner et al. 2014). Increases in air and sea temperatures in recent decades along the western AP have reduced sea ice extent both spatially and temporally (Meredith and King 2005, Meredith et al. 2022). Warming sea water together with the loss of sea ice are expected to shift the regional distributions of pelagic communities, including Antarctic krill (*Euphausia superba*, hereafter krill), myctophids, Antarctic silverfish (*Pleuragramma antarcticum*, hereafter silverfish), and their myriad dependent vertebrate predators (Massom and Stammerjohn 2010, Ducklow et al. 2013, Klein et al. 2018). For example, ice-associated penguins that depend on krill and silverfish are in decline throughout the AP since the early 1980s (Hinke et al. 2007, Trivelpiece et al. 2011).

Antarctic ice seals, including crabeater (*Lobodon carcinophagus*), Weddell (*Leptonychotes weddellii*), leopard seals (*Hydrurga leptonyx*), and the subantarctic Southern elephant seal (*Mirounga leonina*) are important components of Southern Ocean ecosystems as apex predators and major consumers. The AP is disproportionately important for ice seals with substantially higher densities than other surveyed areas of the continent (Southwell et al. 2012). Crabeater seals are extremely numerous, and as krill specialists may be the largest consumer of krill in the AP (Forcada et al. 2012, Hückstädt et al. 2012). In addition to cephalopods, southern elephant seal diets in the northern Peninsula region consist primarily of myctophids (Daneri et al. 2015). Leopard and Weddell seals depend on krill, myctophids, and silverfish to varying degrees based on region, sex, and time of year (Casaux et al. 2006, Casaux et al. 2009, Krause et al. 2020).

Whether or not there is a trend in the total biomass of krill within the AP is debated (Kinzey et al. 2015, Cox et al. 2018, Hill et al. 2019, Kinzey et al. 2019); however, there is evidence that krill are less available to regional predators (Krause et al. 2022) and the krill population may be contracting southward (Atkinson et al. 2019). Further, between 2000 and 2015 Antarctic fur seals (*Arctocephalus gazella*) consumed significantly fewer myctophids, indicating a reduction in availability (Klemmedson et al. 2020). Given these broad scale changes in ice habitat, temperatures, and the availability of prey, substantial changes in the population dynamics and distribution of southern phocids are predicted (Siniff et al. 2008, Forcada et al. 2012, Hückstädt et al. 2020). Climate driven redistribution and prey shifting by leopard seals may have driven a catastrophic decline of South Shetland Antarctic fur seals (Krause et al. 2022, Krause et al. 2023). However, there are a suite of unique challenges that have made AP phocids difficult to detect and survey (Southwell et al. 2008, Forcada et al. 2012, Rogers et al. 2013). Therefore, changes in their population dynamics are extremely difficult to detect given few population counts with large associated uncertainties (Southwell et al. 2012).

Due to its proximity to oceanographic features that concentrate prey, Cape Shirreff, Livingston Island in the northern AP is an important breeding and resting site for Southern Ocean seals and fur seals (Santora and Veit 2013, Krause et al. 2022). As such, it has been recognized by the Antarctic Consultative Treaty Meeting as an Antarctic Specially Protected Area (ATCM 2011). The National Oceanic and Atmospheric Administration (NOAA) United States Antarctic Marine Living Resources Program (U.S. AMLR), in collaboration with the Chilean Antarctic Institute (INACH), have conducted synoptic, approximately weekly counts of Southern Ocean phocids hauled out on Cape Shirreff during most austral summers between 1997/98 and 2022/23. These counts provide a rare and valuable source of information about population and area use changes by Southern Ocean phocids in a climate change hot spot over recent decades.

### Methods

**Survey methods**

The Cape Shirreff phocid census (CSPC) surveys were conducted by INACH from 1997/98 to 2006/07. The U.S. AMLR Pinniped Research Program resumed these censuses in 2009/10, and, except for 2020/21 when the field season was cancelled by the COVID-19 pandemic, has performed them every season through present. Most CSPC surveys were completed within one day (Fig. #), but weather or other extenuating circumstances sometimes resulted in the survey spanning up to three days. During each survey, trained field technicians surveyed all safely accessible regions of Cape Shirreff. While the exact locations surveyed varied slightly across and within seasons, they always included certain locations, hereafter ‘core census locations’. These core census locations span the vast majority of the coastline and phocid haul-out locations at Cape Shirreff, thereby ensuring that, while not comprehensive, CSPC counts are representative of phocid haul-out at Cape Shirreff during each survey window. Locations were surveyed by either walking, or scanning using binoculars from a high vantage point. Counts for each phocid species, including age class and sex when possible, were recorded in field notebooks. After the survey, data were either entered into a database or otherwise archived.

Entered data varied slightly across programs. Specifically, records from INACH surveys include explicit zero records when there were none of a particular phocid species at a location, while U.S. AMLR records did not include explicit zero records. For the purpose of this paper, explicit zero records were added to the U.S. AMLR data for core locations, after conversations with the program directors confirming that these core locations were surveyed during every phocid census survey.

**Data compilation and cleaning**

Data records were compiled from historical documents, field notebooks, Excel files, and a SQL Server database. INACH paper records were entered into Excel files, and then these INACH files, along with historical U.S. AMLR Excel sheets, were imported into the U.S. AMLR Pinniped SQL Server database.

Once in the database, all data were read into R (R Core Team 2023) where they were cleaned and standardized. Location names were converted to standard names, and columns containing count data were aggregated to the lowest resolution across datasets. For instance, some seasons male and female pup counts were recorded separately, but during others only a single pup count was recorded. Thus, all pup counts were aggregated to a single total pup count for each census record. In addition, data were checked for duplicate entries for the same species at the same location during the same census. Dates or count values flagged by automated checks were validated using paper datasheets or scans of field notebooks.

After cleaning, census records were grouped and aggregated by survey to provide a single, comparable count for each survey. Specifically, records were filtered for core census locations, and counts were summed after grouping by census survey and pinniped species. These core census location count values, along with counts for one other specific location for reasons described in Data Records below, are included in the final dataset.

### Data Records

The data presented in this paper are publicly available through {todo, see ‘Code Availability’ section}. The full dataset consists of two CSV files: cspc\_header.csv and cspc\_records.csv. Data in the two files can be joined using the ‘header\_id’ key present in both files. The header ID keys were generated by concatenating the season name with the within-season survey number, and thus all key values are character strings that are unique across CSPC surveys.

The header CSV file contains, in addition to the header ID key, the high-level information for each survey: season\_name, a character string of the field season name; census\_start\_date, the date of the beginning of the census; census\_end\_date, the date the census was completed; surveyed\_san\_telmo, a boolean flag indicating whether or not the Punta San Telmo location was surveyed (see details below); and research\_program, a character string indicating the research program that conducted the survey (‘INACH’ or ‘USAMLR’).

The actual census counts can be found in the records CSV file. See table # for a detailed description of each column in the records CSV. All count data in this file are explicit, meaning that the record has a value of zero if and only if zero of that species/count type were recorded, and a blank if there was no data. Because all phocids found at each surveyed location were recorded under some count type, in practice what a blank count value means is that this specific age class/sex category was not explicitly recorded for that species during that particular survey. In other words, any phocid that may have fallen into that age class/sex category was recorded under a different count type.

Although field technicians generally recorded phocid counts for individual locations, the exact boundaries of these locations may varied across field seasons. Thus, the dataset described in this paper only includes aggregated counts for 1) all core census locations and 2) the Punta San Telmo location. As described in the Methods section, the core census locations consist of all the locations on Cape Shirreff that were surveyed consistently by both the INACH and U.S. AMLR programs, and thus this is the only count comparable across the entire timeseries. The counts for the Punta San Telmo region are also included in this dataset because this region has usually been surveyed since the 2009/10 field season (n=177 out of 184 surveys; see the surveyed\_san\_telmo column in the header CSV).

### Technical Validation

All count records were screened for unreasonable values or duplicate entries, either via R code or visually through plots of the data. Duplicates were filtered out, and any flagged records were checked using scans of technician’s field notebooks. All header records were also screened and confirmed using the field notebook scans. Records were checked for consistency with regards to blank versus zero entries, ensuring that patterns in the data (i.e., when a particular count column should be NA vs zero) matched the data recorded in each season. Program directors were consulted about all assumptions made about these data patterns, as well as survey scope and techniques over the full timeseries.

### Usage Notes

The authors advise users of these data to be aware that there are likely many drivers of phocid haul-out at Cape Shirreff, in addition to the state of phocid populations proximate to Cape Shirreff. For instance, census counts for some species are greatly influenced by the species’ life history traits. There are usually several southern elephant seals breeding at Cape Shirreff. Therefore, counts from CSPC surveys in October-December include both these breeding animals and others that simply come to haul out and rest and/or molt. {*Details about other species? Emphasize that there are some residents and some transients?}*

In addition to the life history cycles of various species, the height of the tide during the survey and inclement weather also appear to have strong influences on census counts {citation?}. Strong precipitation in particular usually resulted in CSPC survey counts of fewer phocids, no matter the time of year. Thus, these factors should always be taken into consideration when drawing conclusions using these data.

Data users should note that the records CSV does not have census date or time columns; this is because the aggregation of count data across core census locations sometimes meant that data were aggregated across multiple days. To associate and use the census records with a specific date, we recommend joining the header and record CSV files and using the census\_start\_date column, as demonstrated in sample code {todo}. Also, users can see file {todo} for example code for making the records data frame long instead of wide.

As described in the Data Records, the only continuous count that can be compared across the full timeseries is the counts for the core census locations. If including counts for Punta San Telmo, users should only use data from the 2009/10 field season onwards. The original phocid census records, meaning counts by the field technicians for individual locations, can only be used with caution and after consultation with the authors. Interested parties, as well as anyone with general questions about how to use these data, should contact the corresponding author.

### Code Availability

All code for importing, cleaning, and processing the Cape Shirreff phocid census data described in this paper, as well as sample processing code, is available at <https://github.com/us-amlr/phocid-census-cs>.

Planned data repository: SCAR Antarctic Biodiversity Portal (<www.biodiversity.aq>), which should also get the data to the Ocean Biogeographic Information System (OBIS) and the Global Biodiversity Information Facility (GBIF).

### Acknowledgements

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### Author contributions

RBC and DJK conceived the project. SMW organized the data cleaning and processing efforts, and led the writing of the manuscript along with DJK. DT, MEG, and DJK collected and contributed data, while RBC digitized the INACH data. All authors provided guidance on data cleaning and use, as well as comments on the manuscript.

### Competing interests

The authors declare no competing interests.

### Figures

Figure #: Data workflow? Leaning no because it is not complex (notebooks -> database -> R -> repository)

Figure #: Map of Cape Shirreff + region for regional orientation. Ok to steal one from a past paper?

Figure #: Temporal distribution of records (figure showing dates of phocid census across field seasons)

Figure #s: Something showing high-level overview of species counts.

### Tables

Table 1: Description of the cspc\_records.csv columns. This will mostly be copied from the AMLR data column descriptions

(https://github.com/us-amlr/phocid-census-cs/blob/main/data/amlr\_data/readme-usamlr.md#data-columns)

### References

ATCM. 2011. Management Plan for Antarctic Specially Protected Area No. 149: Measure 7 Annex. Pages 439-462 *in* F. R. o. t. T.-f. A. T. C. Meeting, editor. Secretariat of the Antarctic Treaty. Antarctic Treaty Consultative Meeting (ATCM) Buenos Aires, Argentina.

Atkinson, A., S. L. Hill, E. A. Pakhomov, V. Siegel, C. S. Reiss, V. J. Loeb, D. K. Steinberg, K. Schmidt, G. A. Tarling, L. Gerrish, and S. F. Sailley. 2019. Krill (Euphausia superba) distribution contracts southward during rapid regional warming. Nature Climate Change **9**:142-147.

Casaux, R., A. Baroni, and A. Ramón. 2006. The diet of the Weddell Seal Leptonychotes weddellii at the Danco Coast, Antarctic Peninsula. Polar Biology **29**:257-262.

Casaux, R., A. Baroni, A. Ramón, A. Carlini, M. Bertolin, and C. DiPrinzio. 2009. Diet of the leopard seal (*Hydrurga leptonyx*) at the Danco Coast, Antarctic Peninsula. Polar Biology **32**:307-310.

Cox, M. J., S. Candy, W. K. de la Mare, S. Nicol, S. Kawaguchi, and N. Gales. 2018. No evidence for a decline in the density of Antarctic krill Euphausia superba Dana, 1850, in the Southwest Atlantic sector between 1976 and 2016. Journal of Crustacean Biology **38**:656-661.

Daneri, G. A., A. R. Carlini, E. R. Marschoff, A. Harrington, J. Negrete, J. A. Mennucci, and M. E. I. Márquez. 2015. The feeding habits of the Southern elephant seal, Mirounga leonina, at Isla 25 de Mayo/King George Island, South Shetland Islands. Polar Biology **38**:665-676.

Ducklow, H. W., W. R. Fraser, M. P. Meredith, S. E. Stammerjohn, S. C. Doney, D. G. Martinson, S. F. Sailley, O. M. Schofield, D. K. Steinberg, and H. J. Venables. 2013. West Antarctic Peninsula: an ice-dependent coastal marine ecosystem in transition. Oceanography **26**:190-203.

Forcada, J., P. N. Trathan, P. L. Boveng, I. L. Boyd, J. M. Burns, D. P. Costa, M. Fedak, T. L. Rogers, and C. J. Southwell. 2012. Responses of Antarctic pack-ice seals to environmental change and increasing krill fishing. Biological Conservation **149**:40-50.

Hill, S. L., A. Atkinson, E. A. Pakhomov, and V. Siegel. 2019. Evidence for a decline in the population density of Antarctic krill Euphausia superba Dana, 1850 still stands. A comment on Cox et al. Journal of Crustacean Biology **39**:316-322.

Hinke, J. T., K. Salwicka, S. G. Trivelpiece, G. M. Watters, and W. Z. Trivelpiece. 2007. Divergent responses of Pygoscelis penguins reveal a common environmental driver. Oecologia **153**:853.

Hückstädt, L. A., J. M. Burns, P. L. Koch, B. I. McDonald, D. E. Crocker, and D. P. Costa. 2012. Diet of a specialist in a changing environment: the crabeater seal along the western Antarctic Peninsula. Marine Ecology Progress Series **455**:287-301.

Hückstädt, L. A., A. Piñones, D. M. Palacios, B. I. McDonald, M. S. Dinniman, E. E. Hofmann, J. M. Burns, D. E. Crocker, and D. P. Costa. 2020. Projected shifts in the foraging habitat of crabeater seals along the Antarctic Peninsula. Nature Climate Change **10**:472-477.

Kinzey, D., G. M. Watters, and C. S. Reiss. 2015. Selectivity and two biomass measures in an age-based assessment of Antarctic krill (Euphausia superba). Fisheries Research **168**:72-84.

Kinzey, D., G. M. Watters, and C. S. Reiss. 2019. Estimating recruitment variability and productivity in Antarctic krill. Fisheries Research **217**:98-107.

Klein, E. S., S. L. Hill, J. T. Hinke, T. Phillips, and G. M. Watters. 2018. Impacts of rising sea temperature on krill increase risks for predators in the Scotia Sea. PloS one **13**:e0191011.

Klemmedson, A. D., C. S. Reiss, M. E. Goebel, R. S. Kaufmann, E. Dorval, T. B. Linkowski, and R. Borras-Chavez. 2020. Variability in age of a Southern Ocean myctophid (Gymnoscopelus nicholsi) derived from scat-recovered otoliths. Marine Ecology Progress Series **633**:55-69.

Krause, D. J., C. A. Bonin, M. E. Goebel, C. S. Reiss, and G. M. Watters. 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**:796488.

Krause, D. J., M. E. Goebel, and C. M. Kurle. 2020. Leopard seal diets in a rapidly warming polar region vary by year, season, sex, and body size. BMC Ecology **20**:32.

Massom, R. A., and S. E. Stammerjohn. 2010. Antarctic sea ice change and variability – Physical and ecological implications. Polar Science **4**:149-186.

Meredith, M. P., and J. C. King. 2005. Rapid climate change in the ocean west of the Antarctic Peninsula during the second half of the 20th century. Geophysical Research Letters **32**:L19604.

Meredith, M. P., M. Sommerkorn, S. Cassotta, C. Derksen, A. Ekaykin, A. Hollowed, G. Kofinas, A. Mackintosh, J. Melbourne-Thomas, M. M. C. Muelbert, G. Ottersen, H. Pritchard, and E. A. G. Schuur. 2022. 2019: Polar Regions. Pages 203-320 *in* H.-O. Pörtner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, and N. M. Weyer, editors. IPCC Special Report on the Ocean and Cryosphere in a Changing Climate. Cambridge University Press, Padstow Cornwall.

Rogers, T. L., M. B. Ciaglia, H. Klinck, and C. Southwell. 2013. Density can be misleading for low-density species: benefits of passive acoustic monitoring. PloS one **8**:e52542.

Santora, J., and R. Veit. 2013. Spatio-temporal persistence of top predator hotspots near the Antarctic Peninsula. Marine Ecology Progress Series **487**:287-304.

Siniff, D. B., R. A. Garrott, J. J. Rotella, W. R. Fraser, and D. G. Ainley. 2008. Opinion: Projecting the effects of environmental change on Antarctic seals. Antarctic Science **20**:425-435.

Southwell, C., J. Bengtson, M. Bester, A. S. Blix, H. Bornemann, P. Boveng, M. Cameron, J. Forcada, J. Laake, E. Nordøy, J. Plötz, T. Rogers, D. Southwell, D. Steinhage, B. S. Stewart, and P. N. Trathan. 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**:49-74.

Southwell, C., C. G. M. Paxton, D. Borchers, P. Boveng, T. Rogers, and W. K. de la Mare. 2008. Uncommon or cryptic? Challenges in estimating leopard seal abundance by conventional but state-of-the-art methods. Deep Sea Research Part I: Oceanographic Research Papers **55**:519-531.

Trivelpiece, W. Z., J. T. Hinke, A. K. Miller, C. S. Reiss, S. G. Trivelpiece, and G. M. Watters. 2011. Variability in krill biomass links harvesting and climate warming to penguin population changes in Antarctica. Proceedings of the National Academy of Sciences.

Turner, J., N. E. Barrand, T. J. Bracegirdle, P. Convey, D. A. Hodgson, M. Jarvis, A. Jenkins, G. Marshall, M. P. Meredith, H. Roscoe, J. Shanklin, J. French, H. Goosse, M. Guglielmin, J. Gutt, S. Jacobs, M. C. Kennicutt, V. Masson-Delmotte, P. Mayewski, F. Navarro, S. Robinson, T. Scambos, M. Sparrow, C. Summerhayes, K. Speer, and A. Klepikov. 2014. Antarctic climate change and the environment: an update. Polar Record **50**:237-259.

Vaughan, D., G. Marshall, W. Connolley, C. Parkinson, R. Mulvaney, D. Hodgson, J. King, C. Pudsey, and J. Turner. 2003. Recent rapid regional climate warming on the Antarctic Peninsula. Climatic Change **60**:243-274.