### Title

CS-PHOC: Weekly census counts of Southern Ocean phocids at Cape Shirreff, Livingston Island (1997-2023)

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### Abstract

Rapid, climatic warming of the Antarctic Peninsula (AP) is driving regional population declines and distribution shifts of predators and prey. Affected species include Antarctic ice seals and the subantarctic southern elephant seal, which rely on the AP region for critical components of their life cycle. However, data collection is difficult in this remote region, and therefore long-term time series with which to identify and investigate population trends in these species are rare. We present the Cape Shirreff Phocid Census (CS-PHOC) dataset: weekly counts of phocids (crabeater, leopard, southern elephant, and Weddell seals) hauled out at Cape Shirreff, Livingston Island, during most austral summers since 1997. Data from these censuses were cleaned and aggregated, resulting in robust and comparable count data from 284 censuses across 23 field seasons. The CS-PHOC dataset, which is publicly available through [www.biodiversity.aq](http://www.biodiversity.aq), will be updated yearly to provide important information about Southern Ocean phocids in the Antarctic Peninsula.

### Background & Summary

The Antarctic Peninsula (AP) is one of the most rapidly warming regions in the world 1,2. Increases in air and sea temperatures in recent decades along the western AP have reduced sea ice extent both spatially and temporally 3,4. 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 5-8. For example, ice-associated penguins that depend on krill and silverfish are in decline throughout the AP since the early 1980s 9,10.

Antarctic ice seals, including crabeater (*Lobodon carcinophagus*), leopard (*Hydrurga leptonyx*), and Weddell (*Leptonychotes weddellii*) seals, as well as the subantarctic Southern elephant seal (*Mirounga leonina*) are important components of Southern Ocean ecosystems as apex predators and major consumers of the above-listed pelagic forage species. The AP is an essential habitat for ice seals, with higher densities than other surveyed areas of the continent 11. Crabeater seals are extremely numerous, and as krill specialists may be the largest marine mammal consumer of krill in the AP 12,13. In East Antarctica, southern elephant seal diet is mostly composed of cephalopods, but in the northern AP their diet consists primarily of myctophids 14,15. Leopard and Weddell seals depend on krill, myctophids, and silverfish to varying degrees based on region, sex, mass, and time of year 16-19.

Whether there is a trend in the total biomass of krill within the AP is debated 20-23. However, evidence suggests that the krill population is contracting southward and away from traditional krill predator foraging hotspots in the northern AP 24. Indeed, over the last 20 years, krill have become less available to some regional predators 25. In addition, between 2000 and 2015, Antarctic fur seals (*Arctocephalus gazella*) consumed significantly fewer myctophids, which was linked to a decline in myctophid availability on the South Shetland Islands slope region 26. 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 both predicted 12,27,28 and have been observed 25. However, a suite of unique challenges, including remote pack-ice environments and periodic haul-outs, makes AP phocids difficult to detect and survey 12,29,30. Therefore, changes in their population dynamics are extremely difficult to detect using the few existing population counts, which have large associated uncertainties 11.

In the northern AP, Cape Shirreff, Livingston Island is an important breeding and resting site for Southern Ocean phocids and fur seals 25,31. As such, it has been recognized by the Antarctic Consultative Treaty Meeting as an Antarctic Specially Protected Area 32. As part of long-term monitoring efforts at Cape Shirreff, the National Oceanic and Atmospheric Administration Fisheries (NOAA Fisheries) United States Antarctic Marine Living Resources Program (U.S. AMLR Program) and the Chilean Antarctic Institute (INACH) have conducted synoptic, weekly counts of Southern Ocean phocids hauled out on Cape Shirreff during most austral summers since 1997/98. These census data, which will continue to be collected by the U.S. AMLR Program and thus updated yearly, provide a rare and valuable source of information about changes in population trends and area use by Southern Ocean phocids in a climate change hot spot.

### Methods

**Survey methods**

All data were collected at Cape Shirreff (62.47o S, 60.77o W) on the north shore of Livingston Island (Fig. 1). Bounded by glaciers to the south, Cape Shirreff is approximately 3 km long and 1.5 km wide. The Cape Shirreff Phocid Census (CS-PHOC, pronounced ‘Seasfolk’) surveys were conducted by INACH from 1997/98 to 2006/07. The U.S. AMLR Pinniped Research Program resumed these surveys in 2009/10, and, except for 2020/21 when the field season was canceled due to the COVID-19 pandemic, have conducted surveys every season since through the time of publication. Most CS-PHOC survey windows (i.e., censuses) were only one day, meaning surveys of all locations were conducted on the same day. However, censuses occasionally spanned two or three days due to extenuating circumstances (e.g., weather; Fig. 2).

The INACH and U.S. AMLR programs both followed the same overall census protocol, where trained field biologists surveyed safely accessible regions of Cape Shirreff and recorded all live phocids. Biologists recorded phocid counts in field notebooks for each species at each location, along with age class and sex when possible. After the survey, data were entered into a database or otherwise archived. Locations were surveyed on foot, by either walking through haul-out locations or using binoculars from a high vantage point when practical. While the full extent of the area surveyed varied slightly across and within seasons, core census locations were always surveyed. These core census locations span the vast majority of phocid haul-out locations at Cape Shirreff (Fig. 1), thereby ensuring that CS-PHOC data are both consistent and representative of phocid haul-out at Cape Shirreff during each census.

**Data cleaning and aggregation**

Data records were compiled from historical documents, field notebooks, Excel files, and a SQL Server database. INACH historical data (i.e., paper records, reports, and Excel files) were consolidated into Excel files. These INACH files, along with historical U.S. AMLR Excel files, were imported into the U.S. AMLR Pinniped SQL Server database using R (v4.3.1)33. Once in the database, all data were read into R, where they were cleaned and standardized as follows. Location names and count types (i.e., age class and sex) 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, for this dataset, all pup counts were aggregated to a single, total pup count for each survey record. In addition, recorded data varied slightly across programs. Specifically, data from INACH surveys included 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. After consultation with the U.S. AMLR Pinniped Program leaders, records with zeroes or NAs as appropriate were created and added to the U.S. AMLR data for core census locations.

After data cleaning and standardization, records were grouped and aggregated to provide a single, comparable count for each species for each census. Specifically, records were filtered for core census locations, and counts were summed after grouping by census and pinniped species. These aggregated core census location counts, along with counts for one other location (Punta San Telmo, described in “Data Records” below; Fig. 1), make up the published CS-PHOC dataset.

**Data publication**

Raw CS-PHOC data are hosted and stored in the U.S. AMLR Pinniped Program database. The aggregated CS-PHOC dataset described in this manuscript have also been made Darwin Core compliant (<https://dwc.tdwg.org>), and published to SCAR Antarctic Biodiversity Portal ([www.biodiversity.aq](http://www.biodiversity.aq), via the Integrated Publishing Toolkit at <ipt.biodiversity.aq>). This will ensure the data is available through Ocean Biogeographic Information System (OBIS) and the Global Biodiversity Information Facility (GBIF). Data from future field seasons will be added once it has been cleaned and processed, ensuring that the published CS-PHOC dataset remains up to date for future analyses.

### Data Records

The CS-PHOC dataset available on [www.biodiversity.aq](http://www.biodiversity.aq) was generated from two CSV files: cs-phoc-headers.csv and cs-phoc-counts.csv, both available in the CS-PHOC GitHub repository. Data in these two CSV files can be joined using the ‘header\_id’ key present in both files. All key values are character strings that represent a unique CS-PHOC survey window. In addition to the header ID key, the headers CSV file contains the high-level information for each census: 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 census (‘INACH’ or ‘USAMLR’).

The actual census counts can be found in the counts CSV file. See Table 1 for a detailed description of each column. All count data in this file are explicit, meaning that each record has a value of zero if and only if zero of that species/count type were recorded, and a blank (i.e., NA) if there were no data.

Field biologists generally split out core areas into smaller areas for surveys; however, the exact boundaries of those areas sometimes varied slightly across field seasons. Thus, the dataset described in this manuscript only includes 1) aggregated counts for all core census locations and 2) counts for 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 been included in most surveys since the 2009/10 field season (n=177 out of 184 surveys; see the surveyed\_san\_telmo column in the headers CSV file).

### Technical Validation

All header records were reviewed and confirmed using field notebook scans. All count records were screened for unreasonable values or duplicate entries via R code, either programmatically or visually through plots of the data. Duplicates were removed, and other data flagged by automated checks were validated using paper datasheets or the field notebook scans. Count records were also checked for consistency with regard to zero vs NA values, ensuring that patterns in the data (e.g., values in a particular count column were NA for a full season) were consistent. All observed patterns, as well as survey scope and techniques over the full timeseries, were checked with program leaders.

### Usage Notes

The authors advise users of these data to be aware that there are likely many intrinsic and extrinsic drivers shaping phocid haul-out behaviour at Cape Shirreff, other than simply regional abundance of a particular species. For example, census counts are greatly influenced by life history traits, such as the timing of breeding and moulting. Breeding southern elephant seal females have a well-established pattern of hauling out to breed between late September to early November, returning to sea to forage, and hauling out again to moult several weeks later; however, juveniles and other non-breeding animals are less tied to that cycle 34. Weddell seals also regularly pup at or near Cape Shirreff between late September to early December (U.S. AMLR, unpublished data). These patterns are reflected in census counts, and should be taken into consideration when drawing conclusions from these data.

Other factors can also influence haul-out probabilities across these species, including the state of the weather (e.g., precipitation), tides, or time of day 11,35-37. Methods exist to correct for these factors in regional census data (e.g., 11); however, the CS-PHOC count records do not have census date or time information, both because of the aggregation of multi-day surveys for this dataset and because survey times were recorded inconsistently across seasons. Sometimes times were recorded for each location, and other times for a full day’s survey effort over multiple locations. While implementing haul-out corrections is thereby impractical for this dataset, CS-PHOC surveys were typically conducted in the middle of the day to maximize sighting probabilities for all species (Fig. 3). Therefore, we are confident that these records are representative and comparable across this broad time series of data. Beginning during the 2021/22 field season, survey start and end times have been recorded for each individual survey record (i.e., each location), and thus implementing haul-out corrections will be possible with future data.

Since the counts CSV file does not have a date column, we recommend joining the header and count CSV files and using the census\_start\_date column as the date for each count record. This process, as well as making the count CSV data long instead of wide, is demonstrated in the example.R file in the CS-PHOC GitHub repository.

As described in the Data Records section, the only counts that can be compared across the full timeseries (1997/98 to 2022/23) are the counts for the core census locations. Examples of possible ways to visualize and explore these data for the full timeseries are shown in Fig. 4. Analyses including counts for Punta San Telmo should only include data from the 2009/10 field season and later. Parties with general questions about these data, or those interested in finer resolution survey data or available start and end time information, should contact the corresponding author.

### Code Availability

All raw files and code for importing, cleaning, and processing the CS-PHOC data described in this manuscript, as well as sample processing code, is available at <https://github.com/us-amlr/cs-phoc> (https://doi.org/10.5281/zenodo.8395876).

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### Author contributions

RBC and DJK conceived the project. SMW organized and led the data cleaning and processing efforts, and wrote the manuscript along with DJK. MEG, DJK, DT, and AA led data collection efforts and contributed data. RBC digitized the INACH data. RBC, MEG, and DJK provided guidance on data cleaning and use, and edited the manuscript. All authors gave approval for publication.

### Competing interests

The authors declare no competing interests.

### Figures

Fig. 1: Fig1\_csphoc\_map.png

Legend: Map of Cape Shirreff, Livingston Island. The left panels show the location of Cape Shirreff. The right panel shows regular CS-PHOC survey locations as thick lines along the coast, shaded dark purple for the core census locations and aquamarine for Punta San Telmo.

Fig. 2: Fig2\_csphoc\_censuses.png

Legend: CS-PHOC dates, the research program that conducted the surveys, and the census survey window, in days. The right panel is a bar plot showing the number of surveys performed in each season. There were no surveys in 2007/08 and 2008/09 due to program transition, and no field season in 2020/21 due to the COVID-19 pandemic.

Fig. 3: Fig3\_csphoc\_survey\_times.png

Legend: Overview of available time of day information from all single-day CS-PHOC survey records with start and end times (n=4066 surveys). Times, which were recorded for most surveys starting in 2009, were sometimes recorded for individual locations (less than one hour), and sometimes for some or all of a survey effort (up to ten hours). Upper panel: survey record start and end times, by hour. Middle panel: The midpoint time, rounded to the nearest hour, of all survey records with start and end times. Lower panel: length of time of survey records with start and end times.

Fig. 4: Fig4\_csphoc\_counts.png

Legend: Example visualizations of CS-PHOC data. A: Mean counts for each month for all species, averaged by season group. B: Mean counts for leopard, Weddell, and crabeater seals, averaged by month and season, with error bars showing the standard deviation. Southern elephant seals were excluded because of their much higher count values. C: Mean counts of age/sex classes for southern elephant seals, averaged by month for each season.

### Tables

Table 1: Table1\_csphoc.csv

Table 1 legend: Names, data types, and descriptions for columns in the cs-phoc-counts.csv data file.

### References

1 Vaughan, D. G. *et al.* Recent rapid regional climate warming on the Antarctic Peninsula. *Climatic Change* **60**, 243-274, doi:10.1023/a:1026021217991 (2003).

2 Turner, J. *et al.* Antarctic climate change and the environment: an update. *Polar Record* **50**, 237-259, doi:10.1017/S0032247413000296 (2014).

3 Meredith, M. P. & King, J. C. Rapid climate change in the ocean west of the Antarctic Peninsula during the second half of the 20th century. *Geophysical Research Letters* **32**, L19604, doi:10.1029/2005GL024042 (2005).

4 Meredith, M. P. *et al.* in *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* (eds Hans-Otto Pörtner *et al.*) Ch. 3, 203-320 (Cambridge University Press, 2022).

5 Massom, R. A. & Stammerjohn, S. E. Antarctic sea ice change and variability – Physical and ecological implications. *Polar Science* **4**, 149-186, doi:10.1016/j.polar.2010.05.001 (2010).

6 Ducklow, H. W. *et al.* West Antarctic Peninsula: an ice-dependent coastal marine ecosystem in transition. *Oceanography* **26**, 190-203, doi:10.5670/oceanog.2013.62 (2013).

7 Klein, E. S., Hill, S. L., Hinke, J. T., Phillips, T. & Watters, G. M. Impacts of rising sea temperature on krill increase risks for predators in the Scotia Sea. *PLOS ONE* **13**, e0191011, doi:10.1371/journal.pone.0191011 (2018).

8 Atkinson, A. *et al.* Stepping stones towards Antarctica: Switch to southern spawning grounds explains an abrupt range shift in krill. *Global Change Biology* **28**, 1359-1375 (2022).

9 Hinke, J. T., Salwicka, K., Trivelpiece, S. G., Watters, G. M. & Trivelpiece, W. Z. Divergent responses of Pygoscelis penguins reveal a common environmental driver. *Oecologia* **153**, 853, doi:<https://doi.org/10.1007/s00442-007-0781-4> (2007).

10 Trivelpiece, W. Z. *et al.* Variability in krill biomass links harvesting and climate warming to penguin population changes in Antarctica. *Proceedings of the National Academy of Sciences*, doi:10.1073/pnas.1016560108 (2011).

11 Southwell, C. *et al.* 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 (2012).

12 Forcada, J. *et al.* Responses of Antarctic pack-ice seals to environmental change and increasing krill fishing. *Biological Conservation* **149**, 40-50, doi:10.1016/j.biocon.2012.02.002 (2012).

13 Hückstädt, L. A. *et al.* Diet of a specialist in a changing environment: the crabeater seal along the western Antarctic Peninsula. *Marine Ecology Progress Series* **455**, 287-301, doi:10.3354/meps09601 (2012).

14 Bradshaw, C. J. *et al.* You are what you eat: describing the foraging ecology of southern elephant seals (*Mirounga leonina*) using blubber fatty acids. *Proceedings of the Royal Society of London. Series B: Biological Sciences* **270**, 1283-1292 (2003).

15 Daneri, G. A. *et al.* 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, doi:10.1007/s00300-014-1629-0 (2015).

16 Casaux, R., Baroni, A. & Ramón, A. The diet of the Weddell Seal *Leptonychotes weddellii* at the Danco Coast, Antarctic Peninsula. *Polar Biology* **29**, 257-262, doi:10.1007/s00300-005-0048-7 (2006).

17 Casaux, R. *et al.* Diet of the leopard seal (*Hydrurga leptonyx*) at the Danco Coast, Antarctic Peninsula. *Polar Biology* **32**, 307-310, doi:10.1007/s00300-008-0567-0 (2009).

18 Krause, D. J., Goebel, M. E. & Kurle, C. M. Leopard seal diets in a rapidly warming polar region vary by year, season, sex, and body size. *BMC Ecology* **20**, 32, doi:10.1186/s12898-020-00300-y (2020).

19 Negri, A., Daneri, G., Coria, N., Corbalán, A. & Negrete, J. Temporal variation in the summer diet of the weddell seal, leptonychotes weddellii, at hope bay, antarctic peninsula. *Polar Biology* **46**, 111-121 (2023).

20 Kinzey, D., Watters, G. M. & Reiss, C. S. Selectivity and two biomass measures in an age-based assessment of Antarctic krill (*Euphausia superba*). *Fisheries Research* **168**, 72-84, doi:<https://doi.org/10.1016/j.fishres.2015.03.023> (2015).

21 Cox, M. J. *et al.* 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, doi:10.1093/jcbiol/ruy072 (2018).

22 Kinzey, D., Watters, G. M. & Reiss, C. S. Estimating recruitment variability and productivity in Antarctic krill. *Fisheries Research* **217**, 98-107, doi:<https://doi.org/10.1016/j.fishres.2018.09.027> (2019).

23 Hill, S. L., Atkinson, A., Pakhomov, E. A. & Siegel, V. 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, doi:10.1093/jcbiol/ruz004 (2019).

24 Atkinson, A. *et al.* Krill (*Euphausia superba*) distribution contracts southward during rapid regional warming. *Nature Climate Change* **9**, 142-147, doi:10.1038/s41558-018-0370-z (2019).

25 Krause, D. J., Bonin, C. A., Goebel, M. E., Reiss, C. S. & Watters, G. M. 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, doi:10.3389/fmars.2021.796488 (2022).

26 Klemmedson, A. D. *et al.* Variability in age of a Southern Ocean myctophid (*Gymnoscopelus nicholsi*) derived from scat-recovered otoliths. *Marine Ecology Progress Series* **633**, 55-69 (2020).

27 Siniff, D. B., Garrott, R. A., Rotella, J. J., Fraser, W. R. & Ainley, D. G. Opinion: Projecting the effects of environmental change on Antarctic seals. *Antarctic Science* **20**, 425-435, doi:10.1017/S0954102008001351 (2008).

28 Hückstädt, L. A. *et al.* Projected shifts in the foraging habitat of crabeater seals along the Antarctic Peninsula. *Nature Climate Change* **10**, 472-477, doi:10.1038/s41558-020-0745-9 (2020).

29 Southwell, C. *et al.* 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, doi:10.1016/j.dsr.2008.01.005 (2008).

30 Rogers, T. L., Ciaglia, M. B., Klinck, H. & Southwell, C. Density can be misleading for low-density species: benefits of passive acoustic monitoring. *PLoS ONE* **8**, e52542, doi:10.1371/journal.pone.0052542 (2013).

31 Santora, J. A. & Veit, R. R. Spatio-temporal persistence of top predator hotspots near the Antarctic Peninsula. *Marine Ecology Progress Series* **487**, 287-304, doi:10.3354/meps10350 (2013).

32 Management Plan for Antarctic Specially Protected Area (ASPA) No. 149 Cape Shirreff and San Telmo Island, Livingston Island, South Shetland Islands *ATCM XLV Final Report* (2023).

33 R Core Team. R: A Language and Environment for Statistical Computing (R Foundation for Statistical Computing, Vienna, Austria, 2023).

34 Le Boeuf, B. J. & Laws, R. M. *Elephant seals: population ecology, behavior, and physiology*. (Univ of California Press, 1994).

35 Lake, S., Burton, H. & Hindell, M. Influence of time of day and month on Weddell seal haul-out patterns at the Vestfold Hills, Antarctica. *Polar biology* **18**, 319-324 (1997).

36 Sato, K., Tsuchiya, Y., Kudoh, S. & Naito, Y. Meteorological factors affecting the number of Weddell seals hauling-out on the ice during the molting season at Syowa Station, East Antarctica. *Polar Bioscience* **16**, 98-103 (2003).

37 Krause, D. J., Goebel, M. E., Marshall, G. J. & Abernathy, K. Summer diving and haul‐out behavior of leopard seals (Hydrurga leptonyx) near mesopredator breeding colonies at Livingston Island, Antarctic Peninsula. *Marine Mammal Science* **32**, 839-867 (2016).

38 de Gracia, N. *The Last Cold Place: A Field Season Studying Penguins in Antarctica*. (Scribner, 2023).