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

### Authors

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### Abstract

Rapid, climate change-fuelled warming of the Antarctic Peninsula 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 peninsula region for critical components of their life cycle. However, data collection is difficult in this remote region, and thus long-term time series with which to identify and investigate population changes or trends in these species are rare. We present the 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. CS-PHOC, which is publicly available through [www.biodiversity.aq](http://www.biodiversity.aq), will be updated yearly to continue 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 (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 & 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, Atkinson et al. 2022). 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 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 (Southwell et al. 2012). Crabeater seals are extremely numerous, and as krill specialists may be the largest marine mammal consumer of krill in the AP (Forcada et al. 2012, Hückstädt et al. 2012). In East Antarctica, southern elephant seal diet is mostly composed of cephalopods, but in the northern AP their diet consists primarily of myctophids (Bradshaw et al., 2003, 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 the krill population is contracting southward and away from traditional krill predator foraging hotspots in the northern AP (Atkinson et al. 2019). Indeed, over the last 20 years, krill have become less available to some regional predators (Krause et al. 2022). 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 (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) and have begun to be observed (Krause et al. 2022). However, a suite of unique challenges, including remote pack-ice environments and periodic haul-outs, has 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 using the few existing population counts, which have large associated uncertainties (Southwell et al. 2012).

In the northern AP, Cape Shirreff, Livingston Island 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). As part of long-term monitoring efforts at Cape Shirreff, the National Oceanic and Atmospheric Administration (NOAA) United States Antarctic Marine Living Resources Program (U.S. AMLR) 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; Fig. 1) 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) surveys were conducted by INACH from 1997/98 to 2006/07 (note that census and survey are used interchangeably throughout the rest of this paper). The U.S. AMLR Pinniped Research Program resumed these surveys in 2009/10, and, except for 2020/21 when the field season was cancelled due to the COVID-19 pandemic, has performed them every season through the time of publication. Most CS-PHOC surveys were completed within one day, but 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 technicians surveyed all safely accessible regions of Cape Shirreff and recorded all live phocids. They collected counts of each species, as well as age class and sex when possible. 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 the coastline and phocid haul-out locations at Cape Shirreff (Fig. 1), thereby ensuring that CS-PHOC counts are representative of phocid haul-out at Cape Shirreff during each census window. Locations were surveyed on foot, either by walking through haul-out locations, or using binoculars from a high vantage point when practical. Counts were recorded in field notebooks. After the census, data were either entered into a database or otherwise archived.

Entered 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 program directors, explicit records with zeroes or missing codes as appropriate, were added to the U.S. AMLR data for core census locations for this dataset.

**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, 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 (R Core Team 2023). 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. For this dataset, all pup counts were aggregated to a single, total pup count for each census record.

After cleaning, 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 core census location count values, along with counts for one other location described in Data Records below, 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 presented in this paper have been published to SCAR Antarctic Biodiversity Portal ([www.biodiversity.aq](http://www.biodiversity.aq), via the Integrated Publishing Toolkit at www.ipt.biodiversity.aq), which will also 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 uploaded once it has been cleaned and processed, ensuring that the published CS-PHOC dataset remains up to date for present and future analyses.

### Data Records

The full dataset consists of two CSV files: cs-phoc-headers.csv and cs-phoc-counts.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 census index, and thus all key values are character strings that represent a specific CS-PHOC survey.

The headers CSV file contains, in addition to the header ID key, 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 survey (‘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 if there were no data.

Field technicians generally split out core areas into smaller areas; however, the boundaries of those smaller scale areas 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 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).

### Technical Validation

All header records were also reviewed and confirmed using the 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 scans of a technician’s field notebooks. Count records were also 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) were consistent. Program directors were consulted about all observed 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 intrinsic and extrinsic drivers of phocid haul-out 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 seals 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 (Le Boeuf and Laws 1994). 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 state of the weather (e.g., precipitation), tides, or time of day (Lake et al. 1997, Sato et al. 2003, Southwell et al. 2012, Krause et al. 2016). Methods exist to correct for these factors in regional census data (e.g., Southwell et al. 2012); however, the CS-PHOC counts CSV does not have census date or time columns as survey times were recorded inconsistently across seasons (i.e., sometimes times were recorded for each beach, and sometimes for a full survey effort), and the aggregation of multi-day surveys for this dataset. While implementing haul-out corrections is thereby impractical for these data, 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. Also, start and end times were recorded for each individual census record beginning in the 2021/22 field seasons, and thus implementing haul-out corrections will be possible for future data.

Since the counts CSV does not have a date column, we recommend joining the header and count CSV files and using the census\_start\_date column as the record date. This, as well as making the records data frame long instead of wide, is demonstrated in sample code in the example.R file in the project GitHub repo.

As described in the Data Records section, the only counts that can be compared across the full timeseries 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. If including counts for Punta San Telmo, users should only use data from the 2009/10 field season onwards. Parties with general questions about these data, or those interested in finer resolution survey data with specific start and end times, 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/cs-phoc>.

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This manuscript is in memoriam of Daniel Torres Castillo (1982-2021), who contributed greatly to the collection of this data in the field. Thank you to Alex Curtis [add other reviewers] whose thoughtful comments improved this manuscript. In addition, “for every long-term population trend reported in a journal article there are decades of field biologists standing in the wind and snow, monitoring penguins or seals, hitting tally-whackers with numb fingers, far from family and friends and anything resembling human civilization” (de Gracia 2023). Our deepest gratitude to the biologists and technicians who make this data set possible.

### Author contributions

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

### Competing interests

The authors declare no competing interests.

### Figures

Fig. 1: Fig1\_cs\_map.png

Legend: Location of Cape Shirreff, Livingston Island. The right-most panel shows a satellite map of Cape Shirreff, with the core census locations shaded red and Punta San Telmo shaded green.

Fig. 2: Fig2\_census\_surveys.png

Legend: Dates of CS-PHOC surveys, as well as the research program that conducted the census and the time span, in days, of the census. The right panel is a barplot 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\_census\_record\_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: census record start and end times, by hour. Middle panel: The midpoint time, rounded to the nearest hour, of all census records with start and end times. Lower panel: length of time of census records with start and end times.

Fig. 4: Fig4\_census\_counts.png

Legend: Possible 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.csv

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

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