# Preview of Award 2224611 - Annual Project Report

Cover |
Accomplishments |
Products |
Participants/Organizations |
Impacts |
Changes/Problems

## Cover

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| Federal Agency and Organization Element to Which Report is Submitted: | 4900 |
| Federal Award or Other Identifying Number Assigned by Agency: | 2224611 |
| Project Title: | LTER: Ecological Response to "Press-Pulse" Disturbances Along a Rapidly Changing West Antarctic Peninsula |
| PD/PI Name: | Oscar Schofield, Principal Investigator<br>Janice McDonnell, Co-Principal Investigator<br>Deborah K Steinberg, Co-Principal Investigator |
| Recipient Organization: | Rutgers University New Brunswick |
| Project/Grant Period: | 09/01/2023 - 08/31/2027 |
| Reporting Period: | 09/01/2023 - 08/31/2024 |
| Submitting Official (if other than PD\PI): | Oscar Schofield<br>Principal Investigator |
| Submission Date: | 08/19/2024 |
| Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions) | Oscar Schofield |

## Accomplishments

*** What are the major goals of the project?**

Seasonal sea ice-influenced marine ecosystems at both poles are characterized by high productivity concentrated in space and time by local, regional, and remote physical forcing. These polar ecosystems are among the most rapidly changing on Earth. The PALmer (PAL) LTER seeks to build on three decades of long-term research along the western side of the Antarctic Peninsula (WAP) to gain new mechanistic and predictive understanding of ecosystem changes in response to disturbances spanning long-term, sub-decadal, and higher-frequency “pulses” driven by a range of processes, including long-term climate warming, natural climate variability, and storms. These disturbances alter food-web composition and ecological interactions across time and space scales that are not well understood. We will contribute fundamental understanding of how population dynamics and biogeochemical processes are responding within a polar marine ecosystem undergoing profound change.

*Intellectual Merit*. Three multidisciplinary, interrelated research themes guide our proposed work:

A. Drivers of disturbance across time/space scales: ecological and latitudinal response. How does the near continuum of long-term “press” (climate warming), sub-decadal (interannual changes in sea-ice cover), and shorter-term“pulse”(storms) disturbance drive changes in the food web across the WAP?

B. Vertical and alongshore connectivity as drivers of ecological change on local to regional scales. How do vertical and alongshore transport and mixing dynamics along the WAP interact to modulate the distribution and variability of ocean physics, and in turn marine productivity, krill, and krill predators?

C. Changing food webs and carbon cycling. How will changes in the structure of the WAP food web affect cycling and export of carbon? Additionally, how will changes in primary producers, and their energy storage, affect higher trophic levels?

Within the newly proposed work we will continue to address the influence from natural climate modes (e.g., El Niño

Southern Oscillation, Southern Annular Mode) on sea ice, weather, and oceanographic conditions that continue to drive change in ecosystem structure and function. Our sampling, analyses, and modeling cover multiple time scales–from diel, seasonal, interannual, to decadal intervals, and space scales–from hemispheric scale investigated by remote sensing, regional scale covered by a summer oceanographic cruise along the WAP, to local scale accessed by daily to biweekly small boat sampling at Palmer Station. Autonomous vehicles and moorings enable us to expand and bridge time and space scales not covered by vessel-based sampling, thus providing a seasonal to annual context. These observations are complemented with process studies that include manipulative experiments conducted during our research cruise and at Palmer Station. An extensive modeling effort with varying complexity allows us to improve mechanistic and dynamical understanding of the underlying processes driving change.

*Broader Impacts*. PAL research on climate change and ecological transformation is harnessed through an education and outreach program promoting the global significance of Antarctic science and research. Using the recently-developed Polar Literacy Principles as a foundation, we will maintain and expand our virtual schoolyard program via virtual fieldtrips and dissemination of new polar instructional materials for K-12 educators to facilitate their professional development and curricula. We will leverage the development of Out of School Time materials for afterschool, 4-H, and summer camp programs; develop and implement an art and science exhibition designed for use in higher education focused on engaging lifelong learners; and produce high quality science communication resources to build awareness of PAL research directly to audiences in the cruise ship industry and indirectly through social media. We will broaden participation through a coordinated diversity, equity, and inclusion plan leveraging both virtual and traditional Research Experience for Undergraduates programs at our institutions aimed at underrepresented students.

*** What was accomplished under these goals and objectives (you must provide information for at least one of the 4 categories below)?**

Major Activities:

The team conducted a very successful cruise onboard the RV Gould (LMG). This marks over three decades sailing aboard the Gould as part of this program. This being the last cruise on the Gould for many was an emotional event, the PAL team is deeply appreciative of the Gould and the amazing Captain and crew. We owe many of our successes to their dedication to our program and their local knowledge and experience operating along the peninsula. We have been blessed to have them as partners for so long.

The 2024 cruise was highly productive, accomplishing the science team's goals. The cruise was coordinated under the great leadership of Deborah Steinberg. The science team completed the 1) full PAL LTER sampling grid with a full complement of core LTER measurements, 2) conducted a series of four process stations including one in the far south close to the Charcot Island, 3) installed a weather station on Hugo Island, 4) recovered two gliders deployed from the NOAA AMLR group, 5) supported opportunistic sampling of mercury, 6) conducted deckboard diel measurements of the photophysiology, 7) collected a full suite of hyperspectral measurements to be combined with the NASA PACE measurements, 8) conducted deckboard measurements of zooplankton fecal pellet production and associated bacterial respiration rates, 9) conducted a full bird census of Avian Island combined with the surveys of Prospect Point and Hugo Island, 10) the whalers collected many biopsy samples from Orcas, humpacks (adults and 1 calf), 11) collected 1 adult elephant seal skull, 12) recovered and deployed two physical oceanographic moorings, and 13) successfully deployed Particle Interception Traps during the Process Station studies coupled to diel mocness zooplankton sampling, and 14) deployed an automatic weather station on Hugo Island.

The 2024 science season at Palmer Station was also a successful season. This was despite the fact that the science team was roughly half of what was in the funded proposal. The team conducted biweekly sampling at Station E and aimed for biweekly bioacoustic sampling as weather, functional RHIBs and personnel limitations allowed. The water column sampling was complemented with full bird

census counts for the Palmer Station penguin rookeries and full whale sampling. The acoustic and the discrete sampling was complemented with zooplankton net tows. The success of these efforts were directly impacted by the availability of the RHIBs. The lack of RHIB functionality required changes to the time series sampling - i.e., the use of zodiacs which is much more labor intensive and potentially less safe given the funded science efforts. Some of the issues are outlined in the report under Section 4 (Changes in approach and reasons for change).

Samples were collected for Laura Motta (sailed on LMG) for mercury analysis of penguin toenails, eggs, and feathers. We deployed 20 GPS-depth loggers on Adelie fledglings in collaboration with the Ross Sea Adelie penguin project to compare foraging behavior and survival between regions. Data suggests all except for one Palmer fledgling died, suggesting there is little recruitment in the breeding population near Palmer.

Specific Objectives:

The PAL LTER efforts are focused on gaining new mechanistic and predictive understanding of ecosystem changes in response to these disturbances spanning long-term, decadal, and higher-frequency “pulse” changes driven by a myriad of processes, including natural climate variability, long-term climate warming, resiliency/recovery in the face of press versus pulse forcing, altered spatial landscapes, and food-web alterations. Sea ice, wind and warming along the WAP are influenced by continental scale climate variability and tropical climate teleconnections, and PAL and collaborators focus on the mechanisms and long term climate impacts associated with the interactions between the Southern Annular Mode, El Niño–Southern Oscillation, Interdecadal Pacific Oscillation, and Atlantic Multidecadal Oscillation.

Our integrated sampling/modeling strategy is based on a multi-faceted program that incorporates the logistical realities of working in this remote environment. The sampling strategy is designed to resolve key ecological processes influenced by press-to-pulse disturbances that are expressed over a range of space/time scales. This is accomplished through a combination of multi-tiered and multi-platform sampling approaches, annual process-based high-resolution seasonal sampling, and field manipulative experiments. The results of the sampling activities inform modeling efforts that fill gaps through improved parameterization of key processes and provide data for assimilation modeling synthesis efforts. In turn, models guide the development of field process studies.

To achieve these science goals, the PAL LTER program has four complementary facets: a regional-scale oceanographic cruise, continuous regional-scale autonomous instrumentation (moorings, gliders, and airborne drones), manipulative experiments, and local-scale daily to weekly sampling in October-March from Palmer Station, including observations and measurements at Adélie, gentoo and chinstrap breeding colonies (PAL is unique in that all three Pygoscelid penguins breed here), and of other seabirds and whales. At Palmer Station, the annual penguin observations were initiated in 1975 and hydrographic sampling began in 1991. For this last year the PAL team conducted both a full field season at Palmer Station and a summer cruise on RV Gould.

Using the newly-developed Polar Literacy Principles as a foundation, we maintained and expanded our virtual schoolyard program via dissemination of new polar instructional materials and learning opportunities for K-12 educators to facilitate their professional development and curricula. We also leveraged the development of Out

of School Time materials for afterschool and summer camp programs, sharing Palmer LTER-specific teaching materials with University, Museum, and 4-H Special Interest Club partners.

Significant Results:

The PAL team has had a successful year getting the LTER work published in the primary literature. Selected findings in the publications are highlighted below:

-Photosynthetic carbon fixation by phytoplankton in the Southern Ocean (SO) plays a critical role in regulating air–sea exchange of carbon dioxide and thus global climate. PPRs are an important adaptation of SO phytoplankton to growth and survival in their cold, iron-limited, and variable light environment. This work was published in the Proceedings of the National Academies.

-Palmer Station located on the south-western coast of Anvers Island is mostly glaciated, on the western side of the Antarctic Peninsula. Behind Palmer Station sits the Marr Ice Piedmont, which once covered most of the rocky terrain and the team published for the first time a 60 year record of glacial retreat behind Palmer Station from 1963 to 2023. The work was published in Antarctic Sciences.

-Climate change is leading to phenological shifts across a wide range of species globally. We reviewed the phenology for species that occupy this region as year-round residents. From an Adélie penguin perspective, earlier sea ice retreat and shifts in the timing of suitable conditions or prey characteristics could lead to mismatches, or asynchronies, that ultimately influence chick survival via their mass at fledging. This work was published in the journal Ecosphere.

-A Southern Giant Petrel Macronectes giganteus was satellite tracked during a long foraging trip. While at rest on the sea surface, the giant petrel drifted in a counterclockwise corkscrew pattern that is characteristic of an inertial oscillation in the Southern Ocean. This demonstrates that tracking data from resting seabirds can be used as passive drifters to estimate ocean surface currents. This work was published in Biodiversity Observations.

-Seasonal fluctuations are key features of the WAP ecosystems. We quantified zooplankton biomass, size structure, and composition at 2 coastal time-series stations in the northern WAP over 3 field seasons (November−March) with different sea-ice, temperature, and phytoplankton conditions. Seasonal succession was apparent, typically in decreasing zooplankton size and a shift to species that are less dependent upon phytoplankton. Various taxa shifted their phenology between years. This work was published in the Marine Ecology Progress Series.

- The notothenioid family Bathydraconidae is a poorly understood family of fishes endemic to the Southern Ocean. Using genetic and morphological data, we document and describe the larval stages of this unique species, offer a novel characteristic to distinguish it from the morphologically similar bathydraconid Prionodracoevansii and use the sampling locations to infer a possible spawning area of A. nudiceps along the western Antarctic Peninsula. This work was published in the Journal of Fish Biology.

- Cryonotothenioids constitute a subgroup of notothenioid fishes endemic to the Southern Ocean that are specialized to exist in a narrow range of near-freezing temperatures. We determined the critical thermal maxima (CTmax) of cryonotothenioid larvae. We sampled larvae of seven species representing three

cryonotothenioid families—Nototheniidae, Channichthyidae, and Artedidraconidae. For channichthyid and nototheniid species, CTmax values were positively correlated with body length, suggesting that younger, less motile larvae may be especially susceptible to rapid warming events. This is the first published test of acute thermal tolerance for any artedidraconid which did not correlate with body length. This work was published in Polar Science.

-Microbes play an important role in the WAP, however little is known about the genetic and metabolic diversity of Antarctic marine microbes. This study identified key microbial community functions and created a valuable sequence library collection for future Antarctic genomics research. This work was published in Frontiers of Marine Science.

-Antarctic iceberg melt rate estimates have been limited to very large icebergs in the open ocean. Here we use a remote-sensing approach to estimate iceberg melt rates from 2011 to 2022 for 15 study sites around Antarctica. Melt rates generally increase with iceberg draft and follow large-scale variations in ocean temperature: maximum melt rates for the western peninsula, western ice sheet, eastern ice sheet and eastern peninsula are ~50, ~40, ~5 and ~5m a−1, respectively. This work was published in the Journal Glaciology.

-The Southern Ocean has long been known to be an important region for CO2 uptake. We find good agreement on the mean Southern Ocean CO2 uptake 1985–2018, 50% smaller than previous estimates; however, the estimates of the temporal change of the Southern Ocean CO2 uptake differ by a factor of two and thus are not in agreement. Knowledge gaps exist not only in winter when observations are typically rare, but equally in summer when biology plays a larger role, which is typically represented too simplistically in the dynamic models. This work was published in Global Biogeochemical Cycles.

- Organic carbon within sea ice is an important aspect of southern ocean carbon cycling. To better understand both the trophic value and the diversity of lipids present within sea ice we employed high-resolution accurate-mass mass spectrometry to analyze ice core samples from six sites collected along the peninsula in November 2018.  These results shed light on the chemical diversity of a dynamic and ecosystem relevant carbon pool.  This work was published in Geochimica et Cosmochimica Acta.

-We describe the spatial distribution, types, and potential origins of marine debris in 2022/2023 near Palmer Station, Antarctica. This study is the first assessment of marine debris in this region and suggests that oceanography, weather patterns, and shoreline geomorphology could play a role in determining where debris will accumulate. This work was published in Marine Pollution Bulletin.

-Autonomous underwater buoyancy gliders have proven to be robust technologies that are capable of filling sampling gaps. Gliders have also provided a more sustained presence in polar seas than ships are able. Along the West Antarctic Peninsula, one of the most rapidly warming regions on this planet, gliders have proven to be a useful tool being used by the international community to link land research stations without requiring major research vessel ship support. This work was published by the Marine Technology Society.

-We examined the changing phenology of the satellite-derived phytoplankton accumulation season west of the Antarctic Peninsula to show that blooms are shifting later in the season over time in ice-associated waters. The timing of the start date

and peak date of the phytoplankton accumulation season occurred later over time from 1997 to 2022 in the marginal ice zone and over the continental shelf. Later phytoplankton bloom timing over the marginal ice zone and continental shelf will have consequences for surface ocean carbon uptake, food web dynamics, and trophic cascades. This work was published by the Marine Ecology Progress Series.

-Ice dynamic change is the primary cause of mass loss from the Antarctic Ice Sheet. Our results show that forcing by warm ocean water can cause the rapid onset of dynamic imbalance and increased ice discharge from glaciers on the Antarctic Peninsula, highlighting the region's sensitivity to future climate variability. This work was published in Nature Communications.

-We showed that Antarctic krill (Euphausia superba) body size and life-history cycle, as opposed to their overall biomass or regional environmental factors, exert the dominant control on the POC flux. Decreases in winter sea ice, an essential habitat for krill, are causing shifts in the krill population, which may alter these export patterns of faecal pellets, leading to changes in ocean carbon storage. This work was published in Nature.

Key outcomes or Other achievements:

- The team published the first record of marine debris in the Palmer region (Gallagher et al 2024a) and quantified potential sources in a regional context (Gallagher et al 2024b). The Palmer debris report was used by the ACA office as evidence of what countries (e.g., numerous Chinese water bottles) and types of activities (fishing) may be contributing to pollution. Marine debris observations are reported to CCAMLR each year.

- We provided information for updating the Management Plan for Antarctic Specially Protected Area (ASPA) No. 139 Biscoe Point, Anvers Island, Palmer Archipelago. Using PAL data and observations, we helped on the proposal to expand the ASPA boundary to protect seabirds against increased tourism.

- The PAL team is taking part in a LTER network synthesis grant "Interannual variability and long-term change in pelagic community structure across a latitudinal gradient". The effort is focused along two major lines of enquiry: 1) examining whether patterns & processes discovered in temperate oceans apply to the LTER pelagic sites, and 2) exploring whether recently proposed global pelagic community responses apply to the LTER sites, including how such responses are modulated by season and how they may have changed over decadal time-frames.

- We participated and presented at a NSF funded workshop on 'Future Directions for Southern Ocean Antarctic Nearshore and Coastal Research' and at a Wilson Center workshop on 'The Rules-Based Order in Antarctica and Global Challenges'.

- We contributed to the BAMS State of the Climate Antarctica and the Southern Ocean report.

- We developed a middle school level curriculum called Data to the Rescue: Penguins Need Our Help! The program was pilot tested in 22 states with over 1500 young people in both in and out of school contexts. In 2024, the kit is being sold through STEfinity and is being considered for adoption in three major school districts (Nevada, New Jersey, and Maryland).

*** What opportunities for training and professional development has the project provided?**

- Education and Outreach training and professional development: We offered professional development to 40 early

career polar scientists and graduate students (2021-2024) to prepare them to utilize our Polar Puzzles and Data to the Rescue resources as part of outreach events (e.g  the national library theme for summer reading Oceans of Possibilities in 2023, STEM outreach for youth programs, and teacher professional development).

- We conducted one-on-one consultations with early career researchers seeking to develop NSF GRF proposals or CAREER awards with an affiliation with ARIS (Center for Advancing Research Impacts in Society).
- We conducted 5 professional development programs for 5th-12th grade educators on using our Polar Literacy materials (https://polar-ice.org/polar-explorer-adventures/) , reaching approximately 82 educators).

This project has been a major supporter for graduate, undergraduate and post-doctora researchers.  Student who have been part of the effort include:

**Postdoctoral Researchers**

Jack Conroy - predictability of zooplankton along the WAP (postdoctoral researcher, UC Santa Cruz)

Kathryn Gallagher (postdoctoral researcher, Stony Brook) - marine debris

Dulcinea Groff (postdoctoral researcher, U. Wyoming)- palmer station weather

Greg Larsen (postdoctoral researcher, Wake Forest University) - seal and giant petrel distributions near Palmer Station

Jessica Turner (postdoctoral researcher, U Connecticutt), remote sensing of phytoplankton

**Graduate Researchers**

Jenny Allen (Graduate Student, UC Santa Cruz)- evolution of social foraging strategies in baleen whales

Frederike Benz (Graduate Student, U Delaware) dynamics of the Southern Bransfield Front.

Natalia Botero-Acosta (Graduate Student, UC Santa Cruz)- Migratory corridors of humpback whales between WAP and Colombia

Michael Cappola (Graduate student, U Delaware) long-term evolution of upper ocean properties along the WAP.

Mason Cole (Graduate Student, UC Santa Cruz)- Spatial ecology of krill and whale foraging inshore and offshore of PAL

Andrew Corso (Graduate Student, Virginia Institute of Marine Sciences)- Fishery ecology

Quintin Diou-Cass (Graduate Student, Rutgers), photoacclimation processes in West Antarctic peninsula.

Benjamin Fisher (Graduate Student,  U. Edinburgh), dissolved organic matter molecular diversity

Heather Forrer (Graduate Student, U. Florida), export flux into the deep sea

Joseph Gradone (Graduate Student, Rutgers) southern Bransfield frontal dynamics

Victoria Hermanson (Graduate Student, UC Santa Cruz) - seabird distriutions

Kenza Himmich (Graduate Student, SorbonneUniversity), thermodynamical versus dynamical seasonal sea-ice changes

Elena (Graduate Student, Polytechnic University of Marche) - otolith identification and variability

Ross Nichols (Graduate Student, UC Santa Cruz)- foraging behavior of humpback whales, seasonal changes in body condition of whales

Logan Pallin (Graduate Student, UC Santa Cruz)- reproductive physiology and stress in baleen whales

Evan Quinter (Graduate Student, U Delaware) storminess changes and impacts of wind forcing on penguin

Oksana Savenko (Graduate Student, UC Santa Cruz)- population structure of humpback whales around PAL and greater WAP

Mya Sharpe (Graduate Student, Rutgers), sea ice melt's impact on phytoplankton community composition

Kristin Steinke (Graduate Student, Oregon State University), reproductive development in female Antarctic krill

Maya I. Thomas (Graduate Student, Virginia Institute of Marine Sciences)- carbon flux dynamics

Arianna Torello (Graduate Student, UC Santa Cruz)- yearly acoustic presence of whales around PAL and vocal repertoire

Xin Wang (Graduate Student, U. Delaware) freshwater dynamics of the WAP shelf.

Meijao Xin (Graduate Student, Chinese Academy of Sciences), large-scale climate drivers of Antarctic temperature trends

**Undergraduate Researchers**

Michele Adams (Undergraduate Student, University of New Hampshire) Adelie penguin vocalizations in relation to chick age and environmental factors.

Grace Breitenbeck (Undergraduate Student, Virginia Institute of Marine Sciences)- Work on the cruise

Aniyah Chambers (Undergraduate Student, UC Santa Cruz)- population structure of humpback whales

Dianelle Fradet (Undergraduate Student, University of New Hampshire) Adelie penguin vocalizations in relation to chick age and environmental factors.

Martin Gonzalez (Undergraduate Student, UC Santa Cruz)- relationship between storm frequency and whale presence around PAL

Eliza Goodell (Undergraduate student, Oberlin)- sea-ice from local visual obs to regional satellite observation

Linda Liu (Undergraduate Student, UC Santa Cruz)- variation within and across bubble net feeding humpback whales around PAL

Meredith Nolan (Undergraduate Student, Virginia Institute of Marine Sciences)- analyzed zooplankton and larval fish samples

*** Have the results been disseminated to communities of interest? If so, please provide details.**

The team maintains a high publication rate in the peer reviewed literature. The publications are in high impact journals appropiate for this work.

*** What do you plan to do during the next reporting period to accomplish the goals?**

The team has ambitious goals for the coming year. The team does not have a cruise in the coming year but will deploy a full team to Palmer Station. Beyond the time series sampling there will be a focus on the sediment trap deployments, glacial ice melt incubation experiments, and increased sampling for whales and penguins. Teams will begin to deploy in late October and stay at Palmer until April 2025.

The team will continue to work with the other LTER pelagic sites in the ongoing synthesis efforts. We are examining whether two specific hypothesized mechanisms explaining long-term variability in populations: (1) The Linear Tracking Window hypothesis proposed that populations are most likely to track stochastic environmental forcing when their generation time matches the characteristic time scale of the environmental signal, and less likely when they are

mismatched. (2) The Double-Integration hypothesis proposed that cumulative integrations of white-noise atmospheric forcing can generate marine population responses that are characterized by strong transitions and prolonged apparent state changes. Second, we will test the Trophic Amplification hypothesis that proposes that global ocean animal biomass declines with climate warming, and that these impacts are amplified at higher trophic levels and at lower latitudes. This hypothesis has been found to be robust across several coupled marine ecosystem models; however, its predictions have not been tested with field data. The third focus of our efforts will examine whether recently proposed patterns of planktonic community organization hold up when exploring more taxonomically resolved data, and how/if these patterns have responded to stochastic or long-term environmental change.

We will conduct a mid-term review in late October 2024.

**Supporting Files**

| Filename | Description | Uploaded By | Uploaded On |
|---|---|---|---|
| Rosenthals 2023 (98).pdf | Gentoo mother and chicks at the Rosenthal Islands. | Oscar Schofield | 08/19/2024 |
| Small Boat Operations during a Gould cruise.pdf | Small boat operations during a cruise aborad the RV Gould | Oscar Schofield | 08/19/2024 |

## Products

**Books**

**Book Chapters**

**Inventions**

**Journals or Juried Conference Papers**
**View all journal publications currently available in the NSF Public Access Repository for this award.**

The results in the NSF Public Access Repository will include a comprehensive listing of all journal publications recorded to date that are associated with this award.

Sarmiento, Jorge L and Johnson, Kenneth S and Arteaga, Lionel A and Bushinsky, Seth M and Cullen, Heidi M and Gray, Alison R and Hotinski, Roberta M and Maurer, Tanya L and Mazloff, Matthew R and Riser, Stephen C and Russell, Joellen L and Schofield, Oscar M and Talley, Lynne D. (2023). The Southern Ocean carbon and climate observations and modeling (SOCCOM) project: A review. *Progress in Oceanography*. 219 (C) . Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Schofield, Oscar on 08/06/2024 ) Full text Citation details

Cimino, Megan A and Goerke, Marissa A and Bent, Shavonna. (2023). Sixty years of glacial retreat behind Palmer Station, Antarctica. *Antarctic Science*. 35 (6) . Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Schofield, Oscar on 08/06/2024 ) Full text Citation details

Turner, JS and Dierssen, H and Schofield, O and Kim, HH and Stammerjohn, S and Munro, DR and Kavanaugh, M. (2024). Changing phytoplankton phenology in the marginal ice zone west of the Antarctic Peninsula. *Marine Ecology Progress Series*. 734 . Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Schofield, Oscar on 08/06/2024 ) Full text Citation details

Larsen, Gregory D. and Varga, Hanna F. and Patterson-Fraser, Donna L. and Johnston, David W. and Cimino, Megan A.. (2024). Drone-based monitoring and geomorphology of southern giant petrel nests near Palmer Station, western Antarctic Peninsula. *Polar Biology*. 47 (5) . Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Schofield, Oscar on 08/06/2024 ) Full text Citation details

Seidel, Dena K. and Morin, Xenia K. and Staffen, Marissa and Ludescher, Richard D. and Simon, James E. and Schofield, Oscar. (2023). Building a collaborative, university-based science-in-action video storytelling model that translates science for public engagement and increases scientists' relatability. *Frontiers in Communication*. 7 . Status = Added in NSF-PAR

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Andrew, Sarah M. and Moreno, Carly M. and Plumb, Kaylie and Hassanzadeh, Babak and Gomez-Consarnau, Laura and Smith, Stephanie N. and Schofield, Oscar and Yoshizawa, Susumu and Fujiwara, Takayoshi and Sunda, William G. and Hopkinson, Brian M. and Septer, Alecia N. and Marchetti, Adrian. (2023). Widespread use of proton-pumping rhodopsin in Antarctic phytoplankton. *Proceedings of the National Academy of Sciences*. 120 (39) . Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Schofield, Oscar on 08/06/2024 ) Full text Citation details

Cimino, Megan and Moffat, Carlos. (2024). Southern giant petrels as indicators of ocean surface currents: Petrels as indicators of surface currents. *Biodiversity Observations*. 14 . Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Schofield, Oscar on 08/06/2024 ) Full text Citation details

Gallagher, Katherine L. and Selig, Gina M. and Cimino, Megan A.. (2024). Descriptions and patterns in opportunistic marine debris collected near Palmer Station, Antarctica. *Marine Pollution Bulletin*. 199 (C) . Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Schofield, Oscar on 08/06/2024 ) Full text Citation details

Kim, Heather H and Laufkötter, Charlotte and Lovato, Tomas and Doney, Scott C and Ducklow, Hugh W. (2023). Projected 21st-century changes in marine heterotrophic bacteria under climate change. *Frontiers in Microbiology*. 14 . Status = Added in NSF-PAR

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Dutta, Avishek and Connors, Elizabeth and Trinh, Rebecca and Erazo, Natalia and Dasarathy, Srishti and Ducklow, Hugh W. and Steinberg, Deborah K. and Schofield, Oscar M. and Bowman, Jeff S.. (2023). Depth drives the distribution of microbial ecological functions in the coastal western Antarctic Peninsula. *Frontiers in Microbiology*. 14 . Status = Added in NSF-PAR

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Holm, Henry C and Fredricks, Helen F and Bent, Shavonna M and Lowenstein, Daniel P and Schrage, Kharis R and Van_Mooy, Benjamin AS. (2024). Lipid composition, caloric content, and novel oxidation products from microbial communities within seasonal pack ice cores. *Geochimica et Cosmochimica Acta*. 368 (C) . Status = Added in NSF-PAR

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details

Pallin, Logan J. and Kellar, Nick M. and Steel, Debbie and Botero-Acosta, Natalia and Baker, C. Scott and Conroy, Jack A. and Costa, Daniel P. and Johnson, Chris M. and Johnston, David W. and Nichols, Ross C. and Nowacek, Doug P. and Read, Andrew J. and Savenko, Oksana and Schofield, Oscar M. and Stammerjohn, Sharon E. and Steinberg, Deborah K. and Friedlaender, Ari S.. (2023). A surplus no more? Variation in krill availability impacts reproductive rates of Antarctic baleen whales. *Global Change Biology*. 29 (8) . Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Schofield, Oscar on 08/06/2024 ) Full text Citation details

Lohmann, Amanda C. and Morton, Joseph P. and Schofield, Oscar M. and Nowacek, Douglas P.. (2023). Cyclical prey shortages for a marine polar predator driven by the interaction of climate change and natural climate variability. *Limnology and Oceanography*. 68 (12) . Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Schofield, Oscar on 08/06/2024 ) Full text Citation details

Hauri, Claudine and Pagès, Rémi and Hedstrom, Katherine and Doney, Scott C. and Dupont, Sam and Ferriss, Bridget and Stuecker, Malte F.. (2024). More Than Marine Heatwaves: A New Regime of Heat, Acidity, and Low Oxygen Compound Extreme Events in the Gulf of Alaska. *AGU Advances*. 5 (1) . Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Schofield, Oscar on 08/06/2024 ) Full text Citation details

Schofield, Oscar. (2024). Watching the sunrise on our ocean planet in a new era of marine science. *ICES Journal of Marine Science*. . Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Schofield, Oscar on 08/06/2024 ) Full text Citation details

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**Licenses**

**Other Conference Presentations / Papers**

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**Patent Applications**

**Technologies or Techniques**

**Thesis/Dissertations**

**Websites or Other Internet Sites**

**Supporting Files**

| Filename | Description | Uploaded By | Uploaded On |
|---|---|---|---|
| Akarotaxis gouldae.pdf | Akarotaxis gouldae, a new species of Antarctic dragonfish (Notothenioidei: Bathydraconidae) from the western Antarctic Peninsula | Oscar Schofield | 08/15/2024 |
| Sea Ice Extent.pdf | Time series of sea ice extent anomalies for Antarctica as a whole (A) and for the West Antarctica Peninsula (B). | Oscar Schofield | 08/15/2024 |
| Shifts in Phytoplankton Photophysiology.pdf | Time series of the photoprotective pigments (PPC) to chlorophyll a ratio overtime as a function of depth. Over time phytoplankton are more bright light adapted as the ocean mixed layer (dotted line) shallows. | Oscar Schofield | 08/15/2024 |
| Glacial Retreat Behind Palmer.pdf | Glacial retreat behind Palmer Station. a. Satellite image of the Palmer Station region taken in 2019 (Digital Globe), with coloured lines representing the location of the glacial terminus in surveyed years. b. Time series of the rate of glacial retreat. | Oscar Schofield | 08/19/2024 |

## Participants/Organizations

**What individuals have worked on the project?**

| Name | Most Senior Project Role | Nearest Person Month Worked |
|---|---|---|

| | | |
|---|---|---|
| Schofield, Oscar | PD/PI | 2 |
| McDonnell, Janice | Co PD/PI | 1 |
| Steinberg, Deborah | Co PD/PI | 2 |
| Cimino, Megan | Co-Investigator | 4 |
| Doney, Scott | Co-Investigator | 2 |
| Friedlaender, Ari | Co-Investigator | 3 |
| Moffat, Carlos | Co-Investigator | 3 |
| Mooy, Benjamin | Co-Investigator | 3 |
| Stammerjohn, Sharon | Co-Investigator | 2 |

**Full details of individuals who have worked on the project:**

**Oscar Schofield**
**Email:** oscar@marine.rutgers.edu
**Most Senior Project Role:** PD/PI
**Nearest Person Month Worked:** 2

**Contribution to the Project:** Principal Investigator

**Funding Support:** National Science Foundation, Rutgers University

**Change in active other support:** No

**International Collaboration:** Yes, Antarctica
**International Travel:** No

**Janice McDonnell**
**Email:** mcdonnel@marine.rutgers.edu
**Most Senior Project Role:** Co PD/PI
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Lead in charge of the Broader Impacts efforts

**Funding Support:** National Science Foundation, Rutgers University

**Change in active other support:** No

**International Collaboration:** Yes, Antarctica
**International Travel:** No

**Deborah K Steinberg**
**Email:** debbies@vims.edu

**Most Senior Project Role:** Co PD/PI
**Nearest Person Month Worked:** 2

**Contribution to the Project:** Co-Investigator, Chief Scientist of RV Gould cruise

**Funding Support:** National Science Foundation, Virginia Institute of Marine Sciences

**Change in active other support:** No

**International Collaboration:** Yes, Antarctica
**International Travel:** Yes, Antarctica - 0 years, 2 months, 0 days

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**Megan Cimino**
**Email:** megan.cimino@noaa.gov
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 4

**Contribution to the Project:** In charge of the sea bird component of this project

**Funding Support:** National Science Foundation, NOAA

**International Collaboration:** Yes, Antarctica
**International Travel:** Yes, Antarctica - 0 years, 4 months, 0 days

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**Scott Doney**
**Email:** scd4c@virginia.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 2

**Contribution to the Project:** Lead of the modeling component of this project

**Funding Support:** National Science Foundation

**International Collaboration:** Yes, Antarctica
**International Travel:** No

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**Ari Friedlaender**
**Email:** arsfried@ucsc.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 3

**Contribution to the Project:** Lead of the marine mammal component of the program

**Funding Support:** National Science Foundation, UC Santa Cruz

**International Collaboration:** Yes, Antarctica
**International Travel:** No

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**Carlos Moffat**
**Email:** cmoffat@udel.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 3

**Contribution to the Project:** Lead of the Physical Oceanography component of the program

**Funding Support:** National Science Foundation, U. Delaware

**International Collaboration:** Yes, Antarctica
**International Travel:** Yes, United Kingdom - 0 years, 8 months, 0 days

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**Benjamin Mooy**
**Email:** bvanmooy@whoi.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 3

**Contribution to the Project:** Lead of the microbial component of the program

**Funding Support:** National Science Foundation

**International Collaboration:** Yes, Antarctica
**International Travel:** No

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**Sharon Stammerjohn**
**Email:** sharon.stammerjohn@colorado.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 2

**Contribution to the Project:** Lead of the sea ice and climate components of the project

**Funding Support:** National Science Foundation

**International Collaboration:** Yes, Antarctica
**International Travel:** No

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## What other organizations have been involved as partners?

| Name | Type of Partner Organization | Location |
|---|---|---|
| British Antarctic Survey | Other Organizations (foreign or domestic) | Cambridge, United Kingdom |

## Full details of organizations that have been involved as partners:

**British Antarctic Survey**

**Organization Type:** Other Organizations (foreign or domestic)
**Organization Location:** Cambridge, United Kingdom

**Partner's Contribution to the Project:**
In-Kind Support
Collaborative Research
Personnel Exchanges

**More Detail on Partner and Contribution:** BAS is a long term formal partner to the PAL LTER program

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**Were other collaborators or contacts involved? If so, please provide details.**

Jeff Bowman, (UC San Diego)

Michael Dinniman (Old Dominion University)

Judith Hauck (Alfred-Wegener-Institut, Germany)

Ya-Wei Luo (Xiamen University, China)

Alex Brearley, Hugh Venables, Heather Regan and Peter Holland, Kate Hendry (British Antarctic Survey)

Elizabeth Shadwick (CSIRO Oceans and Atmosphere, Australia)

Gordon Zhang (Woods Hole Oceanographic Institution)

Heidi Dierssen (Professor, U. Connecticut)

Jessie Turner (Old Dominion University)

Ted Scambos (CIRES, Colorado University at Boulder)

Ted Maksym (Woods Hole Oceanographic Institution)

Phil Reid (Australian Bureau of Met, Tasmania)

Rob Massom (Australian Ant. Division, Tasmania)

Sian Henley (Professor, U. Edinburgh)

Benjamin Fisher (Graduate Student, U. Edinburgh)

Michael Stukel (Professor, U. Florida Talahasse)

Heather Forrer (Graduate Student, U. Florida Talahasse)

Christian Reiss, George Watters (NOAA)

Ann Tarrant (Woods Hole Oceanographic Institution)

Mario La Mesa (Istituto di Scienze Polari)

Laura Motta (WHOI)

Grant Ballard, Annie Schmidt (Point Blue Conservation Science)

Kelly Benoit-Bird (MBARI)

Mark Moline (Udel)

William Sydeman (Farallon Institute)

Mike Polito (UCSC)

Rachel Eveleth (Oberlin College)

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## Impacts

**What is the impact on the development of the principal discipline(s) of the project?**

The Palmer Long Term Ecological Research (PAL) program is focused on developing a comprehensive understanding of the seasonal sea ice-influenced ecosystem along the West Antarctic Peninsula (WAP) – the climate, plants, microbes, animals, biogeochemical processes, ocean, and sea ice south of the Antarctic Polar Front (northernmost extent of ice-influenced water). Since its inception in 1990, the central hypothesis of PAL has been that the seasonal and interannual variability of sea ice affects all levels of the Antarctic marine ecosystem, from the timing and magnitude of primary production to the breeding success and survival of top predators.

*Long-term change and ecosystem transitions*: The WAP has changed significantly over at least the last fifty years with continued change projected into the future. The most rapid sea ice decreases in Antarctica have occurred along the WAP and the Bellingshausen Sea. Seasonal sea ice changes in the WAP region are largely wind driven by tropical Pacific and Atlantic Ocean teleconnections (El Niño Southern Oscillation; ENSO), and the Southern Annular Mode (SAM). There are latitudinal differences as the PAL sampling grid spans a climate gradient between the warmer northern and colder southern regions. In the southern region of the PAL sampling grid, summer upper-ocean mixed layer depth (MLD) has shallowed by a factor of two over the last 20 years, with long-term satellite/ship observations showing concomitant increases in phytoplankton abundance. The increased biomass is consistent with observations/experiments that inner shelf primary productivity is light-limited, which is alleviated by a shallower MLD. However, the recent sea ice reversal resulted in increased annual phytoplankton biomass in northern coastal waters, which reversed long-term phytoplankton declines previously observed there. While the base of the WAP food web has changed significantly, long-term trends in zooplankton communities are mixed. The keystone species Euphausia superba (Antarctic krill) exhibits no significant long-term directional change in the LTER study region, although their populations further north have significantly decreased. Other key macrozooplankton taxa show both increasing and decreasing trends in abundance, and some–such as salps and pteropods–are significantly correlated with ENSO or SAM climate cycles. Higher trophic levels also show mixed responses. Antarctic baleen whales, specifically humpbacks (Megaptera novaeangliae), are increasing along the WAP, recovering from their near extirpation due to commercial whaling. An increase in the population of ice-intolerant gentoo penguins (Pygoscelis papua) is coincident with a decrease in ice-obligate Adélie penguins (P. adeliae) near Palmer Station. The Adélie penguin population has decreased by ~90% near Palmer, with no declines seen at colder southern colonies. While Adélie breeding phenology at Palmer tracks regional trends in sea ice over the last three decades, the population decline from 1974 to 2010 leveled-off during the recent decade of sea ice trend reversal, despite the expectation that increased sea ice would lead to increased chick survival and recruitment. However, penguin populations are not only affected by shifts in sea ice in the ocean, but also shifts on land . For example, precipitation impacts breeding habitat quality on land that then influences breeding success and phenology, and wet and windy weather has been linked to Adélie penguin chick fledging mass.

*Lateral connectivity and vertical stratification*: Along the WAP lateral transports of freshwater, heat, and nutrients affect local stratification, thereby modulating biological productivity and the distribution of organisms. PAL focuses on both local- and large-scale ecological interactions that are structured by a combination of WAP geography, climate forcing, and ocean-atmosphere-ice connections. The warm (>1.5ºC), nutrient-laden Upper Circumpolar Deep Water (UCDW), transported by the Antarctic Circumpolar Current (ACC), abuts the continental shelf and moves into coastal regions, principally through and above cross-shelf canyons . UCDW enters the canyons as intrusions forming eddies that dissipate as they move inshore, mixing with colder, fresher shelf water, and forming modified UCDW (mUCDW). As the eddies are transported shoreward they predominantly lose heat laterally and downward, thus preserving subsurface heat, which is then available to melt marine-terminating glaciers. The mUCDW transport terminates in coastal canyons that are biological hotspots associated with major Adélie penguin colonies. These coastal canyons have significant and recurrent diatom blooms that were hypothesized to result from either enhanced upwelling of nutrient rich mUCDW water or shoaling of the upper MLD allowing phytoplankton to overcome light limitation. Incubation experiments using mUCDW from canyons show nutrients did not promote growth, indicating light is the more important factor.

*Top-down controls and shifting baselines*: We have been focused on determining the status of WAP whale populations and how their sympatric penguin competitors utilized the available prey-scape. Humpback whales are expanding rapidly along the WAP, consistent with observed high pregnancy rates. Humpback whales using the waters encompassing the PAL sampling grid are almost exclusively from a single population that breeds off the west coast of Central and South America. These whales had an average annual pregnancy rate of 64%, with some individuals breeding every year. Given

the energetic demands of such high fecundity (and release of competition with other krill-consuming blue and fin whales which have not recovered from whaling) it is unlikely that krill are a limiting resource for whales. Along the WAP, Adélie and gentoo penguin breeding colonies are often sympatric and possibly compete for prey. In the Palmer region, while their diets and foraging areas can overlap horizontally, each have separate core foraging regions and Adélies tend to feed at shallower depths than gentoos. While penguin and whale foraging regions overlap vertically and horizontally, temporal partitioning occurs where penguins forage mainly during the day and whales at night. Furthermore, the presence of whales in the PAL region during these periods is episodic and largely driven by the presence of dense krill patches. There is again no evidence that krill are a limiting resource during the penguin breeding season.

*Foodweb structure and biogeochemical processes*: Near-shore, coastal waters exhibit strong seasonal biological drawdown of inorganic nutrients as well as pCO2 and dissolved inorganic carbon, with the carbon signal modulated by sea ice, glacial freshwater input, and air-sea exchange. Waters south of Anvers Island are exhibiting changes in physical forcing with a decadal shallowing of the summer MLD that is correlated with increasing chlorophyll a and decreasing pCO2. On decadal time-scales, rising atmospheric CO2 is projected to drive increasing pCO2 and acidification of Southern Ocean surface waters, but the acidification signal is yet difficult to detect in the PAL dataset because of substantial regionally-varying biological and physical factors and interannual climate variability. Consequently, carbonate chemistry parameters, such as aragonite saturation, are not strong indicators of shelled pteropod abundance in the WAP, likely because the WAP is not yet significantly undersaturated with respect to aragonite. Inverse modeling of the WAP marine food web clearly suggests that micro-heterotrophy represents a significant fraction of the carbon cycling, results that are supported by observations of significant viral activity.

**What is the impact on other disciplines?**

The PAL LTER program is providing fundamental insights into ecology. Our framework is based on a suite of biological processes, spanning a range of space/time scales that underlie ecosystem dynamics. Environmental change also reflects physical/chemical forcing across a wide range of spatio-temporal scales with intra-seasonal “pulse” disturbances superimposed on long term “press” disturbances. The corresponding response of the ecosystem to change reflects how species evolved life histories are suited, or not, for the “new” dynamics of the altered system.

PAL LTER has also provided an effort to evolve ocean observing technologies to better sample this remote extreme environment. The program is innovating the use of autonomous gliders working in collaboration with the NOAA and the British Antarctic Service. The use of new technologies is being highlighted in a Special Issue of polar technologies for the Marine Technology Society to be published in late 2024. Additionally, the PAL LTER has joined three other marine LTER on a network synthesis of the system. This effort is focused on the similarities and differences in how pelagic marine ecosystems have been influenced by cyclic and long-term changes in the marine environment. The team is diving deeper into such comparisons, by using comparative data to test a series of conceptual models describing how communities respond to stochastic and long-term change along the latitudinal gradient represented by the four participating LTER sites. The effort is a multipronged team approach exploring whether recently proposed global pelagic community responses apply to the LTER sites, including how such responses are modulated by season and how they may have changed over decadal time-frames.

**What is the impact on the development of human resources?**

This project has been a major supporter for graduate, undergraduate and post-doctora researchers. Student who have been part of the effort include:

**Postdoctoral Researchers**

Jack Conroy - predictability of zooplankton along the WAP (postdoctoral researcher, UC Santa Cruz)

Kathryn Gallagher (postdoctoral researcher, Stony Brook) - marine debris

Dulcinea Groff (postdoctoral researcher, U. Wyoming)- palmer station weather

Greg Larsen (postdoctoral researcher, Wake Forest University) - seal and giant petrel distributions near Palmer Station

Jessica Turner (postdoctoral researcher, U Connecticutt), remote sensing of phytoplankton

**Graduate Researchers**

Jenny Allen (Graduate Student, UC Santa Cruz)- evolution of social foraging strategies in baleen whales

Frederike Benz (Graduate Student, U Delaware) dynamics of the Southern Bransfield Front.

Natalia Botero-Acosta (Graduate Student, UC Santa Cruz)- Migratory corridors of humpback whales between WAP and Colombia

Michael Cappola (Graduate student, U Delaware) long-term evolution of upper ocean properties along the WAP.

Mason Cole (Graduate Student, UC Santa Cruz)- Spatial ecology of krill and whale foraging inshore and offshore of PAL

Andrew Corso (Graduate Student, Virginia Institute of Marine Sciences)- Fishery ecology

Quintin Diou-Cass (Graduate Student, Rutgers), photoacclimation processes in West Antarctic peninsula.

Benjamin Fisher (Graduate Student,  U. Edinburgh), dissolved organic matter molecular diversity

Heather Forrer (Graduate Student, U. Florida), export flux into the deep sea

Joseph Gradone (Graduate Student, Rutgers) southern Bransfield frontal dynamics

Victoria Hermanson (Graduate Student, UC Santa Cruz) - seabird distriutions

Kenza Himmich (Graduate Student, SorbonneUniversity), thermodynamical versus dynamical seasonal sea-ice changes

Elena (Graduate Student, Polytechnic University of Marche) - otolith identification and variability

Ross Nichols (Graduate Student, UC Santa Cruz)- foraging behavior of humpback whales, seasonal changes in body condition of whales

Logan Pallin (Graduate Student, UC Santa Cruz)- reproductive physiology and stress in baleen whales

Evan Quinter (Graduate Student, U Delaware) storminess changes and impacts of wind forcing on penguin

Oksana Savenko (Graduate Student, UC Santa Cruz)- population structure of humpback whales around PAL and greater WAP

Mya Sharpe (Graduate Student, Rutgers), sea ice melt's impact on phytoplankton community composition

Kristin Steinke (Graduate Student, Oregon State University), reproductive development in female Antarctic krill

Maya I. Thomas (Graduate Student, Virginia Institute of Marine Sciences)- carbon flux dynamics

Arianna Torello (Graduate Student, UC Santa Cruz)- yearly acoustic presence of whales around PAL and vocal repertoire

Xin Wang (Graduate Student, U. Delaware) freshwater dynamics of the WAP shelf.

Meijao Xin (Graduate Student, Chinese Academy of Sciences), large-scale climate drivers of Antarctic temperature trends

**Undergraduate Researchers**

Michele Adams (Undergraduate Student, University of New Hampshire) Adelie penguin vocalizations in relation to chick age and environmental factors.

Grace Breitenbeck (Undergraduate Student, Virginia Institute of Marine Sciences)-  Work on the cruise

Aniyah Chambers (Undergraduate Student, UC Santa Cruz)- population structure of humpback whales

Dianelle Fradet (Undergraduate Student, University of New Hampshire) Adelie penguin vocalizations in relation to chick age and environmental factors.

Martin Gonzalez (Undergraduate Student, UC Santa Cruz)- relationship between storm frequency and whale presence around PAL

Eliza Goodell (Undergraduate student, Oberlin)- sea-ice from local visual obs to regional satellite observation

Linda Liu (Undergraduate Student, UC Santa Cruz)- variation within and across bubble net feeding humpback whales around PAL

Meredith Nolan (Undergraduate Student, Virginia Institute of Marine Sciences)- analyzed zooplankton and larval fish samples

**What was the impact on teaching and educational experiences?**

The PAL LTER education and outreach program focuses on increasing the publics' knowledge and excitement for science conducted along the western Antarctic peninsula (WAP) through partnerships with a wide variety of informal science centers, universities, science museums, aquariums, nonprofit organizations, corporations, broadcast media, community and government leaders.

We strive to:

- Promote understanding of the polar ocean environment though our Polar Literacy Initiative
- Support the next generation of young scientists through rich and innovative field and classroom experiences for K-12 students; and
- Provide opportunities to pursue lifelong learning through public outreach initiatives, events, and meetings.

We infuse the science of the WAP into effective practices of teaching and learning through our focus on:

Data Literacy: Our programs highlight the value of long-term ecological research and scientific data collection. Our educational programming such as our Polar Literacy Data Jam and Sci-I program use LTER data to build students' data skills.

Diversity, equity, inclusion, and awareness: We consider diversity, equity, inclusion, and awareness in every aspect of the development and implementation of our programs. Over this project in concert with leveraged NSF funding we developed Polar Camps & Afterschool Programs (Polar CAP). The project's goal was to develop an educational research-based program designed to develop innovative ways of engaging young learners in exploring scientific data while increasing their understanding of the Polar Regions.

Developed during the 2020 pandemic, the Polar CAP materials have been designed to be adaptable for various facilitators and youth groups. The Polar Adventure online modules can be used as a guided tour through the Polar Regions for youth.

Our Facilitator guides offer opportunities and information on how to engage young people in social interaction and collaboration as they learn about the Polar Regions and climate change. We encourage learning through conversation where youth can tap their prior knowledge and share their ideas and insights. Facilitators are encouraged to follow this learning format of Engage, Explore, Make Meaning. The Polar CAP effort represents a joint effort by Rutgers University, California State University – Monterey Bay, Monterey Bay Aquarium Research Institute (MBARI), Eidos Education, Indiana University and Open Minds Media. Special thanks to our contributors including scientists and educators from Lamont Doherty Earth Observatory, Byrd Polar and Climate Research Center, The Ohio State University, Arctic Research

Consortium of the U.S. (ARCUS), and the Long-term Ecological Research Programs – Palmer Station and McMurdo Dry Valleys.

The project developed the  Polar Literacy Principles that outline essential concepts to improve public understanding of these critical and sensitive ecosystems. The full effort is highlighted at https://polar-ice.org/polar-literacy-initiative/.

**What is the impact on physical resources that form infrastructure?**
Nothing to report.

**What is the impact on institutional resources that form infrastructure?**
Nothing to report.

**What is the impact on information resources that form infrastructure?**

We have continued to build on the Information Management (IM) tools and processes, following their transition from Scripps to Rutgers during the previous project.  The IM function includes four core tasks: 1) managing the PAL website, 2) maintaining the personnel and 3) journal databases, and 4) overseeing data management for the project.

- The PAL website received regular software and design updates.  And our blog has featured 16 stories so far this year.
- Regular software and data updates were also made to our custom personnel database, which is designed to track current and past team members.  Updates were synchronized with our team communications channels (comprising a Slack message board and four team email lists, including one for just students) and the LTER Network Office database.
- Our journal database (currently at 724 entries) is maintained in Zotero, and a searchable web interface (based on BLE's Zotero Javascript Search Client Repo) is available on our website.
- Finally, we have continued to refine our core data management workflow, which relies on a custom database for tracking tasks, the Environmental Data Initiative (EDI)'s data portal for archiving data, and their relatively new ezEML interface which streamlines metadata management, review and collaboration. We are still undergoing a thorough review and update of our core and historic datasets (several of which were impacted by pandemic disruptions).  During this project year, we have published 18 updates to 16 datasets (2 weather datasets received 2 updates each).  35 dataset updates are currently in process, which we hope to make in the next year (many are awaiting sample processing or QC review), and several new datasets are also in development.  As of August 2024, our archive includes 51 active datasets and 94 total datasets.

**What is the impact on technology transfer?**
Nothing to report.

**What is the impact on society beyond science and technology?**

The PAL LTER has significant visibility outside of the academic communities. Polar systems are key to the public as model systems illustrating the impact of climate change. This results in great public interest in the state and observed changes in polar systems. This is illustrated by the interest by news organizations to interview PAL LTER scientists. Specific efforts include:

A) Megan Cimino was interviewed by Amanda Ro, a sophomore student at The Bronx High School of Science, who is a staff reporter for the Science Survey (the high school newspaper) and wrote an article about climate change in Antarctica and the Arctic

https://thesciencesurvey.com/spotlight/2024/05/09/the-icy-mysteries-of-antarctica-and-the-arctic/

B) Megan Cimino and Sharon Stammerjohn were interviewed by John Weller of Only One and featured in youtube videos describing climate changes. These videos received ~40k views.

C) Sharon Stammerjohn was interviewed about recent Antarctic sea-ice changes by New Scientist (to be published in the August 16 issue ), by the National Snow and Ice Data Center as part of their 'Ask a Scientist' feature (https://nsidc.org/learn/ask-scientist/has-antarctic-sea-ice-hit-breaking-point), by the Wilson Center who provides nonpartisan insights to policy makers through research and independent scholarship (https://www.wilsoncenter.org/video/melting-point-where-antarctic-sea-ice), and by Douglas Fox, freelance science writer.

D) Carlos Moffat was interviewed about the extraordinary environmental conditions along the WAP during the summer of 2023 (https://insideclimatenews.org/news/12022023/antarctic-ice-shelves-marine-heatwave/)

**What percentage of the award's budget was spent in a foreign country?**

This project anchors extensive field deployments to Antarctica. This represents approximately 60% of the total project budget.

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## Changes/Problems

**Changes in approach and reason for change**

*Adjustments required in the 2023-2024 field season*. For the LTER the transition to cruises every other year makes the Palmer Station time series increasingly critical for documenting the ecology of a changing system. Decreasing availability in the berths at Palmer has had a significant science impact. We appreciate and understand the many struggles/efforts for improving existing infrastructure; however it has become exceedingly difficult to plan and conduct science at Palmer Station. This does not reflect on the significant efforts of personnel at Palmer who remain stalwart and enthusiastic in supporting science. Between the pandemic, dock construction, and most recently station infrastructure (e.g., heat loop project) repairs, the PAL team has ranged from 0 to 5 people, which is at best half of what was in the funded proposals. The limited berths require us to decrease overall sampling. Some of the core measurements such as 14C productivity cannot be supported with the reduced headcount. Additionally, Palmer Station is critical to graduate students who depend on the experimental work for their theses while also supporting/maintaining the overall core time series. Reduction of berths puts these needs in conflict, and it hurts one of the greatest strengths of the LTER program: to provide unique opportunities for field training for the next generation of Antarctic scientists. Reduction of berths also makes it nearly impossible to properly train people for the subsequent season. This is not just a science issue, but a safety one.

*Adjustments have been additionally complicated by shifting bunk availability after the SIP planning process is either completed or very advanced*. For graduate students, it is increasingly difficult to plan/support their thesis work which has been disrupted by these shifting team sizes. For example, the heat loop project required adjustment in the science personnel team size well after the SIP planning had finished and shipping deadlines had passed (i.e., some teams had purchased and shipped gear). There was little advance warning and no communication with the science teams during the planning process. In one example, PI Cimino hired technicians prior to the announcement of personnel cuts – technicians that turned down other jobs to go to Palmer, but then had to be let go. Unfortunately these highly trained people are no longer interested in future opportunities with our program. The changing number of people allowed at the station also affects the planning for experiments. Currently, there are rumors that the heat loop project will continue next year, which will impact the next field season but we have still received no formal communication about this. This information is critical to know prior to submitting our SIPs due in ~1 month. One recommendation is that if berths for PAL science are reduced, we ask to consider if ASC personnel should be reduced to accommodate another PAL scientist. If there are only 5 scientists on station, perhaps the lab manager and research associate role could be combined (as it was in January 2023 when the Palmer Station instrument technician sailed on the LMG as a marine technician).

*One person per team is not sustainable for a full season*. The funded science plans for each of the team efforts are designed for more than a science party of one. One person per team also leads to fatigue and burn-out and there is no way to train or pass down knowledge to new scientists deploying next season to ensure data continuity, all of which are also safety concerns.

*The availability/functionality of the RHIBs*. We appreciate that the RHIBs have been purchased and when working are a great asset; however their record of being available is mixed at best. To our knowledge both RHIBs have not been available the same year together since their delivery, nearly every year there are issues that make them unavailable at least temporarily and their design precludes many on-site repairs by the excellent boating support team at Palmer. The science sampling is critically dependent on these platforms and reaching the time series stations. The newest PAL LTER

iteration is tied to maintaining the Station E location for the time series as it has the cleanest ocean signal. With both RHIBs down this year, we needed to change sampling to other locations or use other less capable boats. This fundamentally alters the science that can be conducted. For example, the zooplankton component of the Palmer time series was severely limited in sampling this season and PI Steinberg's graduate student needing plankton net tows for her thesis work could not use the alternative platforms when the RHIBs are down. Continued focus on the possibilities of expanding functionalities on other vessels when the RHIBs are down is critical. One solution could be installing a winch on a SOLAS 6.0 as a contingency plan. Overall, we do not feel the marine landing craft (MLC) is a backup plan for the RHIBs. Currently, despite recent at-sea trials, the MLC on site since 2004, is not adequate for sampling the >30 year time series at station E. The MLC is not a sea going vessel, is unstable, difficult to navigate and unsafe for our work. Instruments swung and bounced off the Davit in small seas, raising concerns about using heavier and more expensive equipment. Graduate students report that hand lowering Go-Flows to depth from a zodiac is safer than the MLC.

*Also, the floating dock has been useful for loading and transferring heavy gear, but we recommend a review of the floating dock as currently designed*. It is not rated to support the current OSAR boat and has not been in use most of this season due to damage sustained from an iceberg. We recommend having an OSAR boat in the water provides fast response to any incidents. Also, noting that the constant boat issues are especially frustrating and fatiguing for the marine technicians who are needed to operate and maintain the boats. These technicians are extremely capable and willing to put in the extra work to fix the issues, but they are often unable to because of the complexities of the RHIBs. After our extended experience as users of the RHIBs, it is our view that NSF/ASC should strongly consider replacing these vessels for an alternative that is more suitable, both in terms of research needs and endurance and repairability, for the challenging work conditions of Palmer Station if robust solutions can be figured out.

**Actual or Anticipated problems or delays and actions or plans to resolve them**

One anticipated issue is the ability for Palmer to anchor climate robust science time series for the community. Currently the annual time series is collected by the Palmer Station water wall and meteorological data is not sufficiently robust to anchor time series analyses and is often not maintained. Calibrations are not certain, logs are lacking, many times the systems are not reporting data, and sensors/locations are modified without appropriate planning or documentation of changes, affecting the time series. For example, the weather station and snow stakes moved locations, existing documentation on instrument changes and known data quality issues have not been well communicated. The pump system that feeds water to a thermosalinograph (providing critical ambient temperature and salinity data) can bypass this sensor completely, and can additionally pump water from two different intakes. A second system on the pier is not on a regular calibration schedule and the sensors are not providing data of sufficient quality for climate research. Given the major changes observed along the western Antarctic Peninsula it is unfortunate that it is unlikely we have robust climate data from Palmer Station. This is critical as this is the only annual data time series measurements and is publicly available but due to the many errors and poor documentation it should not be published in its current form. *That said, this data could be of GREAT science value and we recommend pulling in scientists to advise on what would be required for collecting a climate relevant data set. In discussion with ASC, we are in agreement that the co-development of a pier-mounted CTD and tide gauge would be a better alternative to how the current ocean time series data is collected. Establishing additional requirements for documentation, metadata recording, and instrument calibration procedures could also greatly improve quality and scientific usability of core station datasets.*

**Changes that have a significant impact on expenditures**
Nothing to report.

**Significant changes in use or care of human subjects**
Nothing to report.

**Significant changes in use or care of vertebrate animals**
Nothing to report.

**Significant changes in use or care of biohazards**
Nothing to report.

**Change in primary performance site location**
Nothing to report.