Not for distribution

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 14-1 NSF 13-588 03/14/14	FOR NSF USE ONLY NSF PROPOSAL NUMBER **1440435**
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) DEB - Long-Term Ecological Research	

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
03/14/2014	1	08010000 DEB	1195	049179401	03/04/2015 7:01pm S

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)	SHOW PREVIOUS AWARD NO. IF THIS IS ☒ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)
135598093	1344502	

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE Columbia University	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE Columbia University 2960 Broadway NEW YORK, NY. 100276902
AWARDEE ORGANIZATION CODE (IF KNOWN) 0027078000	
NAME OF PRIMARY PLACE OF PERF Lamont-Doherty Earth Observatory	ADDRESS OF PRIMARY PLACE OF PERF, INCLUDING 9 DIGIT ZIP CODE Lamont-Doherty Earth Observatory 61 Route 9W Palisades ,NY ,109641707 ,US.

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions): ☐ SMALL BUSINESS ☐ FOR-PROFIT ORGANIZATION ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS ☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT: **LTER Palmer, Antarctica (PAL): Land-Shelf-Ocean Connectivity, Ecosystem Resilience and Transformation in a Sea-Ice Influenced Pelagic Ecosystem**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 6,761,997	72 months	09/01/14	

THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW
- ☐ BEGINNING INVESTIGATOR (GPG I.G.2)
- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C.1.e)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
- ☐ HISTORIC PLACES (GPG II.C.2.j)
- ☒ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date Planned
  PHS Animal Welfare Assurance Number A3415-01
- ☒ FUNDING MECHANISM Research - other than RAPID or EAGER
- ☐ HUMAN SUBJECTS (GPG II.D.7) Human Subjects Assurance Number ______
  Exemption Subsection ______ or IRB App. Date ______
- ☐ INTERNATIONAL ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j)
- ☒ COLLABORATIVE STATUS
  Not a collaborative proposal

PI/PD DEPARTMENT Lamont-Doherty Earth Observatory	PI/PD POSTAL ADDRESS 61 Route 9W PO BOX 1000 Palisades, NY 10964 United States
PI/PD FAX NUMBER 508-457-1548	

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Email Address
PI/PD NAME Hugh W Ducklow	PhD	1977	845-365-8167	hducklow@ldeo.columbia.edu
CO-PI/PD Douglas G Martinson	Ph.D.	1982	845-365-8830	dgm@ldeo.columbia.edu
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				

CERTIFICATION PAGE

Certification for Authorized Organizational Representative (or Equivalent) or Individual Applicant

By electronically signing and submitting this proposal, the Authorized Organizational Representative (AOR) or Individual Applicant is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding conflict of interest (when applicable), drug-free workplace, debarment and suspension, lobbying activities (see below), nondiscrimination, flood hazard insurance (when applicable), responsible conduct of research, organizational support, Federal tax obligations, unpaid Federal tax liability, and criminal convictions as set forth in the NSF Proposal & Award Policies & Procedures Guide,Part I: the Grant Proposal Guide (GPG). Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U.S. Code, Title 18, Section 1001).

Certification Regarding Conflict of Interest

The AOR is required to complete certifications stating that the organization has implemented and is enforcing a written policy on conflicts of interest (COI), consistent with the provisions of AAG Chapter IV.A.; that, to the best of his/her knowledge, all financial disclosures required by the conflict of interest policy were made; and that conflicts of interest, if any, were, or prior to the organization's expenditure of any funds under the award, will be, satisfactorily managed, reduced or eliminated in accordance with the organization's conflict of interest policy. Conflicts that cannot be satisfactorily managed, reduced or eliminated and research that proceeds without the imposition of conditions or restrictions when a conflict of interest exists, must be disclosed to NSF via use of the Notifications and Requests Module in FastLane.

Drug Free Work Place Certification

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent), is providing the Drug Free Work Place Certification contained in Exhibit II-3 of the Grant Proposal Guide.

Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) or Individual Applicant is providing the Debarment and Suspension Certification contained in Exhibit II-4 of the Grant Proposal Guide.

Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:
(1) No Federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any Federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.
(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.
(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

Certification Regarding Nondiscrimination

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is providing the Certification Regarding Nondiscrimination contained in Exhibit II-6 of the Grant Proposal Guide.

Certification Regarding Flood Hazard Insurance

Two sections of the National Flood Insurance Act of 1968 (42 USC §4012a and §4106) bar Federal agencies from giving financial assistance for acquisition or construction purposes in any area identified by the Federal Emergency Management Agency (FEMA) as having special flood hazards unless the:
(1) community in which that area is located participates in the national flood insurance program; and
(2) building (and any related equipment) is covered by adequate flood insurance.

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) or Individual Applicant located in FEMA-designated special flood hazard areas is certifying that adequate flood insurance has been or will be obtained in the following situations:
(1) for NSF grants for the construction of a building or facility, regardless of the dollar amount of the grant; and
(2) for other NSF grants when more than $25,000 has been budgeted in the proposal for repair, alteration or improvement (construction) of a building or facility.

Certification Regarding Responsible Conduct of Research (RCR)
(This certification is not applicable to proposals for conferences, symposia, and workshops.)

By electronically signing the Certification Pages, the Authorized Organizational Representative is certifying that, in accordance with the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Chapter IV.B., the institution has a plan in place to provide appropriate training and oversight in the responsible and ethical conduct of research to undergraduates, graduate students and postdoctoral researchers who will be supported by NSF to conduct research.
The AOR shall require that the language of this certification be included in any award documents for all subawards at all tiers.

CERTIFICATION PAGE - CONTINUED

Certification Regarding Organizational Support

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that there is organizational support for the proposal as required by Section 526 of the America COMPETES Reauthorization Act of 2010. This support extends to the portion of the proposal developed to satisfy the Broader Impacts Review Criterion as well as the Intellectual Merit Review Criterion, and any additional review criteria specified in the solicitation. Organizational support will be made available, as described in the proposal, in order to address the broader impacts and intellectual merit activities to be undertaken.

Certification Regarding Federal Tax Obligations

When the proposal exceeds $5,000,000, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Federal tax obligations. By electronically signing the Certification pages, the Authorized Organizational Representative is certifying that, to the best of their knowledge and belief, the proposing organization:
(1) has filed all Federal tax returns required during the three years preceding this certification;
(2) has not been convicted of a criminal offense under the Internal Revenue Code of 1986; and
(3) has not, more than 90 days prior to this certification, been notified of any unpaid Federal tax assessment for which the liability remains unsatisfied, unless the assessment is the subject of an installment agreement or offer in compromise that has been approved by the Internal Revenue Service and is not in default, or the assessment is the subject of a non-frivolous administrative or judicial proceeding.

Certification Regarding Unpaid Federal Tax Liability

When the proposing organization is a corporation, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Federal Tax Liability:

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that the corporation has no unpaid Federal tax liability that has been assessed, for which all judicial and administrative remedies have been exhausted or lapsed, and that is not being paid in a timely manner pursuant to an agreement with the authority responsible for collecting the tax liability.

Certification Regarding Criminal Convictions

When the proposing organization is a corporation, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Criminal Convictions:

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that the corporation has not been convicted of a felony criminal violation under any Federal law within the 24 months preceding the date on which the certification is signed.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME Maribel Respo	Electronic Signature	Mar 14 2014 12:30PM

TELEPHONE NUMBER	EMAIL ADDRESS	FAX NUMBER
845-365-8829	mrespo@admin.ldeo.columbia.edu	845-365-8112

Direct for Biological Sciences
Division of Environmental Biology
Long-term Ecological Research

Proposal Classification Form
PI: Ducklow, Hugh / Proposal Number: 1440435

CATEGORY I: INVESTIGATOR STATUS (Select ONE)

- ☐ Beginning Investigator - No previous Federal support as PI or Co-PI, excluding fellowships, dissertations, planning grants, etc.
- ☐ Prior Federal support only
- ☐ Current Federal support only
- ☑ Current & prior Federal support

CATEGORY II: FIELDS OF SCIENCE OTHER THAN BIOLOGY INVOLVED IN THIS RESEARCH (Select 1 to 3)

- ☐ Astronomy
- ☐ Chemistry
- ☐ Computer Science
- ☑ Geosciences
- ☐ Engineering
- ☐ Mathematics
- ☐ Physics
- ☐ Psychology
- ☐ Social Sciences
- ☐ None of the Above

CATEGORY III: SUBSTANTIVE AREA (Select 1 to 4)

- ☐ BIOGEOGRAPHY
- ☐ Island Biogeography
- ☐ Historical/ Evolutionary Biogeography
- ☐ Phylogeography
- ☐ Methods/Theory
- ☐ CHROMOSOME STUDIES
- ☐ Chromosome Evolution
- ☐ Chromosome Number
- ☐ Mutation
- ☐ Mitosis and Meiosis
- ☐ COMMUNITY ECOLOGY
- ☐ Community Analysis
- ☐ Community Structure
- ☐ Community Stability
- ☐ Succession
- ☐ Experimental Microcosms/ Mesocosms
- ☐ Disturbance
- ☐ Patch Dynamics
- ☐ Food Webs/ Trophic Structure
- ☐ Keystone Species
- ☐ COMPUTATIONAL BIOLOGY
- ☐ CONSERVATION & RESTORATION BIOLOGY
- ☐ DATABASES
- ☑ ECOSYSTEMS LEVEL
- ☐ Physical Structure
- ☐ Decomposition
- ☑ Biogeochemistry
- ☐ Limnology/Hydrology
- ☐ Climate/Microclimate
- ☐ Whole-System Analysis
- ☐ Productivity/Biomass
- ☐ System Energetics
- ☐ Landscape Dynamics
- ☐ Chemical & Biochemical Control
- ☐ Global Change
- ☑ Climate Change
- ☐ Regional Studies
- ☐ Global Studies
- ☐ Forestry
- ☐ Resource Management (Wildlife, Fisheries, Range, Other)
- ☐ Agricultural Ecology
- ☐ EXTREMOPHILES
- ☐ GENOMICS (Genome sequence, organization, function)
  - ☐ Viral
  - ☐ Microbial
  - ☐ Fungal
  - ☐ Plant
  - ☐ Animal
- ☑ MARINE MAMMALS
- ☐ MOLECULAR APPROACHES
- ☐ Molecular Evolution
- ☐ Methodology/Theory
- ☐ Isozymes/ Electrophoresis
- ☐ Nucleic Acid Analysis (general)
  - ☐ Restriction Enzymes
  - ☐ Nucleotide Sequencing
  - ☐ Nuclear DNA
  - ☐ Mitochondrial DNA
  - ☐ Chloroplast DNA
  - ☐ RNA Analysis
  - ☐ DNA Hybridization
  - ☐ Recombinant DNA
- ☐ Amino Acid Sequencing
- ☐ Gene/Genome Mapping
- ☐ Natural Products
- ☐ Serology/Immunology
- ☐ PALEONTOLOGY
- ☐ Floristic
- ☐ Faunistic
- ☐ Paleoecology
- ☐ Biostratigraphy
- ☐ Palynology
- ☐ Micropaleontology
- ☐ Paleoclimatology
- ☐ Archeozoic
- ☐ Paleozoic
- ☐ Mesozoic

- ☐ Cenozoic
- ☐ POPULATION DYNAMICS & LIFE HISTORY
- ☐ Demography/ Life History
- ☐ Population Cycles
- ☐ Distribution/Patchiness/ Marginal Populations
- ☐ Population Regulation
- ☐ Intraspecific Competition
- ☐ Reproductive Strategies
- ☐ Gender Allocation
- ☐ Metapopulations
- ☐ Extinction
- ☐ POPULATION GENETICS & BREEDING SYSTEMS
- ☐ Variation
- ☐ Microevolution
- ☐ Speciation
- ☐ Hybridization
- ☐ Inbreeding/Outbreeding
- ☐ Gene Flow Measurement
- ☐ Inheritance/Heritability
- ☐ Quantitative Genetics/ QTL Analysis
- ☐ Ecological Genetics
- ☐ Gender Ratios
- ☐ Apomixis/ Parthenogenesis
- ☐ Vegetative Reproduction
- ☐ SPECIES INTERACTIONS
- ☐ Predation
- ☐ Herbivory
- ☐ Omnivory
- ☐ Interspecific Competition
- ☐ Niche Relationships/ Resource Partititioning
- ☐ Pollination/ Seed Dispersal
- ☐ Parasitism
- ☐ Mutualism/ Commensalism
- ☐ Plant/Fungal/ Microbial Interactions
- ☐ Mimicry
- ☐ Animal Pathology
- ☐ Plant Pathology
- ☐ Coevolution
- ☐ Biological Control
- ☐ STATISTICS & MODELING
- ☐ Methods/ Instrumentation/ Software
- ☐ Modeling (general)
- ☐ Statistics (general)
  - ☐ Multivariate Methods
  - ☐ Spatial Statistics & Spatial Modeling
  - ☐ Sampling Design & Analysis
  - ☐ Experimental Design & Analysis
- ☐ SYSTEMATICS
- ☐ Taxonomy/Classification
- ☐ Nomenclature
- ☐ Monograph/Revision
- ☐ Phylogenetics
- ☐ Phenetics/Cladistics/ Numerical Taxonomy
- ☐ Macroevolution
- ☐ NONE OF THE ABOVE

CATEGORY IV: INFRASTRUCTURE (Select 1 to 3)

- ☐ COLLECTIONS/STOCK CULTURES
- ☐ Natural History Collections
- ☐ DATABASES
- ☐ FACILITIES
- ☐ Controlled Environment Facilities
- ☐ Field Stations
  - ☐ Field Facility Structure
  - ☐ Field Facility Equipment
- ☑ LTER Site
- ☐ INDUSTRY PARTICIPATION
- ☐ Technique Development
- ☐ TRACKING SYSTEMS
- ☐ Geographic Information Systems
- ☐ Remote Sensing
- ☐ NONE OF THE ABOVE

CATEGORY V: HABITAT (Select 1 to 2)

TERRESTRIAL HABITATS

- ☐ GENERAL TERRESTRIAL
- ☐ TUNDRA
- ☐ BOREAL FOREST
- ☐ TEMPERATE
  - ☐ Deciduous Forest
  - ☐ Coniferous Forest
  - ☐ Rain Forest
  - ☐ Mixed Forest
  - ☐ Prairie/Grasslands
  - ☐ Desert
- ☐ SUBTROPICAL
  - ☐ Rain Forest
  - ☐ Seasonal Forest
  - ☐ Savanna
  - ☐ Thornwoods
  - ☐ Deciduous Forest
  - ☐ Coniferous Forest
  - ☐ Desert
- ☐ TROPICAL
  - ☐ Rain Forest
  - ☐ Seasonal Forest
  - ☐ Savanna
  - ☐ Thornwoods
  - ☐ Deciduous Forest
  - ☐ Coniferous Forest
  - ☐ Desert
- ☐ CHAPPARAL/ SCLEROPHYLL/ SHRUBLANDS
- ☐ ALPINE
- ☐ MONTANE
- ☐ CLOUD FOREST
- ☐ RIPARIAN ZONES
- ☐ ISLANDS (except Barrier Islands)
- ☐ BEACHES/ DUNES/ SHORES/ BARRIER ISLANDS
- ☐ CAVES/ ROCK OUTCROPS/ CLIFFS
- ☐ CROPLANDS/ FALLOW FIELDS/ PASTURES
- ☐ URBAN/SUBURBAN
- ☐ SUBTERRANEAN/ SOIL/ SEDIMENTS
- ☐ EXTREME TERRESTRIAL ENVIRONMENT
- ☐ AERIAL

AQUATIC HABITATS

- ☐ GENERAL AQUATIC
- ☐ FRESHWATER
  - ☐ Wetlands/Bogs/Swamps
  - ☐ Lakes/Ponds
  - ☐ Rivers/Streams
  - ☐ Reservoirs
- ☐ MARINE
  - ☑ Open Ocean/Continental Shelf
  - ☐ Bathyal
  - ☐ Abyssal
  - ☐ Estuarine
  - ☐ Intertidal/Tidal/Coastal
  - ☐ Coral Reef
  - ☐ HYPERSALINE
- ☐ EXTREME AQUATIC ENVIRONMENT
- ☐ CAVES/ ROCK OUTCROPS/ CLIFFS
- ☐ MANGROVES
- ☐ SUBSURFACE WATERS/ SPRINGS
- ☐ EPHEMERAL POOLS & STREAMS
- ☐ MICROPOOLS (Pitcher Plants, Tree Holes, Other)

MAN-MADE ENVIRONMENTS

- ☐ LABORATORY
- ☐ THEORETICAL SYSTEMS
- ☐ OTHER ARTIFICIAL SYSTEMS

NOT APPLICABLE

- ☐ NOT APPLICABLE

CATEGORY VI: GEOGRAPHIC AREA OF THE RESEARCH (Select 1 to 2)

- ☐ WORLDWIDE
- ☐ NORTH AMERICA
  - ☐ United States
    - ☐ Northeast US (CT, MA, ME, NH, NJ, NY, PA, RI, VT)
    - ☐ Northcentral US (IA, IL, IN, MI, MN, ND, NE, OH, SD, WI)
    - ☐ Northwest US (ID, MT, OR, WA, WY)
    - ☐ Southeast US (DC, DE, FL, GA, MD, NC, SC, WV, VA)
    - ☐ Southcentral US (AL, AR, KS, KY, LA, MO, MS, OK, TN, TX)
    - ☐ Southwest US (AZ, CA, CO, NM, NV, UT)
    - ☐ Alaska
    - ☐ Hawaii
    - ☐ Puerto Rico
  - ☐ Canada
  - ☐ Mexico
- ☐ CENTRAL AMERICA (Mainland)
  - ☐ Caribbean Islands
  - ☐ Bermuda/Bahamas
- ☐ SOUTH AMERICA
  - ☐ Eastern South America (Guyana, Fr. Guiana, Suriname, Brazil)
  - ☐ Northern South America (Colombia, Venezuela)
  - ☐ Southern South America (Chile, Argentina, Uruguay, Paraguay)
  - ☐ Western South America (Ecuador, Peru, Bolivia)
- ☐ EUROPE
  - ☐ Eastern Europe
  - ☐ Russia
  - ☐ Scandinavia
  - ☐ Western Europe
- ☐ ASIA
  - ☐ Central Asia
  - ☐ Far East
  - ☐ Middle East
  - ☐ Siberia
  - ☐ South Asia
  - ☐ Southeast Asia
- ☐ AFRICA
  - ☐ North Africa
  - ☐ African South of the Sahara
    - ☐ East Africa
    - ☐ Madagascar
    - ☐ South Africa
    - ☐ West Africa
- ☐ AUSTRALASIA
  - ☐ Australia
  - ☐ New Zealand
  - ☐ Pacific Islands
- ☑ ANTARCTICA
- ☐ ARCTIC
- ☐ ATLANTIC OCEAN
- ☐ PACIFIC OCEAN
- ☐ INDIAN OCEAN
- ☐ OTHER REGIONS (Not defined)
- ☐ NOT APPLICABLE

CATEGORY VII: CLASSIFICATION OF ORGANISMS (Select 1 to 4)

- ☐ VIRUSES
  - ☐ Bacterial
  - ☐ Plant
  - ☐ Animal
- ☐ PROKARYOTES
  - ☐ Archaea
  - ☐ Cyanobacteria
  - ☐ Bacteria
  - ☐ Noncultured Organisms
- ☐ PROTISTA (PROTOZOA)
  - ☐ Amoebae
  - ☐ Apicomplexa
  - ☐ Ciliophora
  - ☐ Flagellates
  - ☐ Foraminifera
  - ☐ Microspora
  - ☐ Radiolaria
- ☐ FUNGI
  - ☐ Ascomycota
  - ☐ Basidiomycota
  - ☐ Chytridiomycota
  - ☐ Mitosporic Fungi
  - ☐ Oomycota
  - ☐ Zygomycota
- ☐ LICHENS
- ☐ SLIME MOLDS
- ☑ ALGAE
  - ☐ Bacillariophyta (Diatoms)
  - ☐ Charophyta
  - ☐ Chlorophyta
  - ☐ Chrysophyta
  - ☐ Dinoflagellata
  - ☐ Euglenoids
  - ☐ Phaeophyta
  - ☐ Rhodophyta
- ☐ PLANTS
  - ☐ NON-VASCULAR PLANTS
    - ☐ BRYOPHYTA
      - ☐ Anthocerotae (Hornworts)
      - ☐ Hepaticae (Liverworts)
      - ☐ Musci (Mosses)
  - ☐ VASCULAR PLANTS
    - ☐ FERNS & FERN ALLIES
    - ☐ GYMNOSPERMS
      - ☐ Coniferales (Conifers)

☐ Cycadales (Cycads)
☐ Ginkgoales (Ginkgo)
☐ Gnetales (Gnetophytes)
☐ ANGIOSPERMS
☐ Monocots
☐ Arecaceae (Palmae)
☐ Cyperaceae
☐ Liliaceae
☐ Orchidaceae
☐ Poaceae (Graminae)
☐ Dicots
☐ Apiaceae (Umbelliferae)
☐ Asteraceae (Compositae)
☐ Brassicaceae (Cruciferae)
☐ Fabaceae (Leguminosae)
☐ Lamiaceae (Labiatae)
☐ Rosaceae
☐ Solanaceae

☐ ANIMALS

☐ INVERTEBRATES
☐ MESOZOA/PLACOZOA
☐ PORIFERA (Sponges)
☐ CNIDARIA
☐ Hydrozoa (Hydra, etc.)
☐ Scyphozoa (Jellyfish)
☐ Anthozoa (Corals, Sea Anemones)
☐ CTENOPHORA (Comb Jellies)
☐ PLATYHELMINTHES (Flatworms)
☐ Turbellaria (Planarians)
☐ Trematoda (Flukes)
☐ Cestoda (Tapeworms)
☐ Monogenea (Flukes)
☐ GNATHOSTOMULIDA
☐ NEMERTINEA (Rynchocoela) (Ribbon Worms)
☐ ENTOPROCTA (Bryozoa) (Plant-like Animals)
☐ ASCHELMINTHES
☐ Gastrotricha
☐ Kinorhyncha
☐ Loricifera
☐ Nematoda (Roundworms)
☐ Nematomorpha (Horsehair Worms)
☐ Rotifera (Rotatoria)
☐ ACANTHOCEPHALA (Spiny-headed Worms)
☐ PRIAPULOIDEA
☐ BRYOZOA (Ectoprocta) (Plant-like Animals)
☐ PHORONIDEA (Lophophorates)
☐ BRACHIOPODA (Lamp Shells)
☐ MOLLUSCA
☐ Monoplacophora
☐ Aplacophora (Solenogasters)
☐ Polyplacophora (Chitons)
☐ Scaphopoda (Tooth Shells)
☐ Gastropoda (Snails, Slugs, Limpets)
☐ Pelecypoda (Bivalvia) (Clams, Mussels, Oysters, Scallops)
☐ Cephalopoda (Squid, Octopus, Nautilus)
☐ ANNELIDA (Segmented Worms)
☐ Polychaeta (Parapodial Worms)
☐ Oligochaeta (Earthworms)
☐ Hirudinida (Leeches)
☐ POGONOPHORA (Beard Worms)
☐ SIPUNCULOIDEA (Peanut Worms)
☐ ECHIUROIDEA (Spoon Worms)
☐ ARTHROPODA
☐ Cheliceriformes
☐ Merostomata (Horseshoe Crabs)
☐ Pycnogonida (Sea Spiders)
☐ Scorpionida (Scorpions)
☐ Araneae (True Spiders)
☐ Pseudoscorpionida (Pseudoscorpions)
☐ Acarina (Free-living Mites)
☐ Parasitiformes (Parasitic Ticks & Mites)
☑ Crustacea
☐ Branchiopoda (Fairy Shrimp, Water Flea)
☐ Ostracoda (Sea Lice)
☐ Copepoda
☐ Cirripedia (Barnacles)
☐ Amphipoda (Skeleton Shrimp, Whale Lice, Freshwater Shrimp)
☐ Isopoda (Wood Lice, Pillbugs)
☐ Decapoda (Lobster, Crayfish, Crabs, Shrimp)
☐ Hexapoda (Insecta) (Insects)
☐ Apterygota (Springtails, Silverfish, etc.)
☐ Odonata (Dragonflies, Damselflies)
☐ Ephemeroptera (Mayflies)
☐ Orthoptera (Grasshoppers, Crickets)
☐ Dictyoptera (Cockroaches, Mantids, Phasmids)
☐ Isoptera (Termites)
☐ Plecoptera (Stoneflies)
☐ Phthiraptera (Mallophaga & Anoplura) (Lice)
☐ Hemiptera (including Heteroptera) (True Bugs)
☐ Homoptera (Cicadas, Scale Insects, Leafhoppers)
☐ Thysanoptera (Thrips)
☐ Neuroptera (Lacewings, Dobsonflies, Snakeflies)
☐ Trichoptera (Caddisflies)
☐ Lepidoptera (Moths, Butterflies)
☐ Diptera (Flies, Mosquitoes)
☐ Siphonaptera (Fleas)
☐ Coleoptera (Beetles)
☐ Hymenoptera (Ants, Bees, Wasps, Sawflies)
☐ Chilopoda (Centipedes)
☐ Diplopoda (Millipedes)
☐ Pauropoda
☐ Symphyta (Symphyla)
☐ PENTASTOMIDA (Linguatulida) (Tongue Worms)
☐ TARDIGRADA (Tardigrades, Water Bears)
☐ ONYCHOPHORA (Peripatus)
☐ CHAETOGNATHA (Arrow Worms)
☐ ECHINODERMATA
☐ Crinoidea (Sea Lilies, Feather Stars)
☐ Asteroidea (Starfish, Sea Stars)
☐ Ophiuroidea (Brittle Stars, Serpent Stars)
☐ Echinoidea (Sea Urchins, Sand Dollars)
☐ Holothuroidea (Sea Cucumbers)
☐ HEMICHORDATA (Acorn Worms, Pterobranchs)
☐ UROCHORDATA (Tunicata) (Tunicates, Sea Squirts, Salps, Ascideans)
☐ CEPHALOCHORDATA (Amphioxus/Lancelet)
☐ VERTEBRATES
☐ AGNATHA (Hagfish, Lamprey)
☐ FISHES
☐ Chondrichthyes (Cartilaginous Fishes) (Sharks, Rays, Ratfish)
☐ Osteichthyes (Bony Fishes)
☐ AMPHIBIA
☐ Anura (Frogs, Toads)
☐ Urodela (Salamanders, Newts)
☐ Gymnophiona (Apoda) (Caecilians)
☐ REPTILIA
☐ Chelonia (Turtles, Tortoises)
☐ Serpentes (Snakes)
☐ Sauria (Lizards)
☐ Crocodylia (Crocodilians)
☑ AVES (Birds)
☐ Passeriformes (Passerines)
☐ MAMMALIA
☐ Monotremata (Platypus, Echidna)
☐ Marsupalia (Marsupials)
☐ Eutheria (Placentals)
☐ Insectivora (Hedgehogs, Moles, Shrews, Tenrec, etc.)
☐ Chiroptera (Bats)
☐ Primates
☐ Humans
☐ Rodentia
☐ Lagomorphs (Rabbits, Hares, Pikas)
☐ Carnivora (Bears, Canids, Felids, Mustelids, Viverrids, Hyena, Procyonids)
☐ Perissodactyla (Odd-toed Ungulates) (Horses, Rhinos, Tapirs, etc.)

☐ Artiodactyla (Even-toed Ungulates) (Cattle, Sheep, Deer, Pigs, etc.) ☑ Marine Mammals (Seals, Walrus, Whales, Otters, Dolphins, Porpoises)	☐ TRANSGENIC ORGANISMS ☐ FOSSIL OR EXTINCT ORGANISMS	☐ NO ORGANISMS

CATEGORY VIII: MODEL ORGANISM (Select ONE)

☑ NO MODEL ORGANISM MODEL ORGANISM (Choose from the list)	☐ Escherichia coli ☐ Mouse-Ear Cress (Arabidopsis thaliana)	☐ Fruitfly (Drosophila melanogaster)

PROJECT SUMMARY

"LTER: Land-Shelf-Ocean Connectivity, Ecosystem Resilience and Transformation in a Sea-Ice Influenced Pelagic Ecosystem on the Western Antarctic Peninsula."

Overview. Seasonal sea ice-influenced marine ecosystems at both poles are regions of high productivity concentrated in space and time by local, regional and remote physical forcing. Currently these systems are changing as rapidly as any on earth. Over the past 200 years, these ecosystems have served human society as valuable sources of food, fuel and fiber. Today they are important sentinels of climate and ecosystem change. PAL LTER seeks to build on over two decades of long-term research at its Site along the western side of the Antarctic Peninsula to gain new mechanistic and predictive understanding of ecosystem changes in response to natural climate variability, long-term climate change, species exchange and loss, foodweb alterations, pollution, and overexploitation of living marine resources. We will contribute to fundamental theoretical understanding of ecosystems, populations and biogeochemical processes undergoing rapid and in some cases, novel transformations.

Intellectual Merit. Our overarching research question is: **How do seasonality, interannual variability and long term trends in sea ice extent and duration influence the structure and dynamics of marine ecosystems and biogeochemical cycling?** We pose four major research questions:

1. **Long-term change and ecosystem transitions.** What is the sensitivity or resilience of the ecosystem to external perturbations as a function of the ecosystem state?
2. **Lateral connectivity and vertical stratification.** What are the effects of lateral transports of freshwater, heat and nutrients on local stratification and productivity and how do they drive changes in the ecosystem?
3. **Top-down controls and shifting baselines.** How is the ecosystem responding to the cessation of whaling and subsequent long-term recovery of whale stocks?
4. **Foodweb structure and biogeochemical processes.** How do temporal and spatial variations in foodweb structure influence carbon and nutrient cycling, export, and storage?

We investigate the influence of major climate modes (e.g., ENSO, Southern Annular Mode) as they are modulated through variations in sea ice extent and duration to drive changes in ecosystem structure and function over three principal time scales: seasonal, interannual, and decadal intervals and three main space scales: the hemispheric to global scale investigated by remote sensing, the regional scale covered by an annual summer oceanographic cruise along the WAP, and the local scale accessed by small boats at Palmer (USA) and Rothera (UK) Stations throughout the year. Autonomous vehicles, moorings and modeling enable us to expand and bridge time and space scales not covered by vessel-based sampling. We propose a major new initiative adding a cetacean component to study the roles of whales as major top-down determinants of foodweb structure in the seasonal sea ice zone ecosystem. We will also perform process studies to investigate submarine canyons as agents of ecosystem connectivity along the WAP.

Broader Impacts. We will continue to build on our >20-year database of observations of climate change and ecological transformation, widely recognized as an exemplar of these trends. PAL research is harnessed through an education program providing curriculum development, professional enhancement and the design and dissemination of teaching, learning and media products. Our public outreach program encompasses local, regional, and national efforts to reach the broader public and increase understanding of polar science. We leverage local partnerships including the Sandwich STEM Academy and the New England Aquarium, and the Polar Learning and Responding (PoLAR) Climate Change Education Partnership at Columbia's Earth Institute focusing on building new synergies between Arctic and Antarctic, marine and terrestrial scientists and students, governments and NGOs. We will continue to sustain our involvement with the Climate Literacy and Energy Awareness (CLEAN) project keeping a foothold on cross-site projects within the LTER network such as the LTER Education Digital library.

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Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

PROJECT DESCRIPTION

Results From Prior NSF Support

H. W. Ducklow and Douglas Martinson (MBL, Woods Hole and Columbia Univ.) "Palmer, Antarctica Long Term Ecological Research: Looking Back in Time Through Marine Ecosystem Space" (ANT0823101, PLR-1344502, 01 Oct. 2008 – 31 Aug. 2015. $6,293,323)

Overview. The Palmer Long Term Ecological Research (PAL) program seeks to obtain a comprehensive understanding of the Antarctic seasonal sea ice-influenced ecosystem – 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 penguins and whales (Figs. 1, 2). Our site on the western side of the Antarctic Peninsula (WAP) addresses multiple spatial and temporal scales from hemispheric, decadal, climate-relevant scales to regional and local, daily to seasonal, process-relevant scales. Here we describe major research accomplishments and published articles supported under the current award (denoted by * in the Bibliography). In the current award period, we had major personnel turnover and modified our long-term regional sampling program (see 'Long-Term Observations' section below). An explicit numerical modeling component was added to the program to address ecological and biogeochemical questions and explore sources of uncertainty using various approaches including data assimilation. Research progress was made on several modeling fronts: end-to-end food web dynamics; coupled ocean-ice-plankton dynamics; and regional biogeochemistry. We initiated new strategic collaborations with affiliated investigators to extend and enhance PAL research on carbon export processes and trace metal limitation of primary production. We also initiated autonomous monitoring with gliders and a network of instrumented moorings to target specific processes and provide year-round observations. Finally, we performed a pilot feasibility study on the addition of a new cetacean component to our program. PAL has been very productive, doubling our total pre-2008 publications in the past six years.

Intellectual Merit.

We focus presentation of Results from Prior Support on our progress toward the three major hypotheses from the last proposal, highlighting our **ten most significant** recent (2008-13) publications.

H1: Ecosystem transformation. Life histories of most polar marine species have evolved to be phenologically synchronized with the annual cycle of sea ice, a principal physical determinant of ecosystem dynamics. Sea ice in the WAP region is both highly variable and rapidly changing (Stammerjohn et al. 2008a,b, 2011, 2012). The most rapid sea ice decreases (over 1979 to present) are occurring in the WAP and Bellingshausen Sea region, as rapid as those occurring in the Arctic Ocean (**Stammerjohn et al. 2012**). In the Palmer Station region alone, the ice season duration has become about 92 days shorter over the last 35 years of satellite observations (Fig. 1A). The resulting longer ice-free conditions in summer contribute to increased solar ocean warming, further delaying the autumn sea ice advance (Stammerjohn et al. 2011, **2012**). The seasonal sea ice changes in the WAP region are largely wind driven (Massom et al. 2008, Stammerjohn et al. 2011) and are associated with tropical Pacific (El Niño Southern Oscillation) and Atlantic teleconnections and the Southern Annular Mode (SAM) (Stammerjohn et al. 2008b), the latter affected by the former, as well as by ozone depletion, increases in greenhouse gases, and a possible stratospheric inter-hemispheric connection to Northern Annular Mode variability (Rind et al. 2009). The local WAP response to these climate modes is largely manifested in the strength and direction of the meridional winds during spring-autumn, with increased northerly winds driving an earlier spring sea ice retreat and delaying the subsequent autumn sea ice advance.

Wind-driven increases in the upwelling of warm Upper Circumpolar Deep Water (UCDW) on the WAP continental shelf (Martinson et al. 2008, **Martinson et al. submitted**, Martinson & McKee 2012), cause decreased sea ice production (Saenz et al. submitted). Instrumented moorings along with focused glider deployments allowed us to clearly identify how the warm/nutrient-laden UCDW makes its way onto the shelf. UCDW-core eddies embedded in advective intrusions track bathymetry and dissipate near the coast at bathymetric features (canyon heads) where mixing is enhanced.

The sea ice changes are affecting ocean stratification and freshwater balance (Meredith et al. 2010, 2013). To investigate seasonal water-column dynamics in key locations across our sampling area, a 1-D model has been developed coupling sea ice and ocean boundary layer physical mixing modules with a simple nutrient - phytoplankton – zooplankton food web module. Preliminary simulations replicate reasonably well seasonal variations in sea ice retreat, mixed layer depth, and timing of the spring phytoplankton bloom (Saenz et al. in preparation). In offshore waters, simulated phytoplankton bloom magnitude is determined primarily by iron mixed up annually from the thermocline, while other modeling experiments are examining the influence of additional iron sources (e.g., sea ice melt, benthos, glacial runoff) and the impact of synoptic weather events on phytoplankton production/bloom evolution.

These ice-ocean changes affect every component of the polar marine ecosystem (Schofield et al. 2010, Ducklow et al. 2012a), and are a major focus of our proposed research. While changes at the base of the foodweb appear more directly linked to ice-ocean changes, changes in secondary producers, on up to higher trophic levels, are more complex, with both direct and indirect linkages to ice-ocean changes, and also from top-down forcing. There are also different regional (e.g., north-south) responses to environmental forcing. For example, phytoplankton primary producers increased in the southern WAP but have declined in the northern WAP region by up to 90%, with associated shifts from large-celled diatoms (preferred food of Antarctic krill) to smaller cryptophytes (**Montes-Hugo et al.** 2008, **2009**). Bacterial production reflects the phytoplankton changes between north/south areas of our study region (**Ducklow et al. 2012b**). In spite of the long-term loss of diatoms preferred by krill, our long-term macrozooplankton data indicate a cyclic pattern of high krill (*Euphausia superba*) abundance in the northern WAP, with large positive anomalies every ~5 years, but with no apparent long-term change in the northern or southern WAP **(**Fig. 1C; **Steinberg et al. submitted)**. Using long-term observations in the local Palmer Station region, **Saba et al (revised manuscript submitted)** demonstrate the strong dependence of krill recruitment on phytoplankton blooms driven by high ice anomalies in response to large-scale climate forcing (Fig. 1BC). Invading gentoo penguins (*Pygoscelis papua*) have increased sharply in the region since the early 2000s (Fig. 1D; Cimino et al. 2013). These changes formed the basis of a major LTER Network cross-site analysis (**Bestelmeyer et al. 2011**), indicating that the WAP ecosystem passed an abrupt state transition or tipping point around 1993. Prior to 1993, Adélie penguin (*P.adeliae*) population variability (Fig. 1D) was not related to interannual variations in sea ice duration, but since then has become inversely correlated with sea ice, suggesting hysteresis, and possibly an irreversible change in the ecosystem. An additional challenge is how to assess the influence of episodic outliers. For example, this season (2013-14) the spring sea ice retreat at Palmer Station was the latest (late December) since 1986. Discovering the long-term demographic and ecological consequences of episodic versus long-term change is a major goal of our long-term research.

Inverse foodweb model results **(Sailley et al. 2013a)** suggest that krill resources are sufficient to support both current and historical penguin stocks in the region. Our research therefore suggests other sources of Adélie penguin mortality besides krill availability (and note that gentoos and chinstraps (*P. antarctica*), which are also krill consumers, are *increasing*, not decreasing; Fig. 1D). Observations show unequivocally, for example, that upwelling of UCDW associated with near-shore submarine canyons leads to enhanced, predictable production, and to local prey fields that appear to be less variable spatially and temporally than surrounding areas (Kahl et al. 2010, Schofield et al. 2013). These processes mechanistically link Adélie penguin breeding distributions to critical winter and summer foraging areas (Kahl et al. 2010, Erdmann et al. 2011, Oliver et al. 2012, 2013). We also show that PAL Adélie penguin population trends are island-specific, reflecting interactions between breeding habitat geomorphology, predominant wind direction and an increasing trend in snow precipitation events (Fraser et al. 2013). This finding of habitat-specific demography indicates that not all variability in the demography of this species is induced by changes in the marine foraging environment. Finally, retrospective analyses of long-term seabird diet data show that the Antarctic silverfish (*Pleuragramma antarcticum*), an ice-dependent species, is now functionally extinct over the northern half of the study region, which is leading us to reassess the relative roles of krill versus forage fish as key prey species in the foraging ecology of Adélie penguins **(Fraser et al. submitted)**. Critically, the extinction of this prey species is precisely coherent spatially and temporally with well-documented patterns of decrease and in some cases extinction of regional Adélie penguin populations. Our longest time series, moreover, reveal that the absence of *P. antarcticum* in Adélie penguin chick diets induces low fledging weights, a vital determinant of future recruitment, and the likely causal mechanism driving the population changes observed in this species (Chapman et al. 2011). The loss of silverfish from the region is a direct result of decreased sea ice production and loss of their cold winter water habitat (**Martinson et al. submitted**).

Understanding the physiological responses of organisms to temperature is a critical step in developing predictive models of ecosystem responses to climate change. To this end, we have been studying the responses of heterotrophic bacterioplankton to ambient temperature variability. The summer bacterial community is the result of a community-wide response to enrichment with photosynthetically-derived organic matter resulting in a pronounced shift from a diverse winter, largely chemosynthetic to a summer heterotrophic assemblage (Ducklow et al. 2011, Grzymski et al. 2012, Williams et al. 2012, Luria et al. revised and resubmitted) dominated by a relatively few members of the Gammaproteobacteria, Sphingobacteria–Flavobacteria, and Alphaproteobacteria clades (Straza et al. 2010). Our first decade of comprehensive sampling confirms that the WAP bacterial community metabolizes a low fraction of the local primary production **(Ducklow et al. 2012b)**, compared to lower latitude regions (Kirchman et al. 2009). The low activity is not simply due to low temperature inhibition of bacterial physiology. Bacterial production rates on the WAP shelf responded positively to higher ambient temperature in just two of the first nine years of our annual survey. Physiological temperature inhibition was overwhelmed or even reversed by strong responses to resource availability, as indicated by accumulation of phytoplankton biomass. The complex interaction between resource availability and temperature complicates prediction of bacterial responses to increased seawater temperatures in the rapidly warming WAP region.

H2: Climate migration. Southward migration of isotherms and sea ice duration suggest that warming is proceeding from north to south along the Peninsula. For example, within our sampling grid, the current sea ice duration at Adelaide Island, midway along our study area (Fig. 3) is now about the same as it was at Palmer Station 20 years ago; similarly, duration at Charcot Island 300 km further south, is now the same as it was at Adelaide 20 years ago (Fig. 4A). These differential changes in sea ice extent and duration are generating strong contrasts between our northern and southern study areas. Gentoo and chinstrap penguins, both sub-polar species, now have breeding colonies in the north but not the south. Antarctic silverfish also now only occur in the south, but are functionally extinct in the north. Phytoplankton stocks have actually *increased* in the south, in response to release from light limitation caused by an emergence of an open water growing season (**Montes-Hugo et al. 2009**). Although krill stocks have not changed, salps (*Salpa thompsonii*) are expanding their range and increasing in abundance in the southern WAP **(Steinberg et al. submitted)**. Extreme anomalies in krill and salp abundance are negatively correlated, and the conditions favoring these salp blooms (warmer, ice-free waters) are expected to increase in the future. Calcium carbonate-shelled pteropods (*Limacina helicina*) are increasing in abundance and expanding their range throughout the WAP, a trend that is highly correlated with decreasing ice duration (**Steinberg et al. submitted**).

Inverse foodweb model results **(Sailley et al. 2013a)** based on data compilations from 1995-2006 suggest that in the northern region the foodweb is transitioning from the prototypical short, efficient polar food chain dominated by larger phytoplankton and zooplankton toward a more dissipative microbial foodweb dominated by small phytoplankton (Fig. 4D). In the south, foodwebs are multivorous, with energy flows more or less equally divided between large and small sized producers and consumers. We established the first measurements of microzooplankton stocks (Garzio & Steinberg 2013), and demonstrated experimentally that microzooplankton grazing is the major loss term for primary production along the WAP (**Garzio et al. 2013**). Microzooplankton are an integral part of aquatic food webs, yet are still poorly studied in the Southern Ocean. Microzooplankton biomass was positively correlated with chlorophyll-*a* and particulate organic carbon (Garzio & Steinberg 2013), suggesting long-term changes in phytoplankton biomass documented for the WAP may affect microzooplankton as well.

Regional differences in zooplankton community structure affect food web dynamics and biogeochemical cycling. Krill and pteropods are the dominant grazers in the south, whereas salps dominate in the north (Bernard et al. 2012). Macrozooplankton grazing impact was usually low- less than 1% of both phytoplankton standing stock and primary productivity, with the exception of offshore waters where salp blooms occurred and grazing impacts were up to 30% and 169%, respectively. The Antarctic krill *Euphausia. superba* in the south had ca. 20% higher total lipid content than in the north (Fig. 4C) (Ruck et al. in review). If warming persists, the prey quality trends described for *E. superba* combined with the possible decrease in forage fish abundance could affect the ability of apex predators that rely on these prey species to meet their energetic demands. Investigating other changes or possible physiological signs of stress in the plankton food web using enzymatic or other biochemical indicators will be a focus of our continuing efforts.

In the recent award period, we formed new collaborative research partnerships to investigate the biogeochemical consequences of these shifts in foodweb structure. Montes-Hugo et al. (2010) demonstrated that strong northerly winds during spring are associated with enhanced summer biological productivity and dissolved inorganic carbon (DIC) drawdown, the signals attributed to an earlier growing season characterized by decreased spring sea ice cover. Estimating net community production (NCP, conceptually equivalent to export from the productive layer; Ducklow & Doney 2013) was a new area of investigation in the recent grant period. NCP in the surface layer in the north is a complicated function of foodweb structure (Huang et al. 2012), with the largest NCP occurring in cryptophyte blooms, contrary to expectation. Export averages about 10-30% of the primary production (Buesseler et al. 2010), also suggesting a dissipative system with relatively high nutrient recycling. Fecal pellets, mostly from krill, constituted the dominant proportion of total export flux (67%, in summer), and phytodetritus or fecal 'fluff' constituted the remainder (Gleiber et al. 2012). If salps and pteropods continue to expand their ranges and increase in abundance, the associated shift in the food web dynamics in the WAP will alter the regional flow of carbon through the WAP food webs and the export of carbon to depth (Fig. 2BC).

H3: Canyon hotspots. The coastal region is an area of high productivity along the WAP with distinct hydrographic properties and populations (Martinson et al. 2008, Vernet et al. 2008, Ducklow et al. 2013). It has long been recognized that Adélie penguin colonies on the WAP are all located near the coastal termini of cross-shelf canyons or troughs, leading to our hypothesis that these areas are zones of more predictable or even elevated food availability. Adélie penguins concentrate their foraging journeys in these regions. Canyons are known to serve as conduits for the transport of warm, nutrient rich UCDW from offshore into the coastal region (Martinson & McKee 2012). Our one-dimensional (1-D) modeling results also suggest that there is a greater impact from UCDW upwelled heat on ice mass balance in canyon areas than in bathymetrically flat areas where eddies are not active. In this way they are corridors between the open ocean ecosystem of the Antarctic Circumpolar Current and the productive penguin foraging regions along the coast. In the recent award period, we initiated a series of new, annual oceanographic process studies focused over canyon areas in the north (Anvers Island/Palmer Station), central (Adelaide Island/Rothera Base) and south (Charcot Island) regions of our study area (Fig. 3AB). This design enables us to study canyon dynamics over time as a function of climate migration and ecosystem transformation (see Theme A below). The Charcot Island region was rarely explored prior to our first visit in 2009. We confirmed the existence of an Adélie penguin colony there, and then discovered an unmapped canyon reaching to over 800 meters depth with warm UCDW (>1.2^{o}C) below 200 m (Schofield et al. 2013). Using autonomous gliders (Schofield et al. 2013) we have documented how local circulation patterns enhance phytoplankton productivity and we have demonstrated using satellite data that canyons have locally high levels of chlorophyll (Kavanaugh et al. submitted).

The canyon heads are also zones of enhanced top predator foraging activity (Kahl et al. 2010, Oliver et al. 2013). Penguins forage close to shore during diurnal tides and move offshore into the head of the Palmer Deep canyon during semi-diurnal tides (Oliver et al. 2013). Krill biomass nearshore during diurnal tides was significantly higher than during semi-diurnal tides (Bernard & Steinberg 2013). Krill aggregations were also shallower, closer together, and larger in dimension during diurnal tides. Since krill aggregation structure strongly influences their availability as a prey source, we suggest that foraging behavior of Adélie penguins in this region is strongly linked to the variability in nearshore krill aggregation structure and biomass (Bernard & Steinberg 2013). We now propose to carry out a series of cross-shelf investigations of the entire canyon length, using moorings, gliders and shipboard experimental rate measurements of foodweb processes.

Broader impacts.

One of the main aims of PAL Outreach is promoting the global significance of Antarctic science and research. Our newest outreach project, "Antarctica: Beyond the Ice," a 52 - minute documentary about a PAL research cruise, was produced by twelve undergraduate students enrolled at the Rutgers Center for Digital Filmmaking. We hosted six Logan Science Journalism Fellows at Palmer Station, Antarctica during IPY. As a means to expand communications to wider audiences, we hosted live videocasts from Antarctica and complemented them with social media blogging events. Examples include the 21st Conference of the Society of Environmental Journalists and TEDx presentations by Angela Swafford, US correspondent for a leading Hispanic science magazine Muy Interesante. These events have given international audiences opportunities to discuss the latest research along the WAP with our scientists, and have resulted in feature news articles in *Science*, *Nature, Popular Mechanics, Audubon, the New York Times, the Center for Environmental Journalism and National Public Radio*.

We develop and disseminate instructional materials and learning resources for K-12 educators and school leaders to facilitate their professional development and curricular advancement. This effort was highlighted by our book in the LTER Children's Series, *Sea Secrets: Tiny Clues to a Big Mystery* (Cerullo & Simmons 2008). We circulated over 2000 copies to elementary and secondary schools across the U.S and abroad and incorporated instructional materials to support educators integrating marine science into their curricula. Media production continues to be a notable avenue for us to share video clips, podcasts and learning resources throughout a network of aquariums and science museums, educating thousands across the United States. Several of our short media productions are online and in the "Ocean Today" kiosk at the Smithsonian Natural History Museum in Washington, D.C., and the Boston Museum of Science. A critical component of circulating learning resources includes supporting the teachers using them. Palmer LTER E/O has worked with twelve educators funded by the NSF's Research Experience for Teachers (RET) program. Johanna Blasi from the Boston New England Aquarium participated in our 2013 research cruise and hosted the first live Google+ Hangout at Palmer Station for over 10,000 area school children. Dr. Bill Fraser leads a new partnership with the Detroit Zoological Society to advance climate change awareness. His contributions to their newsletter reach approximately 60,000 family members quarterly.

At the LTER network level, PAL E/O coordinator Beth Simmons served on the Education Executive committee as Co-Chair for two years addressing and prioritizing the near term and long range goals of the LTER Strategic Implementation Plan (SIP). She is leading the effort on the newly developed LTER Educational Digital Library (LEDL) project - a collaborative, cross-site LTER initiative stewarding a diverse collection of peer-reviewed learning resources. Its success is attributed to our partnership with the Climate Literacy and Energy Awareness project (CLEAN).

We hosted over 20 REU students and other undergraduates on our annual cruises at Palmer Station and in our home laboratories. Several of our undergraduates have continued their research in the

PAL LTER program as graduate students. In the current grant period we supported 7 MSc, 19 PhD and 11 Postdoctoral students financially or by providing sampling opportunities and data for their research. Two of our former postdocs, Grace Saba and Kim Bernard, recently received NSF awards to conduct their own research at Palmer Station.

Supplemental support. The majority of supplements supported our Education and Outreach Program (Schoolyard LTER, RET and REU) and Information Management. Successful outcomes included writing, publishing and distributing the children's book *Sea Secrets* in collaboration with CCE LTER in the LTER series (Cerullo & Simmons 2008). Additional supplemental awards for Information Management supported development of our DataZoo portal, redesign of the PAL webpages and participation in the LTER Network-wide effort to bring our metadata into compliance for the Network Information System. We purchased several new pieces of equipment including a benchtop flow cytometer that has become a workhorse in our field program and contributed to one Master's thesis, lipid analysis instrumentation that contributed to another, and mooring instrumentation for the physical oceanography program.

Results From Prior NSF Support

Ari Friedlaender is a new coPI in our program. This is a recent award to Friedlaender and colleagues:

Nowacek, D.P. (PI), Friedlaender, A.S., Read, A.J., Johnston, D.W., Halpin, P.N. (Duke Univ.) "*Collaborative Research: The Ecological Role of a Poorly Studied Antarctic Krill Predator: The Humpback Whale, Megaptera novaeangliae.*" (ANT-0739566; 9/15/2008 – 8/31/2012, $548,521).

Intellectual Merit. As a multi-scale and interdisciplinary study of humpback whales (*Megaptera novaeangliae*) and their prey, we combined measurements of whale foraging behavior, the krill prey field, and physical oceanography to describe the ecology of these whales along the WAP in autumn. For the first time, we deployed multi-sensor suction-cup tags to describe the underwater feeding behavior of whales in Antarctic waters. We used a combination of net tows and echosounder (acoustic) surveys to determine the density and abundance of Antarctic krill available to the whales. We used visual survey methods to determine the density and abundance of whales over broad scales to better understand how the distribution of whales reflected local oceanographic and prey conditions. We also collected skin and blubber samples from whales to determine sex ratios and stock structure of the population of whales. We found that in fall, humpback whales aggregate in unprecedented densities in the nearshore bays adjacent to the Gerlache Strait (Johnston et al. 2012), where they overlap with exceptionally large krill swarms (Nowacek et al. 2011). The oceanographic properties of these bays include upwelling and cyclonic circulation patterns that promote krill retention (Espinasse et al. 2012). The humpback whales exhibited extremely regimented behavioral patterns, resting during the day and feeding exclusively at night (Friedlaender et al. 2014). The krill patches fed upon by whales at night were shallower, less dense, and filled a greater portion of the water column than krill patches present during the day (Friedlaender et al. in review-a, Friedlaender et al. 2014). When diving, the whales maximized their energy gains by performing increasingly more feeding lunges per dive with increasing dive depth (Ware et al. 2011). As well, the whales targeted denser krill patches the deeper they dove, offsetting the costs of diving. These observations are consistent with optimal foraging theory. At the population level, a seasonal shift occurs in the sex ratio of humpback whales found around the Antarctic Peninsula, such that females are disproportionately represented in the autumn. This may signify a tendency for pregnant females to depart the feeding grounds last in an attempt to maximize energy gains before migration and calf provisioning (Pallin et al. in review). We also found evidence that late in the feeding season, humpback whales produce song, a behavior typical of feeding grounds (Stimpert et al. 2012). Using photo-ID methods, we documented one of the longest, and previously unknown, migration routes for humpback whales from Antarctica to American Samoa (Robbins et al. 2011). The results of this research provide novel and detailed information about the behavior of whales in Antarctic waters, and their relationship to both krill and oceanographic conditions. The combination of field and analytical methods used provides a foundation for continued work within the LTER framework and will allow us to successfully address the ecological hypotheses presented in our research proposal.

Broader Impacts. Images, animations, and materials from our work are currently displayed at the Smithsonian Institution's Museum of Natural History visited by 6 million people annually. Content from our research has also been integrated into new pedagogical tools, e.g., the Cachalot iPad® application developed as a new teaching tool for undergraduate and graduate courses at Duke University. Finally, material from our work forms a foundation for a massive open online course (MOOC) based at Duke University and focused on marine megafauna. All student theses are available on our website.

Scientific Background and Proposed Research

Seasonal sea ice zone (SIZ) marine ecosystems at both poles are regions of high productivity concentrated in space and time by local, regional and remote physical forcing. Currently these systems are changing as rapidly as any on earth (Montes-Hugo et al. 2009, Brown & Arrigo 2012). Over the past 200 years, these ecosystems have served human society as valuable sources of food, fuel and fiber (Chapin III et al. 2005, Ainley & Pauly 2013). Today they are important sentinels of climate and ecosystem change, and harbor iconic species that serve as symbols of change occurring at all latitudes and on all continents. PAL seeks to build on over two decades of long-term research along the WAP to gain new mechanistic and predictive understanding of ecosystem changes in response to internal and external forcing including natural climate variability, long-term climate change, species exchange and loss, foodweb alterations, pollution, and overexploitation of living marine resources. In doing so we will contribute to fundamental theoretical understanding of ecosystems, populations and biogeochemical processes undergoing rapid and in some cases, novel transformations.

Previous proposals: The major focus of all four previous PAL proposals has been to explore how variations in climate forcing (both variability and change; or pulses and presses, (Collins et al. 2010), are modulated by sea ice to influence ecosystem structure and dynamics along the WAP (Smith et al. 2003). Initially PAL addressed this main hypothesis by studying a few key populations (i.e., diatoms, krill, penguins) in the context of exemplary high and low years in the extent, duration and seasonality of sea ice. By PAL-3 (2002-08), we recognized that our study area was one of the most rapidly warming regions on Earth, and aimed the proposal toward documenting ecological responses to long-term directional climate change. For PAL-4, the PAL research group was reconstituted to provide a more comprehensive, cosmopolitan and process-oriented approach, using the PAL region as a particularly valuable test case due to the rapid pace of climate forcing (Schofield et al. 2010). With this proposal (PAL 5) we emphasize adaptive sampling, process studies and modeling embedded in our local and regional-scale long-term observational program. In addition, we add as a major new research initiative a cetacean component to further our knowledge of end-to-end processes in the regional ecosystem.

Conceptual framework and major research questions: Our conceptual framework addresses the interactions between space/time variability over a range of process-oriented scales driving ecosystem dynamics at our site (Levin 1992). The first, and most fundamental premise is that all the key native populations of animals and plants in the polar ecosystem require sea ice, whether directly or indirectly, for successful completion of their life cycles (Ducklow et al. 2007). This postulate includes phytoplankton (Smith et al. 2008, Vernet et al. 2008, Montes-Hugo et al. 2009), krill and other macrozooplankton (Loeb et al. 1997, Atkinson et al. 2004, Ross et al. 2008), penguins and other seabirds (Fraser & Trivelpiece 1996), and marine mammals (Costa & Crocker 1996, Steinberg et al. 2012a). Even groups such as bacteria, whose populations and life history characteristics are poorly known, show fidelity to sea ice variability (Ducklow et al. 2012b). Another key premise is that physical and ecological processes are expressed over characteristic space/time scales, to which we must match our observations if we are to correctly interpret their interplay (Stommel 1963). Interannual variations in sea ice duration and extent in the WAP region respond to global-scale climate forcing through changes in regional winds (Fig. 2A). Variability in the Southern Annular Mode (SAM) and ENSO results in periods of high and low ice years (depending on the phase of each mode) (Stammerjohn et al. 2008a,b). High primary productivity, krill recruitment and penguin breeding success follow high ice years (Ducklow et al. 2006, Venables et al. 2013, Saba et al. revised manuscript submitted), whereas recruitment is poor or nonexistent in low ice years. In the WAP region a trend toward more positive SAM is driving changes in prevailing winds, heat inputs from the deep ocean and warming air and sea temperatures (Martinson et al. 2008), that combine to diminish annual sea ice extent and duration (Fig. 1A, 2BC) (Stammerjohn et al. 2008a, Saba et al. revised manuscript submitted). These changes appear to be proceeding north to south along the WAP, a process we term *climate migration* (Fig. 2A). With the virtual loss of sea ice from the northern region in our study area the ice-dependent ecosystem may have reached a tipping point (Bestelmeyer et al. 2011, Fraser et al. submitted) with loss of ice-dependent populations, and may now be transitioning toward a new, ice-intolerant or ice-independent ecosystem (Fig. 2; Sailley et al. 2013a).

Both physical circulation and ecosystem dynamics respond to particular features of local circulation and bathymetry in our region (Fig. 2BC). The WAP is an open system, whose most prominent characteristic is the close proximity of the Antarctic Circumpolar Current (ACC, Earth's largest ocean current) to the continental shelf (Martinson & McKee 2012). Interaction between the ACC and continental shelf-slope break initiates the transport of offshore, oceanic properties including heat, nutrients and plankton populations through canyon and trough openings and across the continental shelf toward the coast. As a result of region-specific transport and upwelling processes, cross-shelf canyons appear to be biological hotspots in the WAP system. For example, all the major Adélie penguin colonies occurring along the WAP are located near the coastal termini of major cross-shelf canyons. We have shown that canyon-heads are regions of predictable prey availability for foraging penguins, driven by local upwelling (Schofield et al. 2013). We now understand that specific interactions between the global climate modes, regional circulation and local geomorphological (bathymetric) features are major instruments of ecosystem and population connectivity in our region. In a broader sense, our conceptual framework recognizes the potential for well-established patterns of temporal (interannual climate "pulsing") and spatial (circulation and connectivity) variability to generate different ecosystem states (high and low productivity/recruitment years, within- and between canyon patchiness). Through comparative study we will use these contrasting systems to learn about the dynamics of ecosystem structure and function. We will also exploit the strong climate trend in the WAP region to frame questions about how ecosystem *responses* to climate and circulation might themselves be changing as a function of ecosystem state. Consideration of these patterns through analysis and modeling of long-term data sets leads us to pose the following major questions to guide our research over the next six years (Figs. 2,4-7).

A. **Long-term change and ecosystem transitions.** The response of ecosystems to change (to external forcing) is changing. What is the sensitivity or resilience of the ecosystem to external perturbations as a function of the ecosystem state? (Fig. 4).

B. **Lateral connections and vertical stratification.** Vertical water column stratification determines the bottom-up controls (nutrients, light, resource limitation) on WAP ecosystem dynamics. What are the effects of lateral transports (connectivity: sea ice, glacial meltwater, offshore heat and nutrients, iron) on local stratification and productivity and how do they drive changes in the ecosystem? (Fig. 5).

C. **Top-down controls and shifting baselines.** Whales are recovering from near decimation via harvesting and are regaining their ecological role as top predators. Is the ecosystem responding to this large-scale change in top-down control? Is there competition among upper trophic level predators for resources as a consequence of whale recovery? (Fig. 6).

D. **Foodweb structure and biogeochemical processes.** How do temporal and spatial variations in foodweb structure influence carbon and nutrient cycling, export, and storage? (Fig. 7).

E. **Education and outreach activities.** In what ways do we communicate our results to the public and how are they incorporated in new education initiatives? What are the Broader Impacts of PAL research on the WAP?

The following research description is organized around these major themes. We begin with an overview of the major operational components of our observational program, on which our logistical support is based (see Program Management section, appended). Detailed presentation of our four major research questions A to D follows. We conclude with discussion of our efforts in E) Education and outreach. Information Management and Project Management and Logistics are addressed in supplementary sections.

Long-term observations. The PAL long-term observation program in the WAP (Fig. 3A) has three complementary facets: a regional-scale oceanographic cruise, conducted every Austral summer (January) since 1993 (Waters & Smith 1992, Ducklow 2008); continuous process-oriented regional scale instrumentation (mooring network and gliders); and local-scale, weekly sampling October-March in the vicinity of Palmer Station, including observations and measurements on breeding Adélie penguins, other seabirds and mammals. Penguin observations were initiated in 1975 (Fraser et al. 1992, Fraser & Trivelpiece 1996) and supporting hydrographic sampling commenced with the start of PAL in 1991-92 (Moline & Prézelin 1996, 1997).

Regional oceanographic sampling. The PAL regional sampling grid is occupied during a 28-day cruise (see Project Management) every January to provide a snapshot of conditions during the period of maximum biological activity, including penguin foraging and chick rearing. A suite of physical, chemical and biological core measurements is made on samples collected at discrete depths from the surface to the bottom of the water column at each station. From 1993-2008 we sampled the entire grid of ca. 55 stations on the 200-600 lines at 20 km of cross-shelf spatial resolution (Fig. 3B). In 2009, we added the 100, 000 and -100 lines to extend the sampling grid 300 km to the south (Charcot Island) in order to sample ice-influenced processes no longer encountered regularly in the original PAL grid region due to climate change. Sampling over a 75% larger area without additional cruise time necessitated subsampling the original grid at lower spatial resolution. We now occupy 3 stations per line in the Coastal, Shelf and Slope subregions, (Fig. 3B; underway surface samples are collected at all yellow stations). Our experience over the past 6 years of the new sampling program confirms that we can detect regional and interannual changes and trends over the expanded but less-intensively sampled study region (Ducklow et al. 2012b, Steinberg et al. submitted). We will continue to occupy the -100 to +600 lines as sea ice permits in our regional grid and will supplement ship sampling with dedicated glider surveys at enhanced spatial resolution.

Palmer and Rothera Station nearshore time series. PAL scientists and students have conducted observations and experiments at Palmer Station during the October to March penguin breeding, foraging and chick-rearing season each year since 1991-92 (Ducklow et al. 2013). The main objective of the Palmer Station sampling effort is to document and explain interannual variations in penguin demography in the context of responses of the plankton production system to physical forcing, krill recruitment success or failure (Saba et al. revised manuscript submitted), changes in prey distribution (Bernard & Steinberg 2013, Oliver et al. 2012), and landscape-related processes (Fraser et al. 2013). Core measurements of penguin foraging ecology, breeding success, and population status along with water column studies are conducted daily to weekly via Zodiac boats at islands and hydrographic stations within the safe boating area about 1 and 3 km from the Station (Fig. 3C). A full suite of physical, biogeochemical, optical and ecological measurements are performed on samples collected in the upper 50-75 meters at Stations B and E (Fig. 3C). Since 1997 the British Antarctic Survey (BAS) has operated a counterpart, year-round time series, the Rothera Oceanographic and Biological Time Series (RaTS) at Rothera Base (Fig. 3B), in close coordination with the Palmer Station time series (Clarke et al. 2007, 2008). RaTS is important in part because of its location 400 km south of Palmer Station, where sea ice extent and duration today are about where they were at Palmer 20 years ago (Fig. 4A) The ecosystem at Rothera is thus at an earlier stage of response to climate migration, as presented above. Mike Meredith, the RaTS Leader, has full co-PI status in PAL.

Technological advances in time-series sampling. A difficulty facing our LTER is the spatial and temporal scales (100s of meters - 1000s of kms in space, days to decades in time) that must be sampled to resolve key physical, chemical and ecological processes. This difficulty is magnified by limited ship time and persistent cloud cover that limits remote sensing approaches. Boating regulations at Palmer Station restrict the range over which we can sample local waters using small boats. Therefore, over the last six years we have expanded our overall ability to sample the WAP autonomously. The goal has been to expand 1) the sustained spatial/temporal sampling and 2) the use of systems that provide real-time data to allow for adaptive sampling using autonomous assets. Year-round time series of particle export have been collected by moored sediment traps for two decades, however in the effort to improve the quantitative interpretation of the data, effort has focused on calibrating the moored traps (Buesseler et al. 2010) and adding new estimates of export flux from water column ^{234}Thorium measurements. In addition, full-year time series of temperature (e.g., Fig 5C), conductivity and currents have increased as the number of fixed ocean moorings has increased from one in 2007 to four currently (Figs. 3B, 5A; Martinson and McKee, 2012).

To increase the spatial resolution, our program has incorporated the use of autonomous robotic Webb gliders (Fig. 5B; Schofield et al. 2007). We have conducted 41 glider missions representing 468 days at sea and 8056 kilometers flown underwater. This success has resulted in gliders being incorporated into the British RaTS program, and into other U.S. Antarctic research programs. To date gliders have provided maps of temperature, salinity, currents, phytoplankton, particle load, oxygen, and the physiological status of the phytoplankton. Shallow gliders (0-200 meters) expand the capabilities of Palmer Station sampling by providing sustained measurements outside the boating limits. Often these glider missions are informed by real-time foraging at locations identified by radio-tagged penguins (Kahl et al. 2010, Oliver et al. 2013). Deep-water gliders (0-1500 meters) provide shelf-wide coverage, mapping the episodic intrusions of warm UCDW. Glider efforts will be expanded to improve our understanding of how deep water intrusions are dissipated on the shelf, biophysical regulation of phytoplankton productivity, krill distribution, and the variability in penguin foraging dynamics.

Process Studies. Process studies are a mechanistic complement to our long-term observations. In 2009 (in response to proposal reviewers) we started to perform a series of intensive oceanographic process studies on each summer cruise. Manipulative experiments like those conducted at terrestrial LTER sites (e.g., soil warming, enclosure/exclosure, CO_2 enrichment studies) are usually not feasible in the ocean. Oceanographic process studies provide a means to examine ecosystem-scale processes in detail by devoting extended periods of ship time at specific locations for repeat sampling and additional measurements too time consuming or complicated to perform at routine survey stations (Ducklow & Harris 1993). At the process stations we can perform biogeochemical and ecological rate measurements such as particle sinking (McDonnell & Buesseler 2010) or zooplankton feeding on phytoplankton (Bernard et al. 2012) and bacteria (Garzio et al. 2013). These rates are then analyzed with inverse (Sailley et al. 2013a) and data assimilation (Luo et al. 2010) models to build system-level descriptions of ecosystem processes. We currently allocate about 10 days of ship time each January (out of 28 days total) to conducting 3 process studies along the WAP (Fig. 3AB). Most of our process studies over the past 6 years were located near 3 submarine canyons to test the hypothesis that canyon heads are areas of locally enhanced productivity for optimal penguin foraging and breeding success (see above, Canyon Hotspots).

We propose to conduct comparative studies of canyon processes over the Palmer Deep (Anvers Island), Marguerite Trough (Adelaide Island, Rothera Base) and at Charcot Canyon in at least 4 of the next 6 years. Each study is just 3 days, and is subject to local and event-scale variability. By repeating these studies from year to year we are building up a catalog of canyon-related patterns in hydrography, productivity and foodweb structure. During each study, we will conduct fine-scale glider and vessel-based surveys along and across the axis of each canyon, performing rate measurements and shipboard experiments designed to examine trophic interactions. These will complement moorings deployed within the canyons. Further details on future process studies are described in the thematic sections below.

A. Long-term change and ecosystem transitions.

Motivation. This research theme acknowledges that the response of an ecosystem to change must, with time, also change, given different sensitivities and resiliencies that emerge over time. PAL is now positioned to investigate these changes on multi-decadal time scales and on spatial scales inclusive of distinctly different background states (imposed by the strong latitudinal climate gradient along the WAP). Only with a long-term approach can such a study be possible.

Background. Along the length of the WAP, the sea ice season is decreasing (Fig. 4A), while winds, air temperature (Fig. 1A), sea surface temperature and ocean heat content are all increasing (Orr et al. 2004, Meredith & King 2005, Holland & Kwok 2012). These environmental changes are affecting the marine environment and food web differently north to south (Fig. 4A-D). This is due to different background states on which these trends are superimposed. In the north, the ice season is now too short and too variable to support ice-obligate species (e.g., large phytoplankton, ice krill (*E. crystallorophias*), silverfish, Adélie penguins). The increase in winds and clouds, juxtaposed on a longer open water season, leads to deeper mixed layers and more variable light conditions, resulting in decreased chlorophyll *a* and shifts to smaller phytoplankton (Montes-Hugo et al. 2008). While ice krill were historically found throughout the cold, fresh coastal waters of the WAP (Ross et al. 2008), and at times on the inner shelf, they are now limited to the southern coastal region, where summer sea ice persists (Steinberg et al. submitted). Recent north vs. south comparisons of zooplankton community structure also indicate smaller and less abundant microzooplankton in the north (Garzio & Steinberg 2013) and lower lipid content and thus lower food quality of Antarctic krill in the north (Ruck et al. in review; Fig. 4C). Meanwhile, throughout the WAP there has been an expansion in the range of gelatinous salps and increase in abundance of the pteropod *Limacina helicina*, changes likely occurring as a consequence of these more extensive or longer open-water conditions (Steinberg et al. submitted).

With the near disappearance of sea ice-produced cold Winter Water in the Anvers Island vicinity, fish species previously excluded by the cold barrier (myctophids) are more consistently appearing in near surface waters, replacing silverfish preferring cold waters, as indicated by our long-term seabird diet studies (Fraser et al. submitted). Antarctic silverfish are an energy-rich prey item for the ice-obligate Adélie penguins, and their ‘functional extinction’ in the north in part explains the decreases in Adélie chick weight and recruitment success. Other factors causing the precipitous decline in Adélie penguin populations in the north include the more variable and shorter ice season affecting foraging behavior (Fraser & Hofmann 2003), and an increase in precipitation, with snow burying nest sites and drowning penguin eggs during spring melt (Patterson et al. 2003). These bottom-up and top-down changes are mirrored by changes to the food web, where the north WAP is characterized by an increasingly dominant role of the microbial loop in food web carbon flow (Fig. 4D; Sailley et al. 2013a).

In contrast to the north, the sea ice decreases in the south appear to be causing changes favorable to increasing production. In prior decades, the nearly year-round ice cover reduced irradiance, limited mixing, and prevented blooms. Now, however, the ice season is sufficiently short to support a highly productive ice-edge bloom in spring followed by a longer growth season in summer (Montes-Hugo et al., 2009; 2010). Although the south has also seen an increase in winds, the impact on mixed layer dynamics is less given the (relatively) longer ice season. This classically demonstrates the importance of the background state in determining how a system responds to environmental change. Here, large phytoplankton (diatoms) characterize the food web, and ice-obligate Adélie penguins are increasing in abundance (Fraser et al. submitted). While in the south there is no long-term trend discernable in the abundance of Antarctic krill, salps are increasing in abundance. The dominant pathway for carbon flow in the food web varies from year to year in the south, with no detectable long-term trend toward dominance of either a microzooplankton and microbial-based food web or krill food web (Sailley et al. 2013a).

Environmental variability is increasing with time and shifting seasonally as well north to south. For example, Fig. 4B shows mean annual ice cycles for the northern, mid, and southern regions (vicinity of Anvers, Adelaide, and Charcot Islands, respectively) along with the monthly relative standard deviation (RSD or coefficient of variation) for each region and with time. For all 3 regions, variability increases with time and is overall higher outside of the late winter months (Aug-Oct). Also, the seasonal timing of maximum variability is distinctly different north to south: later in the north (now peaking in June), earlier in the mid region (now peaking in April), and even earlier in the south (now peaking in March) (Fig. 4B). These peak months in variability correspond to the variable onset of the ice season in these three regions. The ecosystem response to the increase and shift in environmental variability undoubtedly contributes to changes in species composition and food web interactions north to south. The increased variability overall would favor species resilient to change, whereas the seasonal shifts in maximum variability may lead to changes in phenology and geographic range, increased trophic mismatches, and perhaps even species loss (Cushing 1978, Edwards & Richardson 2004). Below we describe how these ecosystem responses will be investigated.

Proposed research. Within the context of long-term change, shifts in seasonality or species ranges, and changes in variance, we propose to investigate the sensitivity and resilience of the ecosystem to perturbations as a function of ecosystem state. Motivating questions include the following: (1) Given the rapidity of change in the WAP marine environment (in terms of sea ice loss, increased winds, ocean warming), which species are capable of adaptation, which are vulnerable to ice loss? (2) How do the different background states (north vs south) affect how an ecosystem responds to increased variability or to the (re-) introductions of a top predator (e.g., whales)? (3) What combination of factors favors long-term gradual change in an ecosystem versus an abrupt transition? (4) Is the northern (now sub-polar) ecosystem now more resilient to high frequency (episodic) environmental variability than the southern (polar) ecosystem?

One approach to address these questions is to investigate changes in temporal variance in various ecosystem response variables. Temporal variance is used as an analytical, "leading" indicator of transitions and state changes in ecosystems (Scheffer et al. 2009), with variance becoming more peaked at the transition point between pre- and post-transition states (Bestelmeyer et al. 2011; Fig. 4E). As an example, our >40 year time series of the Adélie penguin breeding population at Anvers Island in the WAP shows an abrupt decline beginning in 1993. Although temporal variance did not indicate this change, after 1993 sea ice duration became highly correlated with Adélie penguin abundance (while prior to 1993 there was no significant correlation between the two). We propose now to expand this analysis to include other ecosystem response variables observed by PAL over the last 22 years. Our analytical approach will consist of the following: (1) identify the space/time scales of causal environmental drivers and biological response variables and then analyze patterns and mechanisms of driver-response relationships, (2) examine frequency distributions of biological response variables to detect changes in variance (on scales relevant to the response variable, e.g., taking into consideration life spans of different species), and (3) identify abrupt transitions and alternative states using the objective evaluation approach of Bestelmeyer et al. (2011; Fig. 4E). In particular, the latter statistical approach will allow us to assess relationships between environmental drivers and biological response variables before and after any detected break points. Our goal is to identify drivers, triggers, and responses, and then investigate the mechanistic linkages within a modeling framework (see below). Ultimately, we hope to improve predictive capability of factors that lead to trophic mismatch and possible species loss versus factors that contribute to ecosystem resilience and transformation.

A second approach involves maximizing the integration of observations and modeling to improve predictions of ecosystem shifts (Murphy et al. 2012), provide a means for testing bottom-up versus top-down controls and feedbacks, and identify the mechanistic linkages. Since sea ice mediated systems are seasonally complex, the polar marine environment presents unique challenges to understanding the processes that drive observed physical and biological changes. For example, sea ice formation and melt may respectively enhance and suppress buoyancy-driven ocean mixing, while the ice cover moderates heat, momentum and gas exchanges (Mellor & Durbin 1975; Hunt et al. 2002). The depth of the mixed layer modulates light availability, allowing changes in timing of sea ice formation and retreat to impact phytoplankton bloom dynamics (Hunt et al. 2002). Ocean dynamics such as advective intrusions carrying eddies with warm UCDW cores redistribute nutrients and plankton. Sea ice algae may further impact the timing and community composition of the springtime phytoplankton bloom (Arrigo & Thomas 2004). These mechanisms of environmental variability, when combined with the short, polar growing season, give rise to potential match/mismatch scenarios between organisms and resources. Finally, although krill have long been the focus of grazing research in the WAP (Smith et al. 1999), our recent studies (reviewed above) have identified important alternative trophic pathways such as through salps or microzooplankton. These discoveries reveal a polar marine environment more nuanced, and with more potential controls and feedbacks than contemplated in previous overviews of polar marine ecosystems.

To examine the rates, timing and relative importance of specific processes, we will use a hierarchy of numerical models to investigate the mechanisms associated with observed ecosystem shifts. The proposed research will build upon the model development work completed during the current grant period on an end-to-end food-web inverse model (Sailley et al. 2013a) and a 1-D sea ice-boundary layer biophysical model (Saenz et al. submitted). The inverse and 1-D biophysical models are portable and configurable so that they can be applied across regional environmental gradients in space (e.g., on/offshore or north/south) and time (seasonal to interannual). In particular, by comparing the predicted and observed ecological responses to variations in sea ice across different regions, we will systematically test our understanding of the ecosystem as encapsulated in the model parameterizations. We will iteratively improve model performance by, for example, incorporating new rate information from PAL process studies. Perturbation studies will also be conducted on the models to assess regional differences in ecosystem resilience.

In order to gain further mechanistic insight into the effects of environmental change on organisms along the climate gradient of the WAP, a third approach is to use biochemical indicators of animal physiological condition and stress (Fig. 4C). In particular, metabolic enzyme activities and biochemical composition are useful tools for evaluating effects of ecological stressors, such as changing temperature and food availability (Dahlhoff 2004, Koop et al. 2011). We will quantify patterns in enzyme activities and physiological condition in zooplankton, particularly Antarctic krill, in concert with our other physical and biogeochemical measurements along the WAP north-south gradient. Metabolic indicators such as lactate dehydrogenase (LDH), an enzyme indicative of anaerobic metabolic potential and responsible for burst swimming activity, and citrate synthase (CS), an enzyme of aerobic metabolism, have been strongly linked with nutritional status in studies of Antarctic krill (Meyer et al. 2002) and other zooplankton and micronekton (Donnelly et al. 2004). Examination of patterns in these, and potentially other biochemical indicators, such as ratios of RNA:DNA -- indicative of protein synthesis and animal growth (Cullen et al. 2003), can be used together to gain insight into the physiological status and nutritional condition of the animals, and help us to understand patterns in their abundance and distribution. This work will build upon our previous efforts using lipid analysis of penguin prey to ascertain prey quality along the WAP north-south gradient (Ruck et al. in review; Fig. 4C), and affects of enhanced CO_2 on metabolic condition of *E. superba* (Saba et al. 2012).

B. Lateral connections and vertical stratification.

Motivation. This theme is focused on understanding how large-scale horizontal transport coupled with regional vertical mixing control the local distribution patterns of organisms (Levin 1992). PAL is well positioned to study how physical processes operating over global scales cascade through the system to influence local spatial patterns and temporal dynamics in marine food webs, and how shifts in the broad scale (100s to 1000s of km) system will alter the spatial and temporal extent of ecological niches and connectivity for the major organisms within the WAP foodweb. This will provide a framework with which to (1) interpret to what degree "patchiness" inherent in this system reflects organism interactions or the inherent physical variability in the WAP, (2) decipher the mechanisms responsible for delivering nutrient-rich waters to canyon heads and seamounts producing biological hotspots, and with that (3) the sensitivity of these mechanisms to global and regional forcings. These can only be accomplished with long-term spatial time-series data.

Background. Considerable effort in PAL has focused on defining local-scale ecological interactions (see above). Now we hypothesize that larger-scale patterns across the WAP are strongly affected by geographic influences on local circulation that are ultimately driven by large-scale climate forcing. The warm, nutrient-laden Upper Circumpolar Deep Water (UCDW), transported by the Antarctic Circumpolar Current (ACC) which abuts the continental shelf (Martinson et al. 2008), is transported to coastal regions principally through and above cross-shelf canyons (Hofmann & Klinck 1998, Klinck 1998, Martinson & McKee 2012). Specifically, upon encountering the Marguerite Trough (Fig. 3B), either the mean flow (which is unstable, McKee, 2013) or its instabilities interact with the topography to yield intrusions of UCDW. In the trough, a cyclonic circulation is set up and warm intrusions are advected along the eastern wall as eddies (Moffat et al. 2009) and across a deep sill onto the shelf proper (Martinson & McKee 2012). The time scales of the intrusions are presumably related to the instability process offshore (McKee 2013), though models suggest that weather-band winds play a role (Dinniman et al. 2011, 2012). One type of region where the eddies dissipate is locations where local bathymetric features such as seamounts drive enhanced mixing (McKee 2013). These local areas appear to be biological "hotspots" within the WAP (Prézelin et al. 2004).

The interaction between the ACC and the shelf break, leading to entry of UCDW onto the continental shelf, is likely sensitive to the proximity of the southernmost filament of the ACC (SACCF) to the continental shelf-break (McKee 2013, St. Laurent et al. 2014). The position of the SACCF is in turn modulated by the band of westerly winds around the Antarctic continent (i.e., westerlies). Thoma et al. (2008) show that the SACCF in the Amundsen Sea impinges farther onto the shelf under stronger westerlies. Over the past several decades, the Southern Hemisphere westerlies have intensified poleward, associated with a deepening of the atmospheric polar vortex over the Antarctic continent; this trend is projected to continue with greenhouse gas warming. Warming of the global deep waters (Levitus et al. 2013) and of the Southern Ocean waters in particular (Gille 2008) have led to warmer UCDW source waters feeding onto the shelf (Martinson in preparation). High-resolution model studies by St. Laurent et al., (2014) suggest that the movement of the ACC towards the shelf-break changes the mechanism, magnitude, and frequency of UCDW shelf-entry. These interactions tie global-scale climate to local (hotspot) and regional (shelf surface layer) ecology. This is supported by paleo-oceanographic data, wherein variation in silt to clay ratio and microfossil composition in sediment cores from the Palmer Deep (Leventer et al. 1996) reflect glaciation and long-term spatial variability in the dynamics of the ACC, and consequently, delivery of warm water onto the WAP continental shelf (Shevenell & Kennett 2002, Warner & Domack 2002). The latter can impact the thickness of sea ice growth (Martinson 1990), leading to changes in sea ice duration (Saenz et al. submitted) thinner ice, faster loss, and vice versa (Fig. 5A).

Eddy intrusions modify subsurface hydrographic properties in the canyons and on the shelf (Fig. 5BC) that in turn influence the biologically active surface layer via vertical mixing processes. The ocean stratification in the polar regions is controlled by salinity, with temperature playing a relatively minor role, hence warmer, saltier UCDW underlies colder, fresher surface waters. The characteristics (e.g., thickness, salinity, lateral continuity) of the biologically-active surface layer are dominated by the growth, lateral transport, and decay of sea ice, exchanges with the underlying deeper water (UCDW) and inputs along the coast (e.g., glacial meltwater). Brine rejection during winter sea ice growth increases the density of the surface layer, removing the shallow summer melt layer on its way to forming the deep winter mixed layer and frigid winter water (WW). The WW regulates the distribution of key species on the continental shelf, for example by acting as a barrier (Fig. 2C) to warmer surface waters for cold-intolerant sub-polar species such as the myctophid fish, *Electrona antarctica,* and king crab (Smith et al. 2012). This reflects their inability to tolerate waters <1 ºC (Lancraft et al. 2004, Donnelly & Torres 2008). The ranges of these sub-polar species will increasingly become important to the WAP as the physical system continues to warm with the UCDW injections of heat and the declines in sea ice formation leading to less WW over time (Fig. 2B).

The summer melt of sea ice also regulates biological activity for the surface waters in the WAP. Annual primary productivity exhibits a high degree of variability (Smith et al. 1998, Loeb et al. 2009), reflecting the interaction between the interannual extent of sea ice and local wind forcing that together regulate the vertical stratification and corresponding phytoplankton productivity (Moline & Prézelin 1996, Garibotti et al. 2005). High chlorophyll years at Palmer Station are associated with years of higher water column stability (Saba et al. revised manuscript submitted), fueling a cascading response through the WAP food web (Fig. 1BC). The Rothera (U.K.) time series shows that ice and winds leading to increased summer stratification also favor large summer phytoplankton blooms (Venables et al. 2013). In contrast, increasing wind and declining sea ice in the northern WAP have been implicated in the observed declines in the regional primary productivity (Montes-Hugo et al. 2009).

Proposed Research. Given the interactions described above, we will focus on understanding how physical transport structures the WAP ecosystem. Specifically we will document connections between large-scale climate patterns and local ecosystem variability by determining: (1) the distance of the SACCF from the shelf break and its relationship to dominant Southern Hemisphere climate patterns, such as the Southern Annular Mode (SAM) and El-Niño Southern Oscillation (ENSO); (2) the frequency of advective intrusions and UCDW-core eddies entering the shelf via canyons as a function of distance measured in (1); (3) changes in local biological hotspots and shelf surface layer characteristics as a function of this frequency; and (4) how the frequency and duration of these regional intrusions link to ecological responses at nearshore canyon heads along the WAP. In addition we will focus on the local scale mechanisms by: (5) assessing how increased wind mixing will impact upper water column stratification, and exploring the consequences for ecosystem structure and function, (6) quantifying how changes in the surface salinity will change the sensitivity to wind mixing and the consequences for ecosystem productivity, (7) defining the range shifts of organisms due to the modification of the major water masses within the WAP, and (8) determine the role of the canyon head in its associated productivity. Specifically, while UCDW is brought to the canyon head via the underlying cyclonic circulation, the processes responsible for upwelling are less clear. Wind forcing is responsible for opening polynyas in these spots, critical to the local penguin population, although climatological winds are not favorable for upwelling (Hurrell et al. 1998). We will test whether the upwelling is related to short-lived wind events or the forcing upward of the stratification due to a physical principle known as the thermal-wind in the canyon initiated by an intrusion. These points are critical to determining the sensitivity of the UCDW delivery to the forcing.

Quantifying the link between shifts in the wind and ocean circulation with the corresponding effects on regional and local ecological processes in the WAP requires a combined multiplatform observational (Fig. 5) and modeling strategy. We will use global climate forcing (SAM, ENSO) as naturally-occurring perturbations that impact the location of the SACCF, which will allow us to quantify the variability of UCDW intrusions onto the WAP shelf using moored temperature, conductivity (salinity) and velocity sensors (Fig. 5C). The mooring approach for the WAP is critical as the UCDW intrusions are short-lived events, i.e., a few days (Martinson & McKee 2012) and not well sampled by ships. Currently we have four moorings. One of the moorings will continue at our primary legacy site at grid station 300.100 (Fig. 3B) to continue the long-term time series. For example, the other three moorings will be configured in a cross-shelf array within a canyon system, i.e., along topographically steered advective flow paths. Initially, a cross-shelf line of moorings will be placed offshore of Adelaide Island, where in 2013 we successfully adaptively piloted a Webb glider to remain within these moving subsurface eddies for over a week. The cross-shelf array will be relocated to study other major canyon systems. During selected years, a deep water (1500 meter class vehicle) Webb glider will be used to transect between the moorings providing a detailed picture of the UCDW eddies and their subsequent modification as they migrate across the shelf (Fig. 5B).

Glider adaptive sampling will also be concentrated at the inner shelf mooring sites to quantify the arrival of the UCDW in the canyon heads, where shallow gliders (200 meter class) will patrol the shoaling UCDW. These shallow gliders will be outfitted with optical backscatter, chlorophyll a fluorometry and Fluorescence Induction and Relaxation (FIRE) systems (Kolber & Falkowski 1992) providing information on response of phytoplankton physiological state to upwelled UCDW. Zodiac sampling at Palmer and Rothera Stations will provide time-series of plankton and biogeochemical properties to complement the mooring and glider operations at the canyon heads. The patterns of the upwelled water and corresponding phytoplankton response will be correlated with satellite-tagged penguin and whale foraging patterns to determine if feeding is concentrated within the UCDW upwelled intrusions. These high-resolution measurements will be embedded within the annual ship (physical-chemical-biological) and satellite observations to provide spatial context for assessing whether these canyons are unique relative to other regions on the shelf.

Quantifying the shifting hydrography and its biological implications will require continued regional-scale sampling of the WAP on our annual cruises, but now augmented in space/time with gliders and moorings. Two deep-water gliders will be deployed north and south of Anvers Island (Fig. 3B) to assess the distribution of WW in areas where it appears to be disappearing (Martinson et al. submitted). This will provide high-resolution data on temperature, salinity, fluorescence, and optical backscatter for determining the presence/absence of WW and its biological implications; and physical properties showing the ongoing effects of sea ice loss throughout the region such as loss of WW, and feedbacks to the local ocean-atmosphere heat balance. Also, to assess potential shifts in the distribution of specific organisms within the region over time we will conduct Canonical Correlation Analyses to assess the environmental gradients most related to the organism and biogeochemical distributions. These analyses will be combined with a generalized additive modeling approach to assess species responses to the gradients (Palamara et al. 2012). For example, those organisms that cannot tolerate the cold WW, will have ranges heavily constrained by the presence/absence of that particular water mass. We also will continue to assess the freshwater budget of the WAP to quantify changes in sea ice and glacial meltwater inputs using oxygen isotope analysis to quantify meteoric water (glacial discharge and precipitation) separately from sea ice melt (Meredith et al. 2013).

A suite of regional 3-D ocean models will be used to support these field and satellite observations to better elucidate lateral and vertical connectivity effects. As part of the current grant we are utilizing mesoscale-resolution (4 km) 3-D physical simulations for the WAP from the Regional Ocean Model System (ROMS) in collaboration with M. Dinniman (Old Dominion Univ.). We are also investigating several regional modeling options which would allow us to conduct more detailed physical sensitivity experiments at sub-mesoscale resolution and to embed plankton ecosystem and biogeochemistry modules. These include collaborative work with E. Curchister (Rutgers) on a coupled ocean-sea ice version of ROMS for the WAP and a Southern Ocean domain simulation using the MIT GCM with PAL coPI M. Meredith (BAS). The regional modeling effort will also tap ongoing efforts by team members to develop and investigate marine ecosystem modeling and climate change response using the NCAR Community Earth System Model (CESM). In particular we will use results from CESM historical and 21st century CMIP5 climate-change simulations (Bopp et al. 2013, Moore et al. 2013) to provide regional climate-change forcing and later boundary conditions. The CESM will provide an excellent means for assessing climate scale forcing of SACCF and the subsequent changes in the UCDW intrusions using the regional scale ROMS model.

C. Top-down controls and shifting baselines.

Motivation. This research theme encapsulates two constructs: one is empirical evidence that humpback whales are regaining their former ecological role in the WAP following near-extirpation due to commercial whaling; the other is the long-standing but controversial hypothesis that changes in whale abundance regulate the demography of other top predators, such as penguins, through top-down competitive interactions for shared prey resources such as krill. PAL is uniquely positioned to investigate these dynamics using its regional sampling grid, which is coherent spatially and temporally with populations of whales and penguins,and encapsulates the long-term approach necessary to study these long-lived species.

Background. This research theme represents a new research initiative and the addition of a new research component to PAL. This initiative is proposed because of our own recognition of its scientific importance and in response to comments in proposal and midterm reviews expressing concern that we were neglecting a major ecosystem component and a major source of krill mortality. We invited cetacean scientists to participate in our last three annual cruises to determine if our current cruise design could accommodate cetacean research. New Co-PI Dr. Ari Friedlaender was a member of the cetacean ecology group at the Duke University Marine Laboratory for the past 7 years and recently moved to Oregon State University. He will continue to collaborate with colleagues at Duke. Addition of the OSU/Duke group gives PAL unprecedented coverage of the Antarctic marine ecosystem, from the smallest to largest organisms on the planet.

Another rationale for adding a cetacean component was the recent reemergence (Trivelpiece et al. 2011) of a long-standing debate regarding the roles of whales in regulating the demography of other top predators, such as penguins and seals. In this context, two main hypotheses have been proposed. The first hypothesis draws on top-down processes, in which changes in whale abundance directly regulate population trends of other predators through competition for krill (Laws 1977). The second focuses on bottom-up processes, in which climate-induced changes in sea ice dynamics mediate a host of biophysical interactions that affect predator populations, including, but not limited to, the extent to which whales may affect the demography of other krill-dependent predators (Fraser et al. 1992, Fraser et al. submitted,). These hypotheses are not mutually exclusive, but the contrast between bottom-up and top-down perspectives provides a rich ecological backdrop for understanding the response of these ecosystem components to climate change, recovery of depleted predator populations, and other processes with profound consequences to society. Indeed, it is these different perspectives on the role of whales in ecosystem dynamics that guide the hypotheses and objectives expressed in this research theme.

Adélie penguins have been the focal top predator in our program since its inception, but during the last decade we have added gentoo and chinstrap penguins in response to their increasing regional populations (Fig. 1D). These species exhibit different affinities to sea ice (Adélies are ice-obligate, gentoos and chinstraps are ice-intolerant), so they are an ideal guild with which to test hypotheses about WAP ecosystem dynamics within the context of bottom-up forcing (Fraser et al. 1992). We now propose to add humpback whales to our observational network. In the 20th century, over 200,000 humpback whales were killed in the Southern Ocean, most of which were taken from the nearshore waters of the Antarctic Peninsula (Hart 2006, Burnett 2012). The recovery of these whales has been delayed by their long life histories, but long-term monitoring efforts in other regions have demonstrated substantial recoveries of this species over the past 30 years (Matsuoka et al. 2011). Humpback whales are now repopulating their former range in the WAP (Friedlaender et al. 2006, Nowacek et al. 2011, Johnston et al. 2012) in the same areas that are inhabited by our three focal penguin species (Cimino et al. 2013).

Top-down processes are posited to have operated through competitive release, in which the massive removal of baleen whales from the Southern Ocean created a “krill surplus” that was subsequently taken up by other krill consumers such as seals, penguins and other seabirds (Laws 1977). This theoretical framework is still being advanced, but now “in reverse.” Thus, it is hypothesized that whale populations have increased to the point that they are once again competing directly with penguins and thus depressing their populations (Trivelpiece et al. 2011). However, as Fraser et al. (1992) noted in their first rebuttal to this theoretical framework, its application is challenged by inconsistencies within and between regions and species. Thus, while chinstrap and Adélie penguin populations are decreasing in the northern WAP, they are increasing in the southern WAP, and gentoos are increasing throughout the WAP, even in northern sectors where they are sympatric with decreasing chinstraps and Adélies (Fig. 1D).

These inconsistencies are relevant to our proposed research for three reasons. First, krill are the major component of the diets of all three species of penguins throughout the WAP (Williams 1995). Second, there is no evidence to suggest that the intensity of whale predation along the WAP varies regionally. Instead, the movements of baleen whales, such as humpbacks, reflect the seasonal distribution of krill over the entire WAP shelf (Friedlaender et al. 2006, Nowacek et al. 2011, Johnston et al. 2012). Indeed, our pilot study of humpback whale movements using satellite telemetry suggests that these animals can cover hundreds of km/week, and individuals observed feeding in the southern WAP one day can be found feeding in the northern WAP a few days later (Fig. 6). While the ecological reoccupation of the WAP by humpback whales is not regionalized, changes in ecosystem structure and dynamics do exhibit strong regional characteristics (see above). How such shifting baselines affect our understanding of how ecosystems work is emerging as one of the most important scientific issues of our time (Pauly 1995, Pauly et al. 1998, Schrope 2006, Ainley & Pauly 2013).

Our new component brings to our program some of the most comprehensive data available on the ecology of baleen whales in the WAP. For humpback whales in particular, we already have a preliminary understanding of their patterns of regional distribution and abundance (Friedlaender et al. 2006, Johnston et al. 2012, Nowacek et al. 2011), fine-scale foraging behavior (Ware et al. 2011, Friedlaender et al. 2014), and seasonal migration patterns beyond the WAP (Dalla Rosa et al. 2008, Friedlaender et al. in preparation). With these data we have begun to explore niche theory in the context of not only understanding if and how whales may actually compete for krill with penguins, an assertion that has never been demonstrated, but also as a necessary first step to help us integrate and guide our proposed research. An important preliminary finding is that although the niche of foraging humpback whales appears to be defined primarily by krill, the niches of Adélie penguins are linked more to their physical environment (land and sea ice) and secondarily to krill (Friedlaender et al. 2011), likely as a result of fundamental differences in evolved life history strategies. Humpback whales are unconstrained by reliance on a solid platform for rest or reproduction and move considerable distances within a feeding season to respond to local changes in krill abundance. In contrast, Adélie penguins are central place foragers and, therefore, their movements are constrained due to parental duties during summer, or available daylight during winter (Fraser & Hofmann 2003, Erdmann et al. 2011). The implication that whales track krill directly while penguins track habitat features that provide predictable access to krill (a focal question addressed during our last funding period, see above) provides a basic framework for using niche and competition theory to explore how top-down versus bottom-up forcing may structure top predator communities in the WAP.

Proposed Research. Our fundamental objective is to investigate how our focal predator guild (humpback whales, Adélie, gentoo and chinstrap penguins) partitions the marine environment in space and time. We envision a sampling program that will capitalize on proven methodologies and permit us to compare movement and distribution patterns and foraging ecology, and allow us to monitor demographic parameters in our penguin study populations that may be sensitive to competition from whales (e.g., foraging trip durations, which may affect chick growth and survival; Fraser & Hofmann 2003). No breeding populations of krill-dependent pinnipeds exist near Palmer Station and, because the logistical constraints of working with sparsely distributed ice-obligate species, we have chosen not to include pinnipeds in our research program.

Cetacean Research, Broad-Scale (Cruise-based sampling). We will establish a research program on the demography, habitat use, and ecological role of humpback whales using a combination of proven methodologies, including visual line transect surveys, biopsy sampling and satellite-linked tag deployments, when the ship occupies the LTER survey grid each January. We will use conventional distance sampling methods (Barlow 2006) and model-based approaches (Hedley & Buckland 2004, Katsanevakis 2007) to estimate the density of humpback whales each year within the PAL region (Fig. 6) (Thomas et al. 2010; Johnston et al. 2012). We will augment these methods with photographic and genetic capture-recapture techniques and independently estimate density from our satellite telemetry deployments as in Whitehead and Jonsen (2013). Over time, we will develop a time-series of density surfaces that will allow us to compare humpback whale distribution to the suite of ecological parameters measured during the cruises and to examine annual overlap with the observed foraging ranges of penguins within the region. We will test how interannual changes in the environment (e.g. sea ice cover) affect whales in a spatio-temporal framework using the methods initially developed by Friedlaender et al. (2006, 2011). We hypothesize that the density of humpback whales within the LTER study region will increase over the study period but that the relationship between the distribution of whales and the physical environmental parameters that provide the greatest access to krill will remain constant over this period, as whales track intra- and inter-annual variation in the distribution of their prey.

We will collect skin and blubber samples from whales each year using conventional remote biopsy sampling techniques. We will use these samples to determine the sex of individual whales, estimate pregnancy rates, and confirm that their diet is comprised entirely of krill. Over time, this information will provide a baseline for the population of humpback whales around the Western Antarctic Peninsula as it recovers from commercial whaling.

We will also deploy satellite-linked ARGOS tags (Gales et al. 2009) each year to document seasonal movement patterns and quantify foraging ranges. We will compare the movement patterns of these whales to the foraging ranges of similarly instrumented penguins. Our recent tagging efforts show that humpback whales feed widely throughout the PAL study region during summer (Fig. 6) but that whales become more concentrated in nearshore waters in fall and early winter (Curtice et al. in preparation). We will conduct state-space movement analyses (Breed et al. 2009) and develop utilization distributions of tagged animals in three dimensions (x, y, and t – see Keating and Cherry 2009) to determine the location of preferred feeding areas and determine the extent to which these preferred areas overlap with process study sites in deep canyons (Fig. 3B). Importantly, we will also determine to what extent these preferred feeding areas overlap in space and time with the foraging areas of Adélie and other penguins. During the critical chick-rearing period for penguins, we hypothesize that the spatio-temporal overlap between foraging ranges of humpback whales and penguins will decrease from north to south. This is likely due to a combination of the amount and persistence of sea ice from the previous winter, the timing of migration and return to feeding grounds by whales, and the relative abundance of krill in these areas.

Fine-scale (Palmer Station-based sampling). The unique PAL data on Adélie and gentoo penguin population trends and foraging ecology provide an opportunity to test ecological hypotheses regarding top-down versus bottom-up control within this system. Explicitly, we will test the hypothesis that the relative abundance of humpback whales within the foraging areas of penguins around Palmer Station will impact Adélie penguin foraging performance, while having no effect on gentoo penguins. Inherent in this hypothesis is the assumption that krill is a limiting resource (Milne 1961). It will be difficult to determine whether or not total krill abundance is limiting, but we can look for changes in the distribution, foraging behavior, and breeding success of penguins as proxies for prey availability within their foraging areas (Fraser & Hofmann 2003). Friedlaender et al. (2011) established that the distribution of humpback whales is closely linked with that of Antarctic krill, but the distribution of Adélie penguins is tightly coupled with physical structures (land and sea ice) that offer habitat for nesting and resting. Antarctic minke and humpback whales offer an example of how closely related, sympatric species partition resources to avoid competition (Friedlaender et al. 2009). On the contrary, however, preliminary evidence suggests that when the relative abundance of humpback whales increases near an Adélie penguin foraging area, the foraging effort of the penguins also increases (Friedlaender et al. 2008). Several factors relate to niche overlap between krill predators (Fraser et al. 1992), but there is evidence that supports the notion that the presence of baleen whales can affect the foraging behavior and reproductive success of penguins (Ainley et al. 2006, 2009).

Thus, we will test the top-down hypothesis that the presence of foraging humpback whales negatively affects the demography of Adélie penguins due to competition for prey, while gentoo penguins and whales partition prey resources and therefore do not compete (Fig. 6). We will establish a long-term whale study at Palmer Station concurrent with the established long-term penguin research program. We will conduct visual line transect surveys from Zodiacs to determine the density and fine-scale distribution of humpback whales in the study area (as discussed above) and augment these surveys with capture-recapture estimates of seasonal abundance. We will compare these metrics of whale density and abundance with foraging trip duration (FTD) for both Adélie and gentoo penguins as determined by existing field methods (cf. Fraser & Hofmann 2003). FTD is a known proxy for foraging effort and can have significant impacts on key aspects of their ecology, such as breeding success and fledging weight, which are key determinants of survival, recruitment and population growth (Chapman et al. 2010, Chapman et al. 2011). We will also deploy multi-sensor suction cup tags (Johnson & Tyack 2003) on humpback whales to collect information on the location, timing, depth, and frequency of feeding events (Ware et al. 2011, Goldbogen et al. 2012, 2013; Friedlaender et al. 2014). Thus, we will determine the feeding behavior of whales spatially (locations of feeding relative to penguin feeding grounds), vertically (depth of feeding in the water column relative to the depth of penguin foraging dives), and temporally (when during day/night whales and penguins forage). Finally, we will conduct acoustic krill surveys using scientific echosounders mounted on Zodiacs (Nowacek et al. 2011, Friedlaender et al. in review-b) to compare prey patch metrics (e.g. depth, density, size and biomass) targeted by penguins and whales. We have used these methods successfully to determine characteristics of prey patches targeted by whales (Hazen et al. 2009); these observations will allow us to compare how penguins and whales target prey patches to either partition or compete for resources.

D. Foodweb structure and biogeochemical processes.

Motivation. Ecosystem metabolic and trophodynamic processes such as photosynthesis, decomposition, respiration, consumption, excretion and egestion drive global biogeochemical cycles of carbon, nutrients and trace metals. We propose a sustainable effort to quantify over the long-term key ecosystem-level processes (export and carbon system properties) and to identify the mechanisms by which ecological community composition influences the rates and distributions of biogeochemical cycling. Polar systems are predicted to be particularly sensitive to ocean acidification due to rising atmospheric CO_2, and therefore we also propose to expand our research on ocean acidification effects at both the organismal and ecosystem scales.

Background. Positive net community production (NCP, the excess of gross primary production over community respiration) typically indicates that fixed organic matter is available for export to depth (Ducklow & Doney 2013). This quantity is functionally equivalent to net ecosystem production in terrestrial systems (Chapin III et al. 2006). The vertical export of fixed organic carbon from the euphotic zone stores carbon in the deep ocean, isolated from the atmosphere over timescales of centuries to millennia, and thus constitutes an important control on climate variability (Sarmiento & Toggweiler 1984). A complex and variable suite of food-web processes contributes to particulate and dissolved organic carbon export (Fig. 7A). Export magnitude and efficiency are regionally variable (Laws et al. 2000, Siegel et al. 2014) and intimately related to phytoplankton (Falkowski & Oliver 2007, Boyd et al. 2010, Huang et al. 2012) and zooplankton (Steinberg et al. 2012b) community composition.

Through strategic collaborations, we have obtained new estimates of particle export from the ^{234}Thorium disequilibrium (Fig. 7B; Buesseler et al. 2010), and of gross primary and net community production rates from discrete-depth oxygen isotopic and Oxygen-Argon ratio (O_2/Ar) data collected at grid stations (Huang et al. 2012). In Huang et al. (2012), highest NCP (and presumably export) occurred in areas where the phytoplankton community was dominated by cryptophytes rather than diatoms, counter to conventional wisdom and to the export flux parameterizations linked to diatom fraction used in many ocean biogeochemical models. During the next funding cycle, we propose to test in detail the linkage of phytoplankton community composition (i.e., cryptophytes vs. diatoms; cell size) to export flux using an expanded, multi-year data set. We do not have ^{234}Th and O_2/Ar data for earlier periods in the Palmer LTER record, but we can infer possible biogeochemical trends based on field and satellite data on phytoplankton community composition. Along the WAP, high surface chlorophyll levels are marked by elevated fucoxanthin levels, a pigment marker for diatoms, and higher relative fractions of large cells (>20 um) (Montes-Hugo et al. 2008). Decadal satellite ocean color trends (Montes-Hugo et al. 2009) therefore indicate substantial reorganization in phytoplankton community composition. The remote sensing data are consistent with observations and model results indicating the planktonic food web in the north WAP is shifting to a more microbial system with increased dominance of small-celled phytoplankton (cryptophytes, Moline et al. 2004) and microzooplankton grazers (Sailley et al. 2013a).

Zooplankton fecal pellets originating mainly from krill are the dominant export mechanism, at least in the north over the continental shelf (Gleiber et al. 2012). Over time, as the north shifts to a more microbial system, we predict reduced magnitude and efficiency of export due to possible reductions in krill and/or increased recycling of POM in the surface layers (Fig. 2BC). Alternatively, increases in salps – indiscriminate filter feeders which, unlike krill, are able to feed on small-celled phytoplankton such as cryptophytes – could lead to increased export, due to their high feeding rates and production of very large, fast-sinking fecal pellets (~ 700 m d^{-1}; Phillips et al. 2009), or to more sporadic export events, due to the ephemeral nature of salp blooms (Gleiber et al. 2012). In the south, where phytoplankton community structure is still largely comprised of diatoms (Montes-Hugo et al. 2008), and given that krill only remove a small fraction of the primary production in the WAP in summer (Bernard et al. 2012), we would predict that export would be high and largely in the form of diatom aggregates.

Elements of the WAP planktonic community may respond differentially to ocean acidification. Uptake of the excess CO_2 into the upper ocean leads to reduced seawater pH, carbonate ion concentration, and calcium carbonate ($CaCO_3$) mineral saturation states linked to declining biological calcification rates in some organisms in the laboratory (Doney et al. 2009). The Southern Ocean around Antarctica is argued to be a hotspot for early biological impacts of ocean acidification in part because cold waters will become undersaturated sooner for some $CaCO_3$ mineral forms (Orr et al. 2005, Steinacher et al. 2009), and there is evidence already for in situ dissolution of pteropod shells (planktonic snails) in undersaturated parts of the water column northeast of the Antarctic Peninsula (Bednaršek et al. 2012). The response of non-calcifying plankton to ocean acidification in polar systems remains largely unstudied. In whole-water perturbation experiments over about two weeks duration (Saba et al. 2012), small phytoplankton-dominated communities (small diatoms, cryptophytes), did not grow efficiently under high CO_2. Specifically, nanophytoplankton (2-20 µm) declined by 84% and exhibited significantly reduced photosynthetic efficiency during the 12-day incubation. Small phytoplankton are becoming more prevalent in waters along the WAP, but these communities may respond negatively to OA, creating a ripple effect in food webs and biogeochemical cycling. Additional perturbation experiments found that feeding by Antarctic krill and nutrient excretion rates increased under high CO_2 conditions, likely a result of increased metabolic demand due to compensation for maintaining internal acid-base balance (Saba et al. 2012).

Proposed Research. In the next award period, we will add new long-term measurements of the ^{234}Th disequilibrium to estimate particle export across the WAP region (e.g., Fig. 7B) and add seawater carbonate chemistry measurements (dissolved inorganic carbon, total alkalinity, pH) to the Palmer Station time series, complementing those made during the annual PAL research cruises (e.g., Fig. 7C) These new measurements will augment data on sinking particle flux and composition over the annual cycle from our moored sediment trap (Ducklow et al. 2008), and our yearly summer vertical profiles of dissolved inorganic nutrients, oxygen, inorganic carbon and alkalinity, and particulate and dissolved organic carbon and nitrogen. We will analyze the biogeochemical data in the context of relevant biological information on planktonic foodweb stocks and mass/energy flows, including: bacterial biomass/production, assimilation and growth rates; in situ and satellite ocean color imagery on phytoplankton biomass, size structure, taxonomy and net primary production; and zooplankton biomass, size-structure, taxonomy, grazing and fecal pellet production rates. Using statistical data analysis techniques (Martinson et al. 2008) and process models, we will relate time/space variations in biogeochemical dynamics to environmental and ecological data to discern the physical and biological controls on them.

Export. Pilot sampling for the ^{234}Th-deficit began as an external strategic collaboration (with K. Buesseler, ANT 0838866, January 2009,10), and we conducted our own measurements in 2012-14 by leveraging existing funds. ^{234}Th-deficit measurements expand our estimates of export, currently limited to a single sediment trap location (Fig. 3B), to the regional scale (Fig. 7B). Targeted measurements will be added to better assess the size structure and taxonomy of the phytoplankton community, specifically size-fractioned chlorophyll, microscopy for taxonomic identification, and HPLC pigments, size-fractioned zooplankton biomass (micro- versus macro- and mesozooplankton), major zooplankton groups that contribute to packaging and fecal pellet export (e.g., krill, salps, copepods). At selected process study sites, we will also continue to measure zooplankton grazing and fecal pellet production rates. Diel sampling of zooplankton biomass can be used to infer the net downward carbon transport due to vertical migration (Steinberg et al. 2000).

To to test our predictions about changing food web structure and particle flux, we propose to augment our sediment trap in the northern WAP with a second trap in the south sited over the shelf at comparable depth (Fig. 3B). This will allow north-south comparison of export over the full annual cycle. We will analyze chemical composition of particles (e.g., POC, PN) and particle type (zooplankton fecal pellets, phytoplankton aggregates). We are currently evaluating the performance of a new moored trap (obtained with a separate OPP award) by deploying it side by side with the existing LTER trap.

A key unknown for Southern Ocean foodwebs is the fraction of NPP entering the dissolved organic matter (DOC, DON) pool for eventual respiration and/or export. We will assess these fluxes by conducting on-deck mesocosm experiments at the process study stations on the annual cruises and at Palmer Station. Rates of DOC release by active phytoplankton can be estimated by modifications of the standard ^{14}C technique to measure primary production (Morán et al. 2011). Recent work in our laboratories indicates that gelatinous zooplankton can be an important source of DOM, and that DOM released by crustacea (copepods) vs. gelatinous zooplankton (ctenophores and scyphomedusae) results in growth of different microbial assemblages (Condon et al. 2011). We will assess DOM release by krill and salps, and other abundant zooplankton (e.g., copepods, pteropods) to a) estimate its relative importance in carbon and nitrogen flow, and b) compare the effects of DOM from krill and salps on bacterial abundance and community composition using flow cytometry (Morán et al. 2011).

Ocean acidification. Stable, solid-state, continuous pH sensors for seawater will be integrated into underway cruise sampling and CTD profiling to enhance our existing measurements of discrete DIC and alkalinity and underway pCO_2 (Fig. 7C; Johnson et al. 2009, Martz et al. 2010). We will also add pH sensors to the Palmer Station seawater intake. Continuous pH sensors will greatly enhance our ability to address questions related to ocean acidification. The continuous data will improve our ability to assess long-term secular trends, spatial patterns, and vertical structure in pH. We will compare the variations in the chemical data to planktonic community composition to assess possible effects on time-space distributions. One focus organism will be shelled pteropods, which are increasing in the WAP, contrary to expectations in an increasingly acidic polar ocean; the pteropod time series also shows highly significant correlations with ENSO climate indices and with sea ice extent and duration (Steinberg et al. submitted). We will also continue to conduct process experiments to assess the sensitivity of polar planktonic species to elevated CO_2 and low pH levels. We will collaborate with Dr. Grace Saba, a former PAL post-doc, to follow up on the krill response to ocean acidification; Dr. Saba was awarded an NSF grant (ANT

1246293) and just recently conducted the first set of experiments at Palmer Station for the three-year project.

Biogeochemical modeling. Several existing models have been used to derive biogeochemical fluxes from ocean color data (e.g., Laws et al. 2001). These models prescribe the amount of primary production flowing into large-particle pools and subsequently entering the sinking flux. The models differ in detailed trophic structure and parameterizations, but follow similar assumptions. We will build on our recent work with a hierarchy of models: an inverse food-web model for the WAP (Sailley et al. 2013a); a local 1-D biological-physical-sea ice model (Saenz et al. submitted, Saenz et al. in preparation); a global mechanistic model that connects satellite data to export (Siegel et al. 2014); and regional and global-scale 3-D ocean biogeochemical modeling (Doney et al. 2008, Jonsson et al. 2013). In Siegel et al. (2014), carbon transfer to higher trophic levels is assessed from the relationship of satellite-derived phytoplankton growth rate and biomass (Westberry et al. 2008) to net rate of biomass accumulation (Behrenfeld et al. 2013); size-dependent partitioning of this carbon between upper-ocean respiration and vertical export is determined from satellite estimates of phytoplankton size class (Kostadinov et al. 2009) and a simple food web model. The model shows good skill globally against ^{234}Th export estimates.

Using both in situ and remote sensing inputs, we will adapt this model to the PAL region and test the extent to which the simple framework can capture spatial variations (inshore to offshore; north to south) and temporal variations (high-ice and low-ice years) in biogeochemistry. We will apply the model both to the new, enhanced biogeochemical data set that will be collected during the next funding period as well as the rich, two-decade long historical PAL data set. To facilitate comparisons against data, we will add prognostic biogeochemical tracers (O_2, ^{234}Th, macro and micro-nutrients, DIC and alkalinity). Sensitivity experiments will be conducted to explore whether model skill can be improved by incorporation of a more sophisticated, size-structured zooplankton foodweb (microzooplankton, copepods, krill, salps) and microbial loop (bacteria, DOC) based on our inverse food-web model (Sailley et al. 2013a). Following Sailley et al. (2013b), we will use the model to characterize predator-prey and competitive interaction strengths as well as the potential for trophic cascades within the planktonic foodweb. The result will be a well tested, time-evolving, seasonal plankton food-web/biogeochemistry box model that can then be incorporated into the 1-D biological-physical-sea ice and regional 3-D ocean models that are required for assessing ecosystem resilience and transitions (Theme A) and the impacts of lateral connectivity and changing vertical stratification (Theme B).

To gain additional insight into the controls on biogeochemical fluxes, we will conduct cross-system comparisons and coordinate measurements with the California Current Ecosystem (CCE) LTER, the other marine pelagic LTER site. We will also organize a session on NEP and export processes at the next LTER All-Scientists Meeting. We exchange scientific findings frequently for comparison with the McMurdo Dry Valleys site, a vastly different Antarctic ecosystem.

E. Education and Outreach Activities.

Motivation and Background. In the last decade and a half, the number of tourists visiting Antarctic Peninsula sites has grown from a few hundred to more than 30,000 each year (IAATO 2014). At the heart of this increase is the public's innate curiosity about Antarctica's distinctive organisms and environment. The PAL Education and Outreach (E/O) program embraces a myriad of opportunities to educate from Palmer station, aboard research ships, and through local, regional and national efforts. We value and utilize an interdisciplinary team involving investigators, post docs, graduate and undergraduate students, and station and affiliated personnel in outreach. This approach affords us the opportunity to sustain diverse, broad outreach partnerships across all educational levels, utilize media, reach out to government agencies and local industries, and interact with tourists and the general public.

Proposed Research. To advance the public's understanding of climate change along the WAP, the PAL E/O program will expand our core strengths, sustain existing relationships and initiate new partnerships with local and regional K – Gray science education programs. This includes local partnerships with the

Sandwich STEM Academy and the New England Aquarium in Massachusetts, and nationally with the other funded projects like the Encyclopedia of Life (EOL) and Columbia University/Earth Institute Polar Learning and Responding Climate Change Education Partnership (PoLaR CCEP). We will continue to contribute to our existing partnerships with the Climate Literacy and Energy Awareness (CLEAN) team and keep working on cross-site projects within the LTER network. We will expand the integration of media, incorporate advanced web technologies like the Palmer Station Penguin Webcam, and elevate our use of social media networks beyond blogs, such as Facebook and Flickr.

In the early part of our next funding cycle we anticipate the completion of the joint PAL-Rutgers University documentary film "Antarctica: Beyond the Ice" which is now being enhanced with 3D animations to help illustrate some of the scientific concepts. It will be ready for broadcast in 2014. Several short science excerpts from the film have already been extracted to be featured on the PBS learning media website.

A major new initiative, the AntarcTECH Penguin Cam project, will use streaming technology to transport students in real time to Torgersen Island, Antarctica, site of an Adélie penguin rookery 2 km from Palmer Station. This will begin during the 2014/15 Adélie penguin breeding season. Adélie penguins, which serve as sensitive bio-indicators of change within the Antarctic ecosystem, will help to bring attention to the impacts of climate change along the WAP. The webcam will serve as a vehicle to engage students in virtual "scientific research sessions" collecting observational data on the arrival and survival of our target iconic species. One of the advantages of using this technology is that it also affords students the opportunity to participate in collaborative "instant text chats" with leading penguin experts while they make their observations. Early implementation in the first funding year will focus on testing user-friendliness and building the Palmer LTER web-infrastructure to coordinate and support these virtual experiences with Palmer station personnel.

To advance the webcam's value to educators, the PAL E/O coordinator will mentor at least eight teachers, facilitating professional development experiences while creating instructional materials to support the webcam-based sessions. Our core target population is five hundred 7th and 8th grade students at the STEM Academy in Sandwich, MA. Instructional materials will concentrate on the life history and behavior of the Adélie penguin. Materials will highlight the interdisciplinary nature of science in Antarctica and will immerse students in real world situations that parallel the scientific research of the PAL LTER team. Assessments will be built based on evaluating how successfully students demonstrate their understanding. Our classroom lessons will be submitted for review of pedagogical effectiveness with the goal of having them posted to existing partner libraries; the CLEAN digital library repository and the LTER Education Digital library. The Palmer LTER E/O coordinator leads the effort to manage the LTER Education Digital Library, so these libraries will serve to disperse our resources to wider audiences and help us stay involved in cross-site LTER network-related projects. Initially, these AntarcTECH lessons and units will begin as online resources, eventually transforming themselves into serving as content for a highly interactive iBook about the Adélie penguins for student use on iPads™ in the classroom. The Palmer E/O coordinator will serve as a key liaison and teacher, while helping over 500 students and their teachers in integrating these experiences into their STEM curricula over the next six years.

The progression of development on the project will also rely on our existing partnership with informal learning centers like the New England Aquarium in Boston and the Boston Museum of Science. Johanna Blasi, our 2013 Teacher at Sea, will facilitate the implementation of some of our content on iPads™ with Aquarium visitors in the Ocean Hall. Informal assessment from this implementation will provide us with feedback in making changes that increase the effectiveness of the iPad™ application and its functionality for use in both formal and informal learning environments. All of the resources that are developed in the AntarcTECH project will align to the Next Generation Science Standards (NGSS) but will also have a climate focus incorporating the climate literacy principles. This effort will further strengthen our partnership with the Climate Literacy and Energy Awareness (CLEAN) team.

With the remoteness of Antarctica, our outreach program relies heavily on digital media to successfully deliver our science to the public. Digital media use is expanding rapidly into learning practices, in both formal and informal ways. Preliminary research even shows that digital educational tools and games provide promise for new paradigms in curriculum and learning (Ito et al. 2008). Therefore, we built into our AntarcTECH penguin webcam project two additional initiatives. The first involves the development of a new memory game to be submitted to the Encyclopedia of Life's Species Match Memory Game. Secondly, we have partnered with Columbia University/Earth Institute Climate Center and their NSF-funded PoLAR project (Polar Learning and Responding Climate Change Education Partnership). The project is dedicated to developing a suite of interactive and game-like tools that capitalize on the iconic imagery of the Arctic and Antarctic. Palmer LTER E/O coordinator and PAL scientists will serve as Antarctic consultants for the project. We will initially create playing cards for use in an Antarctic EcoChains card game that will utilize existing food web species cards from our Sea Secrets children's book. We also recognize the potential to collaborate with the PoLAR project in creating an Antarctic version of the SMARTIC game (Strategic Management of Resource in times of Change). This game is targeted toward tourists but has value in classroom settings as well. The game sets players in situations that call upon them to set resource and development priorities based on changing conditions in the WAP region. Users have to negotiate to resolve conflicts and manage competing interests. Creating a game like this for the WAP has the potential to be sold at Palmer Station and be seen and used by many of the visitors and tourists that come to the Station each year.

Synthesis

In continuing our now 23-year long time series of local, daily to weekly observations at Palmer and Rothera Stations, and regional-scale observations on our annual oceanographic cruises, we will use our historical and proposed new data to gain new fundamental understanding of four central issues in ecology: mechanisms and trajectories of long-term change (Theme A), local to hemispheric, and daily to decadal forcing of ecosystem dynamics modulated by variability of vertical mixing and resource limitation on lower trophic levels (Theme B), competition among upper trophic level predators and top-down controls on ecosystem structure (Theme C) and interactions between biogeochemical fluxes and plankton community composition and trophodynamics (Theme D). Since its inception in 1990, PAL has addressed ecological questions at multiple spatial scales by combining local to regional station- and ship-based oceanographic observations with global remote sensing. Now in our third decade, we are poised to resolve interannual to decadal temporal variability with increased certainty. We exploit the strong teleconnections between climate variability (ENSO, Atlantic Multidecadal Oscillation) and regional meteorological conditions on the WAP to better understand sea ice variability, and in turn, the controls on local ecological dynamics. We will test the hypothesis that large-scale variations in the position of the ACC determine the frequency and intensity of cross-shelf transport of warm, nutrient-rich UCDW in submarine canyons, regulating ocean-coastal connectivity, local productivity and prey availability for penguins and whales. We will use the strong trends in ecosystem properties caused by regional warming and sea ice loss to explore multiscale ecosystem changes at local (Palmer, Rothera Stations) to regional (cruise and sampling grid) scales in response to pulse and press forcings. We will use our changing system to investigate ecological resilience and tipping point indicators. Our high-resolution, multiscale sampling design includes autonomous temporal (moorings, seconds-years) and spatial (gliders, meters-kilometers) efforts to complement traditional small-boat (hours) and ship-based research (days). Finally we use our infrastructure and data archive to encourage and facilitate new research into areas beyond the scope of PAL. Our long-term vision is to build a multinational consortium of international partners along the entire Peninsula, tied together by autonomous observing systems and research collaborations, to further our understanding of this rapidly evolving region.

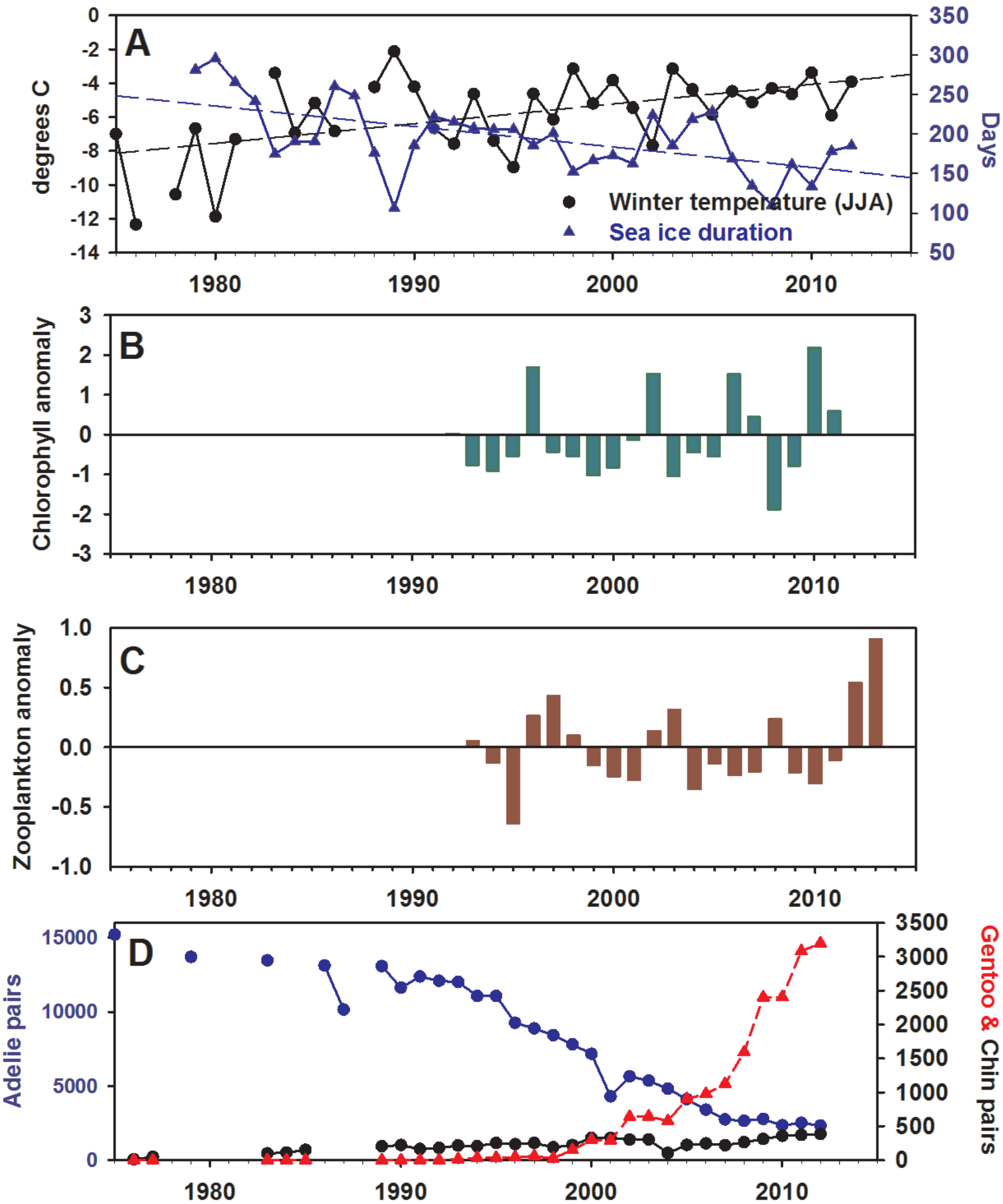

Figure 1. PAL signature long-term datasets. **A)** winter (June, July, August; JJA) surface air temperature at Palmer Station and sea ice duration averaged over the PAL sampling grid (Fig. 3A,B). Trends indicated by regression lines are significant ($p<0.01$). **B, C)** annual summer (January) anomalies of phytoplankton (chlorophyll) stocks at Palmer Station and Antarctic Krill (*E. superba*) abundance in the northern sampling grid. Positive krill anomalies lag chlorophyll by one year. **D)** three species of penguin breeding pairs in the Palmer Station region. Time-series analysis indicates a tipping point around 1993 (Bestelmeyer et al. 2011).

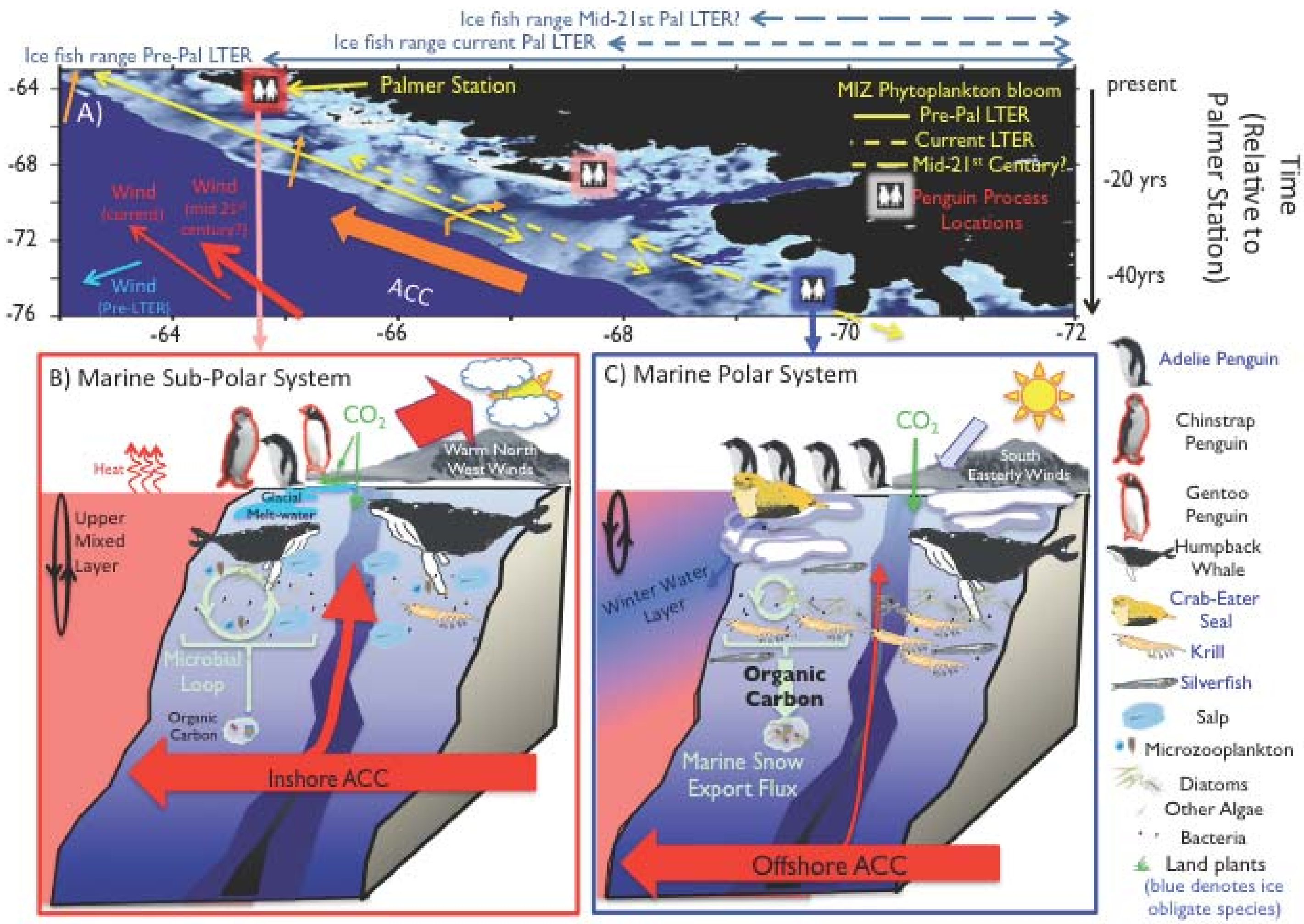

Figure 2. A) PAL spans a space and time gradient that has shifted during the program. The rates/mechanisms of these climate-induced shifts are the focus of Theme A. Panels **B** and **C** represent the current ecosystem gradient within the Pal-LTER. The north has shifted to a sub-polar system. The southern region remains a polar ecosystem. Upwelling of warm UCDW in canyons (red arrows), a major ecosystem driver, is sensitive to climate variability. How large-scale forcing structures local foodwebs is the focus of Themes A, B, and C, and how this forcing affects biogeochemistry is the focus of Theme D. Additionally, Theme C assesses mechanisms and effects of change in upper trophic levels (penguins and whales).

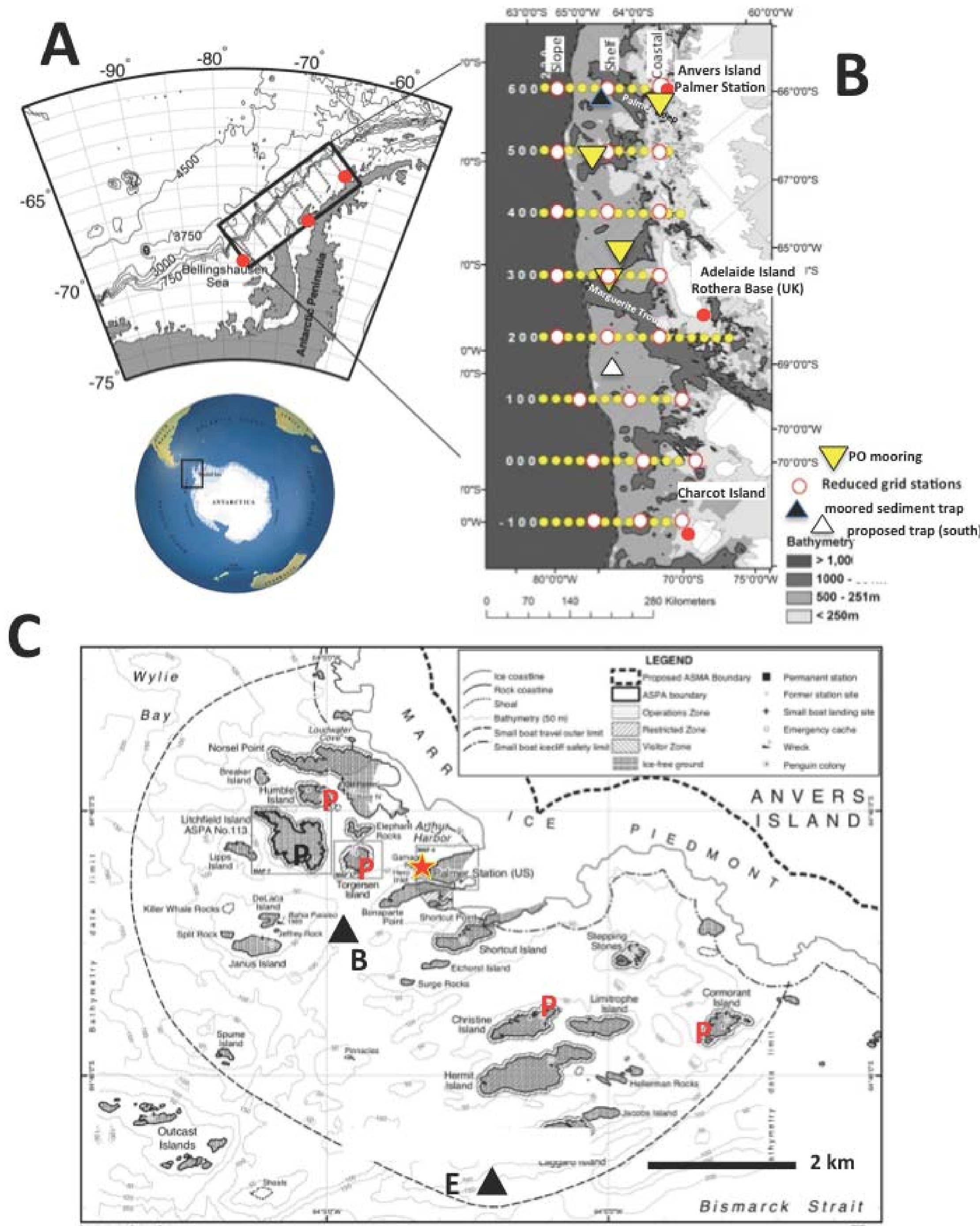

Figure 3. A) PAL study region in the Southern Ocean and along the western Antarctic Peninsula. Map **B** shows long-term hydrographic stations (yellow & white dots), locations of Palmer and Rothera time series and process study stations at 3 locations (red dots) along the peninsula. Prior to 2009 we occupied all yellow stations on the 200 to 600 lines (lines are 100 km apart, stations 20 km apart); in 2009 we expanded south to the +100, 000 and -100 lines, reducing our spatial resolution (white dots w/ red outline). Also shown: moorings (triangles) and cross shelf canyons (grey shading). **C)** detail map of Palmer Station (star) region showing locations of active (**P**) and extinct (**P**) penguin colonies and time series Zodiac hydrostations (triangles).

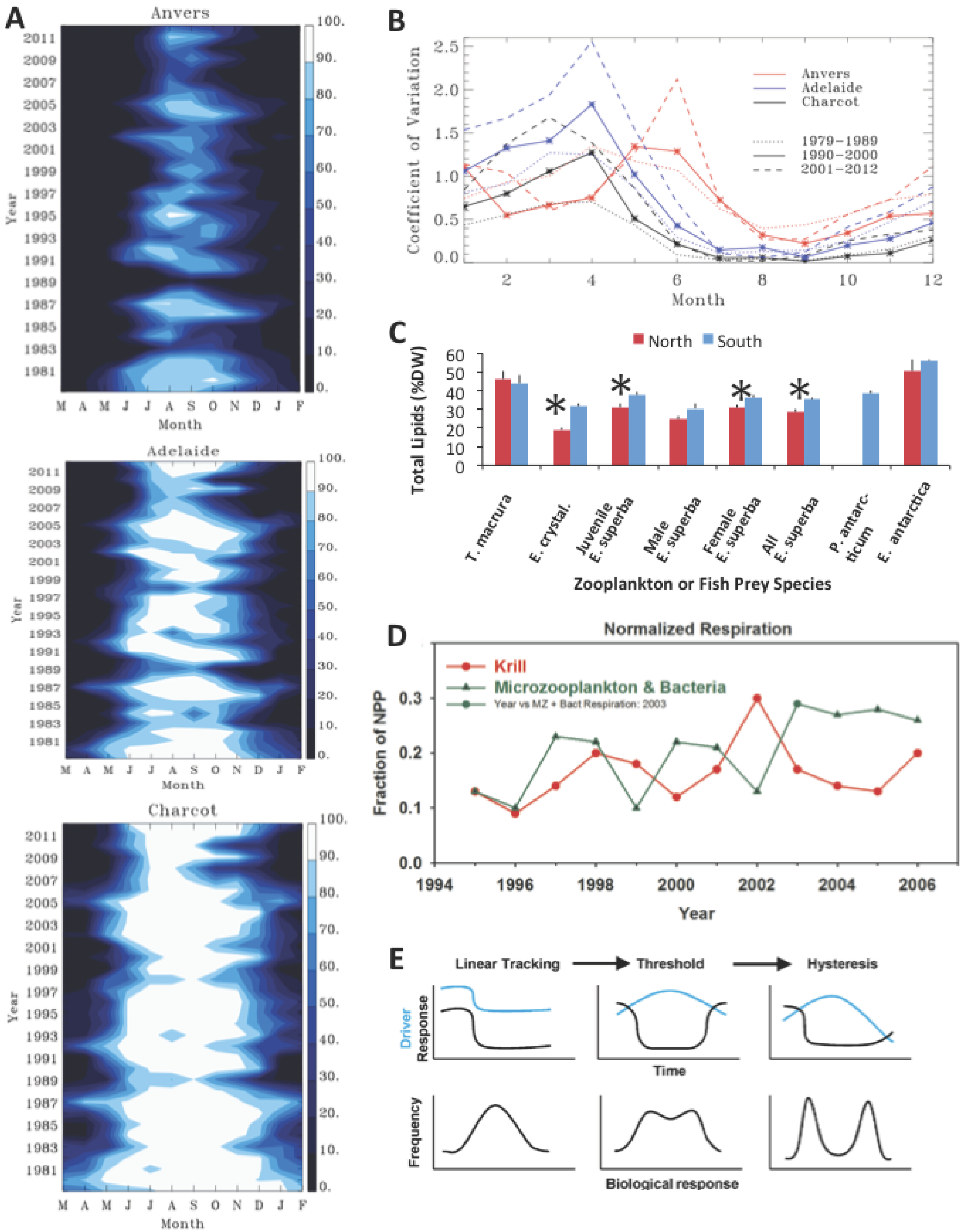

Figure 4. Research Theme A. Long-term change. A) Changes in sea ice seasonality, showing shorter ice seasons with time, north to south (see **Fig. 3** for locations). **B)** Seasonal changes in sea ice variance (coefficient of variation), showing increased variance with time, north to south. **C)** Examples of biochemical indicators, significant (*) differences north vs. south in lipid concentration of penguin prey items (Ruck et al, in review). **D)** Output of inverse foodweb model, showing development of microbe-dominated ecosystem in north (Sailley et al, 2013). **E)** Three classes of driver/response relationships, with shifts to bimodal frequency distributions when threshold or hysteretic change occurs (Bestlemeyer et al, 2011), as hypothesized for the northern and mid regions. We will combine approaches C-E to address questions posed in Theme A.

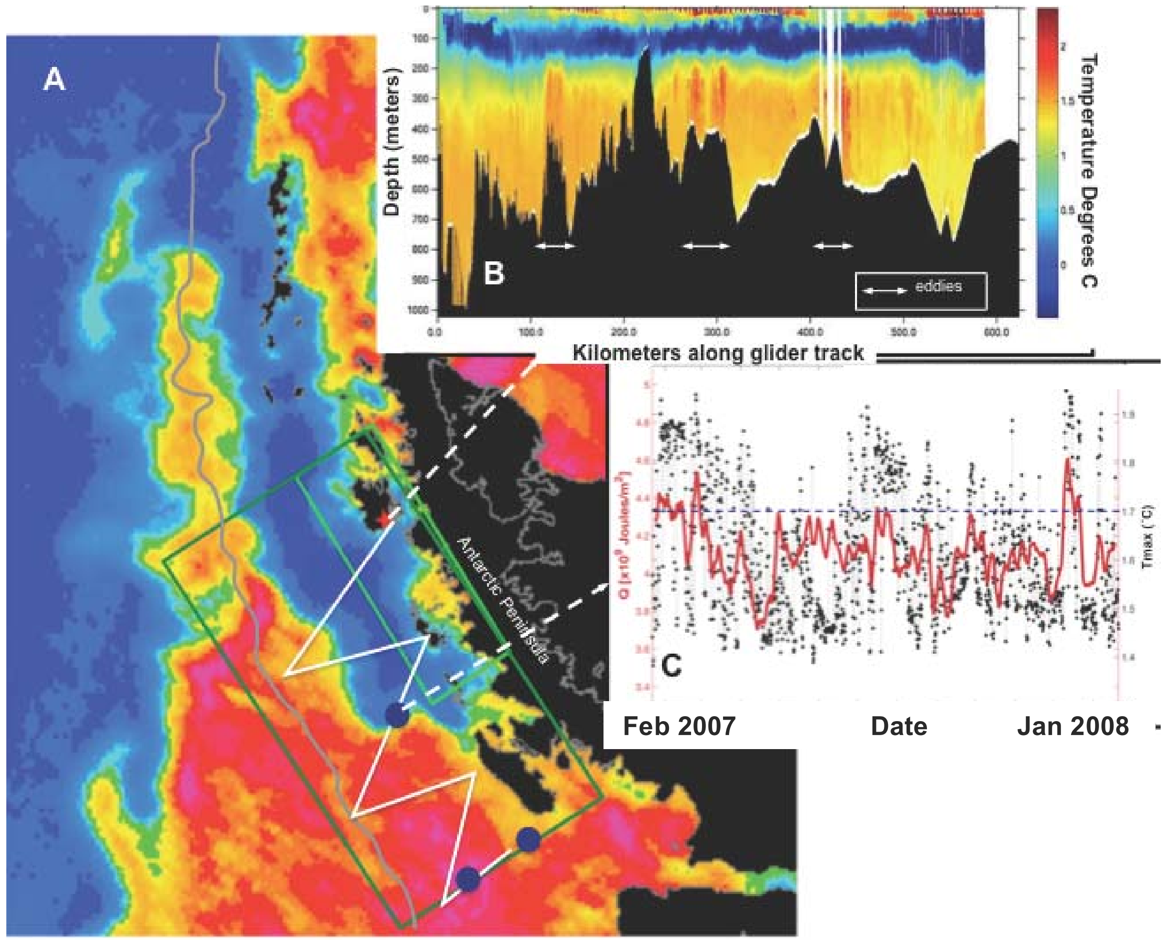

Figure 5. Theme B. Lateral connections and vertical stratification, showing sampling strategy. **A)** A color enhanced satellite image of sea ice concentration during mid-winter in 2009, typical of the past decade. Pink indicates 100% ice cover with blue being 0% ice cover. Bold grey line depicts continental shelf-slope break (1000 meters). The upper western half of the Antarctic Peninsula shows no ice. The ship sampling regions are denoted by the green boxes (high resolution coastal surveys in light green and process study zone indicated by dark green box). White line indicates potential glider flights. Blue dots indicate potential mooring locations. **B)** Spatial sampling is done with gliders. A temperature cross-section sampled in 2011 shows subsurface eddies that are indicated by warm temperatures. **C)** Temporal sampling is done with moorings. Smoothed 2007 time series plot (red line) shows daily variations in the water column heat content (Q), dots show maximum temperature values. Dots above the dashed line indicate presence of an eddy. Nearly every jump in Q coincides with an eddy.

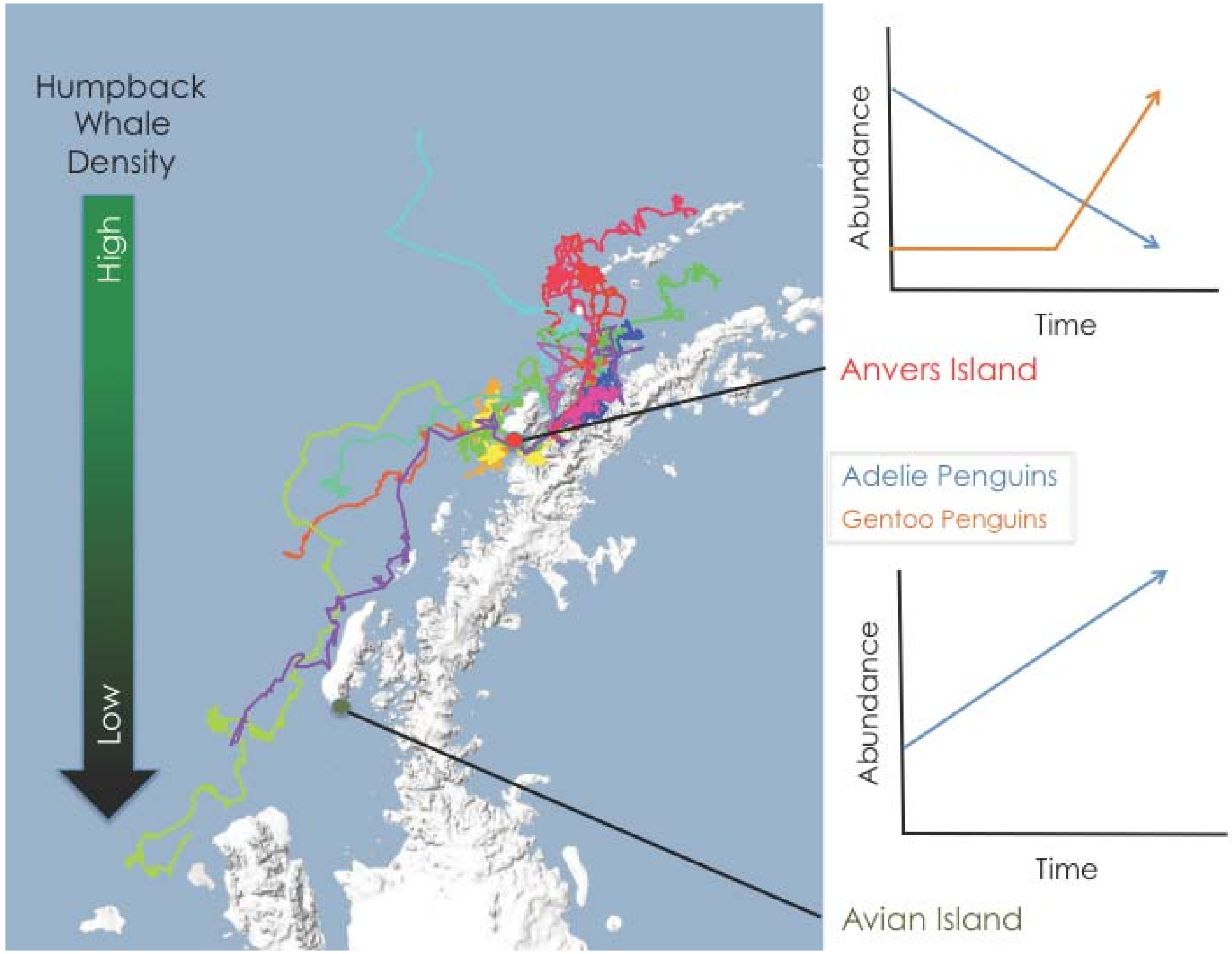

Figure 6. Theme C. Top-down controls and shifting baselines. The greater PAL sampling area showing the distribution and habitat use of humpback whales during January-February in relation to Adèlie and gentoo penguin population trends from north to south. Each colored line on the map is the track of a satellite-tagged humpback whale. While the whales range over a broad spatial extent throughout the PAL sampling region, they are more likely to be found in the northern portion of the study area near Anvers Island than to the south near Avian and Charcot Islands. Population trends of Adèlie and gentoo penguins are shown for two major breeding colonies (Anvers and Avian Islands): Adèlie penguins are decreasing coincident to increases in gentoo penguins and in areas with high abundances of humpback whales, while Adèlie penguins are increasing at Avian Island where there are no gentoo penguins and lower densities of humpback whales.

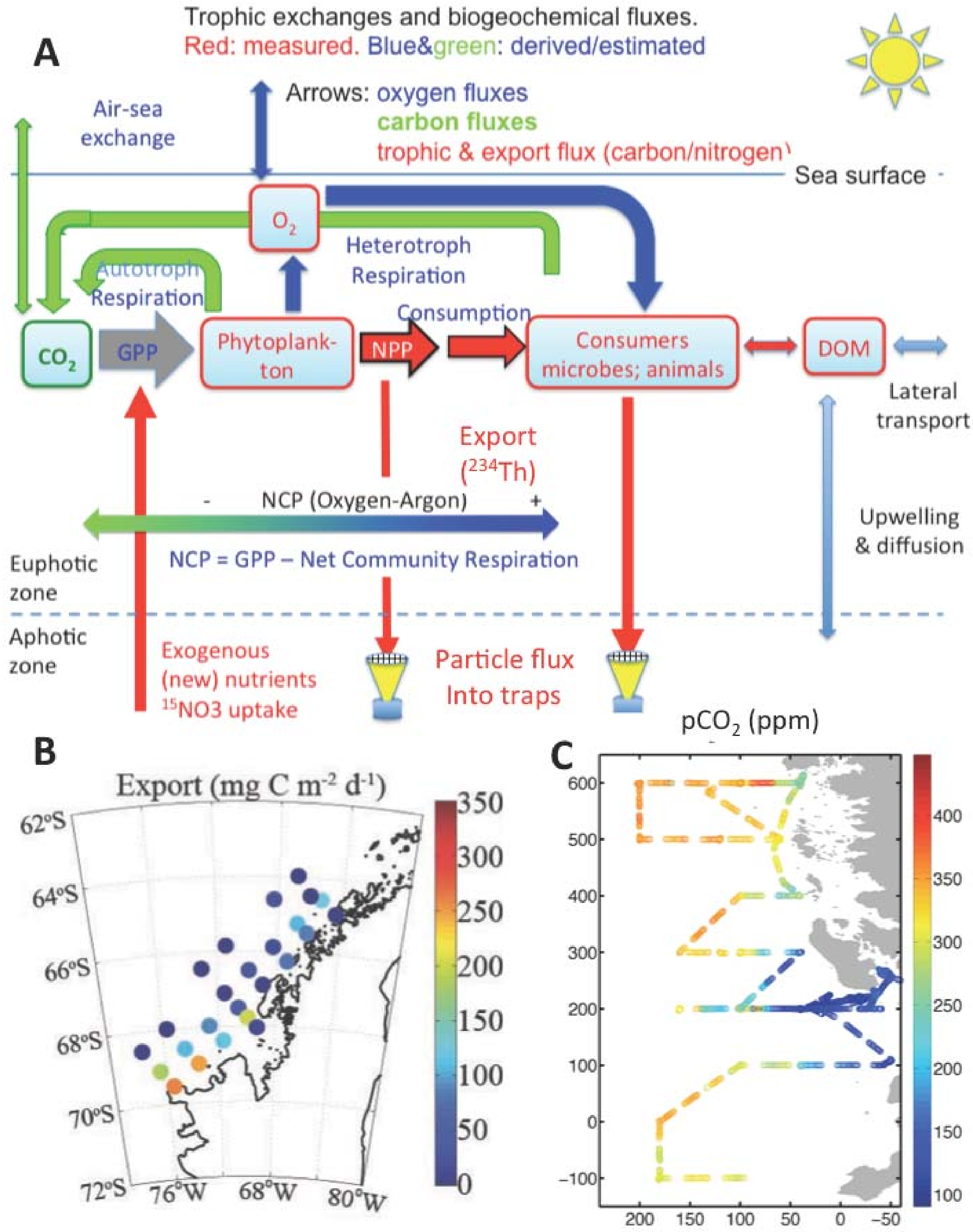

Figure 7. Research Theme D: Foodwebs and biogeochemical processes. A) conceptual diagram showing trophic and biogeochemical fluxes and measurements or derivations of rates and stocks (see color key in title) (after Ducklow & Doney, 2013). **B)** particulate carbon export from upper 100 meters measured by Thorium-234 deficit (unpub data, Jan 2013). **C)** continuous underway pCO2 (ppm) at sea surface along Jan 2012 cruise track.

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(* supported by ANT0823101; # cross-site product, PIs in **bold,** student and postdoc authors underlined)

(Additional 2008-13 PAL publications listed at end of citations)

Our Top Ten publications are in red, with brief annotations.

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Five Recent Products or Publications.

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

Sailley, S.F., **Ducklow, H**., Moeller, H.V., Fraser, W. R., Schofield, O., Steinberg, D.K., Garzio, L.M., and Doney, S. C. **2013**. Carbon fluxes and pelagic ecosystem dynamics near two western Antarctic Peninsula Adelie penguin colonies: an inverse model approach. Marine Ecology Progress Series, 492, 253-272, 2013

Meredith, M.P., Venables, Hugh J., Clarke, Andrew, **Ducklow, Hugh W.,** Erickson, Matthew, Leng, Melanie J., Lenaerts, Jan T. M., van den Broeke, Michiel R. **2013**. The Freshwater System West of the Antarctic Peninsula: Spatial and Temporal Changes. Journal of Climate 26:1669-84.

Ducklow H, Clarke A, Dickhut R, Doney SC, Geisz H, Huang K, Martinson DG, Meredith MP, Moeller HV, Montes-Hugo M, Schofield O, Stammerjohn SE, Steinberg D, Fraser W. **2012**. The Marine Ecosystem of the West Antarctic Peninsula. Chapter 5 PP: 121-159 In: Rogers A, Johnston N, Clarke A, Murphy E (eds) Antarctica: An Extreme Environment in a Changing World. Blackwell, London

Fountain, A. G., J. L. Campbell, E. A. G. Schuur, S. Stammerjohn, M. W. Williams, and **H. W. Ducklow. 2012.** The Disappearing Cryosphere: Impacts and Ecosystem Responses to Rapid Cryosphere Loss. BioScience 62: 405-415.

Five Other Relevant Publications or Products.

Ducklow, H.W., Schofield O, Vernet M, Stammerjohn S, Erickson M. Multiscale control of bacterial production by phytoplankton dynamics and sea ice along the western Antarctic Peninsula: A regional and decadal investigation. **2012.** J. Marine Systems 98-99: 26-39.

Huang, K., **H. W. Ducklow,** M. Vernet, N. Cassar, and M. L. Bender. **2012**. Export production and its regulating factors in the West Antarctica Peninsula region of the Southern Ocean. Global Biogeochem. Cycles, 26: doi:10.1029/2010GB004028.

Buesseler, KO, AMP McDonnell, OME Schofield, DK Steinberg and **HW Ducklow**. **2011**. High particle export over the continental shelf of the west Antarctic Peninsula. Geophysical Research Letters 37, doi:10.1029/2010GL045448.

Schofield, O., **H.W. Ducklow**, D.G. Martinson, M.P. Meredith, M.A. Moline, W.R. Fraser. How Do Polar Marine Ecosystems Respond to Rapid Climate Change. **2010**. Science 328: 1520-1523.

Kirchman, D.L., X.A.G. Moran, and **H. Ducklow**. **2009**. Microbial growth in the polar oceans role of temperature and potential impact of climate change. Nature Reviews of Microbiology. 7:451-459.

Five Synergistic Activities

Ocean Carbon Biogeochemistry Scientific Steering Committee, **2013 -**

National Science Foundation, Office of Polar Programs Blue Ribbon Panel for Future Antarctic Science**. 2011-12** (Norman Augustine, Chair; appointed by White House Science Advisor and OSTP)

Committee for the Workshop on Frontiers in Understanding Climate Change and Polar Ecosystems (J. Grebmeier, J. Priscu, Co-chairs). **2011.** Frontiers in understanding climate change and polar ecosystems: Report of a workshop. Washington DC: National Academies Press. 86 pp.

Committee on Future Science Opportunities in Antarctica and the Southern Ocean.. (W.M. Zapol, Chair). **2011.** Future Science Opportunities in Antarctica and the Southern Ocean. The National Academies Press, Washington, DC, 230 pp.

UNOLS Polar Research Vessel Scientific Requirements Committee (R. Dunbar, Chair), **2011.**

DOUGLAS G. MARTINSON
Lamont-Doherty Earth Observatory (**LDEO**), Palisades, New York 10964

Professional Preparation

California State Univ., Long Beach (**CSULB**)	Geology (major)/Math (minor)	B.S.	1976
LDEO of Columbia Univ.	PaleoClimate/PhysO.	M.A.	1979
LDEO of Columbia Univ.	PaleoClimate/PhysO	Ph.D.	1982
Woods Hole Oceanographic Institution (**WHOI**)	PhysO.	Postdoc-Scholar & Investigator	1982-1983

Appointments

1988 (Fall) Guest Scientist, Alfred-Wegener Institute for Polar and Marine Research, Germany
1992 (Fall) Visiting Professor, Institut d'Astronomie et de Geophysique, Universite Catholique de Louvain, Belgium
1984 - Adjunct Professor [Full (1995), Assoc.(1991), Assist.(1984)], Columbia University
1984 - Doherty Research Scientist (Senior (1994), Regular(1991), Assoc.(1984)], LDEO

Five Recent Publications or Products

Martinson, D.G., and D.C. McKee (2012). Transport of Warm Upper Circumpolar Deep water onto the Western Antarctic Peninsula Continental Shelf., Ocean Sci. 8, 433-442.

Martinson, D.G. (2012). Antarctic circumpolar current's role in the Antarctic ice system: An overview, Palaeogeography, Palaeoclimatology, Palaeoecology 335-336, 71–74.

Martinson DG, SE Stammerjohn, RA Iannuzzi, RC Smith, M Vernet, 2008. Western Antarctic peninsula physical oceanography and spatio-temporal variability. Deep-Sea Research II, doi:10.1016/j.dsr2.2008.04.038.

Martinson, D. G., and R. A. Iannuzzi, 2003. Spatial/temporal patterns in Weddell gyre characteristics and their relationship to global climate, JGR, 108(C4), 8083, doi:10.1029/2000JC000538.

Martinson, D.G. & M. Steele, 2001. Future of the Arctic Sea Ice Cover: Implications of an Antarctic Analog, Geophys. Res. Lets., 28, p.307-310.

Five Other Relevant Publications or Products

Martinson, D.G. & R.A. Iannuzzi, 1998. Antarctic Ocean-Ice Interaction: Implications From Ocean Bulk Property Distributions. *Antarctic Research Series Volume on Antarctic Sea Ice Physical Properties and Processes*, AGU, M. Jeffries, ed., v.74,243-271.

Martinson, D.G., 1991. Open Ocean Convection in the Southern Ocean. *Deep Convection and Deep Water Formation*, Elsevier Science Publishers, Amsterdam (Gascard and Chu, Editors) 37-52.

Martinson, D.G., 1990. Evolution of the Antarctic Mixed Layer and Sea-Ice; Open Ocean Deep Water Formation and Ventilation. *J. Geophys. Res. (JGR)*, 95, 11641-11654.

Martinson, D.G., D.S. Battisti, R.S. Bradley, J.E. Cole, R.A. Fine, M. Ghil, Y. Kushnir, S. Manabe, M.S. McCartney, M.P. McCormick, M.J. Prather, E.S. Sarachik, P. Tans, L.G. Thompson & M. Winton, 1998. Decade-to-Century-Scale Climate Variability and Change: A Science Strategy, *National Academy Press*, Washington, D.C.

Martinson, D.G., N.G. Pisias, J.D. Hays, T.C. Moore, Jr., J. Imbrie and N.J. Shackleton, 1987. Age dating and the orbital theory of the ice ages: development of a high resolution, 0-300,000-Year chronostratigraphy. *Quaternary Research*, 27, 1-29.

Synergistic Activities

2006 *Lecturer,* Geophysical Fluid Dynamics Summer Study Program (Polar Ice), WHOI
2001 *Expert Witness,* Senate Committee Hearing on Climate Change in Arctic
1997 - 2001 *Member,* WCRP, CLIVAR Science Steering Group (writing implementation plan) and Task Force for Project on Climate and Cryosphere (**CliC**) (develop science plan)
1997 - 2000 *Member,* NAS/NRC Committee on Global Change Research
1995 - 1998 *Chair,* NAS/NRC Panel on Climate Variability: Decade to Century Times Scales

BIOGRAPHICAL SKETCH---SCOTT C. DONEY

PROFESSIONAL PREPARATION

University of California at San Diego:	Chemistry	BA, 1986
Massachusetts Institute of Technology--Woods Hole Oceanographic Institution Joint Program:		
	Chemical Oceanography	PhD, 1991
National Center for Atmospheric Research	Ocean Modeling	Postdoc, 1991-1993

APPOINTMENTS

Senior Scientist (2005-present), Woods Hole Oceanographic Institution, Woods Hole, MA.
Associate Scientist w/Tenure (2002-2005), Woods Hole Oceanographic Inst., Woods Hole, MA.
Scientist (1993-2002), National Center for Atmospheric Research, Boulder, CO.

Five Recent Products or Publications

Montes-Hugo, M., S.C. Doney, H.W. Ducklow, W. Fraser, D. Martinson, S.E. Stammerjohn, and O. Schofield, 2009: Recent changes in phytoplankton communities associated with rapid regional climate change along the western Antarctic Peninsula, *Science,* **323**, 1470-1473.

Doney, S.C., I. Lima, R.A. Feely, D.M. Glover, K. Lindsay, N. Mahowald, J.K. Moore, and R. Wanninkhof, 2009: Mechanisms governing interannual variability in upper-ocean inorganic carbon system and air-sea CO_2 fluxes: physical climate and atmospheric dust, *Deep-Sea Res. II,* **56**, 640-655.

Montes-Hugo, M., C. Sweeney, S.C. Doney, H. Ducklow, R. Frouin, D.G. Martinson, S. Stammerjohn, and O. Schofield, 2010: Seasonal forcing of summer dissolved inorganic carbon and chlorophyll *a* on the western shelf of the Antarctic Peninsula, *J. Geophys. Res. Oceans,* **115**.

Sailley, S.F., H.W. Ducklow, H.V. Moeller, W.R. Fraser, O.M. Schofield, D.K. Steinberg, L.M. Garzio, and S.C. Doney, 2013: Carbon fluxes and pelagic ecosystem dynamic near two western Antarctic Peninsula Adélie penguin colonies: an inverse model approach, *Marine Ecology Progress Series*, **492**, 253-272, doi: 10.3354/meps10534

Jonsson, B.F., S.C. Doney, J. Dunne, and M. Bender, 2013: Evaluation of the Southern Ocean O_2/Ar-based NCP measurements in a model framework, *J. Geophys. Res. Biogeosci.,* 118*,* doi:10.1002/jgrg.20032

Five Other Relevant Products or Publications

Doney, S.C., V.J. Fabry, R.A. Feely, J.A. Kleypas, 2009: Ocean acidification: the other CO_2 problem, *Annu. Rev. Mar. Sci.,* **1**, 169-192

Doney, S.C., 2010: The growing human footprint on coastal and open-ocean biogeochemistry, *Science*, **328**, 1512-1516.

Glover, D.M., W.J. Jenkins, and S.C. Doney, 2011: *Modeling Methods for Marine Science*, Cambridge University Press, Cambridge, UK, 592 pp., www.cambridge.org/glover, ISBN-13: 9780521867832

Doney, S.C., M. Ruckelshaus, J.E. Duffy, J.P. Barry, F. Chan, C.A. English, H.M. Galindo, J.M. Grebmeier, A.B. Hollowed, N. Knowlton, J. Polovina, N.N. Rabalais, W.J. Sydeman, and L.D. Talley, 2012: Climate change impacts on marine ecosystems, *Annu. Rev. Mar. Sci.,* **4***,* 11-37.

Bopp, L., L. Resplandy, J.C. Orr, S.C. Doney, J.P. Dunne, M. Gehlen, P. Halloran, C. Heinze, T. Ilyina, R. Séférian, J. Tjiputra, and M. Vichi, 2013: Multiple stressors of ocean ecosystems in the 21st century: projections with CMIP5 models, *Biogeosciences*, **10**, 6225-6245

SYNERGISTIC ACTIVITIES

- Two articles on ocean acidification in *Scientific American*, March 2006 and April 2010
- ASLO electronic e-lecture on ocean acidification for educators and researchers
- Chair of Scientific Steering Committee, U.S. Ocean Carbon and Biogeochemistry (OCB) Program, 2006-2011
- National Climate Assessment 2013, Convening Lead Author for Oceans & Marine Resources Chapter
- Congressional testimony on climate change and ocean acidification, May 2007, June 2008, July 2013

PETER J.S. FRANKS
BIOGRAPHICAL SKETCH
Scripps Institution of Oceanography/University of California, San Diego
La Jolla, CA 92093-0218
(858) 534-7528 pfranks@ucsd.edu

PROFESSIONAL PREPARATION

Queen's University	Biology	B.Sc. (hons., 1st class) 1981
Dalhousie University		Biological Oceanography M.Sc. 1984
MIT/WHOI		Biological Oceanography Ph.D. 1990
Oregon State University	Physical Oceanography	Postdoc 1990-1992

APPOINTMENTS

2010-present: Director, Integrative Oceanography Division
2001-present: Professor, Scripps Institution of Oceanography
1997-2001: Associate Professor, Scripps Institution of Oceanography
1993-1997: Assistant Professor, Scripps Institution of Oceanography
1990-1992: Faculty Research Associate (Courtesy), OSU
1990: Temporary Postdoctoral Investigator, WHOI

FIVE RECENT PRODUCTS OR PUBLICATIONS

2012 Taniguchi, D.A.A., P.J.S. Franks and M.R. Landry. Estimating size-dependent growth and grazing rates and their associated errors using the dilution method. Limnol. Oceanogr.: Methods 10:868-881.
2012 Karaköylü, E.M. and P.J.S. Franks. Reassessment of copepod grazing impact based on continuous time series of in vivo gut fluorescence from individual copepods. J. Plankton Res. 34:55-71.
2012 Omand, M.M., F. Feddersen, R.T. Guza and P.J.S. Franks. Episodic nutrient fluxes and nearshore phytoplankton blooms in Southern California. Limnol. Oceanogr. 57:1673-1688.
2011 Lucas, A.J., C.L. Dupont, V. Tai, J.L. Largier, B. Palenik and P.J.S. Franks. The green ribbon: multiscale physical control of phytoplankton productivity and community structure over a narrow continental shelf. Limnol. Oceanogr. 56:611-626.
2010 Prairie, J.C., P.J.S. Franks and J.S. Jaffe. Cryptic peaks: Invisible vertical structure in fluorescent particles revealed using a planar laser imaging fluorometer. Limnol. Oceanogr. 55:1943-1958.

Five Other Relevant Publications or Products

2013 Rippy, M.A., P.J.S. Franks, F. Feddersen, R.T. Guza and D.F. Moore. Physical dynamics controlling variability in nearshore fecal pollution: Fecal indicator bacteria as passive particles. Mar. Poll. Bull. 66:151-157.
2013 Rippy, M.A., P.J.S. Franks, F. Feddersen, R.T. Guza and D.F. Moore. Physical dynamics controlling variability in nearshore fecal pollution: The effects of mortality. Mar. Poll. Bull. 66:191-198.
2012 Li, Q.P., P.J.S. Franks, M.D. Ohman and M.R. Landry. Enhanced nitrate fluxes and biological processes at a frontal zone in the Southern California Current system. 34:790-801.

2011 Lucas, A.J., P.J.S. Franks and C.L. Dupont. Horizontal fluxes driven by the internal tide support elevated phytoplankton productivity over the inner continental shelf. Limnol. Oceanogr.: Fluids & Env. 1:56-74.

2011 Li, Q.P., P.J.S. Franks and M.R. Landry. Microzooplankton grazing dynamics: parameterizing grazing models with dilution experiment data from the California Current Ecosystem. Marine Ecology-Progress Series. 438:59-69.

SYNERGISTIC ACTIVITIES

• Editorial Board, *Journal of Plankton Research, Journal of Marine Research, Oceanography Journal*
• Took high-school teachers to sea R/V Wecoma (2006), R/V Thompson (2007), R/V New Horizon (2010, 2011)
• Take 30-50 students to sea each year during teaching of Biological Oceanography (SIO280)
• Mentored first-year students in my Biological Oceanography class (SIO280) in publishing papers based on their class projects (Abbriano et al., 2011; Bagulayan et al., 2012).
• Developed new continuum size-structured planktonic ecosystem model.

BIOGRAPHICAL SKETCH

William Ronald Fraser
Polar Oceans Research Group TEL: (406) 842-7442
P.O. Box 368 FAX: (406) 842-7442
Sheridan, MT 59749 E-mail: bfraser@3rivers.net

Professional Preparation

1973: Utah State University, School of Natural Resources; B.S. Major: Wildlife Management.

1989: University of Minnesota, Department of Ecology and Evolutionary Biology; Ph.D. Major: Ecology.

Appointments

2000: President and Lead Investigator, Polar Oceans Research Group, Sheridan, MT.

2000: Adjunct Professor, Department of Oceanography, Old Dominion University, Norfolk, VA.

1994: Adjunct Associate Professor, Department of Ecology, Montana State University, Bozeman, MT.

1991: Adjunct Asst. Professor, Department of Oceanography, Old Dominion University, Norfolk, VA.

1983: Research Associate, Point Reyes Bird Observatory, Stinson Beach, CA.

1974: Wildlife Biologist, Colorado Division of Wildlife Resources, Denver, CO.

Five Recent Publications or Productsd (Five most closely related)

Erdmann, ES, Ribic, CA, Patterson-Fraser, DL, Fraser, WR. **2011**. Characterization of winter foraging locations of Adélie penguins along the western Antarctic Peninsula. Deep Sea Research II 58: 1710-1718.

Fraser, W.R., and Hofmann, E.E. **2003**. A predator's perspective on causal links between climate change, physical forcing and ecosystem response. Marine Ecology Progress Series 265: 1-15.

Friedlaender, A.S., Johnston, D.W., Fraser, W.R., Burns, J., Halpin, P.N.,Costa, D.P. **2011**. Ecological niche modeling of sympatric krill predators around Marguerite Bay, western Antarctic Peninsula. Deep Sea Research II 58: 1729-1740.

Ribic, C.A., Chapman, E., W.R. Fraser, G.L. Lawson, and P.H. Wiebe, P.H. **2008**. Top predators in relation to batyhmetry, ice, and krill during austral winter in Marguerite Bay, Antarctica. Deep Sea Research II 55: 485-499.

Siniff, D.B., Garrott, R.A., Rotella, J. J., Fraser, W.R., Ainley, D.G. **2008**. Projecting the Effects of Environmental Change on Antarctic Seals. Antarctic Science 20: 235-245.

Five Other Relevant Publications or Products

Bestelmeyer, B. T., Ellison, A.M., Fraser, W.R., Gorman, K.B. and 8 others. **2011**. Analysis of abrupt transitions in ecological systems. Ecosphere 2(12): 1-26.

Cimino, M.A., Fraser, W.R., Irwin, A.J., Oliver, M.A. **2012**. Satellite data identify decadal trends in the quality of *Pygoscelis* penguin chick-rearing habitat. Global Change Biology 19 (1): 136-148.

Fraser, W.R., W.Z. Trivelpiece, D.G. Ainley and S.G. Trivelpiece. **1992**. Increases in Antarctic penguin populations: reduced competition with whales or a loss of sea ice due to global warming? Polar Biology 11: 525-531.

Friedlaender, A.S., Fraser, W.,R., Patterson-Fraser, D.L., Qian, S.S., Halpin, P.N. **2008**. The effects of prey demography on humpback whale (*Megaptera novaeangliae*) abundance around Anvers Island, Antarctica. Polar Biology 31: 1217-1224.

Oliver, M.J., Irwin, A., Moline, M.A., Fraser, W.R, Patterson, D., Schofield, O., Kohut, J. **2013**. Adélie penguin foraging location predicted by tidal regime switching. PLoS ONE 8 (1): 1-9.

Synergistic Activities

• SCAR, U.S. Representative, Group of Experts on Seabirds, 1988-present.

• CCAMLR Ecosystem Monitoring Program, USA data contributor, 1987-present.

• U.S. Senate, at the request of Senator John McCain, expert testimony on Western Antarctic Peninsula climate change and its impacts, 2004.

• Blue Ice. Web-based outreach to educate K-12 teachers and students via question and answer sessions from Antarctica, Participant, 1997-2005.

• Media, recent collaborative work with significant outreach. *The Ferocious Summer: Adélie Penguins and the Warming of Antarctica*, Meredith Hooper, Greystone Books, 2007; *The Ice Retreat*, Fen Montaigne, The New Yorker, 2009; *Fraser's Penguins: A Journey to the Future in Antarctica*, Fen Montaigne, Henry Holt, 2010.

BIOGRAPHICAL SKETCH

Ari S. Friedlaender, PhD
Associate Professor, Marine Mammal Institute
Hatfield Marine Science Center, Oregon State University
2030 Marine Science Drive
Newport, OR 97366
ari.friedlaender@oregonstate.edu

Professional Preparation

1996	B.S. Biology, High Honors, Bates College, Lewiston, Maine
2001	M.S. Marine Biology, University of North Carolina, Wilmington, NC
2006	PhD. Ecology, Duke University, Durham, NC

Appointments

2013-	Associate Professor, Oregon State University
2014-	Adjunct Professor, Duke University Marine Laboratory
2010-	Research Associate, Southall Environmental Associates, Aptos, CA
2008-2013	Research Scientist, Duke University Marine Laboratory, Beaufort, NC
2006-2008	Post-Doctoral Research Associate, Duke University

Five Recent Publications or Products

Friedlaender, AS, Tyson, R., Stimpert, and Nowacek, D. *In Press.* Extreme diel variation in the feeding behavior of humpback whales along the Western Antarctic Peninsula in autumn. *Marine Ecology Progress Series.* doi: 10.3354/meps10541

Friedlaender, AS, Johnston, DW, Fraser, WR, Burns, J, Halpin, PN, Costa, DP. 2011. Ecological niche modeling of sympatric krill predators around Marguerite Bay, Western Antarctic Peninsula. *Deep-Sea Research II* 58: 1729-1740. doi:10.1016/j.dsr2.2010.11.018

Friedlaender, AS, et al. 2009. Diel changes in foraging behavior of humpback whales relative to prey distribution. *Marine Ecology Progress Series* doi: 10.3354/meps08003

Goldbogen, J., **Friedlaender A.S**. Calambokidis, J., McKenna, M. Simon, M., and Southall, B. *2013.* Integrative approaches to the study of baleen whale diving behavior, feeding performance, and foraging ecology. *Bioscience* 63:90-100

Hazen E.L**., Friedlaender, A.S**., et al. 2009. Linking 3-dimensional prey aggregations to fine scale foraging patterns of Humpback whales (*Megaptera novaengliae*) in Stellwagen Bank National Marine Sanctuary. *Marine Ecology Progress Series* doi 10.3354/meps08108

Five Other Relevant Publications or Prtoducts

Friedlaender, A.S., G.L. Lawson, and P.N. Halpin. *2009.* Evidence of resource partitioning between humpback and minke whales in the Antarctic. *Marine Mammal Science* 25:402-415

Friedlaender, A.S. *et al.* 2006. Distribution of whales in relation to prey and oceanographic processes in the inner shelf waters of the Western Antarctic Peninsula. *Marine Ecology Progress Series 317: 297-310.*

Goldbogen, J., Calambokidis, J., **Friedlaender, A.S**., Francis, J., Deruiter, SL, Stimpert, AK, Falcone, E, and Southall, BL. *2012.* Underwater acrobatics by the world's largest predator: 360 rolling maneuvers by lunge feeding blue whales. *Biology Letters.* DOI: 10.1098/rsbl.2012.0986

DeRuiter, S., Southall, B., **Friedlaender, AS.,** et al. *2013.* First direct measurements of behavioral responses by Cuvier's beaked whales to mid-frequency active (MFA) sonar. *Biology Letters*

Stimpert, A., Peavey, L., **Friedlaender, A.S.,** and Nowacek, D.P. *2012.* Humpback whale "loud noises": song and foraging behavior on an Antarctic feeding ground. *PLoS One* 7(12): e51214. Doi:10.1371/journal.pone.0051214

Synergistic Activities

- Lead collaborative and multi-disciplinary research projects to deploy multi-sensor tags on over 20 cetacean species
- Developed active collaborations with data visualization, engineering, policy and management, marine sanctuary, veterinary, climate, ocean science, anatomy, physiology, and social science, departments/schools
- Developed novel IPad-based teaching tools and content for Marine Megafauna course (Cachalot) to engage undergraduate students in marine science
- Expert Group on birds and marine mammals, Scientific Committee on Antarctic Research
- Review Panel NSF Office of Polar Programs

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oscar@marine.rutgers.edu http://rucool.marine.rutgers.edu

PROFESSIONAL PREPARATION.

1983-1987 B.A. in Aquatic Biology, Department of Biology, University of California, Santa Barbara,

1989-1993 Ph.D. in Biology, Department of Biology, University of California, Santa Barbara

1994 Postdoctoral Researcher, ICCES, University of California, Santa Barbara

1994-1995 Postdoctoral Researcher, Agriculture Research Service

APPOINTMENTS

2012-Present, Chairman of Department of Marine and Coastal Sciences,

1995-Present Assistant-Associate-Full Professor, Rutgers University, 2001-Present Adjunct Professor, California Polytechnic State University, San Luis Obispo, CA

2000-Present Member of Rutgers Ocean Systems Engineering Center

1999-Present Member of Rutgers Environmental Biophysics and Molecular Biology Program,

1999-2005 Co-Director of the Coastal Ocean Observation Laboratory,

1995-Present Adjunct Research Scientist, Mote Marine Laboratory, Sarasota, FL

FIVE RECENT PUBLICATIONS OR PRODUCTS

Schofield, O., Glenn, S. M., Moline, M. A. 2013. The robot ocean network. American Scientist 101: 434-441.

Schofield, O., Ducklow, H., Bernard, K., Doney, S., Fraser-Patterson, D., Gorman, K., Martinson, D., Meredith, M., Saba, G., Stammerjohn, S., Steinberg, D., Fraser, W. 2013. Penguin biogeography along the West Antarctic Peninsula: Testing the canyon hypothesis with Palmer LTER observations. Oceanography 26(3): 78-80.

Saba G. K., Schofield O., Torres J. J., Ombres E. H., Steinberg D. K. 2012. Increased feeding and nutrient excretion of adult Antarctic krill, *Euphausia superba*, exposed to enhanced carbon dioxide (CO2). PLoS ONE 7(12): e52224. doi:10.1371/journal.pone0052224.

Schofield, O., Ducklow, H. W., Martinson, D. G., Meredith, M. P., Moline, M. A., Fraser, W. R. 2010. How do polar marine ecosystems respond to rapid climate change? Science 328, 1520 DOI: 10.1126/science.1185779

Montes-Hugo M., Doney, S., Ducklow, H., Fraser, W., Martinson, D., Stammerjohn, S., Schofield, O. 2009. Climate induced along-shelf changes in phytoplankton communities of West Antarctic Peninsula. Science RE1164533/CJH

FIVE OTHER PUBLICATIONS OR PRODUCTS

Schofield, **O**., Moline, M. A., Cahill, B., Frazer, T., Kahl, A., Oliver, M., Reinfelder, J., Glenn, S., Chant, R. 2013. Phytoplankton productivity in a turbid buoyant coastal plume. Continental Shelf Research. dx.doi.org/10.1016/j.csr.2013.02.005

Oliver, M. A., Irwin, A., Moline, M. A., Fraser, W., Patterson, D., **Schofield**, **O**., Kohut, J. 2013. Adelie penguin foraging location correlated with local tides. PloS ONE e55163.doi:10.1371/journal.pone.0055163.

Xu, Y., Cahill, B., Wilkin, J., **Schofield**, **O**. 2012. Role of wind in regulating phytoplankton blooms on the Mid-Atlantic Bight. Continental Shelf Research. doi:10.1016/J.CSR.2012.09.011

Miles, T., Glenn, S. M., **Schofield**, **O**. 2012. Spatial variability in fall storm induced sediment resuspension on the Mid-Atlantic Bight. Continental Shelf Research. doi.org/10.1016/j.csr.2012.08.006

Ballantyne F., **Schofield**, **O**., Levin, S. A. 2011. *Featured article*: The emergence of regularity and variability in marine ecosystems: The combined role of physics, chemistry and biology. Scientcia Marina 75(4): 719-731. doi: 10.3989/scimar.2011.75n4719

SELECTED SYNERGISTIC ACTIVITIES

2007-2011 Board of Directors of the Canadian "Ocean Networks Canada"

2009-2011 National Research Council Member for the Committee of "Ocean Infrastructure for the year 2030"

2012-2015 Co-Chair of Scientific Steering Committee of the International Southern Ocean Observing System,

2012 Chair, Science Review Committee of Naval Research Laboratory, Stennis Science Center

2014-2015 National Research Council Advisory Committee on "Developing a Strategic Vision and Implementation Plan for the U.S. Antarctic Program"

Sharon E. Stammerjohn

Institute for Arctic and Alpine Research (INSTAAR)
University of Colorado Boulder, Campus Box 450, 1560 30th Street, Boulder, Colorado 80309
Email: Sharon.Stammerjohn@colorado.edu, Phone: (303) 735-7811, Fax: (303) 492-6388

Professional Preparation

B. A. University of Virginia, **1986 Major:** Environmental Sciences
M. A. University of California Santa Barbara, **1993. Major:** Oceanography
M. Phil. Columbia University, **2004. Major:** Oceanography
Ph. D. Columbia University, **2006. Major:** Oceanography

Appointments

2012-present Senior Research Associate, INSTAAR, CU
2008-2011 Assistant Professor, Ocean Sciences, UCSC
2008 Doherty Associate Research Scientist, LDEO
2006-2007 NOAA Postdoctoral Fellow, NASA GISS, NY

Five Recent Products or Publications

Stammerjohn, S., R. Massom, D. Rind and D. Martinson. **2012**. Regions of rapid sea ice change: an inter-hemispheric seasonal comparison, *Geophysical Research Letters*, doi: 10.1029/2012GL050874.
Stammerjohn, S., T. Maksym, P. Heil, R. A. Massom, M. Vancoppenolle, and K. C. Leonard. **2011**. The influence of winds, sea surface temperature and precipitation anomalies on Antarctic Regional sea ice conditions during IPY 2007, *Deep Sea Research II* 58: 999-1018, doi: 10.1016/j.dsr2.2010.10.026.
Montes-Hugo M., S. C. Doney, H. W. Ducklow, W. Fraser, D. Martinson, S. **Stammerjohn** and O. Schofield. **2009**. Recent Changes in Phytoplankton Communities Associated with Rapid Regional Climate Change Along the Western Antarctic Peninsula. *Science* 323: 1470-1473.
Stammerjohn, S. E., D. G. Martinson, R. C. Smith, X. Yuan, and D.Rind. **2008**. Trends in Antarctic annual sea ice retreat and advance and their relation to ENSO and Southern Annular Mode Variability. *Journal of Geophysical Research* 113, C03S90, doi: 10.1029/2007JC004269.
Stammerjohn, S. E., D. G. Martinson, R. C. Smith, and R. A. Iannuzzi. **2008**. Sea ice in the Palmer LTER region: spatio-temporal variability from ecological and climate change perspectives. *Deep Sea Research II* 55, doi: 10.1016/j.dsr2.2008.04.026.

Five Other Relevant Publications or Products

Ducklow H. W., O. Schofield, M. Vernet, S. **Stammerjohn** and M. Erickson. **2012**. Multiscale control of bacterial production by phytoplankton dynamics and sea ice along the western Antarctic Peninsula: A regional and decadal investigation. *Journal of Marine Systems* 98-99: 26-39.
Maksym, T., S. E. **Stammerjohn**, S. Ackley, and R. Massom. **2012**. Antarctic sea ice -- a polar opposite? *Oceanography*, *25*(3), 140–151. doi:10.5670/oceanog.2012.88.
Massom, R.A. and S.E. **Stammerjohn**. **2010**. Antarctic sea ice change and variability – physical and ecological implications, *Polar Science* 4: 149-186, doi: 10.1016/j.polar.2010.05.001.
Meredith, M. P., M. I. Wallace, S. E. **Stammerjohn**, I. A. Renfrew, A. Clarke, H. J. Venables, D. R. Shoosmith, T. Souster, and M. J. Leng. **2010**. Changes in the freshwater composition of the upper

ocean west of the Antarctic Peninsula during the first decade of the 21st century, *Progress in Oceanography*, doi:10.1016/j.pocean.2010.09.019.

Martinson, D. G., S. E. **Stammerjohn**, R. C. Smith, and R. A. Iannuzzi. **2008**. Palmer, Antarctica, Long-Term Ecological Research program first 12 years: physical oceanography, spatio-temporal variability. *Deep Sea Research II* 55, doi: 10.1016/j.dsr2.2008.04.038.

Synergistic Activities

- Scientific Committee for the International Symposium on Sea Ice in a Changing Environment, International Glaciological Society, 2014
- Scientific Committee on Antarctic Research (SCAR) Antarctic Sea Ice Processes and Climate (ASPeCt), 2011-present
- Polar Research Board, National Academy of Sciences Workshop on the Legacy and Lessons of the International Polar Year, 2011
- Polar Research Board, National Academy of Sciences Workshop on Frontiers in Understanding Climate Change and Polar Ecosystems, 2010
- NSF Workshop on Ecosystem Response to Diminished Snow and Ice in a Warming Climate, 2009

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Professional Preparation

University of California, Santa Barbara (UCSB)	Aquatic Biology	B. A. 1987
University of California, Santa Cruz (UCSC)	Biological Sciences	Ph.D. 1993
University of California, Santa Cruz (UCSC) (Post-doc)	Marine Sciences	1994

Appointments

2008-	Professor, Dept. of Biological Sciences, Virginia Institute of Marine Science (VIMS)
2001-07	Associate Professor, Dept. of Biological Sciences, VIMS (College of William and Mary Class of 1964 Distinguished Associate Professor 2005-)
1995-2000	Project coordinator for Bermuda Atlantic Time-Series Study (BATS), Bermuda Institute of Ocean Sciences (BIOS)
1999-2000	Associate Research Scientist, BIOS
1995-98	Assistant Research Scientist, BIOS
1994-99	Instructor, BIOS. "Biological Oceanography," summer 1994-97, winter 1997-99
1994	Instructor, UCSC "Introduction to Marine Sciences" fall

Five Recent Publications or Products

Garzio L. M., **D. K. Steinberg**, M . Erickson, and H.W. Ducklow (2013). Microzooplankton grazing along the Western Antarctic Peninsula. Aquatic Microbial Ecology, 70: 215-232.

Bernard, K. S. and **D. K. Steinberg** (2013). Antarctic krill biomass and aggregation structure in relation to tidal cycle in a penguin foraging region off the Western Antarctic Peninsula. ICES Journal of Marine Science 70(4): 834-849, doi:10.1093/icesjms/fst088.

Garzio, L.M. and **D.K. Steinberg** (2013). Microzooplankton community composition along the Western Antarctic Peninsula. Deep-Sea Research I, 77: 36-49.

Bernard, K. S., **D. K. Steinberg**, O. M. E. Schofield (2012). Summertime grazing impact of the dominant macrozooplankton off the Western Antarctic Peninsula. Deep-Sea Research I, 62: 111-122.

Gleiber, M. R., **D. K. Steinberg**, and H. W. Ducklow (2012). Time series of vertical flux of zooplankton fecal pellets on the continental shelf of the western Antarctic Peninsula. Mar. Ecol. Prog. Ser. 471: 23-36. doi: 10.3354/meps10021.

Five Other Relevant Publications or Products

Saba, G. K., O. Schofield, J. J. Torres, E. H. Ombres, and **D. K. Steinberg** (2012). Increased feeding and nutrient excretion of adult Antarctic krill, *Euphausia superba*, exposed to enhanced carbon dioxide (CO_2). PLoS ONE 7(12): e52224. doi:10.1371/journal.pone.0052224.

Steinberg, D. K., M. W. Lomas, and J. S. Cope (2012). Long-term increase in mesozooplankton biomass in the Sargasso Sea: Linkage to climate and implications for food web dynamics and biogeochemical cycling. Global Biogeochemical Cycles. 26, GB1004, doi:10.1029/2010GB004026.

Ducklow, H. W., A. Clarke, R. Dickhut, S. C. Doney, H. Geisz, K. Huang, D. G. Martinson, M. P. Meredith, H. V. Moeller, M. Montes-Hugo, O. M. E. Schofield, S. E. Stammerjohn, **D. K. Steinberg**, and W. Fraser (2012). The Marine Ecosystem of the West Antarctic Peninsula. In: A. Rogers, N. Johnston, A. Clarke and E. Murphy (Editors), Antarctica: An Extreme Environment in a Changing World. Blackwell, London.

Beusseler, K.O., A. M. P. McDonnell, O.M.E. Schofield**, D. K. Steinberg,** H. W. Ducklow (2010). High particle export over the continental shelf of the west Antarctic Peninsula. Geophysical Research Letters 37: L22606, doi:10.1029/2010GL045448.

Steinberg, D. K., J. S. Cope, S. E. Wlson, and T. Kobari (2008) A comparison of mesopelagic mesozooplankton community structure in the subtropical and subarctic North Pacific Ocean. Deep-Sea Research II 55(14-15): 1615-1635.

Synergistic Activities

2012- present	Member, The Oceanography Society (TOS) Council
2010- present	Member, University-National Oceanographic Laboratory System (UNOLS) Council
2007-08	Chair, scientific program organizing committee for the Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) workshop "Ecological and Biogeochemical Interactions in the Mesopelagic Zone"
2005- present	Member, Board of Trustees, Bermuda Institute of Ocean Sciences
2004- present	Associate Editor, Deep-Sea Research I

FACILITIES, EQUIPMENT AND OTHER RESOURCES

Personnel. Hugh Ducklow is a fulltime faculty member in the Columbia University Department of Earth and Environmental Sciences. Ducklow will contribute four months of time per year to the project, supported by his Department and Lamont-Doherty. Ducklow is lead PI and has overall responsibility for the proposed research and management of the Palmer Antarctica LTER (PAL). Ducklow will coordinate the research contributions of all project components and serve as the liaison between PAL, NSF and the LTER Network. Ducklow will also supervise administration of the LTER award at Lamont-Doherty Earth Observatory. Through LDEO, Ducklow will arrange and coordinate the annual meetings for the group and the PAL participation in the LTER Triennial All Scientists meeting as well as facilitate PAL participation in cross-LTER Site research and synthesis. Ducklow is responsible for research conducted in the microbial biogeochemistry component of PAL, as described in the proposal. He will conduct research on the annual cruise and at Palmer Station each year, and in his lab at LDEO. Ducklow will be responsible for data analysis and publication of results from the microbial biogeochemistry component, and will mentor a Columbia PhD student working on PAL research.

Doug Martinson is a Lamont Research Professor. LDEO will support three months of Martinson's time on the project each year.

Office. Lamont-Doherty Earth Observatory will provide office space for all LDEO project contributors.

Computer: LDEO supports a multi-platform network with high speed internet access, website support, and mass storage. The Division of Ocean and Climate Physics computer resources consist of a multitude of Unix workstations on a lab-wide network, local workstations, PCs, Macs and laptops. There are also considerable printing, back-up and storage capabilities.

Laboratory. Ducklow has a newly-renovated 600 sq ft lab in the LDEO New Core Lab facility, supporting all the analytical requirements for the Microbial Biogeochemistry component of the proposed research. Ducklow's lab has fume hoods, DI water supply and the following instrumentation: two Accuri C6 benchtop flow cytometers available for field deployments to Palmer Station and the annual research cruise, a RISO (Denmark) Beta Counter for Thorium-234, also available for field deployment, Seal Analytical 4-Channel Continuous Flow Analyzer for dissolved inorganic nutrients, Shimadzu TOC-LC Total organic Carbon Analyzer, UIC Coulometer (dissolved inorganic carbon) and Total Alkalinity titrator, and a McLane WSD-10 Wet Sample divider for splitting sediment trap samples. Elsewhere at LDEO, Ducklow has full access to a radioisotope lab with a Perkin-Elmer Liquid Scintillation Counter; a Becton-Dickinson Influx Sorting Flow Cytometer and CHN Analyzer.

Field. Instrumentation currently deployed in the field includes two moored, time series sediment traps (one McLane PARFLUX 78H-21, one SARL Technicap PPS 3/24S) with all mooring hardware and acoustic releases; and four physical oceanographic moorings containing a total of 4 acoustic releases, 26 temperature sensors, 37 temperature/pressure sensors and 6 electronic current meters with temperature sensors.

The US Antarctic Program maintains and makes available to PAL all field sampling and lab infrastructure, equipment and instrumentation required to carry out the proposed research at Palmer Station and aboard the Antarctic Research and Supply Vessel Laurence M Gould.

Subaward Facilities:

All coPIs with subawards (see Table below) have facilities, lab instrumentation, communications and computing infrastructure appropriate for their specific responsibilities described in the proposal.

Co-PI name	**Institution**
Scott Doney	Woods Hole Oceanographic Institution
Peter Franks	UCSD – Scripps Inst. Of Oceanography
Bill Fraser	Polar Oceans Research Group
Ari Friedlaender	Oregon State University
Oscar Schofield	Rutgers University
Sharon Stammerjohn	University of Colorado-Boulder
Deborah Steinberg	Virginia Institute of Marine Science

Data and Information Management Plan

Overview. The Palmer LTER Information Management (IM) component continues to be an integral part of the site's research program, providing core data and information management services in addition to supporting various scientific, outreach and LTER network needs through the continued development of a comprehensive information management environment. Recent and planned initiatives have been developed in collaboration with representative site personnel to adapt PAL IM's focus and resources to the changing needs of both the individual research project and the overall LTER network. Our primary goals include (1) providing well documented, quality data to the public in a timely manner, (2) continuing to develop a data system that provides effective access to core site and related data, (3) providing support for site science through flexible and innovative data product development and access and (4) maintaining a data and information management that ensures long-term stability and integrity.

Information Management System and Scope

IT System Administration and Infrastructure Support. A portion of the information management budget for PAL, is allocated for IT support, and is provided by the CIS (Computational Infrastructure Support) facility (https://iod.ucsd.edu/compu/computation.html) collocated with PAL IM at Scripps Institution of Oceanography, UCSD. Support by this group includes management of our single physical server machine as well as the three currently operating virtual servers housed on that machine (development machine, production machine and data server) and also desktop support and software licenses for IM personnel. Routine backups are conducted in coordination with the San Diego Supercomputer Center, providing off-site archival services. The CIS group is led by Jerry Wanetick, the current IT director for Scripps. In addition to technical infrastructure support, the CIS group provides PAL IM with invaluable software development and infrastructure planning insight to help maintain stable growth and maintenance trajectories amid rapidly changing technologies and standards.

Data system design and development. The main data access and catalog system for PAL LTER is Datazoo (http://oceaninformatics.ucsd.edu/datazoo/data/pallter/datasets). Built using open source technology (MySQL, PHP, Python, Apache, Javascript), Datazoo utilizes a relational database model that supports the application interface and the generation of EML 2.1 for dataset publishing to PASTA, the data publishing catalog component of the LTER Network Information System.

Much of Datazoo has been designed and developed with service-oriented architecture (SOA) in mind, including the data access component, where published data are stored in a database with an accessible web service and application programming interface (API) that supports data querying (for pre-download browsing) and downloading in multiple formats. An additional component to the system was added in 2010 that added 2-D plotting capabilities (timeseries, scatter, boxplot, contour, contour over a geographical map). The plotting module was designed as a decoupled component with a web service API, giving it the potential for being enabled as a network resource shared by other LTER site data systems or applications.

Datazoo is well integrated with the Unit Registry and Controlled Vocabulary components of the LTER NIS, supporting the use of network-standardized units of measurement as well as a common vocabulary for keywording datasets that supports improved data accessibility within the network catalog (PASTA). Personnel records are stored in a locally developed database with supporting interface, and are also integrated into the data system architecture for linking personnel records with datasets. Datazoo's catalog interface was updated with faceted search capabilities in 2013, based on community feedback, and have improved the ability to categorize and locate data based on a flexible and easily maintainable design that supports both local and wider community vocabularies for data, including the LTER Core Areas designations.

Palmer LTER also makes data collection with more complex file structures available through the use of FileFinder (http://oceaninformatics.ucsd.edu/filefinder/pallter/), a locally developed and maintained application that utilizes file-structure indexing to create collection-specific search interfaces for file browsing, selection, packaging and downloading. Plans for the future, however, include utilizing improving data management infrastructure ("Data management" database, Figure 1) to support the migration of these data into our general data catalog. Additional improvements to the Palmer LTER data system include expanding the Datazo catalog capabilities to provide records for all data resources associated with and utilized by the Palmer LTER research community.

Website. The project website for PAL (http://pal.lternet.edu) was developed and is maintained by the information management component, and was recently re-developed and deployed using the Drupal CMS, supported by an information management supplement. This redevelopment allowed for many improvements over the previous version of the website. One of these improvements was a better structured layout of site content and materials, developed through scoping and review processes involving PAL information management, site scientists and the education and outreach coordinator. In addition, the website's overall appearance and dynamic display capabilities were much improved by the nature of Drupal's modern and well supported community of developers and modules. Using Drupal as the project's website platform also provides for the ability to collaborate with the increasing number of LTER sites choosing to use Drupal for either website or data system development. Components developed within this common framework can be shared across these sites, preventing reinvention, promoting standardization and optimizing personnel resources.

Data management infrastructure and process development. Recently, after IM management personnel changes in 2011, Palmer's Information Management has focused on making major improvements to the fundamental structure supporting data management processes and workflows. Additional databases were added to the system. Most notably, a comprehensive pre-published database ("Data management", Figure 1) was built to support an integrated environment for producing research-critical data products and supporting new or improved elements of quality control and quality assurance. The incorporation of this new database has improved both the quality of published data products as well as Information Management's ability to provide synthetic products to facilitate Palmer LTER research objectives.

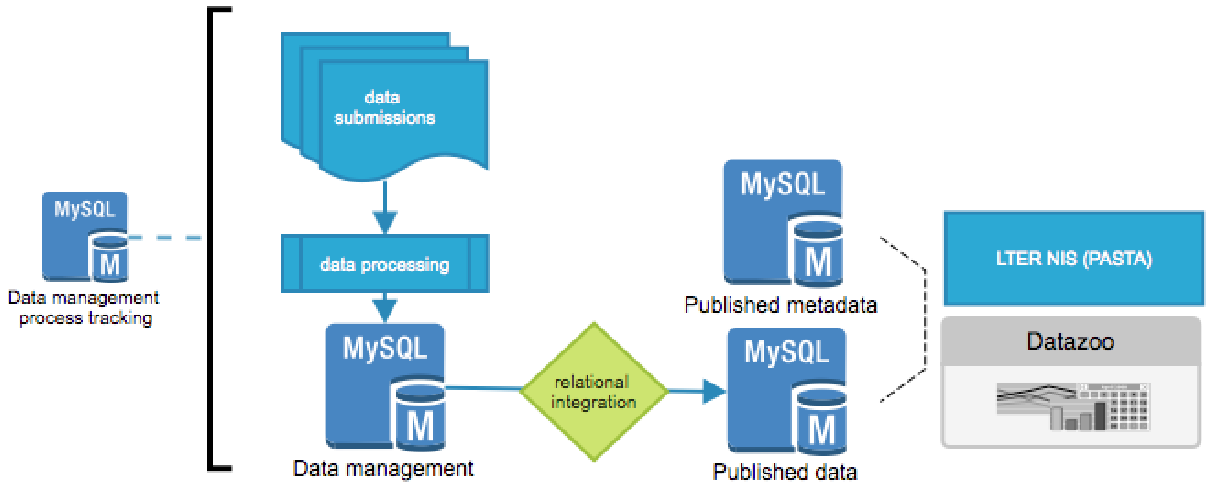

Figure 1: Overview, Palmer LTER data management workflow and infrastructure

A re-designed on-disk file structure, standardized data processing scripts ("data submission" and "data processing", Figure 1) and an activity and process tracking database ("Data management process tracking", Figure 1) were also developed in conjunction with this new database to provide for a well documented and traceable workflow for data submission, documentation, processing and publishing.

Critical support for these efforts was provided through a joint IM supplement, in collaboration with CCE LTER, that provided both sites with shared additional personnel support for helping improve data access and availability at each site. This effort has resulted in a much more efficient and stable data management workflow environment, improving the integration of information management with site science through added data service capabilities and response as well as creating an infrastructure more resilient to personnel turnover and better staged to support the evolving nature of data management requirements for a long-term research project.

LTER Network Standards Support and Involvement

The Palmer LTER data system currently supports the generation of EML 2.1 for the publishing of metadata and data to the most current version of the LTER NIS, PASTA. Additional NIS components, the LTER Unit Registry and the LTER Controllled Vocabulary, are integrated with the local data system to provide data published with standardized units of measurements and a common network keyword vocabulary, supporting improved and standardized data accessibility within the network. In addition, Palmer IM regular contributes meteorological data to the ClimDB, updates personnel listings with the network database (Personnel DB) and maintains site information through SiteDB.

Palmer Information Management continues to be active within the broader LTER IM community. The Palmer Information Manager, J. Conners, currently serves on the LTER Information Management Executive Committee and co-developed the current version of the LTER Unit Registry and has participated in multiple working groups (*Website WG, Web Services WG, Unit WG*) and Tiger Teams, supporting the development of the LTER NIS.

Future Plans and Initiatives

The Palmer LTER IM component has worked on many recent improvements, and is focussed on continuing to develop a responsive information management system and data management workflow that supports on-time publishing of well-documented and quality controlled data as well as support for access to and development of data products essential to PAL research. Below are a set of initiatives, developed collaboratively between PAL information management and scientists, targeted toward improving weakness and developing existing strengths over the next funding cycle.

A. Continue established and develop new interactions between site researchers and information management personnel through the use of regularly scheduled, structured reviews of the PAL information management system as well as other aspects of information management's role in site science.

B. Continued to improve and better develop added workflow elements and infrastructure changes in support of research critical data access, working towards a well-structured data system supporting comprehensive data integration across research components, in addition to improving responsiveness and flexibility in providing scientists access to crucial data products.

C. Augment the existing data system, *Datazoo*, to include support for a more comprehensive catalog of site, collaborator, reference and related data resources important to site research. In addition, where resources allow, the development of additional data system components is planned as an additional phase after the above described catalog expansion.

D. Develop comprehensive IM system documentation for stability through personnel turnover and as communicative resources to better support interactions between IM and research personnel, with regard to publishing data, accessing data resources and also facilitating the introduction of new lab personnel to the information component of the site.

Palmer LTER Conflicts of Interest: Note that this listing does not include persons affiliated with PAL coPI institutions: Columbia univ/Lamont-Doherty, Rutgers univ, Virginia Inst of Marine science, Woods Hole Oceanographic Inst, Scripps Inst of Oceanography/UCSD, Univ of Colorado-Boulder, Polar Oceans Research Group, Orgaon State University and Duke University.			
Name	**Institution**	**Type**	**Co-PI**
Abernathy, Kyler	National Geographic Society	Collaborator	Friedlaender
Ackerley, David	UC Berkeley	Collaborator	Schofield
Ackley, Steve	UTSA	Collaborator	Stammerjohn
Ainley, David	HT Harvey & Associates	Collaborator	Fraser, Stammerjohn
Aita, M.N.	JAMSTEC, Japan	Collaborator	Doney
Alderkamp, Anna	Stanford	Collaborator	Schofield, Stammerjohn
Algeo, Thomas	McMicken College	Collaborator	Schofield
Allen, Jennifer	St. Andrews University	advisee	Friedlaender
Alvain, Sevrine	Universit ´e Lille Nord de France	Collaborator	Doney
Amsler, Chuck	University of Alabama - Birmingham	Collaborator	Fraser
Arnone, Robert	U. Southern Mississippi	Collaborator	Schofield
Arrigo, Kevin	Stanford	Collaborator	Schofield, Stammerjohn
Aufdenkampe, Anthony	Stroud Water	Collaborator	Doney
Aumont, Olivier	Laboratoire de Physique des Océans, France	Collaborator	Doney
Baek-Lee, Joon	Cheju National University	Collaborator	Schofield
Balasuriya, Arjuna	MIT	Collaborator	Schofield
Balch, Barnie	Bigelow	Collaborator	Doney
Ballard, Grant	Point Blue Conservation Science	Collaborator	Fraser
Ballentyne, Ford	U. Kansas	Collaborator	Schofield
Barbosa, Andres	Estación Experimental de Zonas Áridas, Spain	Collaborator	Fraser
Barry, James	MBARI	Collaborator	Doney
Barton, Kerry	BartonK Solutions	Collaborator	Fraser

Name	Institution	Type	Co-PI
Bates, Nick	BIOS, Bermuda	Collaborator	Doney, Steimberg
Batley, Jacqueline	U. Bristol (UK)	Collaborator	Schofield
Beaulieu, Claudie	Princeton	Collaborator	Doney
Bednaršek, N.	NOAA/PMEL	Collaborator	Doney
Beis, Peter	CNRS, France	Collaborator	Fraser
Bench, Shellie	Stanford	Post-doc	Ducklow
Bender, Michael	Princeton	Collaborator	Doney, Ducklow
Berelson, Will	U Southern California	Collaborator	Steinberg
Bergmann, Patricia	NOAA	PhD advisee	Schofield
Bestelmeyer, Brandon	New Mexico State University	Collaborator	Fraser
Birch, Daniel	Umass Dartmouth	Postdoc advisee	Franks
Bisagni, Jim	Univ. Mass-Dartmouth	Collaborator	Ducklow
Bishop, Jim	UC Berkeley	Collaborator	Doney
Bissett, Paul	Weogeo Inc.	Collaborator	Schofield
Blanke, B.	UBO	Collaborator	Franks
Boebel, Olaf	Alfred Wegener Institute	Collaborator	Friedlaender
Bograd, S.	NOAA	Collaborator	Franks
Bonan, Gordon	NCAR	Collaborator	Doney
Bontempi, Paula	NASA	Collaborator	Doney
Bopp, Laurent	IPSL/LSCE, France	Collaborator	Doney
Boss, Emmanuel	U. Maine	Collaborator	Doney
Bowman, Jeff	Univ Washington	Collaborator	Ducklow
Boyd, Phil	U. Tasmania Australia	Collaborator	Doney
Brierley, Andy	St. Andrews University	Collaborator	Friedlaender
Brokaw, Nick	Univ. Puerto Rico	Collaborator	Ducklow
Brown, Wendell	U Mass Dartmouth	Collaborator	Schofield
Brum, Jennifer	Arizona State	Post-doc	Ducklow
Bryan, Frank	NCAR	Collaborator	Doney
Buitenhuis, Erik	Univ East Anglia	Collaborator	Schofield, Doney
Bullister, John	NOAA/PMEL	Collaborator	Doney
Burns, Jennifer	University of Alaska - Fairbanks	Collaborator	Fraser, Friedlaender
Byrd, Barbie	NOAA	Collaborator	Friedlaender
Calambokidis, John	Cascadia Research Collective	Collaborator	Friedlaender
Calil, Paulo	U. Rio Grande, Brazil	Collaborator	Doney
Campbell, John	US Forest Svc	Collaborator	Ducklow

Name	Institution	Type	Co-PI
Capet, X.	LOCEAN-IPSL, France	Collaborator	Franks
Capone, Doug	U Southern California	Collaborator	Steinberg
Carlson, Craig	Santa Barbara	PhD student, collaborator	Ducklow, Steinberg
Carpenter, Edward	San Fran. State U.	Collaborator	Steinberg
Casciotti, Karen	Stanford	Collaborator	Ducklow
Castelao, Renato	U. Georgia	Post-doc	Schofield
Cavicchioli, Rick	Univ NSW, Australia	Collaborator	Ducklow
Cermeno, Pedro	U. Vigo	Collaborator	Schofield
Chao, Yi	UCLA	Collaborator	Schofield
Chapman, Erik	University of New Hampshire	Collaborator	Fraser
Chavez, Francisco	MBARI	Collaborator	Doney
Chein, Steve	NASA JPL	Collaborator	Schofield
Chen, Robert	U. Mass Boston	Collaborator	Schofield
Chen, Ta-Wei	Merill Lynch	PhD Advisee	Martinson, Douglas
Church, Matt	U. Hawaii	Collaborator	Doney, Ducklow
Cimino, Megan	University of Delaware, Lewes	PhD Advisee	Fraser
Clarke, Andrew	B.A.S.	Collaborator	Ducklow, Fraser, Schofield
Coles, Victoria	Univ Maryland	Collaborator	Steinberg
Collins Scott	Univ New Mexico	Collaborator	Ducklow
Condon, Rob	Dauphin Island Lab	co-author, PhD advisee	Ducklow, Steinberg
Condospoti, Lou	USC	Collaborator	Schofield
Costa, Dan	UC Santa Cruz	Collaborator	Fraser, Friedlaender, Steinberg
Craig, Suzzane	Dalhousie	Collaborator	Schofield
Criscitiello, Allison	Unknown	PhD advisee	Martinson, Douglas
Curvo, Juan	Estación Experimental de Zonas Áridas, Spain	Collaborator	Fraser
Dalla Rossa, Luciano	University of British Columbia	Collaborator	Friedlaender
Daly, Kendra	U. South Florida	Collaborator	Doney
de Baar, Hein	University of Groningen	Collaborator	Schofield
del Giorgio, Paul	Univ of Quebec-Montreal	Collaborator	Ducklow, Steinberg
Denning, Scott	CSU	Collaborator	Doney

Name	Institution	Type	Co-PI
DeRuiter, Stacy	St. Andrews University	post-doc	Friedlaender
Deutsch, Curtis	U Washington	Collaborator	Doney, Schofield
Di Lorenzo, E.	Georgia Tech	Collaborator	Franks
Dietrich, M	CNRS, Centre IRD, France	Collaborator	Fraser
Doubell, M.	TUMST	Collaborator	Franks
Druffel, Ellen	UC Irvine	Collaborator	Doney
Dubinsky, Zvy	U. Bar Llat	Collaborator	Schofield
Dunne, John	NOAA/GFDL	Collaborator	Doney
Dupont, C.L.	JCVI	Collaborator	Franks
Dutkiewicz, Stephanie	MIT	Collaborator	Schofield
Edwards, C.A.	University of CA - Santa Cruz	Collaborator	Franks
Egeland, Eric	U. of Trondhiem	Collaborator	Schofield
Ellison, Aaron	Harvard University	Collaborator	Fraser
Emerson, Steve	U. Washington	Collaborator	Schofield
English, Chad	COMPASS	Collaborator	Doney
Enright, Wendy	City of San Diego	PhD advisee	Franks
Erdmann, Eric	University of Wisconsin - Madison	Collaborator	Fraser
Erickson, Matthew	ASC-Lockheed	Collaborator	Ducklow
Espinasse, Boris	Umass Boston	Collaborator	Friedlaender
Fahnenstiel, Gary	NOAA GLERL	Collaborator	Schofield
Falcone, Erin	Cascadia Research Collective	Collaborator	Friedlaender
Feely, Richard	NOAA/PMEL	Collaborator	Doney
Fennel, Katja	Dalhousie	Collaborator	Schofield
Ferrari, R.	MIT	Collaborator	Franks
Finkel, Zoe	U. Mount Allison	PhD advisee	Schofield
Fleener, Craig	Univ Alaska-Fairbanks	Collaborator	Ducklow
Fogarty, Michael	NOAA/NMFS	Collaborator	Doney
Follows, Mick	MIT	Collaborator	Schofield
Ford, Glenn	University of California - Santa Cruz	Collaborator	Fraser
Foster, David	Harvard Forest	Collaborator	Ducklow
Foster, Rachel	U. Stockholm, Sweden	Collaborator	Steinberg
Fountain, Andrew	Portland State	Collaborator	Ducklow
Francis, John	Natl Geographic Soc	Collaborator	Friedlaender

Name	Institution	Type	Co-PI
Frazer, Thomas	U. Florida Gainseville	Collaborator	Schofield
Freeman, Kate	UC Davis	Collaborator	Friedlaender
Gademke, Jason	NOAA	Collaborator	Friedlaender
Gaines, Steven	UCSB	Collaborator	Doney
Gales, Nick	Australian Antarctic Division	Collaborator	Friedlaender
Galindo, Heather	COMPASS	Collaborator	Doney
Gangopadhyay, Avijitt	U Mass Dartmouth	Collaborator	Schofield
Gao, Yu	Phycogen, Inc	postdoctoral advisee	Schofield
Gehlen, Marion	LSCE/IPSL France	Collaborator	Doney
Geisz, Heidi	Florida State	PhD student	Ducklow, Fraser
Gibbs, Sam	U. Southhampton	Collaborator	Schofield
Goebel, N.	University of CA - Santa Cruz	Collaborator	Franks
Goldbogen, Jeremy	Stanford University	Collaborator	Friedlaender
Goldthwait, Sarah	formerly at CA State Humboldt	PhD advisee	Steinberg
Gonzalis-Solis, Juan	University of Barcelona, Spain	Collaborator	Fraser
Goodkin, Naomi	NTU, Singapore	Collaborator	Doney
Gorman, Kristen	Simon Fraser University, Canada	PhD Advisee	Ducklow, Fraser
Graber, Hans	U. Miami	Collaborator	Schofield
Gragson, Ted	Univ Georgia	Collaborator	Ducklow
Graham, Monty	Univ Southern Mississippi	Collaborator	Ducklow
Grebmeier, Jackie	Chesapeake Biol Lab, Univ MD	Collaborator	Doney
Gries, Corinna	Wisconsin	Collaborator	Ducklow
Gruber, Nicholas	ETH Zurich, Switzerland	Collaborator	Doney
Grzymski, JJ	Desert Research Inst	Collaborator	Ducklow, Schofield
Guest, Peter	NPS	Collaborator	Stammerjohn
Guidi, Lionel	U. Hawaii	Collaborator	Doney
Gulland, Francis	Marine Mammal Center	Collaborator	Friedlaender
Halpern, Ben	UCSB	Collaborator	Doney
Hamilton, Steve	Michigan State	Collaborator	Ducklow
Harris, Roger	Plymouth Marine Lab	Collaborator	Schofield
Hashioka, Taketo	JAMSTEC, Japan	Collaborator	Doney

Name	Institution	Type	Co-PI
Hauri, Claudine	U. Alaska, Fairbanks	Collaborator	Doney
Hayes, Paul	U. Bristol (UK)	Collaborator	Schofield
Hazen, Elliott	NOAA	post-doc	Friedlaender
He, Ruoying	UNC	Collaborator	Schofield
Heil, Cindy	Bigelow Labs	Collaborator	Schofield
Henson, Stephanie	NOC, UK	Collaborator	Doney
Hermann, A.J.	Univ of Washington	Collaborator	Franks
Hirata, Taka	Hokkaido U., Japan	Collaborator	Doney
Hoffmann, Forrest	UC Ivine & ORNL	Collaborator	Doney
Hofmann, Eileen	Old Dominion University	Collaborator	Doney, Fraser
Hofmann, Eillen	ODU	Collaborator	Martinson, Douglas
Holbrook, Sally	University of CA - Santa Barbara	Collaborator	Fraser
Hollowed, Anne	NOAA/NMFS	Collaborator	Doney
Hood, Maria	none, retired	Collaborator	Ducklow
Hood, Raleigh	Univ Maryland	Collaborator	Steinberg
Horner-Devine, A.R.	Univ of Washington	Collaborator	Franks
Howard, Will	unknown	Postdoc advisee	Martinson, Douglas
Howarth, Robert	Cornell	Collaborator	Doney
Huey, Raymond	U Washington	Collaborator	Schofield
Hull, P.	Yale	Collaborator	Franks
Hynes, Annette	U. Georgia	PhD Thesis Advisee	Doney
Iglesias Rodriguez, Debora	UCSB	Collaborator	Schofield
Irwin, Andrew	U. Mount Allison	Collaborator	Fraser, Schofield
Ishii, Masao	MRI Tsukuba Japan	Collaborator	Doney
Jhang, Lin	Georgia Tech	postdoctoral advisee	Schofield
Johnsen, Geir	U. Trondhiem	Collaborator	Schofield
Johnson, Rod	Bermuda Institute of Ocean Sciences	Collaborator	Steinberg
Joint, Ian	Plymouth Mar. Lab.	Collaborator	Doney
Jones, Clayton	Teledyne-Webb Research	Collaborator	Schofield
Jongsomjit, Dennis	Point Blue Conservation Science	Collaborator	Fraser
Jonsson, Bror	Princeton	Collaborator	Doney
Joos, Fortunat	U. Bern	Collaborator	Doney
Jourdain, E	Linnaeus University, Sweden	Collaborator	Fraser
Kahl, Alex	US State Department	PhD advisee	Fraser, Schofield

Name	Institution	Type	Co-PI
Kaltenberg, Amanda	Savannah State University	post-doc	Friedlaender
Karaköylü, Erdem	NASA JPL	Postdoc advisee	Franks
Karl DM,	Univ Hawaii	Collaborator	Doney, Ducklow
Katona, Steve	Conservation Internatoinal	Collaborator	Doney
Kawa, Randy	NASA/Goddard	Collaborator	Doney
Kelly, Natalie	Australian Antarctic Division	Collaborator	Friedlaender
Keppel-Aleks, Gretchen	UC Irvine	Collaborator	Doney
Kirchman, David	Univ Delaware	Collaborator	Ducklow
Kirkpatrick, Barbara	Mote Marine Lab	Collaborator	Schofield
Kirkpatrick, Gary	Mote Marine Lab	Collaborator	Schofield
Klausmeier, Chris	U. Wisconsin	Collaborator	Schofield
Klinck, John	ODU	Collaborator	Martinson, Douglas
Knowlton, Nancy	Smithsonian	Collaborator	Doney
Kock, Karl-Herman	Johann Heinrich von Thunen Institute	Collaborator	Friedlaender
Kratz, Thomas	New Mexico State University	Collaborator	Fraser
Kump, Lee	U. Maine	Collaborator	Schofield
Laney, Christine	University of Texas - El Paso	Collaborator	Fraser
Largier, J.L.	Univ of California-Davis	Collaborator	Franks
LaRue, Michelle	University of Minn	Collaborator	Fraser
Lavigne, David	IFAW	Collaborator	Friedlaender
Law, Cliff	NIWA, NZ	Collaborator	Doney
Law, Rachel	CSIRO	Collaborator	Doney
Lawrence, David	NCAR	Collaborator	Doney
Le Quéré, Corinne	U. East Anglia	Collaborator	Doney
Lee, Zhonping	U. South Florida	Collaborator	Schofield
Leger, E	CNRS, Centre IRD, France	Collaborator	Fraser
Leising, Andrew	NOAA	PhD advisee	Franks
Lennert-Cody, Cleridy	IATTC	PhD advisee	Franks
Lenton, Andrew	CSIRO Australia	Collaborator	Doney
Leslie, Heather	Brown	Collaborator	Doney
Levin, Simon	Princeton	Collaborator	Schofield
Levine, Naomi	U. Southern California	PhD Thesis Advisee	Doney
Levis, Sam	NCAR	Collaborator	Doney
Lévy, M.	Univ de Paris	Collaborator	Franks

Name	Institution	Type	Co-PI
Li, Qian	South China Sea Research Institute, China	Postdoc advisee	Franks
Lindsay, Keith	NCAR	Collaborator	Doney
Litchman, Elena	U. Wisconsin	postdoctoral advisee	Schofield
Liu, Jiping	SUNY Albany	Primary Ph.D. advisor	Martinson, Douglas
Lohrenz, Steve	U Mass Dartmouth	Collaborator	Schofield
Lomas, Mike	Bigelow	Collaborator	Doney, Steinberg
Long, Matthew	NCAR	Collaborator	Doney
Longo, Catharine	UCSB	Collaborator	Doney
Lunau Mirko	Germany, no affil	Post-doc	Ducklow
Luo, Ya-Wei	Xiamen Univ, China	PhD student, Postdoc advisor	Doney, Ducklow
Luria, Catherine	Brown Univ	PhD student	Ducklow
Luz, Boaz	Hebrew U.	Collaborator	Doney
Lynch, Heather	Stony Brook University	Collaborator	Fraser
Lyons, Theodore	U. C. Irvine	Collaborator	Schofield
Lyver, Philip	Landcare Research	Collaborator	Fraser
Macias, Diego	CSIC, Spain	Postdoc advisee	Franks
Maggs, David	UC Davis	Collaborator	Friedlaender
Mahone, Kevin	NAVOCEANO	Collaborator	Schofield
Mahowald, Natalie	Cornell	Collaborator	Doney
Marinov, Irina	U. Penn	Collaborator	Doney
Martin, A.P.	National Oceanography Centre, UK	Collaborator	Franks
Matilla, Dave	NOAA	Collaborator	Friedlaender
Mayali, Xavier	LLNL	PhD advisee	Franks
McCallister, Leigh	VA Commonwealth	PhD student	Ducklow
McClintock, James	University of Alabama - Birmingham	Collaborator	Fraser
McCoy, Karen	CNRS, Centre IRD, France	Collaborator	Fraser
McDonnell, Andrew	U. Alaska, Fairbanks	Collaborator	Doney, Ducklow
McGuire, Dave	Univ Alaska-Fairbanks	Collaborator	Ducklow
McKinley, Galen	U. Wisconsin	Collaborator	Doney
Medlin, Linda	Alfred Wegner Institute	Collaborator	Schofield
Meredith, Michael	British Antarctic Survey, UK	Collaborator	Doney, Ducklow, Fraser, Schofield

Name	**Institution**	**Type**	**Co-PI**
Metzel, Nicholas	LOCEAN-IPSL, France	Collaborator	Doney
Mikaloff Fletcher, Sarah	NIWA, NZ	Collaborator	Doney
Millie, David	Florida Institute of Oceanography	postdocral advisor	Schofield
Misumi, Kasumi	CRIEPI, Japan	Collaborator	Doney
Mitchell, Ralph	Harvard University	PhD advisor	Ducklow
Mobley, Curtis	Sequoia Inc.	Collaborator	Schofield
Moeller, Holly	Stanford	Collaborator	Doney, Ducklow, Fraser, Schofield
Moline, Mark	U. Delaware	Collaborator	Fraser, Schofield
Monismith, S.G.	Stanford	Collaborator	Franks
Montes Hugo, Martin	U. Quebec	postdoctoral advisee	Doney, Ducklow, Fraser, Schofield
Montes-Hugo, Martin	Rimouski U., Canada	Collaborator	Martinson, Douglas
Montoya, Joe	Georgia Tech	Collaborator	Steinberg
Moore, D.F.	retired	Collaborator	Franks
Moore, John	Colorado State	Collaborator	Ducklow
Moore, Keith	UC Irvine	Collaborator	Doney
Moran, MaryAnn	U. Georgia	Collaborator	Doney
Morán, X., A. G.	Spanish Inst Oceanography	Collaborator	Ducklow
Moretti, Dave	University of Rhode Island	Collaborator	Friedlaender
Mouw, Colleen	U. Wisconsin	Collaborator	Doney
Muller-Karger, Frank	U South Florida	Collaborator	Doney, Schofield
Murphy, Eugene	BAS, UK	Collaborator	Doney
Murray, Alison	Desert Research Inst	Collaborator	Ducklow
Myers, Kristin	none	Masters student	Ducklow
Ndungu, Ker	U Stockhom	Collaborator	Schofield
Nelson, Norman	UCSB	Collaborator	Schofield
Neuman, Louise	IMAS, Australia	Collaborator	Schofield
Oliver, Jack	EPA	PhD student	Ducklow
Oliver, Matthew	Univeristy of Delaware	Collaborator	Fraser, Schofield
Orr, James	LSCE/IPSL France	Collaborator	Doney
Orton, Philip	SIT	Ph.D. advisee	Martinson, Douglas
Pace, Allen	U. Maryland	Collaborator	Steinberg
Paririe, J.C.	Univ North Carolina	Collaborator	Franks
Park, Geun-Ha	Korea Inst of Ocean Science and Technol	Collaborator	Doney
Parks, Susan	Syracuse University	Collaborator	Friedlaender

Name	Institution	Type	Co-PI
Patra, P.K.	JAMSTEC, Japan	Collaborator	Doney
Patterson-Fraser, Donna	PORG	Collaborator	Doney, Ducklow, Fraser
Peacock, Synte	NCAR	Collaborator	Doney
Peavey, Lindsey	UC Santa Barbara	PhD advisee	Friedlaender
Pedulli, Marco	Univ. Mass-Dartmouth	Collaborator	Ducklow
Peters, Deborah	New Mexico State University	Collaborator	Fraser
Petrov, Dimitri	Stanford	Collaborator	Schofield
Pilcher, Curtis	NASA	Collaborator	Schofield
Pillsbury, Finn	New Mexico State University	Collaborator	Fraser
Pilskaln, Cindy	Univ. Mass-Dartmouth	Collaborator	Ducklow
Pinckney, Jay	U South Carolina	Collaborator	Schofield
Plattner, Gian-Kasper	U. Bern	Collaborator	Doney
Poisbleau, M	Max Planck Institute for Ornithology, Germany	Collaborator	Fraser
Pollard, Ann	Point Blue Conservation Science	Collaborator	Fraser
Pollard, Peter	Griffith Univ., Australia	Collaborator	Ducklow
Polovina, Jeff	NOAA/NMFS	Collaborator	Doney
Post, Anton	MBL	Collaborator	Stammerjohn
Poulin, F.	Univ Waterloo	Collaborator	Franks
Pozdnyakov, Per	U. Trondhiem	Collaborator	Schofield
Prairie, Jennifer	Univ North Carolina	PhD advisee	Franks
Prezelin, Barbara	UCSB	PhD advisor	Schofield
Priscu, John	Montana State	Collaborator	Ducklow
Probert, Ian	Observatoire Océanologique de Roscoff	Collaborator	Schofield
Quay, Paul	U. Washington	Collaborator	Doney
Quetin, Langdon	UCSB	Collaborator	Stammerjohn
Quetin, Langdon	UCSB	Collaborator	Martinson, Douglas
Quigg, Antionetta	Texas A&M	postdoctoral advisee	Schofield
Quillfeldt, P	Max Planck Institute for Ornithology, Germany	Collaborator	Fraser
Rabalais, Nancy	LUMCON	Collaborator	Doney
Randerson, James	UC Irvine	Collaborator	Doney

Name	Institution	Type	Co-PI
Rassweiler, Andrew	Univ California - Santa Barbara	Collaborator	Fraser
Raven, John	U. Dundee	Collaborator	Schofield
Raymond, Peter	Yale	Collaborator	Doney
Ribic, Chris	Wisconsin	Collaborator	Ducklow, Fraser
Riesenfeld Christian	Desert Research Inst	Collaborator	Ducklow
Rind, David	NASA GISS	Postdoc Adviser	Stammerjohn
Rintoul, Steve	CSIRO	Collaborator	Schofield
Rippy, M.A.	Univ of California - Irvine	Collaborator	Franks
Rippy, Megan	Univ of California - Irvine	Postdoc advisee	Franks
Risch, Denise	NOAA	PhD advisee	Friedlaender
Riviere, P.	LEMAR	Collaborator	Franks
Robbins, Ian	California Polytechnic State University	Collaborator	Fraser
Robbins, Jooke	PCCS	Collaborator	Friedlaender
Robertson, Phil	Michigan State	Collaborator	Ducklow
Rodgers, Keith	Princeton	Collaborator	Doney
Rosenberg, Andy	UCS	Collaborator	Doney
Ross, Robin	UCSB	Collaborator	Stammerjohn
Ross, Robin	UCSB	Collaborator	Martinson, Douglas
Rothenberg, Dan	MIT	Collaborator	Doney
Ruckelshaus, Mary	Stanford	Collaborator	Doney
Rumsey, Scott	NOAA	PhD advisee	Franks
Russell, Joellen	University of Arizona	Collaborator	Fraser
Saba, Vince	NOAA/GFDL	Collaborator	Steinberg
Saba, Vince	NOAA/GFDL	Collaborator	Martinson, Douglas
Sabine, Chris	NOAA-PMEL	Collaborator	Ducklow
Sabine, Chris	NOAA/PMEL	Collaborator	Doney
Sailley, Sevrine	PML, OK	Postdoc advisee	Doney, Ducklow, Fraser, Schofield, Steinberg
Samhouri, Jameal	NOAA/NMFS	Collaborator	Doney
Sarma, V.V.S.S.	CSIR-National Institute of Oceanography, India	Collaborator	Doney
Sarmiento, Jorge	Princeton	Collaborator	Doney
Scheidat, Mieke	IMARES	Collaborator	Friedlaender
Schimel, David	JPL	Collaborator	Doney
Schmidt, Andre	U Mass Dartmouth	Collaborator	Schofield
Schmitt, Russell	Univ CA Santa	Collaborator	Fraser

	Barbara		
Name	**Institution**	**Type**	**Co-PI**
Schnetzer, Astrid	North Carolina State U.	PhD advisee	Steinberg
Schorr, Greg	Cascadia Research Collective	Collaborator	Friedlaender
Schultz, Gary	Marshall Univ	PhD student	Ducklow
Schuster, Ute	U. East Anglia, UK	Collaborator	Doney
Schuur, Ted	Univ Alaska-Fairbanks	Collaborator	Ducklow
Secchi, Eduardo	Brazilian Antarctic Program	Collaborator	Friedlaender
Seitzinger, Sybil	U. Gottenborg	Collaborator	Schofield
Seto, K.	Univ of California - Berkeley	Collaborator	Franks
Shankle, Amy	unknown	PhD advisee	Franks
Sharma, Sapna	University of Wisconsin - Madison	Collaborator	Fraser
Shiah, Fuh-Kwo	RCEC Taiwan	PhD student	Ducklow
Siebert, Ursula	University of Hanover	Collaborator	Friedlaender
Siegel, David	UCSB	Collaborator	Doney, Steinberg
Signell, Richard	USGS	Collaborator	Schofield
Silva-Rodriguez, Patricia	Universidad Nacional de la Plata, Argentina	Collaborator	Fraser
Silver, Mary	UC Santa Cruz	PhD advisor	Steinberg
Simon, Malene	Arhuss University	post-doc	Friedlaender
Siniff, Donald	University of Minnesota	PhD Advisor	Fraser
Sitch, Steven	Met Office Hadley Centre UK	Collaborator	Doney
Southall, Brandon	SEA Inc.	Collaborator	Friedlaender
Sparrow, Michael	Cambridge	Collaborator	Schofield
Stanley, Emily	Wisconsin	Collaborator	Ducklow
Stanley, Steve	UC Davis	Collaborator	Friedlaender
Steinbuck, J.V.	Stanford	Collaborator	Franks
Stephens, Britt	NCAR	Collaborator	Doney
Stevick, Peter	College of the Atlantic	Collaborator	Friedlaender
Stich, Stephen	U. Leeds, UK	Collaborator	Doney
Stimpert, Alison	Naval Postgraduate School	post-doc	Friedlaender
Straza, Tiffany	none	Collaborator	Ducklow

Name	Institution	Type	Co-PI
Stukel, Mike	Horn Point MD	Post doc	Ducklow
Summons, Roger	MIT	Collaborator	Schofield
Sundman, Lydia	Sequoia Inc.	Collaborator	Schofield
Swart, Seb	U. Cape Town	Collaborator	Schofield
Sweeney, Colm	NOAA-Boulder	Collaborator	Ducklow
Sydeman, Bill	Farallon Inst.	Collaborator	Doney
Taniguchi, D.A.A.	MIT	Collaborator	Franks
Taniguchi, Darcy	MIT	Postdoc advisee	Franks
Thiele, Deborah	Australian National University, Australia	Collaborator	Fraser
Thomas, A.C.	Univ Maine	Collaborator	Franks
Thomas, Eric	Univ Mass Boston	Collaborator	Schofield
Thomasy, Sarah	UC Davis	Collaborator	Friedlaender
Thompson, David	NASA JPL	Collaborator	Schofield
Thompson, Michael	SBNMS	Collaborator	Friedlaender
Thornton, Peter	ORNL	Collaborator	Doney
Tilbrook, Bronte	CSIRO Australia	Collaborator	Doney
Toole, Dierdre	unaffiliated	Collaborator	Doney
Torres, John	Georgia Tech	Collaborator	Schofield
Torres, Jose	University of South Florida	Collaborator	Fraser, Steinberg
Trees, Chuck	NATO SACLANT	Collaborator	Schofield
Tremblay, Bruno	McGill University	Postdoc advisee	Martinson, Douglas
Troy, C.D.	Stanford	Collaborator	Franks
Tsumune, Daisuke	CRIEPI, Japan	Collaborator	Doney
Twardowski, Michael	Wetlabs Inc	Collaborator	Schofield
Tynan, Cynthia	Associatedn Scientists at Woods Hole	Collaborator	Fraser
Urban, Edward	Univ Delaware	Collaborator	Schofield
Van Bonn, William	Marine Mammal Center	Collaborator	Friedlaender
Van opzeeland, Isla	NOAA	Collaborator	Friedlaender
Van Parijs, Sophie	NOAA	Collaborator	Friedlaender
Vardi, Assaf	Bar Ilan University	Collaborator	Schofield
Venables, Hugh	B.A.S.	Collaborator	Doney, Ducklow, Fraser, Schofield
Voigt, Meike	ETH Zurich, Switzerland	Collaborator	Doney
von Dassow, Peter	Pontificia Universidad Católica de Chile	Collaborator	Doney
Voss Maren	AWI Germany	Collaborator	Ducklow
Waide, Bob	Univ New Mexico	Collaborator	Ducklow

Name	Institution	Type	Co-PI
Walker, Nan	LSU	Collaborator	Schofield
Wanninkhof, Rik	NOAA/AOML	Collaborator	Doney
Ware, Colin	University of New Hampshire	Collaborator	Friedlaender
Warrick, J.A.	USGS	Collaborator	Franks
Webb, Douglas	Teledyne-Webb Research	Collaborator	Schofield
Webb, Eric	U. Southern California	Collaborator	Doney
Webb, Lockhart	New Hampshire	Masters advisor	Martinson, Douglas
Weinrich, Mason	WCNE	Collaborator	Friedlaender
Wennberg, Paul	Caltech	Collaborator	Doney
Whitney, frank	Institute of Ocean Sciences	Collaborator	Schofield
Wiley, Dave	SBNMS	Collaborator	Friedlaender
Williams, Rob	St. Andrews University	Collaborator	Friedlaender
Williams, Timothy	Univ New S Wales, Australia	Collaborator	Ducklow
Williams, Tony	Simon Fraser University, Canada	Collaborator	Fraser
Wilson, Stephanie	U. Bangor, Wales	PhD advisee	Steinberg
Woehler, Eric	University of Tasmania	Collaborator	Fraser
Wofsy, Steve	Harvard University	Collaborator	Doney
Wroblewski, J.S.	Memorial Univ NFLD	Graduate Advisor	Franks
Yager, Patricia	U. Georgia	Collaborator	Schofield, Stammerjohn, Steinberg
Yamanaka, Yasuhiro	Hokkaido U., Japan	Collaborator	Doney
Yamazaki, H.	TUMST	Collaborator	Franks
Yeung, Lawrence	U Southern California	Collaborator	Steinberg
Yoshida, Y.	CRIEPI, Japan	Collaborator	Doney
Young, Jeremy	Natural History Museum, London	Collaborator	Schofield
Young, TJ	Oxford University	Collaborator	Friedlaender
Zhang, Lin	unaffiliated	Postdoc advisee	Doney
Zhou, Meng	Umass Boston	Collaborator	Friedlaender, Schofield
Zhu, Yiwu	Umass Boston	Collaborator	Friedlaender

BETH SIMMONS
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Professional Preparation
2007 California State University, Fullerton, CA, Graduate Credits, Education
2007 University of Portland, ME, Continuing Education Credits, Education
2001 University of California, San Diego, CA, M.A. Curriculum Design
1990 Stonehill College, Easton, MA, B.S., Biology

Positions Held
2014 Education Outreach Coordinator, Palmer Long Term Ecological Research program
2013 Lead Primary Investigator LTER Education Digital Library Project
2011 Research Consultant / Reviewer Climate Literacy Energy Awareness Project (CLEAN)
2011 Consultant Editor National Geography in Shore Areas project (NAGISA)
2011 Field Researcher Palmer Station LTER
2005 Education Outreach Coordinator, California Current Ecosystem LTER
1990 Teacher, Hardwick Eagle Hill, Sandwich Riverview School, Rancho Bernardo High School

Five Recent Selected Products or Publications

Simmons B, Cerullo MM (2008) Sea Secrets: Tiny Clues to a Big Mystery, Vol. Moonlight Publishing, Layfayette, CO

Simmons, B. (2009) Learning from a Time Series: Expand your Perception of Data

Simmons, B. (2010). Beyond the Book Instructional Resources (2010) Ecosystem Illustrations, Species Identification Cards, Climate Change and the Adelie Penguin: Scientists are studying seabirds as indicators of climate change.

Simmons, B. (2011). Evidence of Change: Adelie Penguins; (2011) Smithsonian SANT Ocean Hall, Ocean Today video kiosk, Washington D.C. September

Simmons, B. (2011). Editor, videos for the Museum of Science Boston (2011): Penguins Under Pressure, Penguins and their Neighbors, Robots 1: REMUS, Robots 2: Slocum

Other Relevant Products or Publications

Simmons, B. et. al (2011). Museum of Science, Boston podcast http://www.mos.org/events_activities/podcasts&d=5275

Simmons, B. Instructional Developer (2013). Now you Sea Ice Now You Don't: Penguin Communities Shift on the Western Antarctic Peninsula

Synergistic Activities

Simmons, Beth (2013) Lead Investigator of the LTER Educational Digital Library Project

Education Reviewer, Climate Literacy and Energy Awareness Project, (CLEAN)

Technical Education Research Group, Cambridge, MA. (2011 – present)

Hands Across the Sea, liaison for LTER Schoolyard Book Series project, (2010)

Schoolyard LTER Executive Committee Member, (2004-present)

Sandwich STEM Academy, Science Advisory Board, Sandwich, MA (2014)

BIOGRAPHICAL SKETCH
JAMES CONNERS

Scripps Institution of Oceanography, University of California, La Jolla, CA, USA, 92093
Telephone: (858) 534-2708, FAX: (858) 534-2997, jconners@ucsd.edu

Role in PAL LTER:
Information Manager

Professional Preparation:
2007 B.S. Cognitive Science, University of California San Diego

Positions held:
2007 - 2011: Database programmer / Applications (data system) developer
2011 - present: Information Manager

Area of Expertise:
Information management, database development, application programming

Five recent publications or products:

Baker, Karen S; Kortz, Mason; & Conners, James. (2011). DataZoo: an Oceanographic Information System Supporting Scientific Research. UC San Diego: Scripps Institution of Oceanography. Retrieved from: http://escholarship.org/uc/item/139019q8

Conners, James E. "Addressing Scaling Issues Associated with Data Access." *Databits* Fall 2010 (15 Nov. 2010)

Conners, James E. "Matplotlib: An Open Source Python 2-D Plotting Library." *Databits* Fall 2009 (14 Dec. 2009)

Conners, James E. "MySQL Workbench: A Visual Database Design Tool." *Databits* Fall 2008 (15 Nov. 2008)

Kortz, Mason, and James E. Conners. "Developing and Using APIs in System Design." *Databits* Sprint 2008 (28 June 2008)

Other relevant publications or products.

Conners, James E. "YUI: An Open-source JavaScript Library." *Databits* Fall 2007 (17 Nov. 2007)

Conners, James E. "Database Storage Model Considerations: XML and Relational Database Approaches." *Databits* Spring 2007 (04 July 2007)

Synergistic activities:

Participated in the following LTER Information Management Working groups: IM Website (2010), Units (2011 -), Web Services (2011 -)

Co-developed the Unit Registry (2010) component of the LTER Network Information System, currently being utilized by sites, supporting the standardization of scientific unit documentation within the LTER (http://unit.lternet.edu/)

Participation in multiple Tiger Team groups, coordinated to inform the LTER Network Office on community requirements during the development of PASTA, the current LTER NIS data cataloging and archival system

Participated and presented as a panel member for the "Synthesis through Data Discovery and Use: Past Present and Future" working group at the 2009 All Scientists Meeting (ASM) in Estes Park, CO

Palmer LTER Data Inventory

ID	Dataset	Description	Temporal coverage	PI	Study type / sampling
Current inventory of datasets available through Palmer LTER primary data system / catalog, Datazoo (http://oceaninformatics.ucsd.edu/datazoo/data/pallter/datasets), including system identifiers, dataset label, description, temporary coverage, contributing PI and					
		Population Studies			
88	Adelie Penguin Adult and Chick Counts	Adelie Penguin breeding success and chronology studies - colony-specific chick production	1991 - ongoing	William R. Fraser	Station season
90	Adelie Penguin Bands Seen	Adelie Penguin demography - all sightings of previously flipper banded penguins	1991 - 2006	William R. Fraser	Station season
86	Adelie Penguin Broods	Adelie Penguin breeding success and chronology studies - relative abundance of one and two chick broods	1991 - ongoing	William R. Fraser	Station season
87	Adelie Penguin Census	Adelie Penguin demography - breeding population size and overwinter survival	1991 - ongoing	William R. Fraser	Station season
89	Adelie Penguin Diet	Adelie Penguin diet studies	1991 - ongoing	William R. Fraser	Station season
96	Adelie Penguin Diet - Euphausia suberba	Adelie Penguin diet - number and size of Euphausia superba in diet	1991 - ongoing	William R. Fraser	Station season
97	Adelie Penguin Diet - Fish	Adelie Penguin diet - size and species of fish in each sample	1991 - ongoing	William R. Fraser	Station season
94	Adelie Penguin Diet - Log	Adelie Penguin diet - general information associated with each sample	1991 - ongoing	William R. Fraser	Station season
98	Adelie Penguin Diet - Prey other than Fish and Euphausia suberba	Adelie Penguin diet - number and weight of minor and major prey categories	1991 - ongoing	William R. Fraser	Station season
91	Adelie Penguin Fledgling Weights	Adelie Penguin breeding success and chronology studies - chick fledging weights	1991 - ongoing	William R. Fraser	Station season
92	Adelie Penguin Population on Humble Island	Adelie Penguin breeding success and chronology - Humble Island population, timing of arrival of breeding adults	1991 - ongoing	William R. Fraser	Station season
93	Adelie Penguin Reproduction Success	Adelie Penguin breeding success and chronology - per pair breeding chronology and reproductive success	1991 - ongoing	William R. Fraser	Station season
102	Bird Census Log Moving - Summer	At-sea seabird censuses. Data on the species encountered (including marine mammals), their abundance, distribution and behavior	1993 - ongoing	William R. Fraser	Annual cruise
100	Bird Census Moving - Summer	At-sea seabird censuses. Data on the species encountered (including marine mammals), their abundance, distribution and behavior	1993 - ongoing	William R. Fraser	Annual cruise
95	Bird Census Stationary - Summer	At-sea seabird censuses. Data on the species encountered (including marine mammals), their abundance, distribution and behavior	1993 - ongoing	William R. Fraser	Annual cruise
103	Bird Census Log Moving - Winter	At-sea seabird censuses. Data on the species encountered (including marine mammals), their abundance, distribution and behavior	1993, 1999, 2001	William R. Fraser	Annual cruise
101	Bird Census Moving - Winter	At-sea seabird censuses. Data on the species encountered (including marine mammals), their abundance, distribution and behavior	1993, 1999, 2001	William R. Fraser	Annual cruise
99	Bird Census Stationary - Winter	At-sea seabird censuses. Data on the species encountered (including marine mammals), their abundance, distribution and behavior	1993, 1999, 2001	William R. Fraser	Annual cruise
114	Ammonia Oxidizing Bacteria and Archaea Abundance	Abundance of ammonia oxidizing bacteria and archaea that were collected on LMG 06-01 (archaea) at discrete depths	2006	James T. Hollibaugh	Annual cruise
47	Bacteria	Bacterial properties in discrete water column samples	2002 - ongoing	Hugh Ducklow	Station season
48	Bacteria	Bacterial properties in discrete water column samples	2003 - ongoing	Hugh Ducklow	Annual cruise
219	Structural size measurements and isotopic signatures - Adelie Penguins	Structural size measurements and isotopic signatures of foraging among adult male and female AdÃ©lie penguins (Pygoscelis adeliae) nesting along the Palmer Archipelago near Palmer Station, 2007-2009	2007 - 2009	Kristen Gorman	Station season

Palmer LTER Data Inventory

ID	Dataset	Description	Temporal coverage	PI	Study type / sampling
221	Structural size measurements and isotopic signatures - Chinstrap Penguins	Structural size measurements and isotopic signatures of foraging among adult male and female gentoo penguins (Pygoscelis papua) nesting along the Palmer Archipelago near Palmer Station, 2007-2009	2007 - 2009	Kristen Gorman	Station season
220	Structural size measurements and isotopic signatures - Gentoo Penguins	Structural size measurements and isotopic signatures of foraging among adult male and female chinstrap penguins (Pygoscelis antarctica) nesting along the Palmer Archipelago near Palmer Station, 2007-2009	2007 - 2009	Kristen Gorman	Station season
35	Penguin Counts - Annual Totals	Annual counts of penguin breeding pairs near Palmer Station, Antarctica starting in 1970	1970 - 2006	William R. Fraser	Derived product
208	Standard Body Lengths - E. superba	Standard body length of Euphausia superba collected with a 2-m, 700-um net towed from surface to 120 m.	2009 - ongoing	Debbie Steinberg	Annual cruise
209	Standard Body Lengths - Salpa thompsoni	Length of Salpa thompsoni collected with a 2-m, 700-um net towed from surface to 120 m.	2009 - ongoing	Debbie Steinberg	Annual cruise
150	Zooplankton Abundances	Calculated abundances for krill, salp and species of zooplankton.	1993 - 2004	Robin M Ross	Annual cruise
199	Zooplankton Density - Current	Zooplankton collected with a 2-m, 700-um net towed from surface to 120 m. This dataset is the current (2009 - present) counterpart to Zooplankton Density - Historical. Together these two data sets comprise the full Palmer LTER zooplankton density time series. Please refer to the methods for differences between the two.	2009 - ongoing	Debbie Steinberg	Annual cruise
212	Zooplankton Density - Historical	Zooplankton collected with a 2-m, 700-um net towed from surface to 120 m. This dataset is the historical (1993 - 2007) counterpart to Zooplankton Density - Current. Together these two data sets comprise the full Palmer LTER zooplankton density time series. Please refer to the methods for differences between the two.	1993 - 2007	Debbie Steinberg	Annual cruise
146	Zooplankton Trawl	Antarctic krill wet weight, total length and sexual maturity from throughout the mesoscale Palmer LTER region using 2-M metro trawl towed in the upper 120 m.	1997 - 2007	Robin M Ross	Annual cruise
		Primary Production			
24	Chlorophyll	Chlorophyll and phaeopigments from water column samples	1991 - ongoing	Oscar Schofield	Annual cruise
126	Chlorophyll	Chlorophyll and phaeopigments from water column samples	1991 - ongoing	Oscar Schofield	Station season
156	Inherent Optical Properties	Inherent optical properties at varying depths in the water column	2009	Oscar Schofield	Annual cruise
157	Inherent Optical Properties	Inherent optical properties at varying depths in the water column	2009	Oscar Schofield	Station season
130	High Performance Liquid Chromatography Pigments	Photosynthetic pigments of water column samples analyzed using High Performance Liquid Chromatography (HPLC)	1991 - ongoing	Oscar Schofield	Station season
42	High Performance Liquid Chromatography Pigments	Photosynthetic pigments from samples taken from rosette Go-Flo bottles and analyzed with High Performance Liquid Chromatography (HPLC)	1991 - ongoing	Oscar Schofield	Annual cruise
41	Primary Production	Water column primary production from inorganic carbon uptake for 24h at simulated in situ (SIS) light levels in deck incubators	1995 - ongoing	Oscar Schofield	Annual cruise

Palmer LTER Data Inventory

ID	Dataset	Description	Temporal coverage	PI	Study type / sampling
127	Primary Production	Water column primary production from inorganic carbon uptake for 24h at simulated in situ light levels in deck incubators	1994 - ongoing	Oscar Schofield	Station season
138	Photosynthetic Parameters from Photosynthesis-Irradiance Curves	Photosynthesis-irradiance measurements used to derive P-I relationships and to calculate primary production for each discrete sample	1991, 1993	Barbara Prezelin	Annual cruise
139	Photosynthetic Parameters from Photosynthesis-Irradiance Curves	Photosynthesis-irradiance measurements used to derive P-I relationships and to calculate primary production for each discrete sample	1991 - 1993	Barbara Prezelin	Station season
		Inorganic Matter			
44	Dissolved Inorganic Carbon	Dissolved inorganic carbon and alkalinity of discrete water column samples	1993 - ongoing	Hugh Ducklow	Annual cruise
27	Dissolved Inorganic Nutrients	Dissolved inorganic nutrients including 5 macro nutrients: silicate, phosphate, nitrate, nitrite, and ammonium from water column bottle samples collected during annual cruise along western Antarctic Peninsula, 1991-present.	1991 - ongoing	Hugh Ducklow	Annual cruise
211	Dissolved Inorganic Nutrients	Dissolved inorganic nutrients including 5 macro nutrients: silicate, phosphate, nitrate, nitrite, and ammonium from water column bottle samples collected between October and April at Palmer Station, 1991-present.	1991 - ongoing	Hugh Ducklow	Station season
50	Dissolved Oxygen	Dissolved oxygen of discrete water column samples	1993 - ongoing	Hugh Ducklow	Annual cruise
		Organic Matter			
69	Dissolved Organic Carbon	Dissolved organic carbon (DOC) taken from discrete water column samples collected during annual cruise along western Antarctic Peninsula, 2003-present.	2003 - ongoing	Hugh Ducklow	Annual cruise
70	Dissolved Organic Carbon	Dissolved organic carbon (DOC) taken from discrete water column samples collected between October and April at Palmer Station, 2002-present.	2002 - ongoing	Hugh Ducklow	Station season
36	Particulate Organic Carbon and Nitrogen	Particulate organic carbon and nitrogen measurements from water column sample bottles; cruise PD94-01 not included in time series for lack of samples	1991 - ongoing	Hugh Ducklow	Annual cruise
129	Particulate Organic Carbon and Nitrogen	Particulate organic carbon and nitrogen measurements from Go-Flo bottles sampling the water column from a zodiac	1991 - ongoing	Hugh Ducklow	Station season
26	Offshore Sediment Trap Fluxes	Vertical fluxes of particulate carbon, nitrogen and phosphorus from a sediment trap deployed west of Palmer Station, Antarctica at a depth of 170 meters, 1992-present.	1992 - ongoing	Hugh Ducklow	Derived product (Annual cruise)
		Disturbance Patterns			
214	Palmer Station AWS 2-minute weather	2-minute Automatic Weather Station (AWS) meteorological measurements (precipitation, radiation, cloud base, temperature, etc.) from Palmer Station Antarctica beginning in 2005.	2005 - ongoing	PAL Information Mana	Weather station
28	Palmer Station Weather - Daily Averages	Daily weather observations (air temperature, pressure, wind speed, wind direction, precipitation, sky cover) at Palmer Station, Antarctica (latitude 64deg 46min S; longitude 64deg 03min W) starting in April of 1989	2001 - ongoing	PAL Information Mana	Weather station

Palmer LTER Data Inventory

ID	Dataset	Description	Temporal coverage	PI	Study type / sampling
189	Palmer Station Weather - Monthly Averages	Monthly averages of temperature, pressure and melted precipitation from Palmer Station (LTER). Combines legacy monthly average temperature timeseries (1974-1989) with full time series that includes pressure and melted precipitation (1989-ongoing).	1974 - ongoing	PAL Information Mana	Weather station
46	Inshore Sediment Trap Fluxes	Sediment trap in nearshore waters (1992-1995)	1992 - 1995	David M. Karl	Station season
215	Krill CO2 Perturbation Experiment	Biological and chemical data taken during a CO2 perturbation experiment with adult Antarctic krill, during a Palmer LTER cruise in January 2011	2011	Grace Saba	Station season
49	Sea Ice - Annual Averages	Average yearly sea ice coverage for the PAL LTER region West of the Antarctic Peninsula derived from passive microwave satellite	1978 - ongoing	Sharon Stammerjohn	Derived product
34	Sea Ice - Monthly Averages	Average monthly sea ice coverage for the PAL LTER region West of the Antarctic Peninsula derived from passive microwave	1978 - ongoing	Sharon Stammerjohn	Derived product
151	Sea Ice Annual Indices - Advance, Retreat, Duration	Sea ice duration or the time elapse between day of advance and day of retreat within a given sea ice year for the PAL LTER region West of the Antarctic Peninsula derived from passive microwave satellite	1978 - ongoing	Sharon Stammerjohn	Derived product

		Logs / Reference			
45	Event Log	Palmer (PAL) log of events (cruise happenings ordered by time) is a meta dataset, including lat-lon, datetime, activity, events, etc.	1991 - ongoing	PAL Information Mana	Annual cruise
123	Full Western Antarctic Peninsula Survey Grid	Multiple sets of sampling locations are listed with latitude and longitutde, line and station, and name	N/A	PAL Information Mana	Reference
120	Basic Western Antarctic Peninsula Survey Grid	A basic set of sampling locations is listed with latitude and longitude, line and station, and name	N/A	PAL Information Mana	Reference

Palmer LTER data provided online elsewhere, or in other data systems

	Dataset		**Temporal coverage**	**PI**	
	Palmer LTER quality controlled CTD data from both annual cruises and station seasons, published as file collections	FileFinder (http://oceaninformatics.ucsd.edu/filefinder/pallter/) - Locally developed and maintained application for publishing complex file collections	1991 - ongoing	Doug Martinson	Annual cruise & Station season
	Palmer LTER physical oceanographic profile data archived with NODC	NODC (http://www.nodc.noaa.gov/cgi-bin/OAS/prd/project/details/538)		Doug Martinson	Annual cruise

Project Management and Logistics Requirements.

Site Management. The main PAL site is located at Palmer Station (64º46 S, 64º04 W) on Anvers Island, west of the Antarctic Peninsula, and encompasses both the immediate coastal region and the offshore oceanic region swept annually by the advance and retreat of sea ice. Our regional site extends 800 km south to Charcot Island (**Fig. 3**). This remote LTER site is subject to intense meteorological forcing that creates extreme logistic challenges for conducting research and site management. In spite of logistic challenges and the remote location, our site is increasingly well equipped. It is possibly the most intensely studied region in the Southern Ocean. In addition to assets provided by the USAP at Palmer Station and aboard the Antarctic Research and Supply Vessel (ARSV) *Laurence M. Gould* (LMG), we currently have four physical oceanographic sensor moorings, two time-series sediment traps and conduct several glider surveys each field season.

All US Antarctic researchers are bound by the rigorous regulations of the Antarctic Conservation Act, the US legal instrument governing the provisions of the Antarctic Treaty, regarding site occupation, environmental stewardship and sample collection. The Protocol on Environmental Protection to the Antarctic Treaty designates Antarctica as a natural reserve and sets forth requirements for all activities in Antarctica. Of immediate concern to PAL is ensuring that the site remains undisturbed by uncontrolled human influences such as tourism or unsupervised research activities. The PAL research area is now designated as the Southwest Anvers Antarctic Specially Managed Area (ASMA), conferring additional protection and additional obligations for researchers to define their site management protocols, obtain field permits, and limit human impacts. The SW Anvers ASMA greatly facilitates site protection and largely defines how our site is managed.

Site management of PAL is carried out by the civilian logistics contractor, currently Antarctic Support Contractor (ASC), a consortium of service providers managed by Lockheed-Martin, under contract to the NSF. The NSF controls access of all researchers to the site, and supports most logistic needs including transportation, housing and subsistence, field research support, communications and data transmission, waste management, safety and security. Final research decisions are thus made in close consultation with NSF/ASC at the proposal stage and prior to each field season. There are strict limits to the numbers and identity of personnel we can deploy in the field, and the exact dates of stay. Berthing for our project is limited to 12 at Palmer Station and 20 on the research vessel.

Project Governance and Management. PAL consists of a Lead PI (Ducklow) and ten co-PIs. PAL is divided into 8 scientific components addressing the physical environment and ecosystem dynamics in the region: Climate and sea ice (Sharon Stammerjohn), Physical oceanography (Doug Martinson), Microbial biogeochemistry (Hugh Ducklow), Phytoplankton, optics and gliders (Oscar Schofield), Zooplankton (Debbie Steinberg), Seabirds (Bill Fraser), Cetaceans (Ari Friedlaender) and Modeling (Scott Doney); plus Information Management (James Conners) and Education/Outreach (Beth Simmons). One co-PI is responsible for each component. The component co-PIs jointly plan the detailed logistics for field season research. With the exception of Ducklow, Martinson and Simmons at Lamont-Doherty Earth Observatory (LDEO) at Columbia University, the co-PIs are dispersed at seven different institutions around the country and are supported through subawards from Columbia. All ten PAL co-PIs constitute the governing body of the project. Funding decisions and research issues are decided by the full group through consultation and consensus. In the event of failure to resolve conflicting views (very rare), the lead PI makes decisions, following consultation with the NSF Program Managers or Contractor (if necessary). Formal communication is maintained among PIs by frequent email, weekly to monthly conference calls and an annual meeting. With Ducklow's recent move to LDEO, responsibility for project administration shifts to Columbia University. James Conners has responsibility for Information Management within our project and with respect to the LTER Network. The Integrative Oceanography Division (IOD) at Scripps Institution of Oceanography is the data hub for PAL (see IM Section). We share James and the Scripps IOD resources with California Current Ecosystem (CCE) LTER, thereby achieving economy of scale, and benefitting from scientific as well as IM partnership. Beth Simmons is the project Education and Outreach Coordinator. She works closely with Ducklow through a contract arrangement with Columbia, and with the other coPIs to design, coordinate and manage our EO activities. Conners and Simmons have full co-PI status in our project.

An external advisory group drawn from the polar marine science community and the LTER Network has aided project guidance in the past, and we intend to reconvene and enlist this group's advice in the new award period.

Project turnover and succession. PAL has grown from 7 to 10 co-PIs and successfully managed a 60% personnel turnover since 2002 (only 2 of the pre-2002 co-PIs remain in the current PAL). Three co-PIs (Ducklow, Martinson and Fraser) are in their 60s and have been in the program for 12, 17 and 23 years, respectively. During the upcoming award cycle, PAL will consider further personnel turnover, as we have done in the recent past, through discussion within the program and consultation with outside colleagues. Ducklow will step down from project leadership at the end of the proposed award cycle, and turn it over to another co-PI within the program. The decision will be based on project consensus, willingness to assume leadership, and suitability of a new institution to host the award. We anticipate that consensus on this important decision will be easily reached. The new Lead PI will be selected during the upcoming award period to provide a seamless transition.

Recruitment and Diversity. Logistics constraints profoundly affect our opportunities for formal and informal collaboration, cross-site activities and other research, education and outreach. Nonetheless we try to reserve some of our designated space at Palmer Station and on the research vessel each year for collaborating and independent investigators who want to work with us. We also encourage outside investigators and postdocs to submit proposals to work at Palmer Station and aboard the research vessel, and offer them sampling and data support from our ongoing observational program. This strategy has resulted in about a dozen new projects over the past 6 years, and has significantly broadened our overall scientific productivity. PAL Investigators invite colleagues to join our program as Affiliated Investigators. They are selected through consensus among the PIs because they fill a gap in our expertise or have specific ongoing and closely related research in the PAL Study region. PAL Affiliated Investigator status does not necessarily guarantee financial support, but we do encourage full participation in the scientific activity of PAL including attendance at our annual meetings, access to all data, sample sharing and consideration for berths on the cruises or at Palmer Station, as part of our field teams (see also below).

Undergraduate student interns and volunteers comprise an important element of the field teams at Palmer Station and on our cruises, and are critical to our success. We use the unique opportunity to work in Antarctica to help promote participation by a diversity of students and underrepresented groups at our site. PAL has accomplished this aim through participation in programs such as the NSF Teachers Experiencing the Arctic and Antarctica Program and with Research Experiences for Undergraduates and volunteer opportunities. We will continue to seek increased diversity in our project by working closely with LDEO's Assistant Director of Academic Affairs and Diversity to identify interested students to serve as lab or field interns. Similar connections are being sought at the other co-PI institutions. Co-PIs Stammerjohn and Friedlaender are Early-Career Researchers.

Project Logistics Requirements. As described in our research proposal, PAL long-term observations, process studies and field-based experimental work are conducted both at Palmer Station during each October to April (Austral) growing season, and in January at sea across the PAL sampling grid (Fig. 3) aboard the LMG. With the exception of two additional days of ship time (see below), all of our major logistics requirements remain essentially the same as in the recent award period. At Palmer Station, our proposed research requires 12 berths for five research components allocated as follows: seabirds (Fraser, B-013P, 4 berths), phytoplankton (Schofield, B-019P, 2 berths), zooplankton (Steinberg, B-020P, 2 berths), microbial biogeochemistry (Ducklow, B-045P, 2 berths) and whales (Friedlaender, new component, 2 berths). During the season, team members are exchanged depending on their professional and personal obligations as well as the ship schedule; thus although the maximum number of personnel on Station at any one time is limited to 12, a greater number of people will be travelling to and from the Station. On Station, each group requires a dedicated lab module. We also require 4 dedicated Zodiac boats for the seabird, zooplankton, microbial+phytoplankton and whale groups. The new whale component requires a rigid-hulled inflatable boat (RHIB) for prey mapping and whale surveys, as well as for deploying satellite tags. This RHIB requires a bow pulpit to facilitate tag deployments and could be stationed at Palmer for the season, but loaded onto the LMG during the LTER cruise.

Annual research cruise. The annual oceanographic survey of our regional-scale sampling grid is a key component of our long-term observations and mechanistic process studies. We will continue to accommodate our full science group, including the new whale component, within our existing allocation of **20** science berths. Over the past six years, we had 28 days of LMG ship time dedicated to our research each year. Currently, we cover a 50% larger region due to our southern extension of the sampling grid, with more PIs and more activities, with essentially the same amount of ship time as in the project's original allowance in 1993. With the addition of the new whale component, we have additional sampling requirements, and we therefore request an additional two days of ship time each year (total 30 science days). The small increment will enable the whalers to collect samples and deploy satellite tags from the specialized RHIB. We have hosted our whaler colleagues during the past three cruises, in order to become familiar with each other's work and logistics requirements. As a result, the ship crew and contractor support personnel are now fully capable of supporting the increased needs of our combined projects. It is critical that our cruise period be scheduled at the same dates as in the past (03 January-03 February, ± a few days) to maintain the scientific and statistical integrity of our 22-year long time series, and provide a consistent viewing window for evaluating seasonal and interannual variability.

Related projects. The rapid pace of change in the WAP region, enhanced scientific infrastructure and the growing prominence of our project have resulted in increased numbers of related proposals to conduct cooperative research at Palmer Station, and requests to participate on our annual cruise. We actively encourage new PIs and new scientific research in the PAL region. The LMG has 22 science berths and 6 berths for the contractor science support personnel. We use 20 berths. The two additional science berths are reserved for other projects funded by NSF and requiring coordination or collaboration with PAL. In 2015-2016 these two berths will be used by Dr. R. Sherrell (Rutgers), who is funded separately to investigate the distribution and dynamics of trace metals in the PAL study region. Sherrell's special logistic needs will be covered under his award.

To facilitate logistics review of related proposals, in consultation with NSF we have developed a three-tier system for defining the requirements of proposed research: Level 1: projects we endorse as providing new information of interest to PAL, but for which active collaboration and/or coordination of sampling is not appropriate or necessary. Level 2: projects of close interest, but without a commitment for lab space or berths at Palmer or aboard the LMG routinely assigned to PAL. In some cases we can offer to collect samples for another project if they do not have personnel on site. Level 3: proposals of special interest or critical importance to PAL, but for which berthing and/or lab space is not otherwise available, we can offer to make a PAL berth or berths available for a specified period, and will coordinate sampling as in Level 2. In these cases, the person or persons are displacing a PAL person, and would be required to fulfill that person's research obligations in addition to their own work.

Given the changes in physical climate and ecology that have already occurred along the WAP, and the likelihood of additional changes, possibility including tipping points and other unforeseen events, it is vitally important to maintain and enhance scientific research in the region. PAL looks forward to continuing our 24-year long partnership with NSF, support contractors and international colleagues to provide scientific leadership and increase our understanding of ecosystem-level responses to rapid environmental and climate change.