Title

Krill and Krill Predators: Ecosystem-Based Management in the Gulf of the Farallones-Cordell Bank Krill Production Domain

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Krill and Krill Predators: Ecosystem-Based Management in the
Gulf of the Farallones-Cordell Bank Krill Production Domain

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Project Hypothesis
We will test the primary hypothesis that coastward advection of bottom cold-salty water during intense wind-driven upwelling provides conditions conducive for *E. pacifica* (the more oceanic species) to move onto the continental shelf where they become abundant and available to predators "early" in the season each year. As a corollary, we will test the hypothesis that as upwelling relaxes "later" in the season each year, *E. pacifica* moves offshore where it is less available to predators, and *T. spinifera* (the more coastal species) develops, becoming the dominant euphausiid in shelf waters and predator diets.

Project Goals and Objectives
The overall project goal is to determine how the distribution, abundance and reproductive dynamics of *E. pacifica* and *T. spinifera* in the Gulf of the Farallones-Cordell Bank krill production domain varies within each season in relation to interannual variation in oceanography. Building upon our pilot studies (2004-2005), and our long term studies of auklet predator-prey relationships (1977-2005) on the Farallon Islands, we will acquire 3 new years of data (~5 surveys per year; ~15 in total) to determine how interannual variability in upwelling parameters (timing, intensity, amplitude, flow) affects krill and krill predator-prey dynamics in these marine sanctuary waters. To meet this goal, we will conduct replicate shipboard surveys within the upwelling period each year (February–September) to evaluate how within-season variation in upwelling and primary productivity affects *E. pacifica* and *T. spinifera* distribution, abundance, and reproduction. We will augment and enhance our hydroacoustic surveys with net samples of euphausiids and the overall zooplankton community. We will conduct field surveys each year (2006-2008) and develop statistical models of krill and physical oceanography, krill reproductive dynamics, and the ecology of krill-krill predators in year 2 and year 3.

Briefly Describe Project Methodology
We propose an integrated, collaborative, multi-disciplinary study of the physical oceanographic processes that determine the distribution, abundance and demography of euphausiids in the Gulf of the Farallones - Cordell Bank region, encompassing NOAA-National Marine Sanctuary waters (GFNMS and CBNMS). Our field surveys will consist mostly of small boat operations covering a grid of parallel lines, running perpendicular to the bathymetry from near shore to beyond the 1000-m isobath, covering much of the offshore region of both marine sanctuaries. It will take 3 days to survey the entire grid during each month of sampling. During each cruise, we will measure physical oceanographic parameters, sample the overall zooplankton community, conduct standardized and opportunistic net tows for euphausiids, measure acoustic signals, and identify and enumerate the krill predator community.

Describe progress and accomplishments toward meeting goals and objectives.
In 2006, we completed three 3-day cruises and one 10-day extended cruise in collaboration with NOAA's National Marine Sanctuaries. In 2007, we completed two 10-day cruises in collaboration with NOAA-NMS and one 3-day cruise. In 2008, we completed one 10-day cruise with NOAA-NMS and two 3-day cruises including June 2008. The 3-day cruises were conducted on board the RV *John Martin* (Moss Landing Marine Lab) and the 10-day cruises were conducted on board the NOAA Ship *McArthur II*. Data collected on these cruises are fully comparable between them and with previous cruises carried out in 2004 and 2005 (total = 10). To date, including 2004 and 2005, we have carried out a total of 21 cruises that surveyed the physical oceanography, zooplankton community (particularly krill and copepods), and marine bird and mammal abundance and distribution in the region. We found that delayed and reduced

upwelling in 2005 and 2006 were associated with significant changes in zooplankton communities and declines in abundance of major zooplankton taxa in the upper water column; the abundance of krill decreased while there was an increase in salps and other gelatinous zooplankton (which are less energy-dense and more acoustically reflective than krill) during these years. Reduced upwelling appears to result in low abundance of adult stages of *Euphausia pacifica* in the study area. This study illustrates the dynamic nature of the zooplankton community which can change drastically in response to climate, resulting in negative effects on higher trophic levels. Enhanced upwelling conditions in 2007 (i.e., stronger alongshore winds and colder water temperatures) have led to increases in krill abundance and decreases in gelatinous taxa. *Thysanoessa spinifera* assemblages were dominated by larval stages, while adult *Euphausia pacifica* were more common in 2007 zooplankton collections. These changes in the zooplankton community had positive feedback on the abundance and distribution of higher trophic levels at sea, and on chick productivity of seabirds breeding on the Farallon Islands.

PROJECT MODIFICATIONS:
There are no modifications in objectives and approach to be used at this time.

PROJECT OUTCOMES:
Data and databases (multiple funding sources include RLG, NFWF, MFF, Anon., and CA-SeaGrant)
Physical Data: 1) CTD cast database (stations vertical). All processed and geo-referenced CTD cast information. 2) TSG database (underway surface). All filtered and geo-referenced underway TSG information.

Biological Data: 3) Krill acoustic biomass database. All processed and geo-referenced krill simates. 4) Zooplankton net tows database. All ID and counts transformed to densities and geo-referenced. 5) Marine bird/mammal database. All counts binned at 3-km and geo-referenced.

Intellectual property, analysis, models, techniques
All data, analysis, models and techniques belong to PRBO and are available upon request by means of a 'data sharing or collaboration agreement,' for single use and for scientific purposes that do not overlap with ongoing analysis being done by PRBO and current collaborators.

Instruments, equipment: All instruments and equipment used in this project were provided as in-kind support or purchased by a combination of sources of funding including primarily philanthropic foundations.

Data, analysis, models, instruments, equipment related to this project are currently shared with: 1) NOAA-NMS have copy of all data collected during collaborative cruises on the McArthur II. 2) Rachel Fontana, Graduate student at University of California Davis (Bodega Marine Laboratory). 3) Ben Saenz, Graduate student at Stanford University. 4) Nina Karnovsky, Professor at Pomona College 5) Myriax Pty, has requested data to beta test Eonfusion a new software for marine research.

IMPACT OF PROJECT:
Findings from our project were used in the California Marine Life Protection Act (MLPA) Initiative process for developing potential marine reserve designs in the Gulf of the Farallones-Cordell Bank region. We formulated conservation and management recommendations to protect the marine food webs in this region. We provided distribution and abundance maps of marine birds and mammals (to show areas of high importance); we developed statistical models to understand these observed distributions and abundances in relation to krill abundance, oceanographic conditions and local physiography; and we proposed design considerations for marine protected areas in the Gulf of the Farallones-Cordell Bank region.

Publications
Technical Reports
Title: Ecosystem-Based Management for the Gulf of the Farallones-Cordell Bank Region: Planning for MLPA Implementation
Authors: J. Jahncke, J., M.L. Elliott, B.L. Saenz, B., W.J. Sydeman. Date: March 2007 (Report to Resource Law Fund Foundation)

Title: Krill of the Farallon Escarpment
Authors: J. Jahncke, M.L. Elliott, B.L. Saenz
Date: November 2007 (Report to National Fish and Wildlife Foundation)

Conference papers, proceedings, symposia

Title: Seabirds as Indicators of Short Term Environmental Variability: Farallon Cassin's Auklets 2005
Authors: R.W. Bradley, P. Warzybok, J. Jahncke, W.J. Sydeman and V. Kousky.
Date: February 2006
Conference Title: Pacific Seabird Group 33st Annual Meeting
Location: Girdwood, AK

Title: Krill and krill-predator response to unusual weather in the Gulf of the Farallones, California
Authors: J. Jahncke, B.L. Saenz, C. Rintoul and W.J. Sydeman
Date: February 2006
Conference Title: 2006 Ocean Sciences Meeting
Location: with B.L. Saenz, C. Rintoul and W.J. Sydeman.

Title: Krill and krill-predator responses to short-time scale variability in wind-driven upwelling in the Gulf of the Farallones, California
Authors: J. Jahncke, B.L. Saenz, C. Rintoul, R. Bradley and W.J. Sydeman
Date: June 2006
Conference Title: Symposium on climate variability and ecosystem impacts on the North Pacific: A basin-scale synthesis
Location: Honolulu, HI

Title: Of GLIMs and GAMs, error estimation and ecological modeling: comparative evaluation of statistical methods for analyzing seabird survey data.
Authors: N. Nur, J. Jahncke and W.J. Sydeman
Date: February 2007
Conference Title: Pacific Seabird Group 34th Annual Meeting
Location: Pacific Grove, CA

Title: Timing and availability of krill regulates prey consumption by Cassin's auklets in central California
Authors: M. Elliott, J. Jahncke, C.L. Abraham and W.J. Sydeman
Date: February 2007
Conference Title: Pacific Seabird Group 34th Annual Meeting
Location: Pacific Grove, CA

Title: Effects of climate variability on zooplankton community structure in the Gulf of the Farallones, California
Authors: J. Jahncke, M. Elliott, B.L. Saenz, M.D. Galbraith and W.J. Sydeman
Date: February 2008
Conference Title: 2008 Ocean Sciences Meeting
Location: Orlando, FL

Title: Seabird responses to climate variability at multiple time-scales
Authors: Jahncke, J.
Date: February 2008
Conference Title: Colloquium Spring 2008. Sonoma State University
Location: Rohnert Park, CA

Title: Climate variability and zooplankton in the Gulf of the Farallones-Cordell Bank National Marine Sanctuaries, California
Authors: with M. Elliott, B.L. Saenz, M.D. Galbraith and W.J. Sydeman
Date: February 2008
Conference Title: 2008 Sanctuary Current Symposium: Impacts of climate change on our oceans
Location: Monterey Bay, CA

Peer-reviewed

Title: Ecosystem responses to short-term climate variability in the Gulf of the Farallones, California.
Authors: J. Jahncke, B.L. Saenz, C.L. Abraham, C. Rintoul, R.W. Bradley, and W.J. Sydeman
Date: 2008
Journal Name: Progress in Oceanography
Issue/Page Numbers: 77: 182-193 doi:10.1016/j.pocean.2008.03.010

Title: Planktivorous auklet Ptychoramphus aleuticus responses to ocean climate, 2005: Unusual atmospheric blocking?
Authors: W.J. Sydeman, R.W. Bradley, P. Warzybok, C.L. Abraham, J. Jahncke, K.D. Hyrenbach, V. Kousky, J.M. Hipfner, M. D. Ohman
Date: 2006
Journal Name: Geophysical Research Letters
Issue/Page Numbers: 33: L22S09 doi:10.1029/2006GL026736

Brochures/Fact Sheets
Title: The Farallon Islands National Wildlife Refuge
Authors: PRBO Conservation Science
Date: Summer 2007

Title: Predators and Prey of the Farallon Islands
Authors: PRBO Conservation Science
Date: Fall 2007

Title: Predator Foraging Areas at the Farallones
Authors: PRBO Conservation Science
Date: Winter 2008

Electronic Publications
Title: Bringing hands-on research experience to the classroom
URL: http://teacheratsea.noaa.gov/2008/lancaster/index.html
Authors: Beth Lancaster
Date: live as of April 2008

Title: Euphausiids in the Gulf of the Farallones website on the Cordell Bank NMS SIMoN (Sanctuary Integrated Monitoring Network website:
URL: http://sanctuarysimon.org/cordell/sections/oceanography/project_info.php?projectID=90
Authors: J. Jahncke and M. L. Elliott
Date: live as of March 2008

Title: Gulf of the Farallones Marine Protected Area (MPA) Project website on the Cordell Bank NMS SIMoN (Sanctuary Integrated Monitoring Network) website:
URL: http://sanctuarysimon.org/cordell/sections/oceanography/project_info.php?projectID=91
Authors: J. Jahncke and M. L. Elliott
Date: live as of March 2008

Title: Marine Birds and Mammals at the Farallon Islands
URL: http://data.prbo.org/cadc/sefimap/
Authors: J. Jahncke, C. Rintoul, D. Jongsomjit
Date: live as of March 2007

Title: SEAS 2006: Sanctuary Ecosystem Assessment Surveys, Taking the pulse of the ocean
URL: http://sanctuaries.noaa.gov/missions/2006gfnms/welcome.html
Authors: M.J. Schramm, C. Preston, D. Devlin
Date: live as of July 2006

Newsletters, periodicals
Title: Gulf of the Farallones: Ecosystem-Oriented Research, Units of Conservation: Single Species to Ecosystems.
Authors: Jaime Jahncke
Date: Fall 2007
Newsletter: Observer 150, PRBO Conservation Science

Title: New Study to Explain Cause of Seabird Die-Offs
Authors: Christina S. Johnson
Date: February 16, 2006
Source: News Release, California Sea Grant, UC San Diego

Title: In the Feeding Shadow of the Farallones
Authors: Jaime Jahncke and Claire Peaslee
Date: Spring 2005
Newsletter: Observer 140, PRBO Conservation Science

Media Coverage
Title: Gulf of the Farallones: Ecosystem-Oriented Research, Units of Conservation: Single Species to Ecosystems.
Authors: Jaime Jahncke
Date: Fall 2007
Newsletter: Observer 150, PRBO Conservation Science

Title: New Study to Explain Cause of Seabird Die-Offs
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Cooperating Organizations
Cordell Bank National Marine Sanctuary
Gulf of the Farallones National Marine Sanctuary
Farallon National Wildlife Refuge, USFWS
Pacific Marine Environmental Laboratory, NOAA
US Army Corps of Engineers

Awards
Best presentation at the BIO Topic Session on "Life history and ecology of euphausiids in coastal and oceanic waters around the Pacific Rim". North Pacific Marine Science Organization 14th Annual Meeting. Vladivostok, Russia. [talk: Krill and krill-predators: Habitat associations in the dynamic Gulf of the Farallones, California. J. Jahncke B.L. Saenz, C. Rintoul and W.J. Sydeman]

Keywords
California Current, Upwelling, Cassin's auklets, *Ptychoramphus aleuticus*, common murres, *Uria algae*, euphausiids, krill, *Euphausia pacifica*, *Thysanoessa spinifera*,

Notes
Papers in preparation and planned
Title: Distribution and abundance of krill and krill-predators in the Gulf of the Farallones
Authors: Jahncke, J., B.L. Saenz, M.L. Elliott, R. Fontana.
Title: Temporal and spatial patters in community composition of zooplankton in the Gulf of the Farallones
Authors: Jahncke, J., M.L. Elliott, M. Galbraith, R. Fontana.
Title: Investigating the relationship between marine organisms and waters masses,
Authors, Fontana, R., J. Jahncke, J.L. Largier
Title: Creation, Propagation, and biological activity associated with fronts off Northern California
Authors, Fontana, R., B.L. Saenz, J. Jahncke, J.L. Largier
Title: Seasonal patterns of local acoustically-derived krill distribution in the Gulf of the Farallones.
Author: Saenz, B.L. and J. Jahncke
Title: An evaluation of hydroacoustic krill biomass estimation in the Gulf of the Farallones.
Authors: Saenz, B.L., S. Urmy and J. Jahncke
Title: Bottom-up control of Cassin's auklets on the Farallon Islands
Author: Elliott, M.L., C.L. Abraham, B.L. Saenz and J. Jahncke
Title: Temporal and spatial variation of the copepod community in the Gulf of the Farallones
Author: Elliott, M.L., B.L. Saenz and J. Jahncke, R. Fontana.
Title: Effects of variation in oceanographic conditions on seabird prey consumption in the Gulf of the Farallones
Authors: Roth, J.E. and J. Jahncke.

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