Program Number

13120114 and 13120120

Program Title

Long-Term Monitoring of Marine Conditions and Injured Resources and Services

Team Leads Submitting the Summary

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Time Period Covered by the Summary

1 February 2013 to 31 January 2014

Date of Summary

1 March 2014

Program Website

www.gulfwatchalaska.org

CONTENTS

INTRODUCTION AND PROGRAM OVERVIEW

The overarching goal of the Gulf Watch Alaska long-term ecosystem monitoring program is to provide sound scientific data and products that inform management agencies and the public of changes in the environment and the impacts of these changes on *Exxon Valdez* oil spill (EVOS) injured resources and services. This report describes work completed in year two of the first five-year period of the ecosystem monitoring program in the spill-affected region.

The long-term monitoring program has six main objectives.

1) Sustain and build upon existing time series in Prince William Sound, lower Cook Inlet and the adjacent Gulf of Alaska coast.
2) Provide scientific data, data products and outreach to management agencies and a wide variety of users.
3) Develop improved monitoring for certain species and ecosystems.
4) Develop science synthesis products to assist management actions, inform the public and guide the evolution of monitoring priorities for the next 20 years.
5) Enhance connections and integration of monitoring projects between the Gulf Watch Alaska and Herring Research and Monitoring (HRM) programs.
6) Leverage partnerships with outside agencies and groups to integrate data from a broader monitoring effort than that funded by the Trustee Council.

The Gulf Watch Alaska program is composed of integrated program management, data services, science synthesis, conceptual modeling, and outreach efforts (five projects), as well as the 15 ecosystem monitoring projects. Field sampling for most projects occurs each year, with the exception of some projects noted below. The program is structured into the components shown below, with the responsible entities for each project shown. For reader clarity, this report will include project information in this order, with heading titles adhering to the guidelines for contents in Section III. Annual Project Reports and Annual Status Summaries in the EVOSTC Reporting Policy and reporting templates revised 1.13.2014.

<u>Integrated program management, data services, outreach, science synthesis and modeling</u>

- Program coordination and logistics – Prince William Sound Science Center (PWSSC) and Alaska Ocean Observing System (AOOS)
- Outreach - AOOS
- Data management –AOOS/Axiom Consulting
- Historical data management and synthesis – National Center for Ecological Assessment and Synthesis (NCEAS) – EVOS TC Project# 12120120
- Science coordination and synthesis – NOAA Kasitsna Bay Laboratory (KBL)
- Conceptual ecological modeling– Alaska Sea Life Center (ASLC)

<u>Environmental drivers monitoring component</u>

- Gulf of Alaska mooring (GAK1) monitoring – University of Alaska Fairbanks (UAF)

- Seward Line monitoring – UAF
- Oceanographic conditions in Prince William Sound – PWSSC
- Oceanographic monitoring in Cook Inlet – Alaska Department of Fish and Game (ADFG), Kachemak Bay Research Reserve (KBRR)/ NOAA KBL
- Continuous plankton recorder –Sir Alister Hardy Foundation for Ocean Science (SAHFOS)

Pelagic monitoring component

- Ability to detect trends in nearshore marine birds – U.S. National Park Service (USNPS) Southwest Alaska inventory and monitoring Network (SWAN) – year 1 (no year 2 funding)
- Long-term killer whale monitoring – North Gulf Oceanic Society (NGOS)
- Humpback whale predation on herring – NOAA National Marine Fisheries Service (NMFS) Auke Bay Laboratory
- Forage fish distribution and abundance – U. S. Geological Survey (USGS) Alaska Science Center
- Prince William Sound marine bird surveys – U.S. Fish and Wildlife Service (USFWS)

Benthic monitoring component

- Nearshore benthic systems in the Gulf of Alaska – USGS Alaska Science Center/ USNPS SWAN, Coastal Resources Associates
- Ecological Communities in Kachemak Bay – UAF

Lingering oil component

- EVOS oil exposure of harlequin ducks and sea otters – USGS Alaska Science Center
- Oil level and weathering tracking – NOAA/NMFS Auke Bay Laboratory

Overview of Work

Progress Toward Objectives

Work during this year has focused on execution of the monitoring projects and improvement of public data accessibility, cataloging, and publication, as well as development of initial synthesis report products in preparation for the 2015 joint science conference. Program management efforts included science coordination, planning and conducting quarterly and annual principal investigator (PI) meetings, development of the year 3 workplan proposals, addressing Science Panel comments for the year three workplan, and identifying and contacting members for the Science Advisory Committee (see Table 1 for list of program milestones completed). We have also worked to develop integrated program synthesis tools and continue to revise and improve the program website for outreach and data access. The program administration team completed all fiscal and administrative reports as required. .

Specific accomplishments related to the program objectives include:

Objective 1. Sustain and build upon existing time series in Prince William Sound, lower Cook Inlet and adjacent Gulf of Alaska coast.

- Successfully completed all planned field work for all projects this year, including data review by PIs (For specific milestones accomplished by each project, see Appendix B).
- Loaded all 2012 data sets to the Ocean Workspace; completed metadata for all projects; and published data through the data portal for both historic and ongoing work.

Objective 2. Provide scientific data, data products and outreach to management agencies and a wide variety of users.

- Significantly improved public access to Gulf Watch Alaska data through the AOOS Gulf of Alaska data portal.
- Substantially updated and expanded the program website (www.gulfwatchalaska.org), including the addition of multiple sections describing the overall program, individual projects and people. Developed an interactive graphic design that facilitates user understanding of ecological connections.
- Documented and published 94 of the 419 data sets that we identified from historical EVOS funding. An additional 18 data sets have been obtained and are being documented for publication, and will soon be released.
- Provided outreach workshops at public events in Cordova, Valdez and Homer.
- Principal investigators provided multiple presentations and posters at scientific conferences. Science Team lead, Kris Holderied, gave presentations on the overall program at the Alaska Marine Science Symposium, University of Alaska Fairbanks science seminar, and U.S. Naval Academy.

Objective 3. Develop improved monitoring for certain species and ecosystems.

- Refined sampling protocol for forage fish data collection that improves sampling efficiency.
- Developed marine birds working group with the focus of identifying methods to detect trends in abundance and compile data sets with other indices (such as productivity) that may be useful for examining patterns related to environmental conditions (see K. Holderied, *Science Coordination and Synthesis* and H. Coletti, *Data Analysis in Marine Birds* project reports for further details.
- Developed environmental drivers working group to address differences in zooplankton sampling methods (see S. Batten, Continuous Plankton Recorder project report for further details.)

Objective 4. Develop science synthesis products to assist management actions, inform the public and guide the evolution of monitoring priorities for the next 20 years.

- Developed the time-series analysis framework and preliminary synthesis projects, in coordination with North Pacific Research Board's Gulf of Alaska Integrated Ecosystem Research Program (NPRB GOAIERP) and EVOSTC HRM program PIs.
- Completed the initial expert-informed conceptual model, which will be revised as a dynamic tool during the entire program. Started development of visualization tools and sub-models for smaller ecosystem components such as marine birds and forage fish.

- Finalized initial herring/whale/plankton conceptual model and now are in process of expanding its scope and refining through outside evaluation (see Conceptual Modeling report in Appendix A for further detail).
- Developed a theme and outline for the November 2014 science synthesis report, including a list of papers and lead scientists for each paper. This work is in preparation for the 2015 joint HRM and GWA science conference.

Objective 5. Enhance connections between and integration of monitoring projects and between the Gulf Watch Alaska and Herring Research and Monitoring (HRM) program.

- Developed small working groups to facilitate cross specialty communication and participation with shared vessel time and staff time between projects and programs to accomplish this year's field work.
- Restructured the Ocean Workspace and provided training for all program PIs to facilitate internal communication and publication of data.
- Worked closely with the HRM program Science Coordinator in developing the synthesis report theme and products to ensure cross-program questions are considered. Working closely on the development and writing of this document with the HRM science coordinator.

Objective 6. Leverage partnerships with outside agencies and groups to integrate data from a broader monitoring effort than that funded by the Trustee Council.

- Developed small working groups within specialties (i.e., marine birds, environmental drivers) to identify the types of data needed and outside sources that could be obtained to build on analyses of environmental conditions related to ecological indices.
- Worked with NPRB GOAIERP scientists to share information and address parallel goals between the two programs.
- Solicited data and presentations of data from outside of the program for incorporation in the annual meeting and time series workshop. Invited participants from NOAA, USGS, University of Washington, and the GOAIERP.

Science Synthesis Progress

The Science Coordinator (Dr. Tammy Neher) put a substantial effort into science synthesis and coordination during this past year (see Science Coordination and Synthesis project report for detail). Highlights from this year's work include:

- Developed and implemented tools to foster discussion, compare and contrast data, and visualize data gaps. These include the time series workshop held in conjunction with the annual PI meeting with visualization of anomalous patterns of 20 different data sets from both within and outside the program (see example, Figures 1 and 2, and Science Coordination and Synthesis report Appendix A for further detail).
- Development of Synthesis report theme and content outline.
- Developed two specialized working groups to resolve differences in sampling methods, develop strategies to address data gaps and questions.
- Designed a new website that includes interactive graphics to foster thinking about interactions between systems for users.

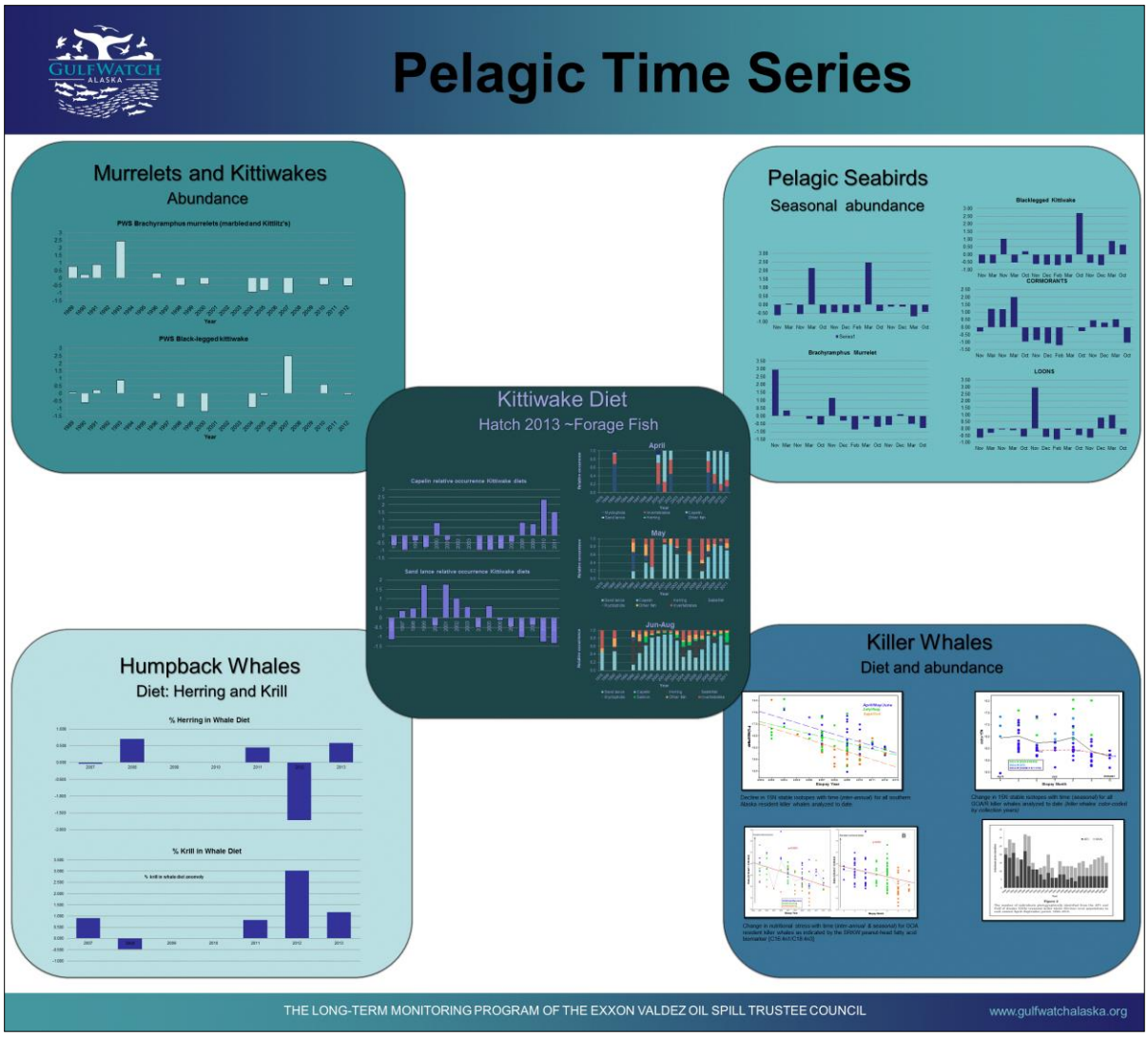

Figure 1. The Pelagic component time series poster presented at the GWA annual PI meeting time series workshop.

PROGRESS TOWARD HYPOTHESES

The focus of the annual meeting this year was on discussion of temporal and spatial patterns across various components of the program and on ideas for the underlying mechanisms which drive those patterns. The overall theme of the science synthesis report is: *Quantifying temporal and spatial variability across ecosystems to better understand the mechanisms of change in the Northern Gulf of Alaska Ecosystems*. Scientists also discussed several analytical approaches to examining spatial and temporal variability within the different data sets, including using cluster analyses (demonstrated in the Benthic component projects here) and principal components analyses of environmental conditions to determine drivers of variability in plankton biomass, mussel and herring growth. Analytical approaches will be a continuing area of emphasis for this next year under consulting with the program Science Advisory Group. Several, primarily 'bottom up' factors were suggested as potential drivers, including:

- Are long term ecological shifts due to extreme environmental conditions that impact trophic levels? For example, strong, atypical temperature, wind, and precipitation/run off levels during key seasonal periods leading to unusual conditions (i.e., the *coccolithophore* bloom in Bering Sea in 1997-1998, processes driving productivity and high recruitment years for herring, high settling success rate of barnacles and mussels in 2010).
- What are some of the drivers of variability in nearshore environments (identify temporal and spatial scales of variability; examine patterns of seasonal temperatures, upwelling, wind mixing and correspondence with patterns in metrics from nearshore communities such as species composition, abundance, and distribution)?
- Does the changes in variability in the data (spatial/temporal) provide indications of a new ecosystem regime shift in response to climatic cycles? What are the relevant time scales for assessing potential shifts for the ecosystem as a whole and for individual species?
- How do changing conditions in PWS and Cook Inlet track with changes in the larger Gulf of Alaska?
- Is there predictability in pulses of productivity and what are the drivers?

Table 1. Progress toward program milestones (please see Appendix B for a complete list of milestones achieved for each project within the program)

Deliverable/Milestone	Status
Conduct project field data collection surveys	Completed.
Submit annual work plan for review	Completed 1 September 2013.
Conduct annual program meeting and periodic conference calls/ short meetings to coordinate administrative needs and provide forum for collaboration	Completed January, May, July, and November 2013 and January 2014 at AMSS.
Plan and collaborate with HRM for joint science program	Several planning phases complete; work continues on development of synthesis report.
Select Science Advisory Group	Completed March 2014
Provide outreach and data access tools for the program	Revised website and data portal were launched in September 2013; small-scale improvements are ongoing.
Complete annual report	Completed 1 March 2014.

Noteworthy Issues and Findings within Program

The program continues as proposed, with minor changes that have been added and vetted through EVOSTC staff and the Trustee Council. Both lingering oil component projects have undergone minor changes. Due to the unique findings of Drs. Esler's and Ballachey's Harlequin duck project in year 2, an additional year of sampling has been added to verify findings. Field work planned for 2014 in Dr. Carls' lingering oil in sediments monitoring program has been delayed until 2015 (with corresponding delay in funding requests) to incorporate findings from other EVOSTC-funded projects on bioremediation (Boufadel, EVOSTC #11100836) and lingering oil distribution modeling (Nixon, EVOSTC #12120117), and accommodate a substantial revision to the hydrocarbon

database. Both of these changes were requested, and approved, in the Year 3 work plans submitted in September 2013. A summary of noteworthy issues and findings for each project is listed below and additional information can be found in the individual project reports in Appendix A.

PROGRAM COORDINATION AND LOGISTICS – HOFFMAN (PWSSC, 12120114-B)

All fiscal and administrative reporting requirements were met in Year 2 of Gulf Watch Alaska. PWSSC issued and managed sub-award contracts for all non-Trustee Agency Long-term Monitoring (LTM) Year 2 projects. PWSSC monitored spending, fulfilled subaward invoices, completed an annual audit in November 2013, and extended outreach funding as directed by McCammon and the outreach steering committee. PWSSC coordinated all logistics for the annual LTM PI meeting and processed all travel expenses for that meeting. Additionally, the semi-annual program report and the Year 3 *Exxon Valdez* Oil Spill Trustee Council (EVOSTC) work plans that were due on September 1, 2013 were coordinated, completed, and submitted. Principal Investigator (PI) meetings were held on a roughly quarterly basis as field seasons and PI schedules permitted. PI meeting dates during this reporting period were as follows: November 13 & 14, 2013 (in-person annual PI meeting; Anchorage, in collaboration with the EVOSTC-funded Herring Research and Monitoring program lead) and January 22, 2014 (in-person at the Alaska Marine Science Symposium). Program component leads gave presentations on overall progress at the annual PI meeting and teams collaborated across projects and components to advance synthesis work. The Management Team (Molly McCammon, Kris Holderied, Katrina Hoffman, Tammy Neher) worked closely with leadership from the Herring Research and Monitoring program and the EVOSTC staff to establish and clarify program reporting requirements. All financial and project reports have been submitted to the EVOSTC as required under this program.

OUTREACH– MOLLY MCCAMMON (AOOS, 12120114-B)

The Outreach and Community Involvement Steering Committee includes key outreach staff from AOOS, the PWS Science Center (PWSSC), Kachemak Bay Research Reserve (KBRR), Alaska SeaLife Center (ASLC), North Pacific Research Board (NPRB), COSEE Alaska (COSEE), NOAA and USGS. Marilyn Sigman, a marine educator with the COSEE Program is now providing some additional staff support to our outreach efforts as part of her COSEE responsibilities. The Steering Committee meets informally throughout the year, and held one in-person meeting on Feb. 2, 2014. During this reporting period, substantial changes were made to the website, www.gulfwatchalaska.org and data portal, which serve as the primary outreach mechanism for the Gulf Watch Alaska program and data. Several program principal investigators and collaborators participated in a variety of public outreach events during this reporting period, including educational presentations at the Cordova high school and brown bag seminars at PWSSC, Women in Science workshops for girls grades K-8 in Anchorage, an hour-long Alaska Public Radio Network call-in show in November, 2013 featuring the program, and outreach activities at public events in Valdez, Homer and Cordova. Planning for Year 3 activities occurred during the February meeting.

DATA MANAGEMENT– MCCAMMON/BOCHENEK (AOOS/AXIOM, 12120114-D)

Project investigators continue to provide core data management oversight and services for the Gulf Watch Alaska ecosystem monitoring program and all milestones have been met for this reporting period. The focus continues to be on establishing protocols for data transfer, metadata requirements and salvage of historic data, both for those data funded by the *Exxon Valdez* Oil Spill Trustee Council and ancillary historic data from other projects. Investigators are meeting with National Center for Ecological Analysis and Synthesis (NCEAS) investigator Matt Jones to coordinate future activities. PIs have participated in regular PI meetings, including the in-person meeting in November 2013 and the January 2014 data management meeting and are coordinating activities between the Herring and Gulf Watch Alaska programs. In addition, the AOOS Ocean Research Workspace, rolled out to PIs in Year 1, continues to be used as the internal staging area for PI data and work products, with individual PI user and group profiles created and other functional improvements. Several training seminars have been held via webinars, and PIs are now using the system to organize and consolidate their project level data. Software engineers at Axiom are providing support for the Workspace, resolving bugs and implementing new functionality in response to user feedback. All 2012 data are now posted on the Workspace, per the Program Management data sharing protocols. The Gulf Watch Alaska Data Portal was released in September 2013 as a key component of the Alaska Ocean Observing System's Gulf of Alaska Data Portal. The portal showcases Gulf Watch Alaska project data once it becomes public, alongside environmental data sets ingested by the project team.

HISTORICAL DATA MANAGEMENT AND SYNTHESIS – JONES (NCEAS, 12120120)

Project personnel have been simultaneously developing software systems for management, documentation, and distribution of project and historical data in collaboration with Axiom and the other PIs on the Gulf Watch Alaska program and conducting a data salvage effort to locate, document, and organize historical data from EVOSTC-funded projects. Data collation has proceeded effectively, with us having documented and published 94 of the 370 data sets that were identified from historical EVOS funding. The main obstacle to publishing data sets has been lack of information on the files being sent or inability to gain access to identified data sets. Specifically this includes files without column headers, folders of hundreds of files without explanation of the contents, duplicate data sets being sent with small unexplained differences making it difficult to determine what should be published, lack of units and acronym definitions, outdated file formats that must be converted, and files with graphs and embedded comments.

For data management software, we have prototyped a data catalog using the Metacat data repository system, and configured it for use for LTM data. This catalog provides data documentation and data files for all collated data sets, provides versioning to allow updates to data sets, and provides a publicly accessible web interface for searching for data and downloading data. We have also developed a new version of the Morpho data documentation application for use with this portal, and staff have continued to work with Gulf Watch Alaska scientists regarding the use of Morpho for local data management.

SCIENCE COORDINATION AND SYNTHESIS – HOLDERIED (NOAA KBL, 12120114-H)

Dr. Tammy Neher was hired as the Gulf Watch Alaska science coordinator and began working with the program in late March 2013. With consistent staff support in place this year, we have

significantly improved communication, integration and synthesis efforts both within the program and to outside entities. During this year, efforts have focused on coordination of data and metadata delivery from the PIs, providing quality control on incoming datasets, planning and holding the program annual meeting, planning for the 2015 joint LTM-HRM program science conference and report preparation. We have been working to develop integration and visualization tools both for within and outside the program, and improving access to program information and data. We continue to work on the coordination aspect outside of the program, including sharing information with the NPRB Gulf of Alaska Integrated Ecosystem Research Program (GOAIERP) and the Herring Research and Monitoring program. During this reporting period we worked extensively with principal investigators to create project level metadata, develop synthesis and visualization tools for integration within the program and public outreach, and assist with development of the Ocean Workspace, program website and public data portal. We also facilitated the formation and meeting of two small working groups to address needs highlighted by the EVOSTC Science Panel in the Year 3 work plans.

A time series workshop was held during the November 2013 annual PI meeting to help prepare for the joint synthesis workshop, provide synthesis brainstorming tools, and develop the outline for the Science Synthesis report for the Gulf Watch Alaska Program. Data from over 20 different data sets from within Gulf Watch Alaska projects and outside projects conducted in the Gulf of Alaska region were used to create time series anomaly graphs. Large posters with anomaly graphs from multiple disciplines were created to facilitate discussions on temporal and spatial trends in ecosystem data at the annual PI meeting in November (Figures 1 and 2 shows examples, see individual project report for further details). Data graphics were grouped under each component of the program with one additional poster showing patterns in environmental index data (such as annual means for the Pacific Decadal Oscillation, Bakken upwelling, and the Northern and Southern Oscillation indices). Comments from the PI discussions were used to form hypotheses and products for the program synthesis report to be developed this year.

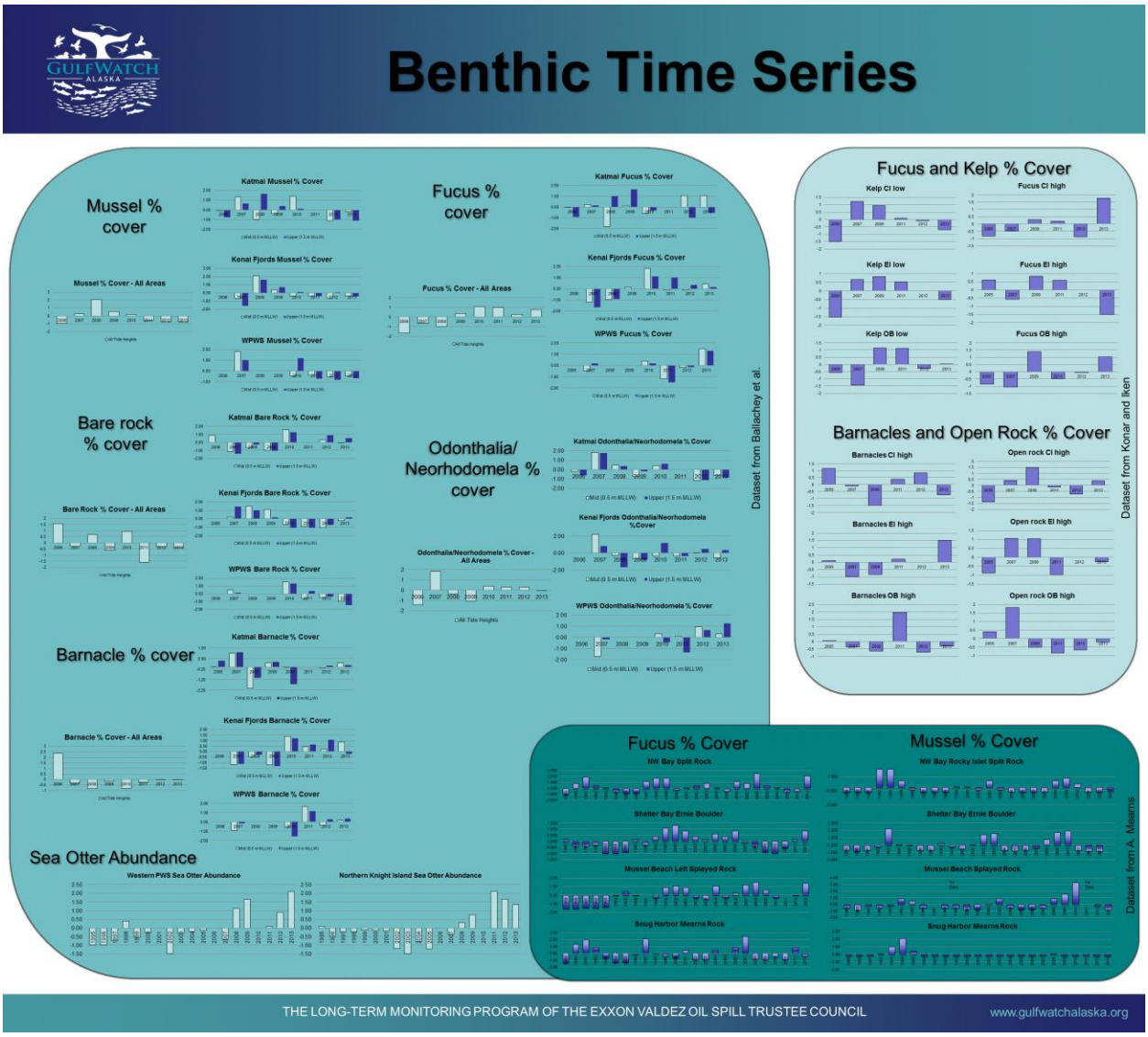

Figure 2. Poster example showing the Benthic component data time series from the 2013 GWA program PI meeting and Time Series Workshop.

CONCEPTUAL ECOLOGICAL MODELING – HOLLMEN (ASLC, 12120114-I)

Analysis of input from the November 2012 PI meeting and development of conceptual models is ongoing. We have developed a generic Gulf of Alaska (GOA) conceptual ecosystem model using input gathered at the November 2012 PI meeting and a visual diagram based on conceptual model diagrams developed by teams of benthic, pelagic and environmental driver project PIs, representing key linkages based on PI input (Figure 3.). The generic model serves as a visual representation of the current state of knowledge about the structure and function of the GOA ecosystem, as well as an iterative tool to be updated annually to demonstrate learning contributions by LTM research. Analysis of PI input on the ecological linkage rating tool exercise from the November 2012 PI meeting is complete, including a summary of results from the example submodel from the 2012 meeting, and refinement of the linkage rating tool for further model development. A presentation describing the development of conceptual ecological models for the

LTM program was given at the PICES annual meeting in October 2013. The title of the presentation was: *Development of conceptual ecological models to support the Gulf Watch Alaska long-term monitoring program*. The project was also presented at the annual program Principal Investigator meeting held in November in Anchorage.

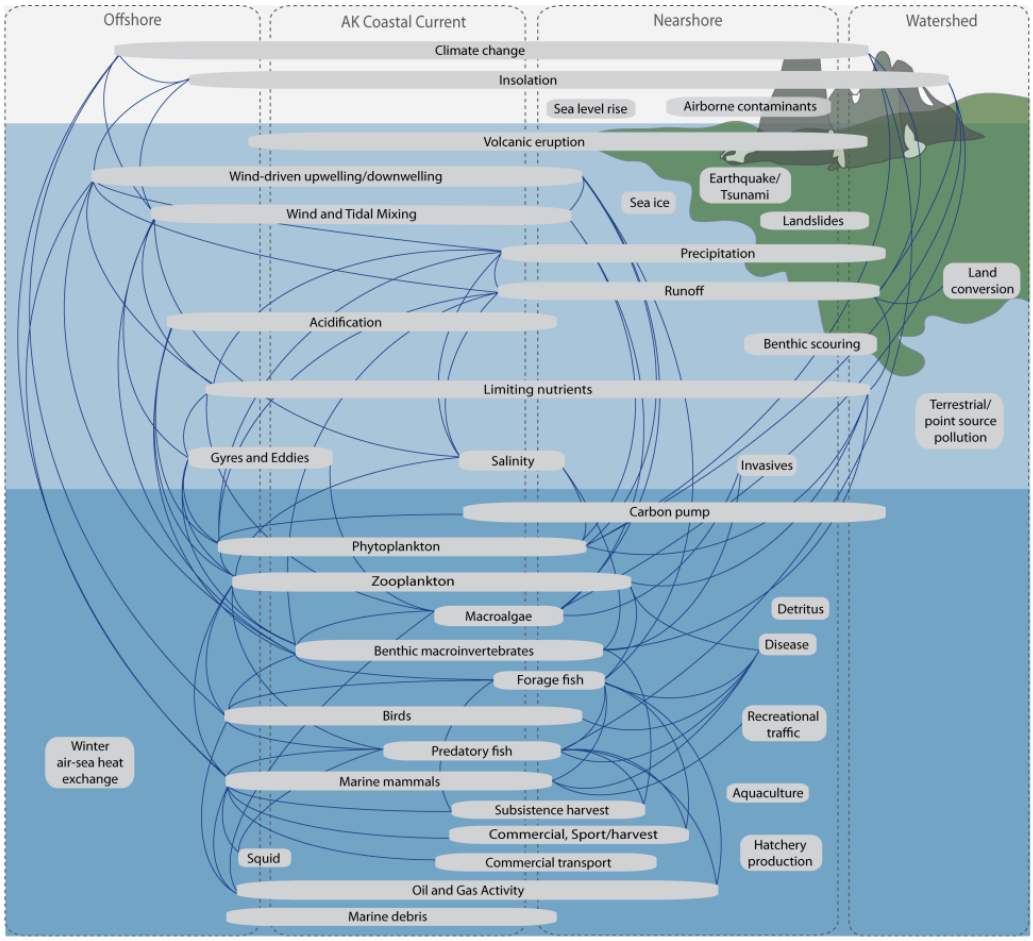

Figure 3. Visualization of the General Conceptual Ecological Model developed from the expert informed linkage rating workshop held during the November 2012 PI meeting.

GULF OF ALASKA MOORING (GAK1) MONITORING – WEINGARTNER (UAF, 12120114-P)

All field sampling thus far has been completed as proposed during this reporting period. Sampling activities this past year include 1) quasi-monthly CTD casts at station GAK 1 (August, September, November, and December 2013, and January 2014) and the recovery and re-deployment of a string of 6 temperature-conductivity-pressure (TCP) recorders on a mooring at GAK 1. Researchers have been working on relating long-term Seward sea-level variability to forcing mechanisms. The ultimate goal is to determine if the long-term record in Seward can be used as a proxy for transport in the Alaska Coastal Current (ACC). Preliminary findings suggest that the annual cycle of sea level variations at Seward are in-phase with dynamic height (vertically-integrated density) at GAK 1. At periods of days to ~1 month the sea level variations are significantly coherent with and in-phase with the along-shore winds over the Gulf of Alaska shelf, especially in fall, winter and early spring. Given that the wind is also coherent with ACC transport at these periods, it appears that Seward Sea

level anomalies at these periods may be useful as an index of ACC transport. The project graduate student will complete his MS thesis in summer 2014 reporting these findings. These results are promising, insofar as historical measurements suggest that short period (3 – 30 days) transport variations in the Alaska Coastal Current are largely wind-forced.

SEWARD LINE MONITORING – HOPCROFT (UAF, 12120114-J)

The spring cruise was conducted April 25 to May 9 2013 in conjunction with NPRB's Gulf of Alaska project. All primary sampling objectives were accomplished along the Seward Line and within PWS, with the exception that several multinets needed to be conducted at dawn (rather than during darkness). The late-summer cruise was conducted Sept 11-26, 2013 also in conjunction with the NPRB Gulf of Alaska project. Poor weather required that intermediate stations not be sampled along the line. All data is available from the May cruise, except for multinets in PWS. Processing of most data is completed for September, with the exception of multinets. Extremely poor weather on both cruises prevented execution of all process work on zooplankton (a secondary priority). Oceanographically, the Seward Line during the May 2013 cruise was 0.7 °C below the long-term mean temperature. Temperature during September was 0.5 °C below the long-term mean. Macro-nutrient and chlorophyll concentrations measured during May suggest the spring bloom was in progress along the Line during the cruise.

OCEANOGRAPHIC CONDITIONS IN PRINCE WILLIAM SOUND – CAMPBELL (PWSSC, 12120114-E)

Three surveys of Prince William Sound were conducted during the reporting period, and all 12 standard stations were occupied. All CTD data has been processed, with seasonally detrended anomalies calculated for temperature and salinity. There were generally warmer than average surface temperatures during winter at most stations, and warmer than average summer temperatures. Below the surface the picture was often the opposite, with cooler anomalies. Surface salinity during winter trended toward more saline conditions, while salinity anomalies in the summer trended towards fresher than average (often by a considerable margin), particularly at the nearshore head-of-bay stations. Again, the sign of the anomaly was often different at depth, when compared to the surface. Work is ongoing to put these observations into the context of the ~30 year CTD database.

Plankton, nutrient, and chlorophyll-a samples were collected from all stations with no incidents. As of January 2014 all plankton samples have been enumerated (both from this project and the Lower Cook Inlet samples), and all chlorophyll-a filters have been run. Analysis of the nutrient samples continues to lag behind expectations; the protocols for capillary electrophoretic (CE) analysis of macronutrients are still actively in development by a chemistry technician at PWSSC. All nutrient samples are being kept in frozen storage, and are stable indefinitely (they are 0.2 μm filtered prior to freezing). Catching up on the backlog is a priority, and if progress is not made soon on the CE methodologies (in Q1 of 2014), we will start working through the backlog using standard wet-chemical techniques.

The Autonomous Moored Profiler system did not perform flawlessly; however, we have learned a great deal about the many failure modes. This system is cutting-edge technology (this model is serial number 7), and some issues are to be expected, particularly given that this is by far the most northerly, coldest, deepest, and most remote deployment of such a system to date. We will use

what we have learned in 2013 to ensure successful deployments in 2014, and anticipate deploying the profiler in April 2014 to capture the spring bloom at daily resolution.

Oceanographic monitoring in Cook Inlet – Doroff (ADFG KBRR) and Holderied (NOAA KBL, 12120114-G)

In 2013, we conducted 297 conductivity-temperature-depth (CTD) stations in lower Cook Inlet and Kachemak Bay. Monthly Kachemak Bay oceanographic and plankton surveys were conducted from February 2013 through January 2014 with the exception of November 2013, when sampling was not conducted due to weather and boat issues. Quarterly lower Cook Inlet surveys were successfully completed in April and July 2013 but only the Kachemak Bay portion of the survey could be completed in February 2013 due to adverse weather conditions. An additional along-Kachemak Bay transect was completed in February to compare to intensive summer results. The fall quarterly survey was conducted over a two week period in late October and early November 2013, due to a long period of adverse weather conditions. During this reporting period, 64 zooplankton samples were collected, preserved, and are being analyzed at the Prince William Sound Science Center. During summer 2013, we leveraged help for field work and data analysis from NOAA Hollings Scholar undergraduate summer interns at NOAA Kasitsna Bay Laboratory and additional funding from the NOAA Integrated Ocean Observing Program/Alaska Ocean Observing System. These partnerships allowed us to conduct additional intensive small boat CTD surveys during June and July, to assess tidal and spatial variability of marine conditions in Kachemak Bay. Continuous water quality and meteorological data, and monthly nutrient and chlorophyll data were collected from the Homer and Seldovia KBNERR System-wide Monitoring Program stations, and the Bear Cove water quality mooring was successfully deployed for ice-free months. Chlorophyll-a probes were also operated on the water quality stations all year, though some biofouling occurred during summer months. Anomalies from the oceanographic data are being compared to climate indicies, including the Pacific decadal oscillation (PDO), to biological data collected in the intertidal zone by other Gulf Watch Alaska researchers (Brenda Konar and Katrin Iken) and to oceanographic data collected along the Seward Line (Russ Hopcroft), at the GAK1 mooring (Tom Weingartner) and in Prince William Sound (Rob Campbell). Phytoplankton data has been correlated with oceanographic and nutrient data to assess environmental triggers for harmful algal blooms. Results have been presented at the PI meeting in November 2013, the Alaska Marine Science Symposium in January 2014 and the Kachemak Bay Harmful Algal Bloom conference in February 2014.

Continuous plankton recorder – Batten (SAHFOS, 12120114-A)

Two of the six CPR transects were completed as scheduled during this reporting period, in August and September. Sample analysis and QC of the plankton data has been completed for the first 3 transects, while preliminary processing for the final 3 transects is finished and preliminary data are available with QC ongoing. When the temperature sensor was downloaded after the first transect, the data were found to be unreliable (unreasonably high temperatures were recorded on the last part of the transect). These data were discarded and a new sensor attached for the remainder of the year, which returned appropriate data. Preliminary review of the data suggests a bias towards smaller species, if biomass is low but abundance realtively high. Diatoms showed a strong spring peak in May and a secondary autumn peak in September, otherwise monthly values were slightly lower than average, but within the range seen before. Estimated mesozooplankton biomass was

generally lower than average until September, while abundances were quite high in June and September.

Ability to detect trends in nearshore marine birds – Coletti (USNPS SWAN, 12120114-F)
A contract statement of work was finalized during June of 2013. Changes from previous versions of the proposal included determining which species to focus the analysis on. The species chosen were: harlequin duck, black oystercatcher and pigeon guillemot. These species represent various foraging guilds, are all nearshore reliant and occur in varying densities across habitats. The resulting proposal is summarized in the individual project report, Appendix A.

The contract was submitted to the NPS contracting officials during July of 2013 and was put out to bid in early August of 2013. No bids were submitted. At this point, no funds have been committed and there has been further discussion on how to proceed. Re-advertisement of the bid is a possibility as well as completing the work within NPS by the SWAN biometrician or an interagency agreement with FWS to complete the analysis.

Long-term killer whale monitoring – Matkin (NGOS, 12120114-M)
A long awaited publication on the life history and population dynamics of the southern Alaska resident killer whale population from 1984-2010 was finalized and accepted for publication by *Marine Mammal Science*. Fieldwork was initiated in May 2013 and completed in October 2013. During 63 days of fieldwork on the *R/V Natoa* and 4 days on other vessels, we logged 39 encounters with killer whales, 29 with residents, 4 with AT1 transients, 4 with Gulf of Alaska transients and 2 with offshores. We completed photo analysis from October 2013 to January 2014 and prepared and delivered at the annual LTM PI meeting in November. Additional work included updates to numerous databases at North Gulf Oceanic Society with 2013 field data including survey and encounter access database and biopsy and tagging summaries. We filtered tagging data and constructed maps and tracks and associated dive data for tagged whales. Samples of tissue and scales were sent out for analysis. In collaboration with other projects, we supplied our humpback whale photo-identification and encounter data to Project 12120114-N (Humpback Whale Predation on Herring in Prince William Sound). Facebook and web sites were updated during this period as well.

Humpback whale predation on herring – (NOAA, NMFS Auke Bay Laboratory, 12120114-N)
During the reporting period three whale surveys were completed (April 2013, September/October 2013, and December 2013). In addition to whale data, forage fish and zooplankton were collected during the fall and winter surveys, these samples will be analyzed for energy density and stable isotopes. QA/QC has been completed for all whale data collected to date. We will complete the final a whale survey of the 2013/2014 field season during April 2014. An additional five-day whale survey is planned for the summer of 2014 with leveraged funds.

Forage fish distribution and abundance – (USGS Alaska Science Center, 12120114-O)
During this reporting period we worked on 2012 data processing, and created metadata in Morpho. Datasets uploaded to the Workspace include oceanography (water column temperature, salinity, chlorophyll *a*, water clarity, photosynthetically active radiation, oxygen), nutrients (nitrate, nitrite, ammonium, phosphate, and silica concentrations at two depths per station), zooplankton (species,

stage, biomass per volume filtered), fish (species, abundance, length, weight by station), and predators (marine bird and mammal distribution and behavior). We began work on a project outreach website hosted by USGS that we expect to be ready for viewing soon. In July-August 2013, we conducted year two field work, which included a hydroacoustic-trawl and beach seine survey mainly in the eastern Sound. We also did exploratory work to investigate the feasibility of incorporating aerial spotting surveys in conjunction with the herring research program (i.e., Scott Pegau's aerial survey work with Mike Collins, a Cordova pilot). We spent four days validating aerial survey observations (species, age class, hydroacoustic measures of density and biomass). We also tested adaptive cluster survey design methods for placement of hydroacoustic transects in areas with high density of target species, and opportunistically sampled forage schools when we encountered them.

PRINCE WILLIAM SOUND MARINE BIRD SURVEYS – IRONS/KULETZ (USFWS ALASKA REGION, 12120114-K)
This project had no field work scheduled in 2013, although we analyzed data and presented an oral paper on some of our results:

Cushing, D.A., D.D. Roby, K.J. Kuletz, and D.B. Irons. 2013. Changes in abundance of *Brachyramphus* murrelets in Prince William Sound, Alaska, 1989-2012. Pacific Seabird Group Conference, Portland, OR.

SEABIRD ABUNDANCE IN FALL AND WINTER – BISHOP (PWSSC, 12120114-C)
Three late fall and winter avian surveys were performed during this reporting period. The same observer (J. Stocking) participated in all surveys. Ships of opportunity used for our surveys included vessels surveying herring (PWS Science Center), shrimp (ADFG) and humpback whales. The October survey, previously conducted in conjunction with a NOAA humpback whale survey, was replaced in 2013 by the ADFG shrimp survey. The ADFG shrimp survey is a preferable alternative because of its broad-scale coverage of PWS as well as increased consistency in route due to the repeated visits to established sites.

The manuscript by Dawson, Bishop, Kuletz and Zuur, "Using ships of opportunity to assess winter habitat associations of seabirds in subarctic coastal Alaska," has been accepted pending revisions by the journal *Arctic*. In addition, the manuscript by Bishop, Watson, Kuletz and Morgan, "Pacific herring consumption by marine birds during winter in Prince William Sound, Alaska," has been accepted pending revisions by the journal *Fisheries Oceanography*. Both of these manuscripts are based on work from EVOS-funded seabird monitoring in Prince William Sound conducted just prior to the beginning of the LTM program. We have continued work on the database.

NEARSHORE BENTHIC SYSTEMS IN THE GULF OF ALASKA – BALLACHEY (USGS ALASKA SCIENCE CENTER), COLETTI (USNPS SWAN) AND DEAN (COASTAL RESOURCES ASSOCIATES, 12120114-R)
Field work for year 2 (the 2013 field season, with field work from March through July) was completed with no problems or concerns, with project components completed on schedule. Six field trips were conducted, including 1 to Katmai National Park (KATM), 2 to Kenai Fjords National Park (KEFJ), 2 to western PWS (WPWS), and 1 to northern PWS (NPWS). At Katmai, Kenai Fjords and WPWS, we visited and sampled sites that were established in previous years, and in NPWS, we established and sampled new sites. Work completed in all areas included monitoring of rocky intertidal, soft sediment and mussel sites, eelgrass beds, and black oystercatcher nests, as well as

collection of sea otter forage data. We also completed a winter bird survey at Kenai Fjords, summer bird surveys in Katmai and Kenai Fjords, and sea otter carcass collections in WPWS, Katmai and Kenai Fjords. An aerial survey of sea otters was completed in WPWS. An aerial survey in Kenai Fjords was scheduled for completed August 2013 but due to several factors (primarily weather-related), was not completed. The project is closely coordinated with the intertidal work being done in Kachemak Bay (KBAY; K. Iken and B. Konar; Gulf Watch Alaska Nearshore Project 13120114-L). Mussels were sampled at 3 locations in northern PWS and were submitted to NOAA for contaminant analyses as part of their Mussel Watch program. A report entitled "*Intertidal Invertebrate and Algae Monitoring: Power to Detect Temporal Trends*" was submitted to NPS by WEST, Inc. in 2012. Currently, further work on these statistical analyses with WEST is being conducted with an anticipated completion sometime during the spring of 2014 (funding for this component provided by NPS). We continued collections of nearshore species for stable isotope analyses and plan to establish priorities for future stable isotope sampling. Analyses of stable isotopes (carbon and nitrogen) in these samples are underway in the laboratory of Dr. S. Newsome. In addition, we are developing assays to evaluate gene expression and physiological status of mussels, as a tool for monitoring long-term health of the nearshore, in collaboration with Drs. L. Bowen and K. Miles (USGS-WERC) and T. Hollmen (AK SeaLife Center); a poster on this effort was presented at the 2014 Alaska Marine Science Symposium. A live oyster (*C. gigas*) was found during a sampling trip to Johnson Bay in WPWS in June 2013. The oyster was presumed to be at least 5 yrs old due to the perennial seaweeds growing on it as well as its size. No other oysters were found in the vicinity. A report on this finding was prepared by M. Lindeberg, and all appropriate agencies (including NOAA, ADF&G, and USGS) have been informed.

ECOLOGICAL COMMUNITIES IN KACHEMAK BAY – IKEN AND KONAR (UAF, 12120114-L)

Work during this period included data compilation and preliminary analyses from this year's and previous years' sampling events. During the summer monitoring event, we sampled five rocky intertidal sites, four seagrass sites, and for the first time in this project also four mixed sediment clam beaches (Port Graham, Jakolof Bay, China Poot Bay, Bear Cove). Insufficient low tide level at Bishop's Beach and Bluff Point prohibited us from complete surveys of tidal levels at those sites. Limpet (*Lottia persona*) and mussel (*Mytilus trossulus*) size-frequency distributions were assessed at three rocky sites (Port Graham, Outside Beach, Cohen Island).

For all habitats and communities assessed, we found strong site-specific differences within Kachemak Bay in 2013. For several of these measures, such as rocky intertidal community structure, these differences are persistent over multiple years. Community structure is more similar among the three sites along the south shore of Kachemak Bay and along the two sites along the north shore with more pronounced differences between the two shores, likely driven by the stronger glacial influence on the nearshore system of the northern shore.

Among mussel collection sites in 2013, a very large recruitment peak was observed in Port Graham that did not occur at the other two sites (one order of magnitude larger at Port Graham). In collaboration with Dr. Suresh Andrew Sethi at US Fish and Wildlife Service, we assessed if mussels recruit annually into the system based on mussel size-frequency data obtained in 2012 and 2013. For this we calculated age distribution from size-frequency distribution based on published growth data for *Mytilus trossulus* (Millstein and O'Clair 2001). A cohort analysis was then applied to the age

structure at the three rocky intertidal sites in Kachemak Bay. Age population structure was then analyzed for cohorts. At all sites, mussels reached about 3 years of maximum age. The even distribution of age classes to overall population suggests that recruitment occurs every year in Kachemak Bay. The reasons for the limited life span of mussels in Kachemak Bay is currently unknown but we will begin to compare these results to the otter scat and diet data to assess if predation pressure may be one of the causes.

EVOS OIL EXPOSURE OF HARLEQUIN DUCKS AND SEA OTTERS – BALLACHEY (USGS ALASKA SCIENCE CENTER, 12120114-Q)

Sea otters were captured and sampled in western PWS in summer 2012, and blood samples from those otters were analyzed for biomarker and health assays using gene transcription analyses. A final report on the gene transcription results recently was completed, and is provided as an attachment to this individual project report (Appendix A); highlights of associated sea otter studies through 2013 are included in the Nearshore Benthic Annual Report (Project component 12120114-R). Harlequin ducks were captured in PWS in March 2013 and liver biopsies collected for assays of cytochrome P4501A (CYP1A), a biomarker of exposure to oil. A summary of the findings from harlequin ducks over more than a decade of sampling in western PWS is provided in the individual project report and in a final report to the EVOSTC.

OIL LEVEL AND WEATHERING TRACKING – CARLS (NOAA/NMFS AUKE BAY LABORATORY, 12120114-S)

Hydrocarbon analyses and biomarker measurements have been completed for Gulf of Alaska samples and the draft report is in review (Project 11100112-B, Irvine et al). Measurement of hydrocarbons in three species of shrimp (pink, coonstripe and spot) from Prince William Sound is underway in the laboratory (PWSRCAC). Tissue processing is nearly complete and raw data are available for 91%. Sediment analysis will follow (10 samples). Data from the shrimp project (sediment and shrimp) will indicate whether benthic sediment is meaningfully contaminated with oil and if so, if those hydrocarbons are biologically available to macrofauna.

COLLABORATIONS

The program investigators held two all-hands teleconference calls, and two meetings during this reporting period to facilitate communication between team members, coordinate administrative activities and start synthesis planning. In addition, the management team also held multiple teleconference calls and two shorter, in-person meetings with the Science Coordination Committee to ensure that administrative and science needs were met within the program components. Two small working groups were formed to address the questions pointed out by the science panel regarding the marine birds and zooplankton sampling efforts. These groups are developing plans to improve the comparability of data across different regions and projects. (see the Science Coordination and Synthesis report 12120114-H for further details).

Program investigators continue the collaboration with the NPRB GOAIERP program scientists, including hosting members of their team to present at the GWA program annual meeting. We also have included data from outside the program for the time series workshop to enhance the data sets presented during the workshop. Data/presentations from projects outside of the GWA program were provided by Alan Mearns (NOAA), Kasitsna Bay Laboratory intern Starr Brainerd (American

University), and Jason Waite (GOAIERP). Invitations to attend were sent to GOAIERP program PIs, NOAA Weather Service staff, and University of Washington faculty members. Please see also above sections for additional coordination and collaboration details.

Finally, program principal investigators continue the cross program collaborations with the Herring Research and Monitoring program. Team leads from both programs attended annual program meetings in November and March. In addition, GWA principal investigators shared vessel time (Bishop, Piatt/Arimitsu), data (Campbell) and aerial tracking information (Piatt/Arimitsu).

Community Involvement/TEK and Resource Management Applications

Several new outreach and community involvement tools were developed and used during this past year. The outreach and science teams worked to develop a completely revised program website with an interactive graphic that allows users to view different pieces of an ecosystem and see how they are all part of the marine environment (Figure 4 illustrates, please see www.gulfwatchalaska.org for the functional website). The webpage also includes links to the data portal, where access to both the historic and current program data is provided. We continue to outreach and revise both the website and the data portal to improve public access and use. Planning is now underway to include spill-region community participation in the upcoming Community Based Monitoring workshop April 1-2, 2014.

Figure 4. The new Gulf Watch Alaska interactive program page, highlighting the Pelagic component of the program.

Please see McCammon Outreach and Community Involvement individual project report, Appendix A for a complete list of outreach and community activities.

Information and Data Transfer

Gulf Watch Alaska principal investigators published information in peer-reviewed journals, reports, newspapers, and magazines about their projects (Table 2) and participated in a wide variety of conferences and workshops. Principal investigators also participated in a variety of public outreach events and programs, including an NPR radio show, Discovery labs in Homer, and brown bag seminars and education workshops in Cordova (see McCammon Outreach and Community Involvement Appendix A for further detail). All of the monitoring projects have published 2012 data and are now in process of publishing 2013 data to the program's data portal.

Table 2. Summary of publications, written reports, and newspaper articles generated by Gulf Watch Alaska Principal Investigators in 2013.

Authors	Title	Journal/Status
Hollmen T. and S. A. Sethi	Conceptual ecological models to synthesize, organize, and priortize research in socioecological systems.	In prep.
Doubleday, A.J., Hopcroft, R.R.,	Seasonal and interannual patterns of larvaceans and pteropods in the coastal Gulf of Alaska, with relationships to pink salmon survival	Journal Plankton Research, submitted
Coyle, K.O., Gibson, G.A., Hedstrom, K., Hermann, A.J., Hopcroft, R.R.	Zooplankton biomass, advection and production on the northern Gulf of Alaska shelf from simulations and field observations.	J. Marine systems, 128, 185-207. 2013
Coletti, H. A., T.A. Dean, K.A. Kloecker and B.E. Ballachey.	Nearshore marine vital signs monitoring in the Southwest Alaska Network of National Parks: 2012.	Natural Resource Technical Report NPS/SWAN/NRTR—2014/756. National Park Service, Fort Collins, Colorado.
Dean, T.A., J.L. Bodkin and H.A. Coletti	Protocol Narrative for Nearshore Marine Ecosystem Monitoring in the Gulf of Alaska, Version 1.1.	Natural Resource Technical Report NPS/SWAN/NRTR—2014/756. National Park Service, Fort Collins, Colorado.
Saulitis, E.	Into Great Silence	Book, published, Beacon Press. 2013.
Saulitis, E.	The Woman Who Loves Orcas	Cover article, OnEarth Magazine, March 2013.
Matkin, C.	30 Years of tracking Killer Whales	Delta Sound Connections newspaper, 2013
Batten, Sonia	Large Ships, Little Critters	Delta Sound Connections newspaper, 2013
Campbell, Rob	Oceanographic Change	Delta Sound Connections newspaper, 2013
Bishop, M.A. and K.J. Kuletz.	Seasonal and Interannual Trends in Seabird Predation on Juvenile Herring. *Exxon Valdez* Oil Spill Restoration Project Final Report	Project 10100132-H, Prince William Sound Science Center, Cordova, Alaska.
Ballachey, B. E., J.L. Bodkin, and D.H. Monson.	Quantifying long-term risks to sea otters from the 1989 *Exxon Valdez* oil spill: Reply to Harwell & Gentile (2013).	Marine Ecology Progress Series 488:297-301. doi:10.3354/meps10498
Ballachey, B., D. Monson, G. Esslinger, K, Kloecker, J. Bodkin, L. Bowen and K. Miles	2013 Update on Sea Otter Studies to Assess Recovery from the 1989 *Exxon Valdez* Oil Spill, Prince William Sound, Alaska.	U.S. Geological Survey Open-File Report 2014-xxxx, 40 p., http://dx.doi.org/10.3133/ofr2014xxxx.

Bodkin, J.L., D. Esler, S.D. Rice, C.O. Matkin, and B.E. Ballachey.	The effects of spilled oil on coastal ecosystems: lessons from the Exxon Valdez spill.	Pp. 311-346 in B. Maslo and J. L. Lockwood, eds. Coastal Conservation.Cambridge University Press.
Bishop, M.A., J. Watson, K. Kuletz, and T. Morgan	Pacific herring consumption by marine birds during winter in Prince William Sound, Alaska.	*Fisheries Oceanography* Accepted, pending revisions.
Fisheries Oceanography Accepted, pending revisions.	Winter habitat associations of seabirds in subarctic Alaska.	In review, Arctic.
Stewart NL, Konar B, Doroff A.	Sea otter (*Enhydra lutris*) foraging in a heterogeneous environment in Kachemak Bay, Alaska.	Bulletin of Marine Science. *In revision*
Esler, D.	Long-term Monitoring: Lingering Oil Evaluating Chronic Exposure of Harlequin Ducks and Sea Otters to Lingering *Exxon Valdez* Oil in Western Prince William Sound. *Exxon Valdez* Oil Spill Trustee Council Restoration Project Final Report	Project 12120114-Q, Pacific Wildlife Foundation and Centre for Wildlife Ecology, Simon Fraser University, Delta, British Columbia, Canada.

Response to EVOSTC review, Recommendations, and Comments.

The Science Panel provided comments on Year 3 work plan proposals on September 27, 2013. The program management team returned a lengthy response to EVOSTC staff on October 28, 2013 (delayed by the federal government shutdown), which was subsequently shared with the Science Panel and Trustees. The EVOSTC staff provided comments to the response on December 6, 2013, with thanks for the level of information and clarifications. Recommendations for follow-up actions included revising report formats to provide the level of detail desired by the Science Panel and holding a data management meeting between EVOSTC staff, Gulf Watch Alaska program leads, and agency data managers. In addition, the program science team coordinated small working groups within the program to specifically address concerns regarding differences in seabird and plankton sampling methods. At the January 2014 data management meeting, Science Panel members in attendance relayed that they appreciated the very detailed responses and that the responses allayed many of their concerns. EVOSTC staff recently sent a summary from the data management meeting and we plan to submit a response to the summary that clarifies some inaccurate information. In December 2013 and January 2014, we worked closely with EVOSTC staff and the HRM program lead to refine and ensure compliance with program reporting requirements for Year 2 annual report and upcoming Year 3 work plan proposals. We are pleased to have open communication with EVOSTC staff around practical accommodations that result in both robust and streamlined reporting requirements.

Budget

Please see the Excel workbook with summary forms included with this report submission.

APPENDIX A INDIVIDUAL PROJECT REPORTS

A. PROGRAM COORDINATION AND LOGISTICS- HOFFMAN (PWSSC, 12120114-B)

1. Project Number: *See,* Reporting Policy at III (C) (1).

12120114-B

2. Project Title: *See,* Reporting Policy at III (C) (2).

Program coordination and logistics & outreach

3. Principal Investigator(s): *See,* Reporting Policy at III (C) (3).

Molly McCammon, Alaska Ocean Observing System (AOOS) & Katrina Hoffman, Prince William Sound Science Center (PWSSC)

4. Time Period Covered by the Report: *See,* Reporting Policy at III (C) (4).

February 1, 2013-January 31, 2014

5. Date of Report: *See,* Reporting Policy at III (C) (5).

March 1, 2014

6. Project Website (if applicable): *See,* Reporting Policy at III (C) (6).

www.gulfwatchalaska.org

7. Summary of Work Performed: *See,* Reporting Policy at III (C) (7).

Program Coordination and Logistics: PWSSC issued and managed sub-award contracts for all non-Trustee Agency Gulf Watch Alaska (GWA) Year 2 projects. PWSSC monitored spending, fulfilled subaward invoices, completed an annual audit in November 2013, and extended outreach funding as directed by McCammon and the outreach committee. PWSSC coordinated all logistics for the annual GWA PI meeting. PWSSC processed all travel expenses for the annual PI meeting.

All program reporting requirements were fulfilled, see Table A-1 for milestones completed. We coordinated, completed, and submitted the semi-annual program report that was due on March 1, 2013. We coordinated, completed, and submitted the semi-annual program report that was due on September 1, 2013. We coordinated, compiled, and submitted the Year 3 work plan proposals that were due on September 1, 2013. PI meetings were held on a roughly quarterly basis as field seasons and PI schedules permitted. PI meeting dates were as follows: February 26, 2013 (teleconference), July 10, 2013 (teleconference), November 13 & 14, 2013 (in-person annual PI meeting; Anchorage, in collaboration with the EVOSTC-funded Herring Research and Monitoring program lead); January 22, 2014 (in-person at the Alaska Marine Science Symposium). Program component leads gave presentations on overall progress at the annual PI meeting and teams collaborated across projects

and components to advance synthesis work. The PMT worked closely with leadership from the Herring Research and Monitoring program and the EVOS Trustee Council staff to establish and clarify program reporting requirements. We submitted all financial and project reports to NOAA as required.

The Gulf Watch Alaska program management team (PMT), consisting of Molly McCammon, Kris Holderied, Katrina Hoffman and Tammy Neher actively managed the program throughout the reporting year. The PMT met on average twice per month and no less than 24 times in the reporting year. The majority of these meetings were via teleconference. One annual in-person PMT meeting was held in Homer, AK on September 30, 2013. Additionally, the PMT gave a 20-month program update to members of the EVOS Trustee Council at their meeting in Anchorage on October 24, 2013. As needed, PMT teleconferences included members of the Science Coordinating Committee (Hopcroft; Weingartner; Ballachey; Lindeberg). Some teleconferences included members of the data management team (Bochenek; Jones). The entire PMT plus the data management team prepared for and attended the EVOSTC-funded data management meeting in collaboration with EVOSTC staff, Science Panel members, and Trustee Agency data management representatives on January 29 & 30, 2014.

Outreach and Community Involvement:

Not applicable to this project.

Table A-1. Status of project milestones for year 2

Deliverable/Milestone	Status
Subaward contract management & monitoring of spending	Contracts issued and managed to six organizations for nine subaward projects. All spending monitored.
Timely submission of narrative and financial reports	All reporting deadlines to EVOSTC and NOAA met in program year.
Conduct annual audit	Completed at PWSSC in November 2013
Attend annual PAC meeting	PAC meeting was cancelled due to government shutdown. We look forward to engaging with the PAC in future years.
Formation of Science Review Panel	After communication between PMT and EVOSTC staff, delayed to Year 3 to maximize volunteer efficiency and influence.
Administration of travel expenses for annual PI meeting	Fulfilled by PWSSC.
Administration of expenses for activities directed by the Outreach and Community Involvement committee	Fulfilled by PWSSC.

Conduct annual PI meeting	Coordinated and held in November 2013
Attend AMSS	Robust attendance by GWA PIs
Conference on community-based citizen science monitoring potential	Delayed to Year 3
Develop data visualizations for website	Significant website updates completed and visualizations and data accessible through Gulf of Alaska Data Portal at http://data.aoos.org/maps/search/gulf-of-alaska.php

8. Information and Data Transfer: See, Reporting Policy at III (C) (8).

- Program update delivered by Holderied to a plenary audience at AMSS in Anchorage, January 23, 2014.
- Two-page spread on Gulf Watch Alaska in the 2013 science news magazine *Delta Sound Connections*
- Hoffman highlighted the GWA program to 47 attendees at PWSSC's *Copper River Nouveau: South* reception in Seattle, WA on May 21, 2013.
- GWA data available on Gulf of Alaska Data Portal at http://data.aoos.org/maps/search/gulf-of-alaska.php
- Program information available on the Internet at http://www.gulfwatchalaska.org/

9. Response to EVOSTC Review, Recommendations and Comments: *See,* Reporting Policy at III (C) (9).

The PMT received comments from the Science Panel on Year 3 work plan proposals on September 27, 2013. We returned a robust reply to EVOSTC staff, which was subsequently shared with the Science Panel and Trustees. At the January 2014 data management meeting, Science Panel members in attendance relayed that they appreciated the very detailed responses and that the responses allayed many of their concerns.

In December 2013 and January 2014, we worked closely with EVOSTC staff and the HRM program lead to refine and ensure compliance with program reporting requirements for Year 2 annual report and upcoming Year 3 work plan proposals. We are pleased to have open communication with EVOSTC staff around practical accommodations that result in both robust and streamlined reporting requirements.

10. Budget: *See,* Reporting Policy at III (C) (10).

See program budget Attachment.

B. Outreach and Community Involvement – McCammon (AOOS, 12120114-B)

1. Project Number: *See,* Reporting Policy at III (C) (1).

12120114-B

2. Project Title: *See,* Reporting Policy at III (C) (2).

Outreach and Community Involvement

3. Principal Investigator(s): *See,* Reporting Policy at III (C) (3).

Molly McCammon, Alaska Ocean Observing System (AOOS) & Katrina Hoffman, Prince William Sound Science Center (PWSSC)

4. Time Period Covered by the Report: *See,* Reporting Policy at III (C) (4).

February 1, 2013-January 31, 2014

5. Date of Report: *See,* Reporting Policy at III (C) (5).

March 1, 2014

6. Project Website (if applicable): *See,* Reporting Policy at III (C) (6).

www.gulfwatchalaska.org

7. Summary of Work Performed: *See,* Reporting Policy at III (C) (7).

The Outreach and Community Involvement Steering Committee includes key outreach staff from AOOS, the PWS Science Center (PWSSC), Kachemak Bay Research Reserve (KBRR), Alaska Sealife Center (ASLC), North Pacific Research Board (NPRB), COSEE Alaska (COSEE), NOAA and USGS. Marilyn Sigman, a marine educator with the COSEE Program is now providing some additional staff support to our outreach efforts. The Steering Committee met and informally throughout the year.

Outreach materials: The committee completed all of the materials identified as the basic suite of outreach materials for the program: a new name (*Gulf Watch Alaska*, *The Long-term Monitoring program of the Exxon Valdez Oil Spill Trustee Council)*, logo, website domain, PowerPoint and poster templates, pop-up displays, display banners, brochure, presentation folder and bookmarks. Individual project profiles were delayed while the program website was developed, but are now being developed. These materials were used at a number of events this past year: Ocean Fest in Valdez on March 18, 2013 (250 attendees); Copper River Delta Shorebird Festival in Cordova May 2-5, 2013; Kachemak Bay Shorebird Festival in Homer May 9-12, 2013; and Alaska Marine Science Symposium January 20-23, 2014.

GWA Website: The Committee contracted with Eric Cline to design, and Axiom Consulting to develop, a new program website: www.gulfwatchalaska.org that is hosted by AOOS. The website will serve as a primary means for outreach to the general public, and provides access to reports, background material, contact information, and program data through the AOOS Gulf of Alaska data portal.

Day in Sound project: The Committee contracted with Affinity Films (Mary Katzke) to develop a proposal for a possible Day in our Sound project similar to the Day in our Bay sponsored by the Bristol Bay Native Corporation. The proposal has been circulated broadly to a number of foundations and organizations, but has not been successful in securing other funding. We are now looking at other options for reaching out to youth in the region.

PWSSC products: Materials were again developed for the 2-page insert highlighting the Gulf Watch Alaska (GWA) and Herring Programs included in the summer 2013 Delta Connections newspaper that is printed and circulated by the PWSSC throughout PWS and other spill impacted areas.

Due to staff changes, only one GWA researcher presented at the weekly lecture series in Cordova (hosted by Prince William Sound Science Center). This was Dr. Sonia Batten's talk on November 15, 2013 highlighting her continuous plankton recorder work. She also spoke to two grade 10 classes at the Cordova High School on "The World of Plankton."

No PWSSC also creates a radio program/podcast called *Field Notes* radio programs were produced this year since PWSSC has been revising this program under their institution rebranding efforts. These are 3-5 minute long audio-visual programs aired on KCHU radio station KCHU, which reaches the PWS and Copper River basin areas. Three *Field Notes* about GWA research are pending.

KBRR products: Kachemak Bay Research Reserve (KBRR) was awarded a subcontract for development and delivery of three 2013 public Discovery Labs. Planning took place in June of 2013 and the public Discovery Labs were held on July 24, 26, and 27, with 276 total participants (Figure B-1). This year's lab, coordinated by KBRR Education Coordinator Jessica Ryan, provided an overview of the Gulf Watch Alaska program and each of its components (Environmental Drivers, Benthic, Pelagic, and Lingering Oil) and featured research methods and results in order to demonstrate the scientific process at work. A Lab description was developed and advertising conducted via electronic calendars, through radio PSAs, in the newspapers and with flyers. EVOS Gulf Watch was listed as a sponsor of the lab in all advertising, and two Gulf Watch banners were on display at each lab.

The following individuals assisted with the labs in person: Tammy Neher with GulfWatch, Kris Holderied with NOAA's Kasitsna Bay Lab along with three summer Hollings Scholars, Liz Labunski with USFWS, Sarah Traiger with UAF, Angie Doroff with KBRR, and Jessica Ryan with KBRR (using materials provided by PIs Craig Matkin and John Moran).

Figure B-1 Hollings Scholar Chris Perkins discusses ocean acidification with a young visitor at the July 24th Discovery Lab.

EVOS TC and PAC meetings: Outreach activities were highlighted at the fall meeting of the Trustee Council on October 24, 2013. Due to the government shutdown in October, the fall meeting of the Public Advisory Committee was cancelled.

Community Based Monitoring Outreach: Planning is underway for an April 1-2, 2014 workshop to develop "Best Practices" and "Lessons Learned" for CBM. Participants will be solicited from spill-area communities, and a half-day follow-up session will be held targeted specifically on the GWA geographic region.

Agency Manager Outreach: Planning is underway for educational activities and outreach to federal and state agencies charged with managing GWA fish and wildlife resources. These will likely occur in fall 2014.

Outreach to PIs: Updates on outreach activities are highlighted at all PI meetings, both those on teleconference and in person. PIs are encouraged to participate in community activities, and to submit photos, videos and other materials for use by the team.

Presentations: Gulf Watch Alaska principal investigators provided a wide range of both scientific conference and public presentations (also see Table B-1):

Poster Presentations:

- *Brenda Ballachey* - Gene transcript profiles in mussels (*Mytilus trossulus*) from Prince William Sound, Alaska, 2012 & 2013, as indicators of nearshore ecosystem health. Alaska Marine Science Symposium, January 2014, Anchorage AK
- *Mayumi Arimitsu* – Hydrogen and carbon isotopes trace glacier runoff through coastal marine food webs in the Gulf of Alaska. Alaska Marine Science Symposium, January 2014, Anchorage AK

- *Campbell, Robert* – State of the Sound: Trends in the surface oceanography of Prince William Sound. Alaska Marine Science Symposium, January 2014, Anchorage AK
- Holderied, K.*, M. McCammon, K. Hoffman, B. Ballachey, R. Hopcroft, M. Lindeberg, and T. Weingartner. 2014. Gulf Watch Alaska: Ecosystem monitoring to assess long-term oil spill impacts in the context of North Pacific climate change. Poster presentation. Ocean Sciences meeting, Honolulu, HI.
- Holderied, K.*, M. McCammon, K. Hoffman, S. Rice, B. Ballachey, T. Weingartner, and R. Hopcroft. Jan 2013. Kenai Fish Habitat Partnership Science Symposium. Gulf Watch Alaska – Ecosystem monitoring at the intersection of spilled oil and climate change. Poster presentation (Holderied).
- Holderied, K. M. Mccammon, Hoffman, S. Rice, B. Ballachey, T. Weingartner, and R. Hopcroft- Ecosystem monitoring at the intersection of spilled oil and climate change.
- James Kelly, jbkelly@alaskas.edu; Thomas Weingartner, tjweingartner@alaska.edu- Seward sea level variability: Sources and implications
- State of the Sound: Trends in the surface oceanography of Prince William Sound. Poster presented at Alaska Marine Science Symposium.
  Batten, S. "*Zooplankton communities in the Gulf of Alaska*" - Alaska Marine Science Symposium, January 2014, Anchorage AK
- Iken K, Konar B. 2014. Strong local dynamics of intertidal communities in Kachemak Bay – a Gulf Watch project. Alaska Marine Science Symposium, January 2014, Anchorage AK
- Carls, M. Spilled oils: static or dynamic and bioavailable? Alaska Marine Science Symposium, January 2014, Anchorage AK

PI Presentations:

- On November 12, 2013 Gulf Watch Alaska was highlighted on the Alaska Public Radio "Talk of Alaska" show hosted by Steve Heimel. Three GWA scientists: Kris Holderied (director, NOAA Kasitsna Bay Laboratory), Craig Matkin (director, North Gulf Oceanic Society), and John Piatt (research wildlife biologist, U.S. Geological Survey—Alaska Science Center) participated in the live broadcast to answer questions about the program's research including call-in questions from around the state. This interview can be heard at the following url: http://www.alaskapublic.org/2013/11/08/monitoring-in-the-north/.
- *Heather Coletti* gave a talk to the interpretive staff of Kenai Fjords National Park (KEFJ) regarding GWA. Seward, AK, Spring 2013.
- USGS Alaska Science Center Research Wildlife Biologist *Dan Esler* presented a seminar describing ongoing marine monitoring and research on February 11, 2014, as part of a seminar series at the Pacific Wildlife Research Centre of Environment Canada, Delta, British Columbia.
- USGS Alaska Science Center participated in the 21st annual Women of Science and Technology Day in Anchorage, AK on February 1, 2014. The event is designed for girls in grades K–8 to attend workshops in science, technology, engineering and math (STEM) and give them a chance to meet women who have careers in science and are passionate about science. GWA researcher *Kim Kloecker* provided hands-on activities where students

conducted a variety of field sampling techniques used in "Gulf Watch Alaska." The workshop taught students how scientists investigate the health of the nearshore ecosystem through intertidal sampling, random point quadrat sampling and what is it like to be a wildlife biologist collecting data. The activities simulated the rocky and soft intertidal zones allowing the students to calculate the percent cover of a few of the intertidal 'species' and to compare and discuss the differences of each tidal zone. Tubs of sand were used to dig and sieve clams in order to measure and graph the clam sizes and then compare the size distributions of a an area with sea otters and an area without sea otters. *Kloecker* also participated in this event in 2013.

- On March 27, 2013 *Brenda Ballachey*, USGS Alaska Science Center Research Physiologist, presented a talk at the University of Calgary for students enrolled in a course titled Environmental Site Assessment. The talk "The *Exxon Valdez* Oil Spill: Perspectives and Lessons, 24 Years Later" discussed sea otter recovery in Prince William Sound some 24 years after the Exxon Valdez Oil Spill.
- On January 17, 2014 *Brenda Ballachey* gave a talk about sea otter recovery in Prince William Sound some 20 years after the 1989 Exxon Valdez Oil Spill. The talk was hosted by the Canadian Federation of University Women—Calgary North, a non-profit organization, which focuses on improving the advancement of women and children through the pursuit of education and human rights.
- On April 19, 2013 Alaska Science Center (ASC) Biologist *Kim Kloecker* presented materials to 25 Kindergarten and first grade students as part of their "Alaskan Animals" science curriculum. Kim conducted hands-on activities and shared information about the biology and ecology of sea otters and the research the ASC carries out. To help reinforce the concepts presented, an otter art project and a sea otter adaptation game were provided as follow up activities. Concepts included: adaptations and marine mammal biology.
- PI *Mayumi Arimitsu* presented a seminar for the University of Washington's Fisheries Acoustics group on November 1, 2013. She discussed survey design issues in monitoring long-term changes in forage fish, using Gulf Watch Alaska forage fish work as a case study. The seminar highlighted lessons learned and innovative methods for combining technology.
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Table B-1 Summary of Oral Presentations by Gulf Watch Alaska Principal Investigators in 2013-2014.

Investigator	Presentation Title	Event/location
Holderied, K.	Gulf Watch Alaska- Ecosystem monitoring highlights from the 2013 season	AMSS
Esler, D., J. Bodkin, B. Ballachey, D. Monson, G. Esslinger, K. Kloecker, S. Iverson, K. Miles and L. Bowen.	25 Years after the Exxon Valdez oil spill: recovery timelines of Harlequin duck and sea otter populations	AMSS
Arimitsu, M.	Geographic structure of ocean food webs along 4000 km of Alaskan coast: implications for marine predators.	AMSS

Hopcroft, R.	Measuring the pulse of the Gulf of Alaska: 16 years of oceanographic observations along the Seward Line and within Prince William Sound.	AMSS
Weingartner, T.	Alaska's shelf seas: oceanographic habitats and linkages	AMSS
Matkin, C.	Are recent changes in dietary patterns of Southern Alaska Resident killer whales leading to nutritional stress?	AMSS
Holderied, K., Neher, T. Labunski, L. Traiger, S., Doroff, A. Matkin, C., Moran, J., and J. Ryan	Kachemak Bay Research Reserve Discovery Lab: The Exxon Valdez oil spill, monitoring ecosystems 25 years after and beyond.	KBRR Discovery lab.
Coletti, H.	Gulf Watch Alaska nearshore monitoring in the National Parks of Alaska.	Interpretive staff presentation
Esler, D.	Marine monitroing and research following the Exxon Valdez oil spill	Pacific Wildlife Research Centre of Environment Canada, seminar
Kloecker, K.	Women of Science and Technology.	Educational workshop for girls.
Ballachey, B.	The *Exxon Valdez* Oil Spill: Perspectives and Lessons, 24 Years Later	University of Calgary student seminar
Kloecker, K.	Alaskan animals	Educational workshop for k-1st grade students
Arimitsu, M.		University of Washington Fish accoustic group seminar
Holderied, K.	Moving Towards the Next Phase of Monitoring after the Exxon Valdez Oil Spill: A New Integrated Program.	UAF Science seiminar series
Hollmen, T. E. and S.A. Sethi	Development of conceptual ecological models to support the GulfWatch Alaska long-term monitoring program.	PICES annual meeting.
Hopcroft, R.	Estimates of the composition, abundance, and biomass of pteropods and larvaceans in the coastal Gulf of Alaska (2) The Gulf of Alaska's salp bloom of 2011: ignorance or harbinger of change?	ASLO Meeting – New Orleans, Louisiana (February 2013)
Campbell, R.	PWS herring survey: Plankton and oceanographic observations.	EVOSTC Herring project meeting.
Batten, S.	"Ship of opportunity sampling of lower trophic levels"and "Variability in lower trophic levels on the Alaskan Shelf"	PICES annual meeting.
Matkin, C.	Killer whale life history in the Gulf of Alaska	NRDC (New York), Center for Coastal Studies, Wellfleet Audubon (Cape Cod) Maui Whale Fest, Kenai
Moran, J.	Humpback whale life history and diet	Marine Mammal Class guest lecturer for Heidi Pearson, UAS Biology Seminar Class guest lecturer for Sherry Tamone, University of Redlands lecture for Lei lani Stella, and the Sixth Annual Juneau Marine Naturalist Symposium.

Straley, J.	Humpback whale life history and diet	Safari tour boat for a week during the summer 2013 and presented at the Craig Whale Fest.
Cushing, D.	Changes in abundance of Brachyramphus murrelets in Prince William Sound, Alaska, 1989-2012	AMSS, and Pacific Seabird Group.

Other materials:

- National Park Service PIs posted blogs relating to monitoring work in Kenai Fjords National Park in 2012 and 2013 (only 2013 blog is still active): http://www.nps.gov/kefj/blogs/Sea-Otter-Snacks-and-Clam-Counts-Studying-the-Nearshore-Ecosystem.htm
- Two YouTube videos have been made and are posted on the Alaska NPS YouTube site: http://www.youtube.com/watch?v=T2EDwztHhZM

  http://www.youtube.com/watch?v=QcTi3RmB2aE

C. DATA MANAGEMENT- BOCHENEK/MCCAMMON (AOOS, 12120114-D)

1. Project Number: *See,* Reporting Policy at III (C) (1).

13120114-D

2. Project Title: *See,* Reporting Policy at III (C) (2).

Data Management Support for the EVOSTC Long Term Monitoring Program

3. Principal Investigator(s): *See,* Reporting Policy at III (C) (3).

Rob Bochenek

4. Time Period Covered by the Report: *See,* Reporting Policy at III (C) (4).

February 1, 2013-January 31, 2014

5. Date of Report: *See,* Reporting Policy at III (C) (5).

March 1, 2014

6. Project Website (if applicable): *See,* Reporting Policy at III (C) (6).

www.gulfwatchalaska.org
https://workspace.aoos.org/group/5186/projects

7. Summary of Work Performed: *See,* Reporting Policy at III (C) (7).

Project investigators continue to provide core data management oversight and services for the Long-term Monitoring Program known as Gulf Watch Alaska. The focus continues to be on establishing protocols for data transfer, metadata requirements and salvage of historic data, both those data funded by the Exxon Valdez Oil Spill Trustee Council and ancillary historic data from other projects. Investigators are meeting with National Center for Ecological Analysis and Synthesis investigator Matt Jones to coordinate future activities. PIs have participated in regular PI meetings, including the in-person meeting in November 2013 and the January 2014 data meeting and are coordinating activities between the Herring and LTM programs. In addition, the AOOS Ocean Research Workspace, rolled out to PIs in Year 1, continues to be used as the internal staging area for PI data and work products, with individual PI user and group profiles created. Several training seminars have been held via webinars, and PIs are now using the system to organize and consolidate their project level data. Software engineers at Axiom are providing support for the Workspace, resolving bugs and implementing new functionality in response to user feedback. All 2012 data are now posted on the Workspace, per the Program Management data sharing protocols. The Gulf Watch Alaska Data Portal was released in September 2013 as a key component of the Alaska Ocean Observing System's Gulf of Alaska Data Portal. The portal showcases Gulf Watch Alaska project data once it becomes public, alongside environmental data sets ingested by the project team. Please see milestones Table C-a for a list of completed project activities.

Table C-1. Project milestones status

Objective/Deliverable/Milestone	Status
Objective 1: Continue to provide data management oversight & services, including data structure optimization, metadata generation & data transfer. Audit data and restructure and reorganize for public access.	Ongoing
Objective 1: Continue to cultivate and support the functional capabilities of the AOOS Ocean Workspace to address GWA researcher needs.	Ongoing
Objective 2: Improve search capabilities of GWA projects in the GOA Data by exposing underlying file level metadata.	Completed, 15 January 2014
Objective 3: Develop analysis & visualization tools	Identified future visualizations at Nov 2013 PI meeting.
Objective 4: Organize & integrate historical datasets	Ongoing
Objective 5: Integrate all data & metadata into AOOS GOA Data Portal.	Portal completed, 1 September 2013; then ongoing.
Objective 6: Augment AOOS with DataONE services	Worked with NCEAS to incorporate current data and AOOS GOA portal as DataONE node with short-term solution: completed Feb 2014 .Long-term solution in planning.
Objective 7: NCEAS synthesis	No activities

Objectives 1 and 2

The primary results produced by this project include the acquisition and documentation of Gulf Watch Alaska PI-produced data sets and the aggregation of ancillary environmental data sets for integration into the AOOS Gulf of Alaska (GOA) Data Portal. Investigators continue to

modify the Ocean Workspace in response to user feedback. The increase in use by PIs is represented in the following figures. All 2012 data are now posted on the Workspace, per the Program Management data sharing protocols.

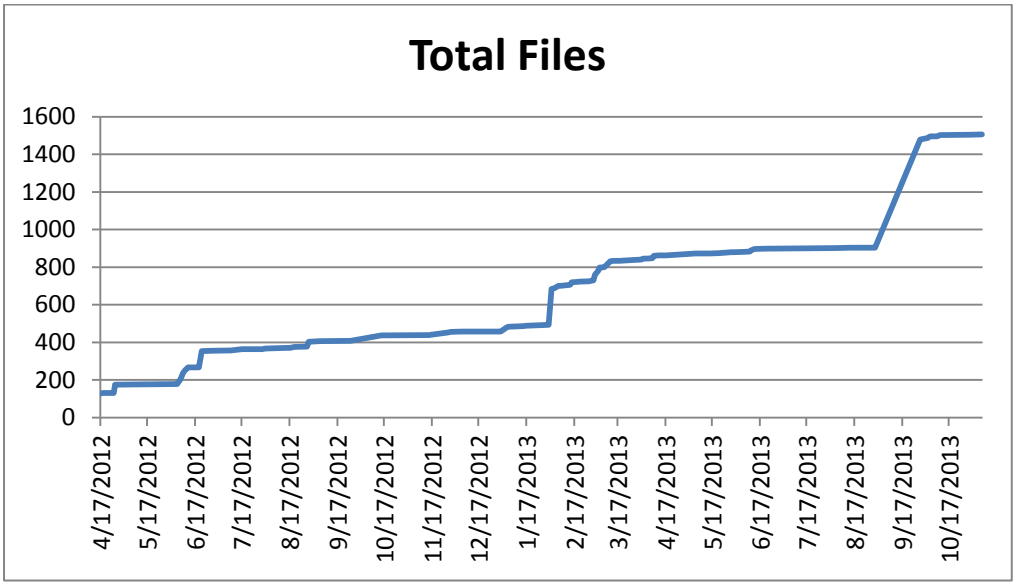


Figure C-1. The number of files uploaded by Gulf Watch Alaska team members.

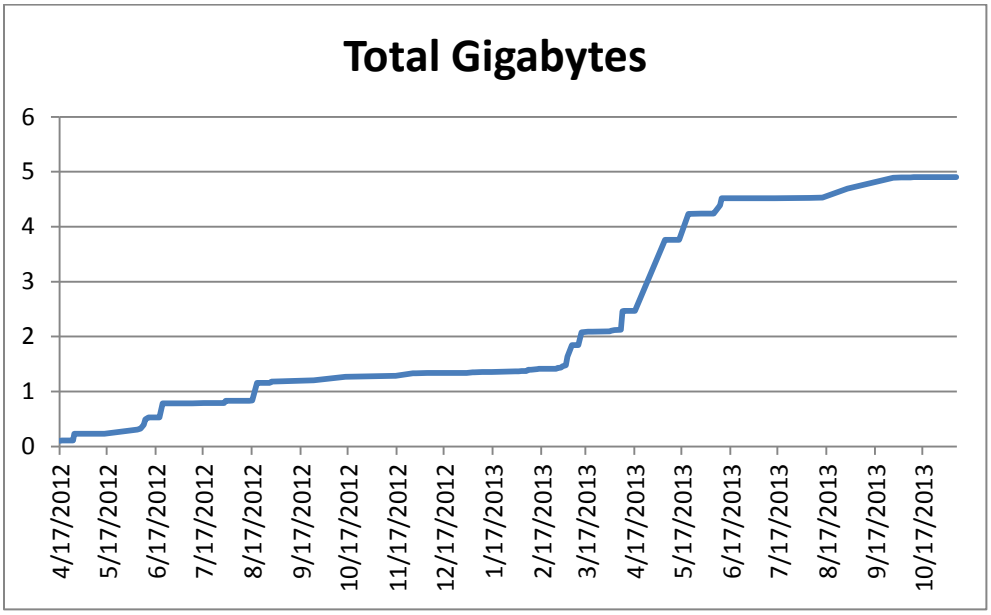


Figure C-2. The amount of total storage used by Gulf Watch Alaska team members.

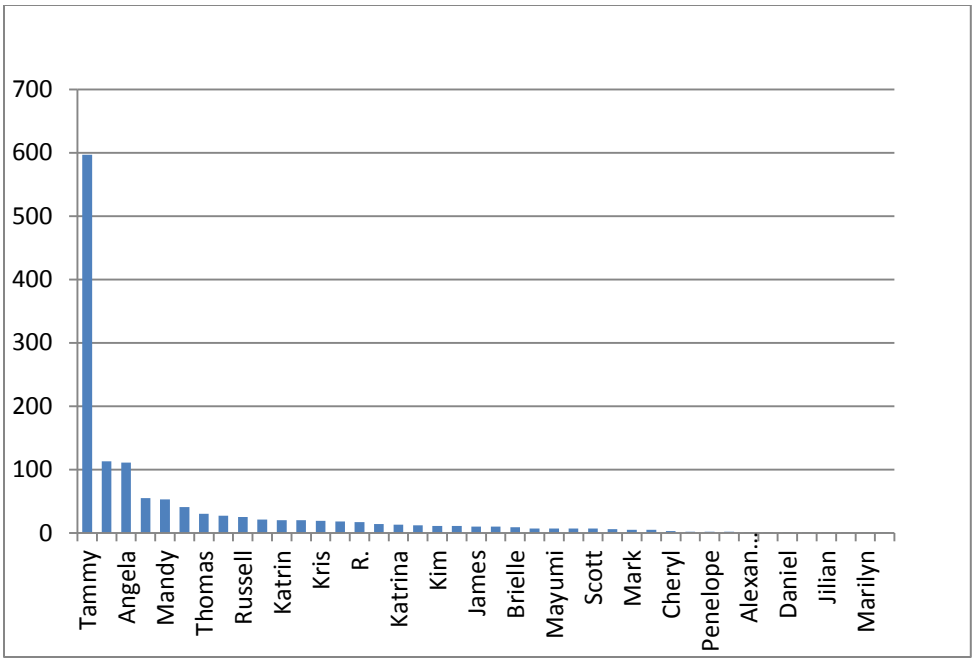


Figure C-3. The distributions of file upload effort across individual Gulf Watch Alaska users.

The Ocean Workspace is a web-based data management application built specifically for storing and sharing data among members of scientific communities as an internal staging area prior to public release of data on a completely public portal. Twelve regional and national research groups currently use the Workspace, which has over 200 active individuals sharing thousands of digital files. The Workspace provides users with an intuitive, web-based interface that allows scientists to create projects, which may represent scientific studies or particular focuses of research within a larger effort. Within each project, users create topical groupings of data using folders and upload data and contextual resources (e.g., documents, images and any other type of digital resource) to their project by simply dragging and dropping files from their desktop into their web-browser. Standard, ISO 19115-2 compliant metadata can be generated for both projects and individual files. Users of the Workspace are organized into campaigns, and everyone within a campaign can view the projects, folders and files accessible to that campaign. This allows preliminary results and interpretations to be shared by geographically or scientifically diverse individuals working together on a project or program before the data is shared with the public. It also gives program managers, research coordinators and others a transparent and front-row view of how users have structured and described projects and how their programs are progressing through time. The Workspace has the following capabilities:

Secure group, user, and project profiles — Users of the Workspace have a password protected user profile that is associated with one or more disciplinary groups or research programs. The interface allows users to navigate between groups in which they are involved through a simple drop down control. Transfer of data and information occur over Secure Socket Layer (SSL) encryption for all interactions with the Workspace. The Workspace supports authentication through Google accounts, so if users are already logged into their Google account (e.g., Gmail, Google Docs, etc.), they can use the Workspace without creating a separate username and password.

Metadata authoring — Metadata elements currently available to researchers in the Workspace are common to the Federal Geographic Data Committee (FGDC) designed Content Standard for Digital Geospatial Metadata (CSDGM) and the ISO 19115 standards for geospatial metadata, extended with the biological profiles of those standards. Axiom also developed an integrated FGDC biological profile extension editor that allows users to search the ~625,000 taxonomic entities of the Integrated Taxonomic Information System (ITIS) and rapidly generate taxonomic metadata. Because the Workspace is a cloud-based service, researchers can move between computers during the metadata generation process in addition to allowing team members and administrators to simultaneously review and edit metadata in real time (Figure C-4).

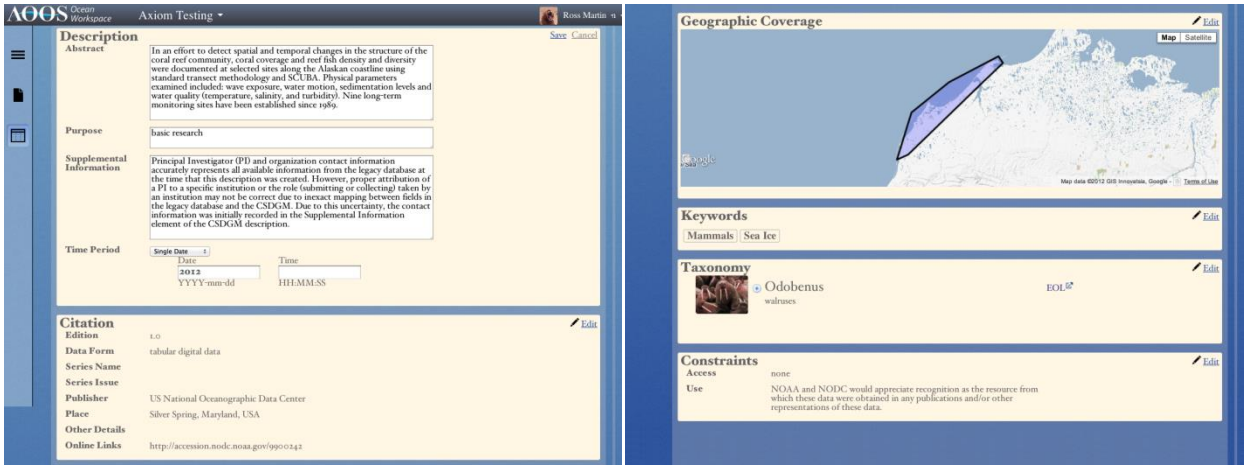


Figure C-4. Screenshots of the Workspace metadata interface. The first screenshot shows the interface to author basic descriptive and citation metadata fields. The second screenshot displays a tool which allows researchers to describe the geographic region of the project.

Advanced and secure file management — A core functionality of the Workspace is the ability to securely manage and share project-level digital resources in real-time with version control among researchers and study teams. Users of the Workspace are provided with tools that allow them to bulk upload files, organize those documents into folders or collections, create projects with predefined and user-created context tags, and control, read, and write permissions on files within projects (Figure C-5). The Workspace also has the ability to track file versions: if a user re-uploads a file of the same name, the most current version of the file is displayed, but access is provided to past versions as well.

Figure C-5. Screenshots of project and file management in the Workspace. The first screenshot shows a list of projects to which the example user has access rights. The second screenshot displays the interface a researcher would use to organize independent files.

<u>Objectives 2, 5 and 6</u>

In September 2013 the data management team also released the Alaska Ocean Observing System's Gulf of Alaska (GOA) Data Portal, which integrates data and project information produced by Gulf Watch Alaska researchers with 260 additional GIS, numerical modeling and remote sensing data resources (Figure C-6). The team was able to leverage the AOOS portal which has been developed using other funding and has these additional features: an integrated search catalog which allows users to search by category or key word, ability to preview data before downloading files, and advanced visualization tools. Once the program's monitoring data has been ingested into the Ocean Workspace, QA/QC'D, and approved as final, then it is ingested into the GOA Data Portal for full public access.

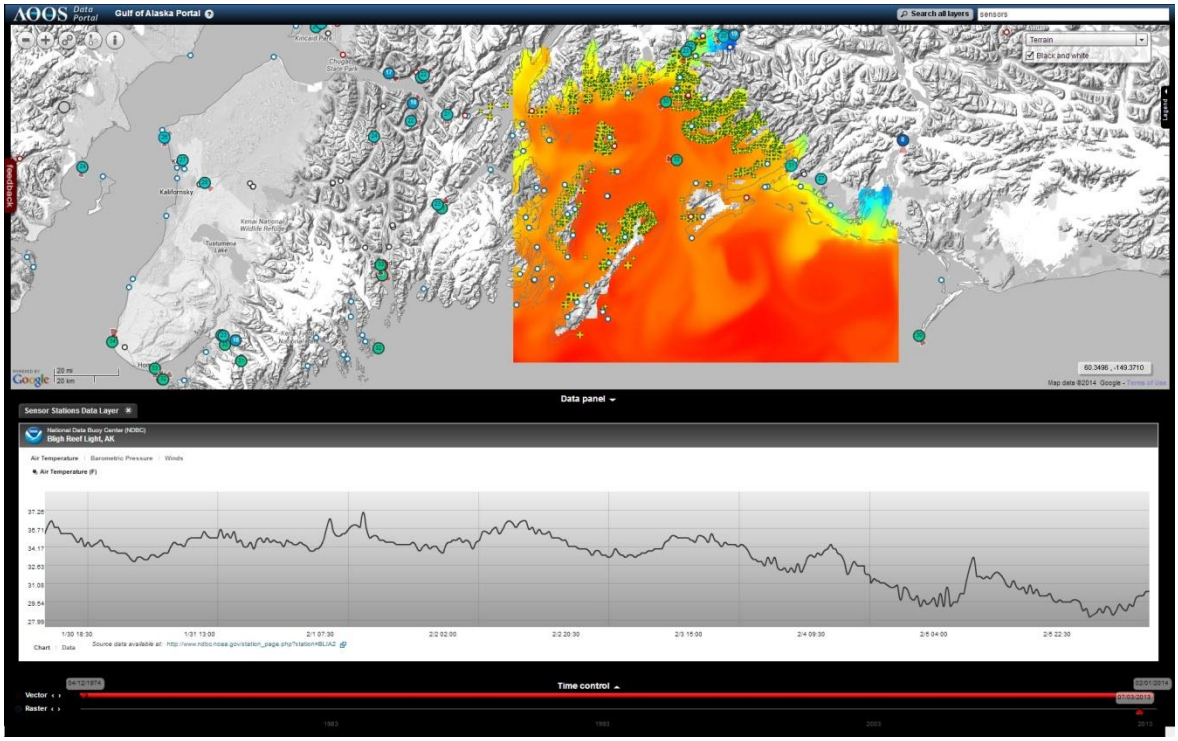


Figure C-6. Screenshot of AOOS GOA Data Portal.

Meetings

The AOOS data team at Axiom Consulting participated in the January 29-30, 2014 *Exxon Valdez* Oil Spill Trustee Council-sponsored data meeting in Anchorage. The team presented work to data and demonstrated both the GWA Ocean Research Workspace application and the GOA Data Portal. As a result of this meeting, the data team will work with the Program Management Team and the Science Coordinating Committee to enhance metadata requirements for the program. In addition, the data team created the following Life Cycle Table to clarify expectations of roles and responsibilities relating to data within the LTM Program.

Table C-2. Gulf Watch Alaska and Herring Research and Monitoring Programs data life cycle, February 2014.

	PIs	Program Mgmt Team	AXIOM	NCEAS	EVOSTC & Trustee agencies
Data collection & any telemetry	PI/agency responsibility; established sampling protocols for each component.	Review & maintain sampling Standard Operating Procedures (SOPs). Coordinate, with Science Coordinating Committee, consistency in sampling across the program.	Store current Standard Operating Procedures within Ocean Research Workspace.		Fund data collection projects and programs. Establish basic requirements: quality data, well documented, publicly accessible, archived.
QA/QC	PI responsibility based on agency/entity requirements. Documentation of instrument calibration & data QA/QC procedures to be included in sampling SOPs & project metadata.	Review QA/QC documentation before accepting data. Limited QA/QC performed on metadata to ensure it has required information (e.g. date, time, location, etc.) and data fields are appropriately documented (e.g. units in column headers).	Working with GULFWATCH program coordinator (Tammy Neher), specific datasets are aggregated together and reviewed for problems to prepare for synthesis efforts. Mostly rely upon PI for QA/QC.	For historical data, limited QA/QC (e.g., columns, domain, units) is performed and provided in metadata documentation to ensure it has required information. If original PIs are unavailable then any issues are simply noted in metadata.	Establish clear requirements for program and coordinate on agency data standards.
Metadata	PI responsibility to provide metadata according to agency and team standards.	Works w/PIs & data team to develop requirements. Assists PIs & reviews project level and file level metadata files.	Metadata can be created through the Workspace on the project level or file level using the ISO suite of protocols with taxonomic extensions (ITIS). Other metadata formats can be	For historical data projects, NCEAS researches data and provides metadata as available to reconstruct the data set. Metadata are extracted from reports, papers, and other available materials.	Coordinate on agency metadata requirements and standards.

			incorporated as well.	Metadata are provided in EML format using tools developed at NCEAS (web entry, and Morpho entry).	
Internal data access/staging	Post data on Ocean Research Workspace as soon as possible, but no later than 1 year after collection.	Keeps records of data availability. Assists PIs in posting data on Ocean Research Workspace. Coordinates with Axiom/AOOS and NCEAS on user requirements for Workspace.	Provide Workspace as internal staging area for use by team. Work w/team to develop additional functionality for team use. Workspace is highly leveraged tool that is password protected.	Use Redmine ticket system to track the lengthy process of finding, acquiring, and processing historical data. As data are processed, they are inserted as private objects into the GoA Member Node, and then made public as the documentation is completed.	
Data security			Data are archived on AOOS server in Anchorage & at mirror site in Portland OR.	Historical data are archived on the NCEAS GoA Member Node, replicated to DataONE, and a copy is made on the AOOS data servers. DataONE checks validity of content through rolling audit.	Provide requirements, if any, for agency data archive.
Data analysis, synthesis & visualization	Produce data analyses, synthesis documents and data visualizations from project data.	Coordinates with PIs, AOOS, Axiom and NCEAS to produce synthesis and visualization products and reports.	Provides team with full access to all data for potential applications. Provide team access to all ancillary	Historical data are made publicly available via the GoA Member Node, and can be accessed from the web,	

			AOOS data & tools. Provide time series animations & syntheses on request from science team & outreach team.	analytical environments like R, and workflow systems like Kepler and VisTrails.	
Data discovery (search function)	Ensures that data are complete, QA/QCd & have complete metadata records.	Determines when data & metadata are ready to be published to public AOOS portal.	Incorporates data & metadata into AOOS GOA data search catalog w/additional GWA & historical EVOSTC tags. Setting up process for connecting to DataONE.	Historical data are listed on the AOOS GoA data portal, and are searchable on the DataONE portal as well as the KNB.	
Public data delivery	Reviews published data on data portal for accuracy.	Reviews published data on data portal for accuracy. Keeps track of program data delivery status.	When data meet all above requirements, publish data & metadata into the AOOS Gulf of Alaska portal for broader public access & use.	Historical data and metadata can be downloaded from AOOS GoA Data Portal, the GoA DataONE member node, and DataONE replica servers.	Public data access is required.
Long-term archive			AOOS data system is being used for long-term storage. With other funding, now developing methods for automated delivery to national archives (e.g., NODC) and to DataONE nodes.	Provide linkages to DataONE to replicate data across diverse institutions to protect against funding and policy failures. Historical data have 3 replicas nationally, working with Axiom on replication processes for current data streams.	Long-term archiving required by trustee agencies.

8. Information and Data Transfer: *See,* Reporting Policy at III (C) (8).

- Publications produced during the reporting period;

  None completed.

- Conference and workshop presentations and attendance during the reporting period; The technology

  Several demonstrations of the Ocean Workspace have been given to a wide variety of users including Gulf Watch Alaska PIs and PIs with the North Pacific Research Board's Gulf of Alaska Integrated Ecosystem Research Program, a related program for which AOOS also provides data management services. Molly McCammon referred to this project in her talk at the Lowell Wakefield Symposium in Anchorage March 29, 3013. The project was highlighted in talks by Molly McCammon/Rob Bochenek, and by Kris Holderied at the Alaska Marine Science Symposium (AMSS) in January 2014. The AOOS Gulf of Alaska Data Portal, featuring GWA data sets, was demonstrated at AMSS during several workshops.

9. Response to EVOSTC Review, Recommendations and Comments:

The EVOS staff and Science Panel raised several concerns in September of 2013 regarding the data management component of both the Gulf Watch Alaska (GWA) and Herring Research and Monitoring (HRM) Programs. An additional two-day workshop was held in January 2014 to review the data management components of both monitoring programs. Program PIs responded to the Science Panel concerns in detail in October 2013 (see below). They also participated in the workshop, which was also attended by regional agency data management staff, members of the EVOSTC Science Panel and EVOSTC staff.

Science Panel Comments

The science panel is concerned about progress on data management. The data management proposal drew heavily on their old proposal without including sufficient updated evidence of interactions between the programs' PIs and the data management team. In addition, there does not appear to be a data management policy or QA/QC policy created as the programs approach Year Three. In addition, no milestones were reported in the newly submitted proposals, so it was difficult to gauge how much progress had been made in the last two years. Moreover, it was not clear how data would be available for synthesis. The panel recommends that the Council condition funding upon the creation of a credible and detailed data management policy and a QA/QC policy and include clear milestones in for their proposal.

Regarding a QA/QC policy: such a document is a basic need of any data management plan. We note too that instruments commonly need to be calibrated before and after use to be able to adjust for measurement drift, if it occurs. With two separate data centers operating under the EVOSTC program it is crucial that a high level of QA/QC be maintained. The Science Panel is concerned that

adequate attention is not being devoted to this fundamental aspect of data management. It is particularly important that to assemble complete metadata to ensure that long-term data sets can be verified and understood once the current participants have moved on to new positions. For example, EPA and NSF require detailed data management and QA/QC plans as part of all proposals. Large monitoring programs, such as NSF's LTER and oceanographic programs, devote considerable time and effort to addressing these critical needs.

Example: As a specific example, the Ocean Tracking Network (OTN) has four nearly full-time people creating metadata forms that are required to be filled out, submitted and checked for QA-QC before data can be added to the database. Since OTN is currently adding equipment to tracking arrays in PWS, it would be particularly appropriate at this time to arrange communication between senior OTN data managers with EVOSTC program data PIs to ensure that data standards are adequate. As with OTN, and as emphasized in the initial funding of the EVOSTC programs, skilled data management resulting in data that can be relied upon by the scientific community and resource agencies will ultimately determine the long-term success and influence of the programs. The contact at OTN is Bob Branton (bob.branton@gmail.com) or (bob.branton@dal.ca).

Team Lead Response

All of the GWA projects have sampling protocols that address QA/QC, including instrument calibration. The sampling protocols are maintained on the GWA's Research Workspace account. In addition, all PIs were required to sign a Program Management Plan, which included a detailed Data Management and Public Access Policy. That policy was developed after review of a multitude of data policies for programs such as GLOBEC, NSF LTERs, NCEAS, North Pacific Research Board's Bering Sea and Gulf of Alaska Integrated Research Programs, PISCO, ORNL (NASA), and TEAM Network.

Because of limited funding for data management services in this proposal (about 7% of total budget), the Program Management Team and Science Coordinating Committee adopted an approach that provide tools for PIs to assist with managing their data themselves. These tools include assistance with writing metadata in ways that follow national standards, and use of the Research Workspace to provide greater data and information access to the entire program team for use in synthesis and analysis activities. We would greatly appreciate more funding and staff to devote to this effort, but the entire program has been encouraged to work within the existing budget limits. Despite those limitations, we have conducted two metadata training sessions with project investigators, and the AOOS and NCEAS teams have conducted training and data prioritization activities relating to data management for PIs at all of the annual meetings. Finally, in addition to the metadata tools developed by AOOS for managing current monitoring data, NCEAS has employed a full-time Projects Data Coordinator and three half-time graduate student assistants that conduct historical data salvage, metadata generation, and data QA. This has resulted in the salvage of extensive data from the region that had been previously funded by EVOSTC, and is now publicly accessible and will be used in synthesis activities. See Appendix B for details.

Our approach has been to leverage the resources of the Alaska Ocean Observing System's data management system, which is the only one of its kind with the mission of serving as a regional data

assembly center and archive for Alaska ocean and coastal data and information products. All PIs submit their data annually to a private, password-protected GWA account on the AOOS Research Workspace. That data is then available for all program members to access and use for synthesis and analysis activities. At agreed upon times, the most current, QA/QC'd data are "published" from this site into the publicly accessible Gulf of Alaska portion of the AOOS Ocean Portal. We are also developing an automated means to publish this data to a DataONE node and to NOAA's National Oceanographic Data Center.

As with most research and monitoring programs, we have had challenges changing the culture from individuals holding on to their own data on personal computers, to one of more open access and sharing. However, we are making progress, and the investigators see the value in doing so. We have already started making data publicly available and are actively working with our PIs, science coordinator, NCEAS and data management team to further streamline processes for internal data sharing and public access.

In addition, the Program PIs consolidated all of the data management protocols (in the original proposal, annual reports and Program Management Plan) into the following Data Management Plan document

Coordination and Collaboration with Other Efforts

AOOS brings a significant level of leveraged resources, infrastructure, regional data management projects and partnerships to this proposed effort. The data management effort for the LTM and herring projects could not be accomplished for the budgeted amount by a team without these leveraged resources.

1. AOOS – ($550k annually to AOOS DM). Alaska oceanographic data management effort. Supports open source, standards based data system that serves up and archives real-time sensor feeds, models & remote sensing data, GIS data layers, and historical datasets. Data system developed on interoperability concepts and meets NOAA Integrated Ocean Observing System standards and protocols for streaming data feeds to national data assimilation centers. Data Management Committee chaired by Dr. Phil Mundy provides ongoing advice, prioritization and direction to the team at Axiom Consulting & Design. AOOS board is made up of federal and state agencies, and major marine research institutions in the state that have committed to data sharing. The AOOS board has committed to supporting a statewide data system for as long as AOOS exists. Federal funding is stable, with small annual increases. In the event AOOS was to end, all data and data products would be transferred to the University of Alaska.
2. Northern Forum/USFWS Seabird Data System ($50k). Project involves the creation and population of a series of new seabird metric databases (diet and productivity) and integrating these new databases with legacy seabird databases (species distribution and abundance at seabird colonies, pelagic species distribution and abundance, USGS seabird monitoring databases and NPRB's North Pacific Seabird Diet Database). Modern spatially explicit, web based data entry interfaces have and continue to be developed to assist researchers existing in distributed agencies to contribute their historic and current seabird

metric data into standard data structures. Project will result in vastly increasing the amount and quality of seabird species distribution, diet and other seabird data available for use in retrospective analysis and management. Though data includes areas around all of Alaska, most available data is located in GOA and PWS.

3. GOAIERP – The NPRB has contracted with AOOS/Axiom to support the Gulf of Alaska Integrated Ecosystem Research Program using the Research Workspace and AOOS data system. This leveraged activity, once completed, will provide a large amount of additional scientific data for the Gulf Watch and Herring programs.
4. Alaska Data Integration Working Group (ADIWG) – AOOS collaborates with the Alaska Climate Change Executive Roundtable on this initiative to develop protocols for serving up project data to increase data sharing among federal and state agencies.
5. Cook Inlet Regional Citizens Advisory Council ($40k) – contract with Axiom to develop a data management system for their oceanographic and contaminants data in Cook Inlet as prototype Cook Inlet Response Tool.

10. Budget: *See,* Reporting Policy at III (C) (10).

There were no deviations from the predicted budget

D. Historical Data Compilation and Synthesis- Jones (NCEAS, 12120120)

1. Project Number: *See,* Reporting Policy at III (C) (1).

12120120

2. Project Title: *See,* Reporting Policy at III (C) (2).

Collaborative Data Management and Holistic Synthesis of Impacts and Recovery Status Associated with the Exxon Valdez Oil Spill

3. Principal Investigator(s): *See,* Reporting Policy at III (C) (3).

Matthew B. Jones

4. Time Period Covered by the Report: *See,* Reporting Policy at III (C) (4).

February 1, 2013-January 31, 2014

5. Date of Report: *See,* Reporting Policy at III (C) (5).

March 1, 2014

6. Project Website (if applicable): *See,* Reporting Policy at III (C) (6).

www.gulfwatchalaska.org

7. Summary of Work Performed: *See,* Reporting Policy at III (C) (7).

Project personnel have been simultaneously developing software systems for management, documentation, and distribution of project and historical data in collaboration with Axiom and the other PIs on GulfWatch and conducting a data salvage effort to locate, document, and organize historical data from EVOSTC-funded projects (see data dissemination section below and Table D-1 for progress toward project milestones).

Metacat data management software

For data management software, we have prototyped a data catalog using the open source Metacat data repository system, and configured it for use for historical data that was funded through the EVOSTC. This catalog provides data documentation and data files for all collated data sets, provides versioning to allow updates to data sets, and provides a publicly accessible web interface for searching for and downloading data. During this project reporting period, we released three new versions of the open source Metacat data management system, versions 2.2, 2.3, and 2.4, all of which are freely downloadable in binary and source code form. Historically, Metacat used a server-side client interface with web pages delivered from server-side scripts. Starting with version 2.2, and improved in versions 2.3 and 2.4, we included a client-side user interface that is easily customizable and provides fast search for data sets of interest using common search filters.

Metacat 2.2 provides:

- A new AJAX-based client user interface (MetacatUI) that is customizable and provides fast, interactive result filtering
- Improved identity management for users to register and requiring email verification
- Numerous miscellaneous bug fixes

Metacat 2.3 provides:

- SOLR indexing features to metacat-index for querying and sorting by authors and taxonomic coverage.
- Control over the log level from the SOLR libraries using Metacat's log4j file.
- Database indexes for better log reporting performance via the DataONE API
- An updated MetacatUI with support for spatial and taxonomic query filters
- An updated account/identity management script

Metacat 2.4 provides a number of bug fixes and enhancements including:

- Streamlined process for publishing with a DOI
- Access policy synchronization with the DataONE Coordinating Node
- Indexing support for EML singleDateTime coverage values
- Indexing support for read/download events forming the basis of a future statistics reporting service
- Improved package download structure and file naming conventions
- A new user interface (MetacatUI) that provides a customizable web interface for searching and browsing the contents of a Metacat repository. This feature was used to implement the historical data section of the Gulf of Alaska Data Portal

All Metacat software releases can be downloaded from
http://knb.ecoinformatics.org/software/metacat

Gulf of Alaska Historical Data Portal

These Metacat releases, and in particular the new MetacatUI user interface to improvements, were the basis for the historical data portal that we established this year for EVOSTC-funded data sets

(Figure D-1).

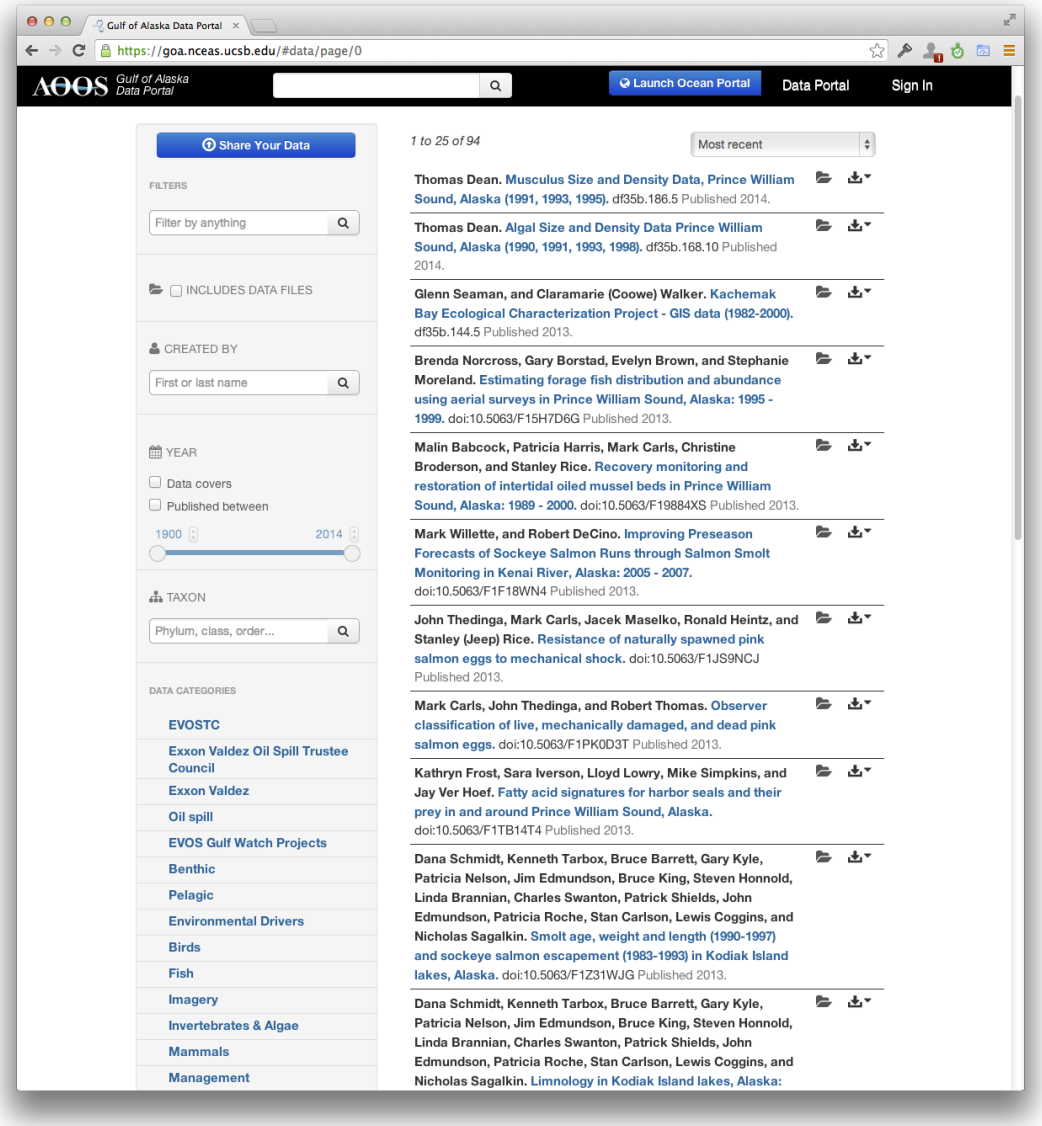


Figure D-1. Gulf of Alaska Historical Data Portal provides a comprehensive list of recovered historical data sets that can be filtered by keyword, creator, temporal period of data coverage, and taxonomic coverage of the data. Data sets are presented in citation format for easy reference.

The Gulf of Alaska Data Portal represents the definitive store of data for GulfWatch Alaska historical data sets. We customized the Metacat user interface to match the look and feel of the GulfWatch Alaska web site, and through several iterations stabilized on the look and feel of the Gulf of Alaska Historical Data Portal (Figure D-1). A flexible metadata index backs the portal, so new filters can easily be added as needed to meet project needs. For example, other customized deployments of the interface include a spatial data search feature, which could be easily added to the historical data portal.

For each data set, we display a detailed metadata description following the Ecological Metadata Language (EML) standard that is used throughout the ecological research community. This standard and the software tools that we provide to support it allows for detailed descriptions of the data set, its ownership and disposition, and its coverage in space, time, and biological taxa. In addition, for each data entity (e.g., table, image) within a data set, we provide detailed information about that entity (its size, checksum, format, identifier, etc.) and its attributes (e.g., what values were measured, their methods, units, ranges, coded values, and missing value codes). These detailed metadata are critical for long-term preservation of the data, as they are essential to effective interpretation and re-use of the data (Figure D-2).

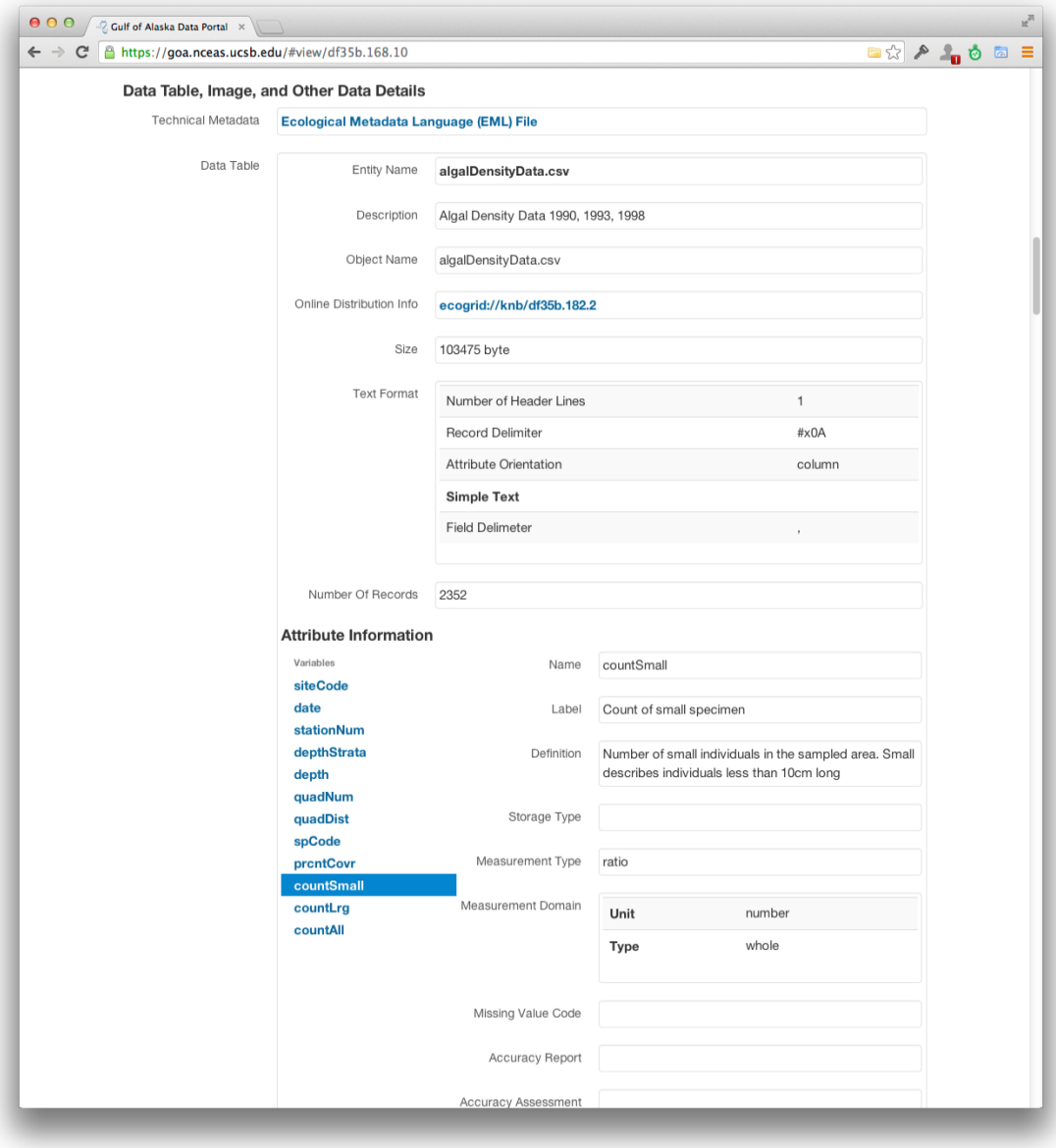


Figure D-2. Web display showing a portion of the entity and attribute metadata for one of the EVOSTC-funded historical data sets. Each data table, GIS layer, and image is described with detailed metadata, including units, coded values, and other essential information.

We operate the historical data portion of this portal at NCEAS (at https://goa.nceas.ucsb.edu), and provide these interactive search and discovery features for all of the historical data, as well as detailed human-readable and machine-readable metadata descriptions of these data sets.

Digital Object Identifiers (DOI)

We have extended Metacat, and by extension the GoA historical data portal, to be able to assign Digital Object Identifiers which provide a persistent handle for a specific version of a data set that can be cited unambiguously in scientific papers and other works. For example, the citation for one of the data sets is:

> Brenda Norcross, Gary Borstad, Evelyn Brown, and Stephanie Moreland. Estimating forage fish distribution and abundance using aerial surveys in Prince William Sound, Alaska: 1995 - 1999. doi:10.5063/F15H7D6G Published 2013.

Just as for journal articles, when this DOI is cited in a paper or report, it can be resolved via the international DOI Foundation to provide the exact current location of the data set today, preventing the problems that have traditionally arisen due to web site changes that cause link failures and data loss. In addition, because the DOI is independent of the site on which the data is currently stored, it allows multiple replicas of the data to be stored and be accessible across different repositories.

Researchers within the GulfWatch Alaska program and throughout the state can log into the historical data portal, upload their data using a web interface (or through other tools, see below), and when they are finished editing the data set, can choose to publish the data with a DOI. This publication ensures that the data are publicly accessible, assigns a DOI, and registers the DOI with both DataCite and DOI Foundation.

Application Programming Interface (API)

In addition to the web user interface, we also provide a machine-readable user interface for the historical data portal. The Metacat software exposes a standard REST-based API that allows various types of software to interact with the system to access data and metadata, and to upload new data sets and their descriptions. This API conforms to the DataONE REST API specification, making it compatible with a wide variety of other repository systems in use around the world. The API has enabled us to expose the data to external software systems for metadata management (Morpho), and data analysis and visualization (e.g., the R system for statistics). The latter access via tools like R is particularly useful for synthesis applications, as it allows direct data access from analysis scripts, thereby providing a direct means of describing an end-to-end analysis and modeling project.

In addition, the REST API allows other repositories to interact with the Metacat system and thus we can automate the movement and replication of data across repositories. We describe how we have already accomplished this for DataONE member nodes in the next section. Over the next year, we plan to continue working with Axiom to enable their data systems to directly utilize this API to both pull data that has been entered into the historical data catalog to their system at AOOS, and to push data from AOOS into the historical data catalog and thus further into the DataONE network.

Replication as a DataONE Member Node

Long-term preservation of data is a challenging and difficult undertaking, partly because the very institutions trusted with data archival are themselves ephemeral over decadal time scales. One mechanism to guard against institutional changes in priority or funding failures (see the National Biological Information Infrastructure for a recent example) is to create rigorously identified replicas of data sets in multiple institutional repositories. While the probability of any one of these repositories failing over decades is high, a diverse suite of repositories has a low probability of failure. This emphasis of data replication across diverse institutions that utilize independent funding streams from Federal, State, and Private sources is a fundamental tenet of the architecture of the DataONE data federation. DataONE consists of multiple Member Nodes, each of which operates independently and provides repository services to their community of interest. By joining DataONE as a Member Node, an organization also is able to replicate their data to multiple other nodes, thereby gaining the requisite institutional diversity needed for long-term preservation. DataONE itself has automated processes that monitor the health of all of the Member Nodes in the network, ensuring that the data stored there is accessible via the standard DataONE API and that the data replicas are valid. Should a Member Node fail or data be corrupted, the DataONE monitoring systems detect this and automatically ensure that additional replicas are made on other Member Nodes, maintaining the reliability of the system. By automating this process and sharing the costs across many institutions, DataONE provides both an efficient and cost-effective means to preserve data for the long-term.

Because of these benefits, we have configured and registered the historical data portal Metacat system as a DataONE Member Node. We have configured the system to ensure that 3 replicas of each data set are created and maintained in the system. The authoritative copy is maintained at the Gulf of Alaska Historical Data Catalog (urn:node:GOA), and replicas are created at the KNB repository (urn:node:KNB), the University of New Mexico replication repository (urn:node:mnUNM1), and the Oak Ridge National Laboratory (urn:node:mnORC1). Figure D-3 shows how these replicas are geographically distributed across the western, central, and eastern US, which also provides for convenient and efficient access from multiple locations. Even if one of these locations is temporarily disconnected from the Internet, data are still available from replica servers around the country.

Figure D-3. Movement of data replicas in Member Nodes of the DataONE Network. The Gulf of Alaska Historical Data Metacat server is located in Santa Barbara, CA. Data are automatically replicated to the KNB repository in Santa Barbara, the University of New Mexico data repository, and the Oak Ridge National Laboratory repository. In addition, a copy of the historical data and metadata are manually copied to the AOOS data system, headquartered in Anchorage.

Currently, a copy of the data is transferred to AOOS manually by project staff in order to ensure that a copy exists in the AOOS data system. We have begun discussions with Axiom engineers about mechanisms to automate this process so that data can flow seamlessly into AOOS. In addition, over the next year we will continue to strive to facilitate getting the AOOS system to be able to push data replicas into the DataONE network.

Morpho metadata entry tool and training

We also developed a bug fix release (1.10.1) of the open source Morpho data documentation application for use with this portal, and conducted two tutorials with GulfWatch scientists regarding the use of Morpho for local data management. These tutorials allowed us to introduce data documentation practices to two groups of GulfWatch Alaska researchers, some of whom have incorporated Morpho into their data management.

Table D-1. Status of project milestones for year 2

Deliverable/Milestone	Status
Assess/Validate year 1 datasets and metadata submitted through AOOS and NCEAS	Completed, April 2013
Prototype data discovery and management tools demonstration	Completed, July 2013
Participate in LTM program PI meeting	Completed, November 2013
Complete integration of data salvaged into AOOS DM System for data collated from PIs via manual copy	Completed, November 2013
Full release of data discovery and management tools (Released Metacat 2.2, 2.3, 2.4; Morpho 1.10.1; Historical Data portal)	Completed, January, 2014

8. Information and Data Transfer: See, Reporting Policy at III (C) (8).

At UCSB we employed a Projects Data Coordinator (Clark) and three graduate student research assistants (Couture, Freeman, McDonald) to correspond with historical project PIs, and try to collate data and compile metadata. This effort advanced historical data collation during the year, with us having documented and published 94 of the 419 data sets that we identified from historical EVOS funding. An additional 18 data sets have been obtained and are being documented for publication, and will soon be released. We have corresponded with PIs for an additional 168 data sets, but have not yet received data from them, have gotten no response regarding 62 data sets, and have classified 76 data sets as unrecoverable. See Figure 4 for a breakdown of data sets by status. The main obstacle to publishing data sets has been lack responsiveness of investigators in providing data (or responding at all), and lack of information on the files that are sent. Specifically this includes files without column headers, folders of hundreds of files without explanation of the contents, duplicate data sets being sent with small unexplained differences making it difficult to determine what should be published, lack of units and acronym definitions, outdated file formats that must be converted, and files with graphs and embedded comments. It has also been difficult to confirm that we have all of a project's data due to the lack of information provided, and many PIs are unable to describe their historical data to us.

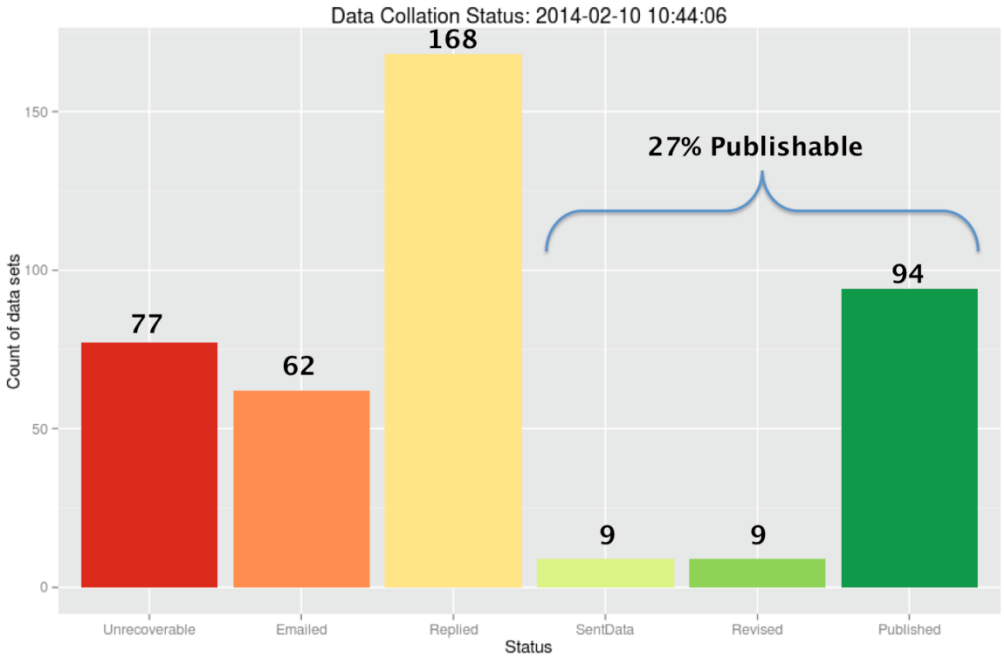


Figure D-4. Current status of data collation for 419 historical data sets identified as products of prior EVOSTC funding through inventory efforts. Already published, revised data awaiting final approval, and data that we already have in hand represent 27%

All 94 of these published and documented data sets have been replicated in the DataONE network and manually deposited in the AOOS data management system using the Ocean Workspace interface.

9. Response to EVOSTC Review, Recommendations and Comments: *See,* Reporting Policy at III (C) (9).

Science panel concerns over the importance of the NCEAS synthesis efforts have been embraced; synthesis activities will be initiated in February, 2014 as scheduled. Interactions between NCEAS and Axiom on development of data management systems and solutions have proceeded at a low level, with periodic conversations and agreement on design goals. We hope to increase the intensity of collaboration during year 3 of the project.

10. Budget: *See,* Reporting Policy at III (C) (10).

Please see the attached budget workbook.

E. Science Coordination and Synthesis- Holderied (NOAA KBL, 12120114-H)

1. Project Number: *See,* Reporting Policy at III (C) (1).

12120114-H

2. Project Title: *See,* Reporting Policy at III (C) (2).

Science Coordination and Synthesis

3. Principal Investigator(s): *See,* Reporting Policy at III (C) (3).

Kris Holderied

4. Time Period Covered by the Report: *See,* Reporting Policy at III (C) (4).

February 1, 2013-January 31, 2014

5. Date of Report: *See,* Reporting Policy at III (C) (5).

March 1, 2014

6. Project Website (if applicable): *See,* Reporting Policy at III (C) (6).

www.gulfwatchalaska.org

7. Summary of Work Performed: *See,* Reporting Policy at III (C) (7).

We have focused our efforts on planning for the upcoming joint program science conference and in planning holding the program annual meeting, developing integration and visualization tools both for within and outside the program, and improving access to program information and data. We continue to work on the coordination aspect of the project, including sharing information with the NPRB Gulf of Alaska Integrated Ecosystem Research Program and the Herring Research and Monitoring program. A science coordinator, Tammy Neher, was hired and began working in the Gulf Watch Alaska program in late March. This position provides a facilitator for communication, integration, and synthesis both within the program and to outside entities.

Below is a summary of science coordination and synthesis work performed during the reporting period by project objective, Table E-1 highlights the project milestones and deliverables met during this reporting period.

Objective 1. Improve communication, data sharing and coordinated field work planning between principal investigators of the individual monitoring projects, as well as with other agencies and research organizations

Two teleconferences were held with all principal investigators (PI) and the science coordinating committee (SCC) for Gulf Watch Alaska in June and July 2013. Most investigators attended the teleconference meetings and those that did not received meeting notes and held short discussions with the science coordinator. The annual program meeting was attended by all

principal investigators (or representatives) in November and a second meeting was held in conjunction with the Alaska Marine Science Symposium in January, with all principal investigators present in person or by phone. Meeting agendas, summaries and other materials are posted on the program workspace. The program's Science Coordinating Committee met in June, September, and November in order to plan the PI meetings, provide input on needed data management services, provide guidance and approval for changes in sampling protocol, discuss the Science Synthesis report and plan, provide input on development of the Science Advisory Group, develop the year 3 work plans, and address on-going program coordination issues.

Two small work groups were formed to address coordination of differences in individual project sampling methods and how the data could best be analyzed to address program research questions. The Marine Birds working group (composed of investigators from the two seabird monitoring projects, harlequin ducks, conceptual modeling, and benthic projects) met by conference call in December to discuss approaches to analyses of current data, data gaps, and topics for papers to include in science synthesis report due in November 2014. The group identified two projects for inclusion in the synthesis report:

1) Power analyses to determine the ability to detect changes in populations through time for both pelagic and nearshore species (separated by those groups respectively).
2) Collection/compilation of productivity data and comparison to abundance data as this may be a more useful metric of success than abundance estimates when examining influences of environmental conditions on populations.

The group also identified several data gaps and projects for future work:

1) Winter abundance data for specific species is lacking and potentially very important. Future work should include winter abundance surveys (March).
2) Can distribution data be used to develop linkages to other species such as forage fish – identifying hot spots? Examine clustering data to determine utility of this approach.

The second working group was comprised of investigators from the environmental drivers component with the goals of coordinating zooplankton sampling techniques and analytical approaches and developing a consistent format for reporting oceanographic data collected by SeaBird SeaCat instruments. The group has been working through email correspondence to address these goals. The group agreed on analyses and coordination of the zooplankton data as described in the addendum to S. Batten, Continuous Plankton Recorder project report in this Appendix. Oceanographic data collected using Seabird SeaCat instruments will be archived in the original .cnv format for each individual file on the ocean workspace, but will be made publically available in the data portal in ASCII text format for each site through time accompanied with a file containing the information for each site and pertinent metadata for each project.

We continue to make changes to the Ocean Workspace portal to facilitate communication between principal investigators and accessibility to data. We worked with our partners at Axiom to develop new functions on the Workspace portal, including search options, hierarchical nested folders, plus adding improvements to the file and project level metadata tools. We plan to have file-

level metadata directly linked to publically accessible files on the data portal in March. Currently, metadata files are provided in eml, xml, and csv formats directly on the portal. All projects have data loaded and accessible on the portal. Project-level metadata is available for immediate viewing on the portal with each project description: http://data.aoos.org/maps/search/gulf-of-alaska.php#search?q=&tagId=91&page=1. We also developed several guidance documents to streamline use of the work space, coordinate file naming conventions, and file structure. Currently, we are continuing to work with Axiom to develop modifications to the data access portal of the program to facilitate user access and enhance public use.

Objective 2. Improve and document integration of science monitoring results across the LTM program - working with the PIs, data management and modeling teams as well as other agencies and research organizations.

Teleconferences and data sharing discussions were held with North Pacific Research Program (NPRB) Gulf of Alaska Integrated Ecological Research Program (GOAIERP) staff and Gulf Watch and NOAA research. Dr. Franz Mueter (UAF, GOAIERP) shared his retrospective analyses, data, and results with the Kris Holderied and Tammy Neher. NOAA's Varis Ransi provided updated salinity graphics developed from NOAA's satellite data models for the GOIERP and Gulf Watch investigators.

We continued our work developing and enhancing a variety of tools to communicate the scope and timing of the monitoring effort between program investigators and to a broader audience of resource managers, other researchers and the general public. We have substantially improved our public access website and data access portal, with both a public access website and data portal currently in the testing phase and plans to go live with the public website in September and the data portal in November.

Objective 3. Improve communication of monitoring information to resource managers and the public through data synthesis and visualization products and tools – working with the data management, conceptual ecological modeling and outreach teams, as well as other agencies and research organizations.

Through our work with the GOAIERP program, we have adopted the "report card" framework (Mueter et al. 2013) and modified this approach to use to identify patterns and facilitate discussion during the Gulf Watch program annual meeting. We held a time series workshop using the 'trend card' approach that allowed coordination with the NPRB programs as well as facilitated communication within the group. The trend cards are a visual tool to facilitate discussion regarding sampling methods, identify data gaps, and develop hypotheses about emerging pattern in the data as well as raise additional questions. The approach allows us to examine the potential for relationships between various hypothetical drivers of systemic ecology based on concepts identified in the Gulf Watch program conceptual model and in previous Gulf of Alaska studies using large-scaled climate indices and the long-term monitoring data (Figure E-1).

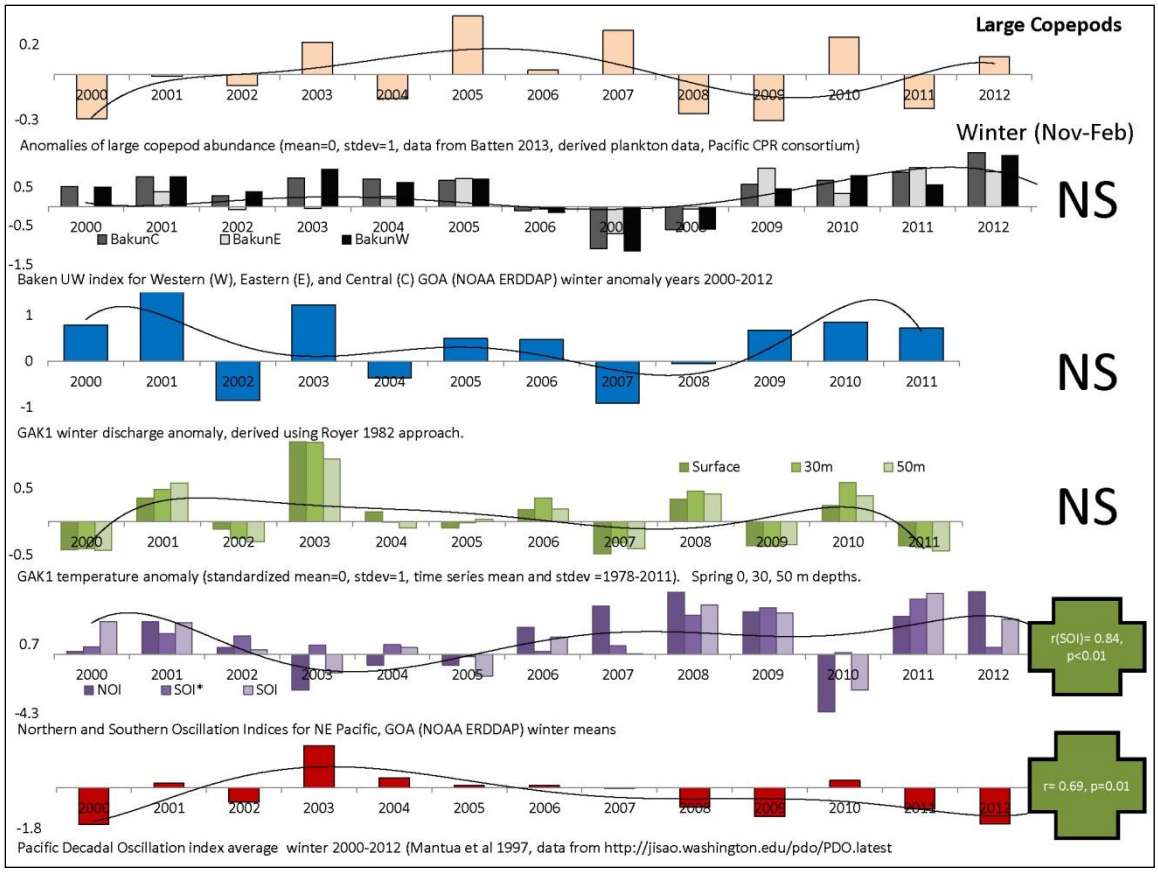


Figure E-1. Example of a trend card for large copepod abundance during winter months associated with regional climate index data.

Data from over 20 different data sets from within Gulf Watch Alaska projects and outside projects conducted in the Gulf of Alaska region were presented on large posters (Figures E-2, E-3 show examples). Graphics for the data were grouped under each component of the program plus one poster showing patterns in environmental index data (such as annual means for the Pacific Decadal Oscillation, Bakken upwelling, and the Northern and Southern Oscillation indices). Program scientists were invited to view and comment on the patterns and these comments were used to form hypotheses and products for the program synthesis report to be provided in November 2014.

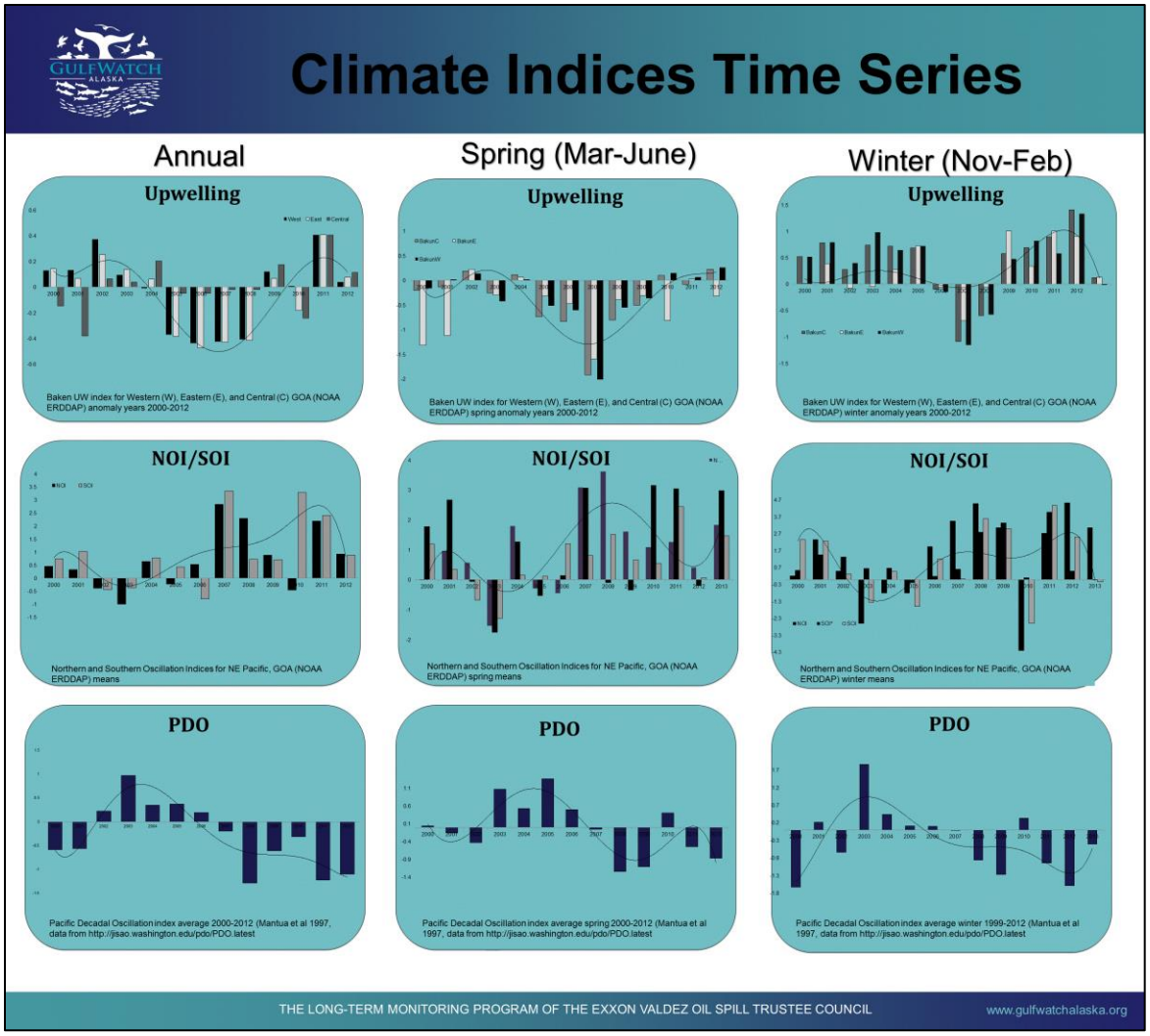


Figure E-2. Time series workshop posters showing patterns for Gulf of Alaska regional climate Indices.

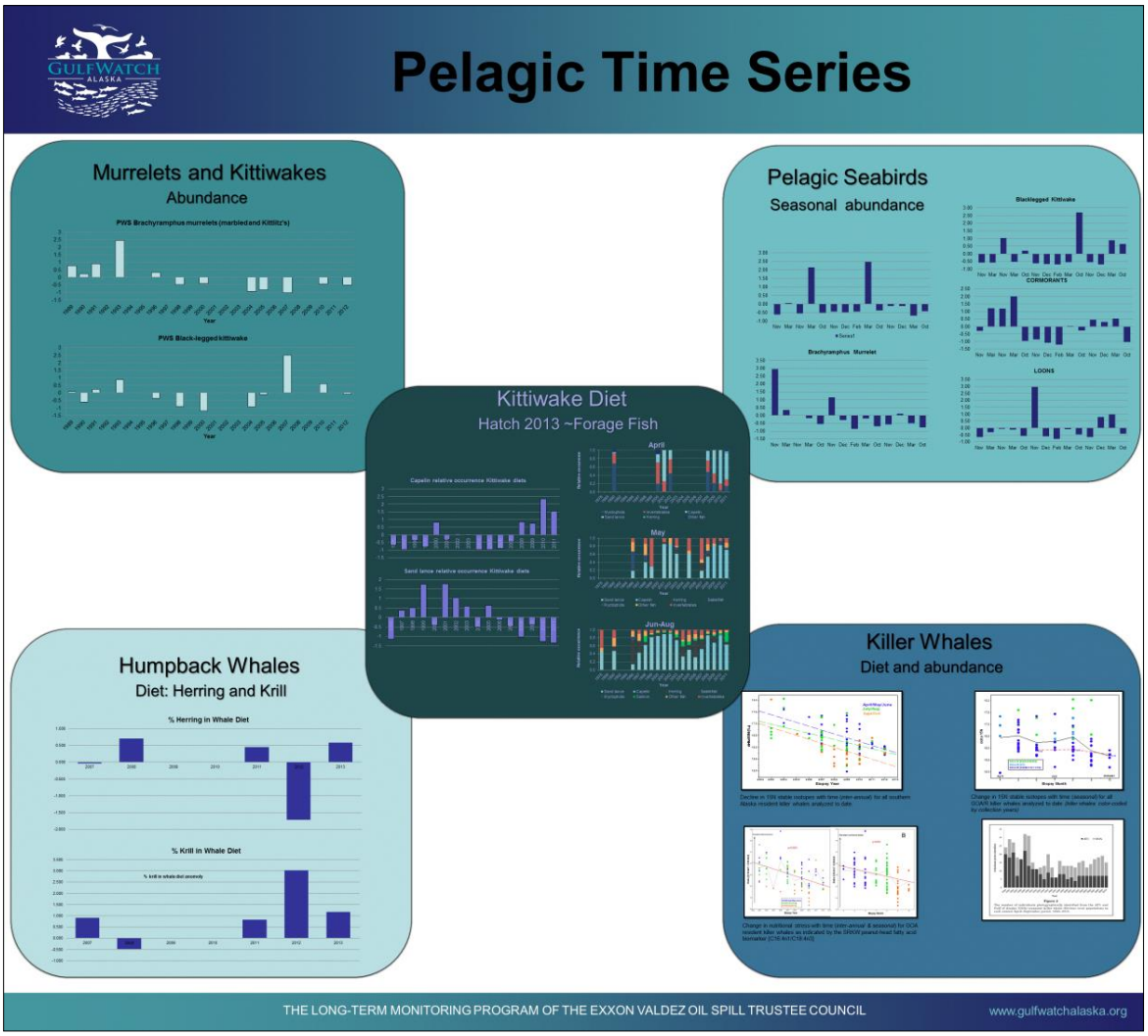


Figure E-3. Pelagic component poster presented at the GWA time series workshop.

We also discussed questions from the original program proposal (abbreviated from the McCammon et al. 2012) during this meeting and developed an outline for the synthesis report. Questions included:

- Are patterns in species metrics and environmental conditions similar between shelf and off shelf areas and across the Gulf of Alaska (East, West, central)?
- What are some of the potential relationships between injured resources/plankton and environmental conditions?
- What are some of the drivers of variability in near shore environments (identify temporal and spatial scales of variability, examine patterns of seasonal temperatures, upwelling, wind mixing and correspondence with patterns in metrics from near shore communities, i.e. species composition, abundance, and distribution).
- Does the variability in the data (spatial/temporal) reflect a new regime shift of climatic cycles?

- How does PWS track with change in the broader geography?
- Is there predictability in the pulses and what are the drivers?

Some additional hypotheses that could be examined with these data include:

- Oscillating control (Coyle et al. 2011): are shifts in zooplankton production related to ecosystem shifts in species abundances and community composition favoring pelagic versus benthic communities?
- Match/mismatch (Durant et al. 2007): Two part question- a) does the timing in zooplankton production (community composition and abundances of key prey items) correspond to environmental patterns; and b) are there relationships with availability of specific zooplankton prey and predators that correspond to availability (timing and abundance)?
- River/lake hypothesis (Eslinger at al. 2001): related to the Bakun upwelling index (Bakun 1973). The river/lake hypothesis associates the degree to which upwelling occurs resulting in changes in zooplankton community in PWS. Alternatively, zooplankton abundances/composition is driven by phytoplankton composition and is nutrient limited. One question might address which of these two hypotheses best explains the variability in plankton communities associated with environmental conditions.

Table E-1. Science Coordination and Synthesis project: summary of status of deliverables or milestones.

Deliverable/Milestone	Status
Assist in initial planning of joint Gulf Watch Alaska-Herring Research and Monitoring programs workshop	The Management Team provided comments on the proposed agenda for the workshop in June, 2013. Additionally, Kris Holderied and Tammy Neher have been working with Scott Pagau to prepare the synthesis reports for both programs to be provided prior to the workshop. Finally, we held a time-series synthesis workshop in conjunction with the annual PI meeting in November that identified products for the synthesis report, as well as developed small working groups to tackle specific needs within the program.
Develop an example interactive data visualization tool in coordination with data management and conceptual ecological modeling teams.	A data visualization portal is currently operational; data from all projects are loaded and available for access.
Submit year 3 work plan.	Year three work plans were prepared or edited as needed and were provided Sept. 3 to Trustee Council staff.
Facilitate annual PI meeting	The Management team, in conjunction with the Science Coordinating Committee, planned the meeting agenda and facilitated applicable sections to their pieces. An outside facilitator, Ms. Stacey Buckelew, facilitated the group discussion during the time series workshop on the final day.
Conduct annual PI meeting	Meeting was planned with time series data workshop in conjunction. Meeting was held Nov.
Attend Alaska Marine Science Symposium and provide update to GWA program	Kris Holderied presented an update to the GWA program at the symposium on Thursday, January 23. The program also held a short PI meeting to coordinate reporting, product development, and progress updates.
Submit report on synthesis of all available	The NCEAS project is submitting a progress report on the historical

historical data from LTM projects	data collection in conjunction with this annual report.
Submit annual project report	This document constitutes report submission.

8. Information and Data Transfer: See, Reporting Policy at III (C) (8).

We have assisted the outreach team in development of the program website. Program PIs and their staff have participated in two public outreach events: public Discovery Labs at the Kachemak Bay Research Reserve in Homer, Alaska in July and the International Shorebird Festival in Cordova, Alaska in May. Additionally, we worked with the outreach team, Eric Cline (TerraGraphica), and Brian Stone (Axiom Consulting) to design and build the Gulf Watch Alaska website, including providing the content and review. We continue to this work to improve and update the website as time progresses.

Publications: No publications were generated under this project

Conference and workshop presentations and attendance:

Multiple public presentations were made in a variety of venues on the integrated Gulf Watch Alaska program during year 2. Kris Holderied gave Gulf Watch Alaska program overview talks for a UAF marine science program seminar and the Alaska Marine Science Symposium, posters were presented at the Kenai Fish Habitat Partnership Science Symposium and the 2014 Ocean Sciences conference, and the Gulf Watch program was the focus of one week of Kachemak Bay Research Reserve Discovery labs with over 300 people attending three separate workshops.

Holderied, K. April 2013. UAF Marine Science Seminar Series. Moving Towards the Next Phase of Monitoring after the Exxon Valdez Oil Spill: A New Integrated Program. Oral presentation (Holderied).

Holderied, K.*, M. McCammon, K. Hoffman, S. Rice, B. Ballachey, T. Weingartner, and R. Hopcroft. Jan 2013. Kenai Fish Habitat Partnership Science Symposium. Gulf Watch Alaska – Ecosystem monitoring at the intersection of spilled oil and climate change. Poster presentation (Holderied).

Holderied, K.*, M. McCammon, K. Hoffman, B. Ballachey, R. Hopcroft, M. Lindeberg, and T. Weingartner. 2014. Gulf Watch Alaska: Ecosystem monitoring to assess long-term oil spill impacts in the context of North Pacific climate change. Oral presentation. Alaska Marine Science Symposium, Anchorage, Alaska.

Holderied, K.*, M. McCammon, K. Hoffman, B. Ballachey, R. Hopcroft, M. Lindeberg, and T. Weingartner. 2014. Gulf Watch Alaska: Ecosystem monitoring to assess long-term oil spill impacts in the context of North Pacific climate change. Poster presentation. Ocean Sciences meeting, Honolulu, HI.

Data and or Information products: We compiled data from multiple sources for use in development of the time series workshop, held in conjunction with the program annual meeting this fall. Data were presented as time series anomalies for the four components of the program in large posters.

The purpose of the workshop was to use these visual aides to identify potential patterns and discuss analyses that could be used to elucidate patterns and potential relationships with the goal of further developing these ideas for inclusion in the synthesis report and joint science workshop. The program PIs also worked to identify specific papers to be completed for inclusion in the synthesis report, under the theme: "Describing variability in the Gulf of Alaska Ecosystems". This report will be submitted to the council in November, 2014 for use in the 2015 joint Science Workshop.

Project data uploaded to program data portal: Not applicable to this project.

9. Response to EVOSTC Review, Recommendations and Comments: *See,* Reporting Policy at III (C) (9).

We thank the panel for their comments to the program, there were no comments directed to this project.

10. Budget: *See,* Reporting Policy at III (C) (10).

Please see the attached budget form

F. CONCEPTUAL ECOLOGICAL MODELING- HOLLMEN (ASLC, 12120114-I)

1. Project Number: *See,* Reporting Policy at III (C) (1).

12120114-128102

2. Project Title: *See,* Reporting Policy at III (C) (2).

Long-term Monitoring: Synthesis and Conceptual Modeling - Conceptual Ecological Modeling

3. Principal Investigator(s): *See,* Reporting Policy at III (C) (3).

Tuula E Hollmen (Principal Investigator)

Suresh A Sethi (Collaborator)

4. Time Period Covered by the Report: *See,* Reporting Policy at III (C) (4).

February 1, 2013-January 31, 2014

5. Date of Report: *See,* Reporting Policy at III (C) (5).

March 1, 2014

6. Project Website (if applicable): *See,* Reporting Policy at III (C) (6).

www.gulfwatchalaska.org

7. Summary of Work Performed: *See,* Reporting Policy at III (C) (7).

A modeling workshop was conducted in November 2012, to elicit input from Gulf Watch Alaska Principal Investigators. The workshop had two primary objectives:

1. Develop a parsimonious conceptual model which identifies: a) natural and anthropogenic forcing factors, b) key biophysical processes and biophysical components which play a central role in the functioning of the system, and c) linkages between model elements
2. Test a rating tool to elicit expert opinion to assess the following properties of linkages within a conceptual submodel: a) strength of linkage, b) natural variability of linkage, c) spatial scale of linkage, d) temporal scale of linkage, and e) state of knowledge about the linkage.

During the workshop, investigators were asked to participate in a conceptual modeling session to identify a set of components that belong in a generic conceptual model for the North Gulf of Alaska, and then to generate a visualization linking those components together in a conceptual description of the North Gulf of Alaska. The challenge set forth was to create a general conceptual model for the Gulf of Alaska which contained the minimum amount of complexity necessary to describe the system. Participants were given a starting list of components and a skeleton of a conceptual model. Visualizations categorized model elements into forcing factors, biophysical processes, and biophysical components. The spatial arrangement of elements indicated the spatial scale at which the model components operated, and linkages represented interactions in the conceptual model. Additionally, we conducted an expert assessment of a conceptual model linkages survey, to develop a linkage rating tool to be utilized in iterative updating of our conceptual models. We asked the PIs

to rate properties of linkages (strength, spatial scale, temporal scale, variability, and state of knowledge) in an example conceptual ecological submodel, using rating scales provided, and to provide feedback on the draft tool. During the reporting period, Principal Investigator input from the modeling workshop has been organized and analyzed.

General conceptual ecosystem model:

We received 19 responses including lists of model components (*n* =19) and visual representations (*n* =16) of a general North Gulf of Alaska conceptual model from program PIs. These investigator responses were analyzed to produce the first version of our consensus conceptual model. Steps of the data analysis included: consolidation of a comprehensive list of model elements, refinement of the list of model components, generation of a conceptual model response matrix that was used to translate visual arrangement of model elements into a numeric matrix, generation of a matrix for the spatial domain of elements on the master list, and using R script, determining expert consensus on a) which elements from the master list should be retained in a final conceptual model, b) the spatial domain of elements retained in the final model, and c) the linkages between elements retained in the final model. The final step of the process involved reconstructing a visual representation of the conceptual model (Figure F-1).

Linkage rating tool: We received 19 responses from program PIs (GWA PI's *n* = 18 + 1 J. Miller, USFWS) on the submodel linkage rating survey. PI input for the submodel exercise was entered into response matrices and summarized. Responses were processed in the R statistical programming environment (RDCT, 2013). We used a simple majority rule (50% or more) to determine whether a linkage should be retained in a final consensus model. We used the mean linkage rating value amongst those respondents who included a retained linkage to reflect a consensus rating, and we assessed group agreement by calculating the standard deviation of responses for a retained linkage. The consensus model contained eight linkages throughout the herring-whale model (Figure F-2). Overall, participants had the highest degree of consensus when rating the temporal and spatial scale at which linkages operate (Table F-1), and least amount of consensus regarding the strength of linkages. As an example of using respondent ratings to prioritize areas for future research attention in the herring-whale system, we calculated the ratio of strength of interaction to state of knowledge for linkages (Table F-2). Linkages with high scores indicate high strength of interaction but low current state of knowledge. Interactions involving ocean acidification were rated as highest priority, followed by the effect of zooplankton on herring. The latter of which was rated as having the best state of knowledge amongst linkages, however, the linkage was also rated as high impact.

Please also see Table F-3 for a list of project milestones and progress during this past year.

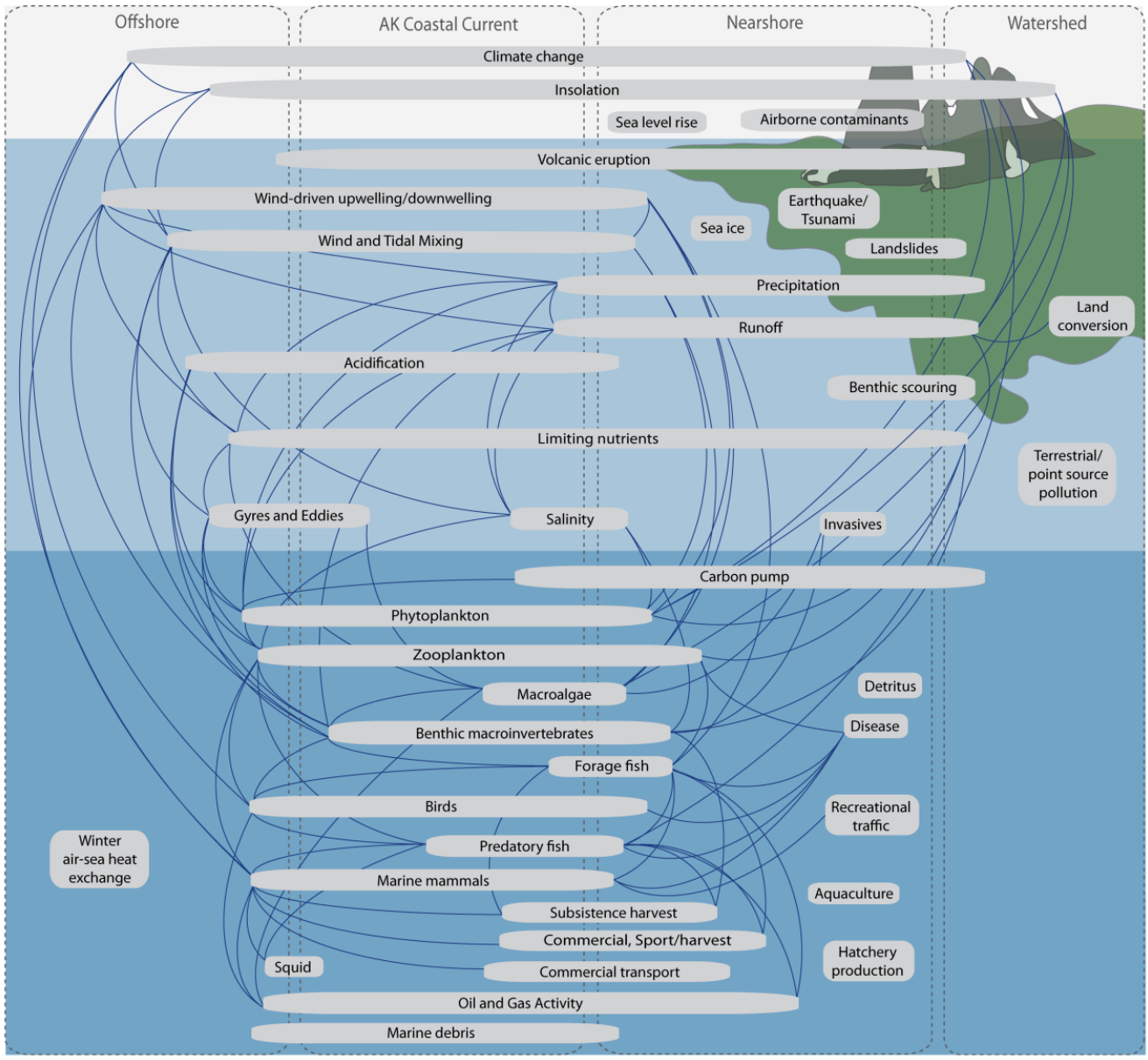


Figure F-1. Visual representation of the overall Conceptual Ecological Model.

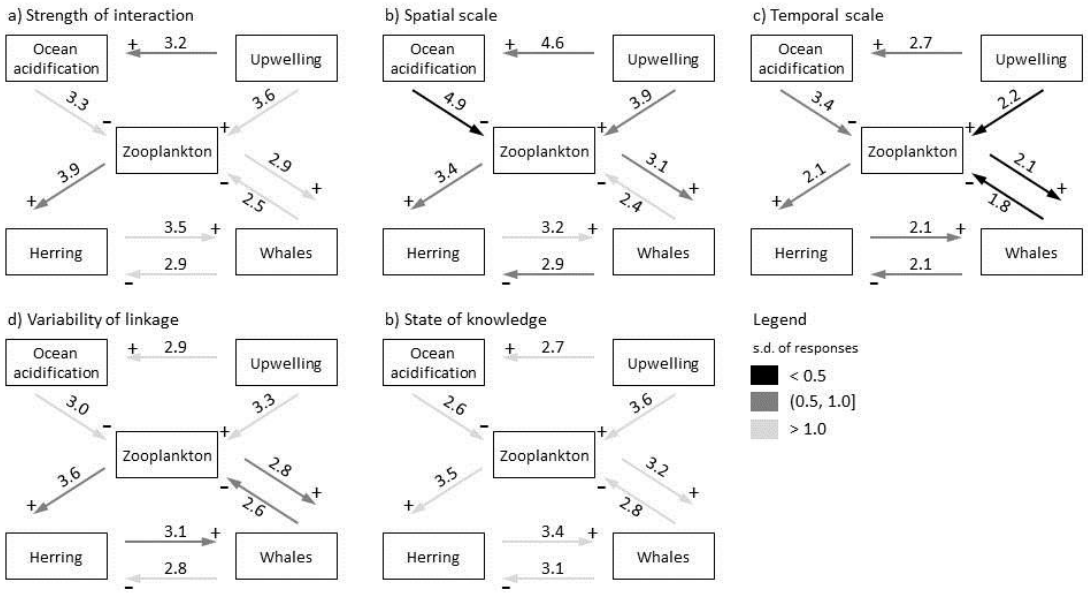


Figure F-2. Linkage rating tool showing eight linkages throughout the herring-whale model.

Table F-1. Overall agreement assessment of linkage ratings for the herring-whale model.

Linkage property	s.d.[a]
Strength of interaction	1.11
State of knowledge	1.09
Variability of linkage	1.01
Spatial scale	0.87
Temporal scale	0.62

[a]*Values are the mean of the standard deviation (s.d.) of responses for a given rating question across all linkages.*

Table F-2. Ratio of strength of interaction to state of knowledge for linkages in the herring-whale model[b].

Linkage	Ratio
acidification-zooplankton	1.26
upwelling-acidification	1.19
zooplankton-herring	1.13
herring-whale	1.04
upwelling-zooplankton	1.02
whale-herring	0.96
zooplankton-whale	0.91
whale-zooplankton	0.90
[b]*X-Y represents the effect of X on Y.*	

Table F-3. Status of project milestones for year 2

Deliverable/Milestone	Status
Conduct modeling workshop	Completed, November 2012
Complete first interactive and data visualization tools for selected components	Completed, January 2014
Design draft conceptual model	Completed, January 2014
Attend annual PI meetings and Alaska Marine Science Symposium	Completed, November 2013 and January 2014

8. Information and Data Transfer: See, Reporting Policy at III (C) (8).

- Conference presentation: Hollmen, TE and Sethi SA. Development of conceptual ecological models to support the GulfWatch Alaska long-term monitoring program. PICES annual meeting, Nanaimo, BC, October 2013
- Manuscript in preparation: Conceptual ecological models to synthesize, organize, and prioritize research in socioecological systems.
- Data and/or information products developed during the reporting period: Visualization of generic conceptual ecosystem model for Gulf Watch Alaska program (Figure 1), visualization of interactive linkage rating tool (Figure 2), elicited PI input from model development exercises (3 attachments).

9. Response to EVOSTC Review, Recommendations and Comments: *See,* Reporting Policy at III (C) (9).

Our responses to the recommendations received in 2013 were outlined in fall 2013 and included a detailed appendix, much of which is summarized in this report. The response to the science panel

comments are summarized from McCammon et al. Response to EVOS TC Science Panel FY 2014 Proposal Comments:

- Project began 1.5 years ago and is a partnership between Dr. Tuula Hollmen and Dr. Suresh Sethi, providing complementary experience in complex ecological processes and biometric analyses.
- Plans are to provide first model by March 2014 (Figure 1, included in this report), and iteratively update and refine the model throughout the program
- The final model will be a product of iterative updates that can be used for education, outreach, and analysis

10. Budget: *See,* Reporting Policy at III (C) (10).

Please see attached budget workbook.

G. Gulf of Alaska Mooring (GAK1)- Weingartner (UAF, 12120114-P)

1. Project Number: *See,* Reporting Policy at III (C) (1).

13120114-P

2. Project Title: *See,* Reporting Policy at III (C) (2).

Long-term Monitoring of Oceanographic Conditions in the Alaska Coastal Current from Hydrographic Station GAK 1

3. Principal Investigator(s): *See,* Reporting Policy at III (C) (3).

Thomas Weingartner

4. Time Period Covered by the Report: *See,* Reporting Policy at III (C) (4).

February 1, 2013-January 31, 2014

5. Date of Report: *See,* Reporting Policy at III (C) (5).

March 1, 2014

6. Project Website (if applicable): *See,* Reporting Policy at III (C) (6).

www.gulfwatchalaska.org and http://www.ims.uaf.edu/gak1/

7. Summary of Work Performed: *See,* Reporting Policy at III (C) (7).

Please see Table G-1 for a list of the project milestones and progress during this past year. Our sampling activities include 1) quasi-monthly CTD casts at station GAK 1 (periods of sampling given in Table G-2) and the recovery and re-deployment of a string of 6 temperature-conductivity-pressure (TCP) recorders on a mooring at GAK 1. This mooring is recovered and re-deployed annually in March of each year. After the mooring is recovered the TCPs are sent to Seabird for post-calibration.

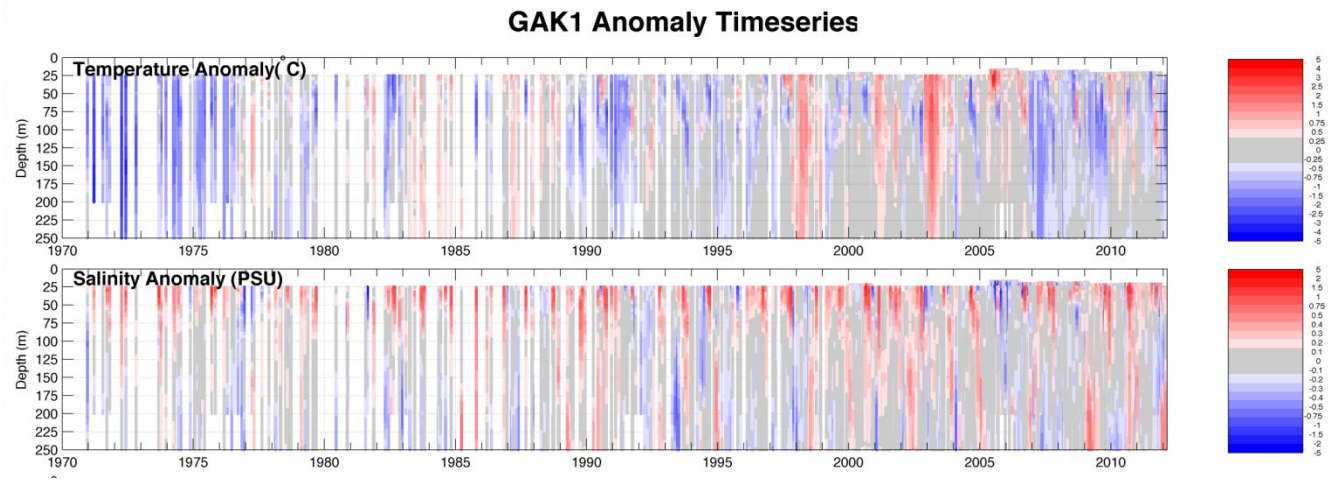
Table G-1. Status of project milestones for year 2

Deliverable/Milestone	Status
February CTD cast at GAK 1	Completed
March mooring recovery and re-deployment at GAK 1	Completed
March CTD cast at GAK 1	Completed
April CTD cast at GAK 1	Completed
May CTD cast at GAK 1	Completed
June CTD cast at GAK 1	Completed

August CTD cast at GAK 1	Completed
September CTD cast at GAK 1	Completed
November CTD cast at GAK 1	Completed
December CTD cast at GAK 1	Completed

Some interesting findings:

- Most (~90%) of the variability in Seward sea level is due to the inverted barometer effect due to atmospheric pressure variations and tides.
- Seward sea levels (after removing tidal and inverted barometer effect contributions) are coherent with the along-shore winds at time periods of from 3 – 30 days. At the annual cycle, sea level variations are primarily associated with changes in salinity (and to less extent temperature) at GAK1. This thermosteric contribution to sea level variability amounts to ~ 20 cm at the annual time period.
- Since the installation of the mooring at GAK 1 we have seen a transition from weak or above normal temperature and salinity anomalies to one in which temperatures have been colder than normal (for the 2000 – 2012 period shown in Figure G-1), while salinity anomalies have generally not shown a trend. The spring of 2013 (at least through March 2013) was unusually cold throughout the water column.



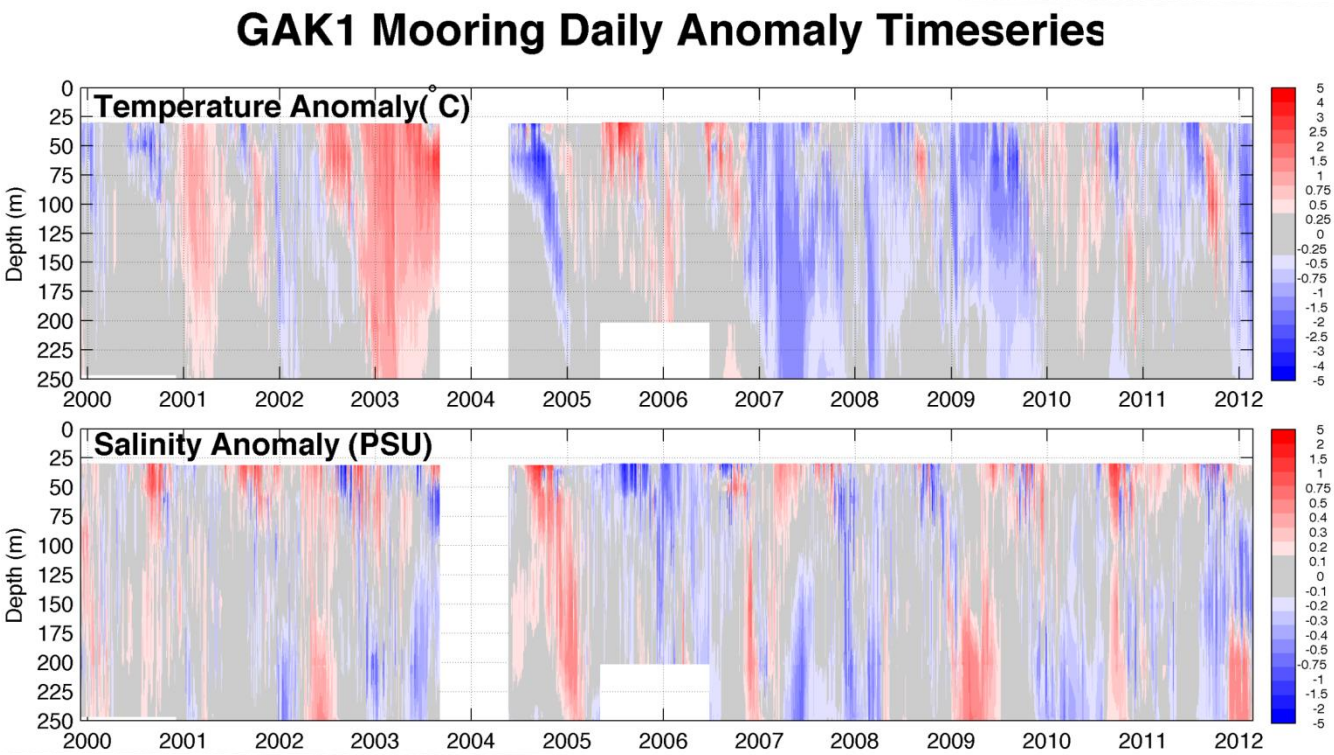


Figure G-1. Over the ~45 year time series (based on monthly CTD samples) the decade since 2000 has generally been cooler than normal as seen below. When viewed from this longer temporal context, the period since 2005 has been cooler than normal, although the cold anomaly in winter 2013 is not as strong as in the figure above. The other striking feature evident in the 1970 – 2012 anomaly time series is that the cold anomalies tend to be much more frequent (but not as strong) as the warm anomalies. The reason for this is not clear at this writing. Finally, we are predicting that spring 2014 will be warmer and fresher (at least at the surface) than normal.

8. Information and Data Transfer: See, Reporting Policy at III (C) (8).

- Publications produced during the reporting period; **NONE**
- Conference and workshop presentations and attendance during the reporting period;

Weingartner attended the Alaska Marine Science Symposium in January 2013 and also the PI meeting in November 2013. The following posters were given at AKMSS in January 2013.

Ecosystem monitoring at the intersection of spilled oil and climate change. Kristine Holderied, kris.holderied@noaa.gov; Molly McCammon, mccammon@aoos.org; Katrina Hoffman, khoffman@pwssc.org; Stanley Rice, jeep.rice@noaa.gov; Brenda Ballachey, bballachey@usgs.gov, Thomas Weingartner, TWeingartner@alaska; Russell Hopcroft, rrhopcroft@alaska.edu

Seward sea level variability: Sources and implications. James Kelly, jbkelly@alaskas.edu; Thomas Weingartner, tjweingartner@alaska.edu

- Data and/or information products developed during the reporting period, if applicable; and Weingartner's graduate student (James Kelly) has used the GAK 1 data sets to investigate sea level variability in Seward. The goal here is to determine the causes for sea level variations and eventually to determine if Seward Sea level can be used as a proxy for current variations in the ACC. We find that the annual cycle of sea level variations at Seward are in-phase with dynamic heath (vertically-integrated density) at GAK 1. At periods of days to ~1 month the sea level variations are significantly coherent with and in-phase with the along-shore winds over the Gulf of Alaska shelf, especially in fall, winter, and early spring. Given that the wind is also coherent with ACC transport at these periods it appears that Seward Sea level anomalies at these periods may be useful as an index of ACC transport. The student will complete his MS thesis in summer 2014.
- Data sets and associated metadata that have been uploaded to the program's data portal.

All Data through 2012 has been uploaded to www.gulfwatchalaska.org and http://www.ims.uaf.edu/gak1/

9. Response to EVOSTC Review, Recommendations and Comments: *See,* Reporting Policy at III (C) (9).

There were no recommendations for this project.

10. Budget: *See,* Reporting Policy at III (C) (10).

Please see attached budget workbook.

H. SEWARD LINE- HOPCROFT (UAF, 12120114-J)

1. Project Number: *See,* Reporting Policy at III (C) (1).

12120114-J

2. Project Title: *See,* Reporting Policy at III (C) (2).

LTM Program - Seward Line Monitoring

3. Principal Investigator(s): *See,* Reporting Policy at III (C) (3).

Russ Hopcroft

4. Time Period Covered by the Report: *See,* Reporting Policy at III (C) (4).

February 1, 2013-January 31, 2014

5. Date of Report: *See,* Reporting Policy at III (C) (5).

March 1, 2014

6. Project Website (if applicable): *See,* Reporting Policy at III (C) (6).

www.gulfwatchalaska.org

http://www.sfos.uaf.edu/sewardline/

7. Summary of Work Performed: *See,* Reporting Policy at III (C) (7).

The work performed remains consistent with the original workplan. The spring cruise was conducted April 25 to May 9 in conjunction with NPRB's Gulf of Alaska project. All primary sampling objectives were accomplished along the Seward Line and within PWS, with the except that several multinets needed to be conducted at dawn (rather than during darkness), see Table H-1 for milestones completed during this year. The late -summer cruise was conducted Sept 11-26, also in conjunction with NPRB Gulf of Alaska project. Poor weather required that intermediate stations were not sampled along the line. All data is available from the May cruise, except for multinets in PWS. Processing of most data is completed for September, with the exception of multinets. Extremely poor weather on both cruises prevented execution of all process work on zooplankton (a secondary priority).

Some interestings findings from this year include:

- During 2013 the Seward Line was cooler then normal, both duing spring an at the end of the summer (Figure H-1).
- Mulivariate analysis of the first 15 years of data shows strong across-shelf gradients, correlated with salinity.
- Larger zooplankton species are more strongly and coherently stuctured by this across-shelf gradient than smaller zooplankton species which show a greater influnce of year-to-year variability.

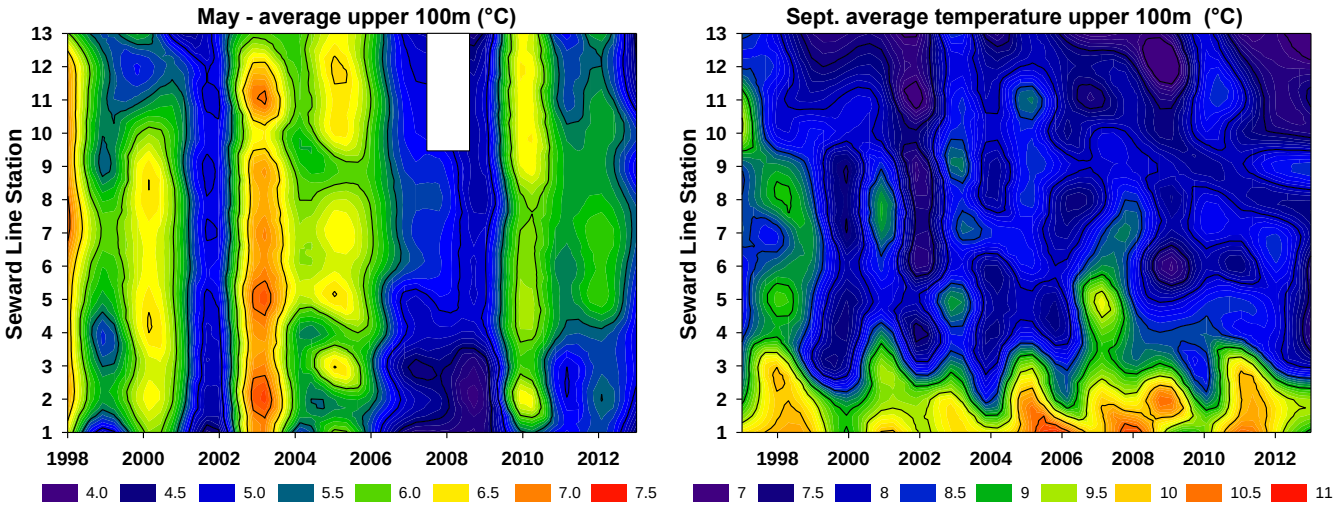


Figure H-1. Oceanographically, the Seward Line was 0.7 °C below the long-term mean temperature during the May 2013 cruise. Temperature during September was 0.5 °C below the long-term mean. Macro-nutrient and chlorophyll concentrations measured during May suggest the spring bloom was in progress along the Line during the cruise.

Table H-1. Status of project milestones for year 2

Deliverable/Milestone	Status
2012 data delivered	Completed in full, fall 2013
2013 May cruise	Successfully completed
2013 September cruise	Successfully completed

8. Information and Data Transfer: See, Reporting Policy at III (C) (8).

- Doubleday, A.J., **Hopcroft, R.R.**, *submitted*. Seasonal and interannual patterns of larvaceans and pteropods in the coastal Gulf of Alaska, with relationships to pink salmon survival J. Plankton Res.
- Coyle, K.O., Gibson, G.A., Hedstrom, K., Hermann, A.J., **Hopcroft, R.R.**, 2013. Zooplankton biomass, advection and production on the northern Gulf of Alaska shelf from simulations and field observations. J. Mar. Sys. 128, 185-207.
- ASLO Meeting – New Orleans, Louisiana (February 2013) **- Presentation:** ***(1)*** Estimates of the composition, abundance, and biomass of pteropods and larvaceans in the coastal Gulf of Alaska ***(2)*** The Gulf of Alaska's salp bloom of 2011: ignorance or harbinger of change?
- Alaska Marine Science Symposium – Anchorage, Alaska (January 2014) - **Presentation:** Measuring the pulse of the Gulf of Alaska: Seward Line, 1997-2013
- All 2012 and prior, data sets and associated metadata have been uploaded to the program's data portal

- 2013 raw CTD profiles and underway data uploaded to website following each cruise.

9. Response to EVOSTC Review, Recommendations and Comments: *See,* Reporting Policy at III (C) (9).

The EVOS reviews were favorable to the Seward Line component – no action required

10. Budget: *See,* Reporting Policy at III (C) (10).

Please see attached budget work book.

I. OCEANOGRAPHIC CONDITIONS IN PRINCE WILLIAM SOUND –CAMPBELL (PWSSC - 12120114-E)

1. Project Number: *See,* Reporting Policy at III (C) (1).

12120114-E

2. Project Title: *See,* Reporting Policy at III (C) (2).

Long term monitoring of oceanographic conditions in Prince William Sound

3. Principal Investigator(s): *See,* Reporting Policy at III (C) (3).

Robert W. Campbell

4. Time Period Covered by the Report: *See,* Reporting Policy at III (C) (4).

February 1, 2013-January 31, 2014

5. Date of Report: *See,* Reporting Policy at III (C) (5).

March 1, 2014

6. Project Website (if applicable): *See,* Reporting Policy at III (C) (6).

www.gulfwatchalaska.org

7. Summary of Work Performed: *See,* Reporting Policy at III (C) (7).

The six planned surveys of Prince William Sound were conducted during the reporting period (table I-1), and all 12 standard stations (fig.1) were occupied. Two CTD casts were found to have missing data after the first cruise, caused by setup problems with a new model of seabird CTD purchased in 2013 under another project; the problems were rectified through the manufacturer before the second cruise. The Satlantic SUNA nitrate sensor on the CTD was destroyed by flooding in June (a polycarbonate bulkhead connector failed). The PWSSC's insurer has declined to cover the loss (~$15K), so the project will have to go forward without the sensor, using nitrate measured from water samples.

All CTD data has been processed, seasonally detrended anomalies of temperature and salinity are shown in fig. I-2 and I-3. There were generally warmer than average surface temperatures during winter at most stations, and a warmer than average summer. Below the surface the picture was often the opposite, with cooler anomalies. Surface salinity during winter was trended toward more saline conditions, while salinity anomalies in the summer trended towards fresher than average (often by a considerable margin), particularly at the nearshore head-of-bay stations. Again, the sign of the anomaly was often different at depth, when compared to the surface. Work is ongoing to put these observations into the context of the ~30 year CTD database.

Plankton, nutrient, and chlorophyll-a samples were collected from all stations with no incidents. As of January 2014 All plankton samples have been enumerated (both from this project and the Lower Cook Inlet samples), and all chlorophyll-a filters have been run. Analysis of the nutrient samples continues to lag behind expectations – the protocols for capillary electrophoretic (CE) analysis of

macronutrients are still actively in development by a chemistry technician at PWSSC. All nutrient samples are being kept in frozen storage, and are stable indefinitely (they are 0.2 μm filtered prior to freezing). Catching up on the backlog is a priority, and if progress is not made soon on the CE methodologies (in Q1 of 2014), we will start working through the backlog using standard wet-chemical techniques.

The Autonomous Moored Profiler (AMP) mooring was tested in Nelson Bay near Cordova in May-June, testing was suspended after the local cellular provider switched off all cellular data in June (telemetry to/from the system is by a cellular data link). It was found early on that the floatation foam could not tolerate a 60 m cast (it compressed and lost buoyancy). This project is doing the deepest deployment to date of this system, and the compression of the foam was something of a surprise to the manufacturer. The profiler was fitted with temporary PVC flotation to finish out the year, and will be fitted with syntactic foam for 2014 deployments. A short deployment was done in June at the AMP site in central PWS with high frequency cycling (a cast every 30 minutes), and the system was recovered when battery voltage became low. A second longer deployment was done in late August, with casts conducted every 24 h into late September. That deployment worked fairly well, and the time series of temperature and salinity shows the breakdown of stratification during autumn storms (fig. I-4). In sum, although the AMP system did not perform flawlessly, we have learned a great deal about the many failure modes. This system is a bleeding-edge technology (this model is serial number 7), and some issues are to be expected, particularly given that this is by far the most northerly, coldest, deepest, and most remote deployment of such a system to date. We will use what we have learned in 2013 to ensure successful deployments in 2014, and anticipate deploying the profiler in April 2014 to capture the spring bloom at daily resolution.

Table I-1. Status of project milestones for year 3.

Deliverable/Milestone	Status
PWS Survey	Completed, 7 March 2013
PWS Survey	Completed, 7 May 2013
PWS Survey	Completed, 6 June 2013
PWS Survey	Completed, 26 August 2013
PWS Survey	Completed, 1 October 2013
PWS Survey	Completed, 8 November 2013
Process CTD data	Completed, 8 January 2014
Enumerate Plankton samples	Completed, 15 January 2014
Chlorophyll-a measurements	Completed, 15 January 2014

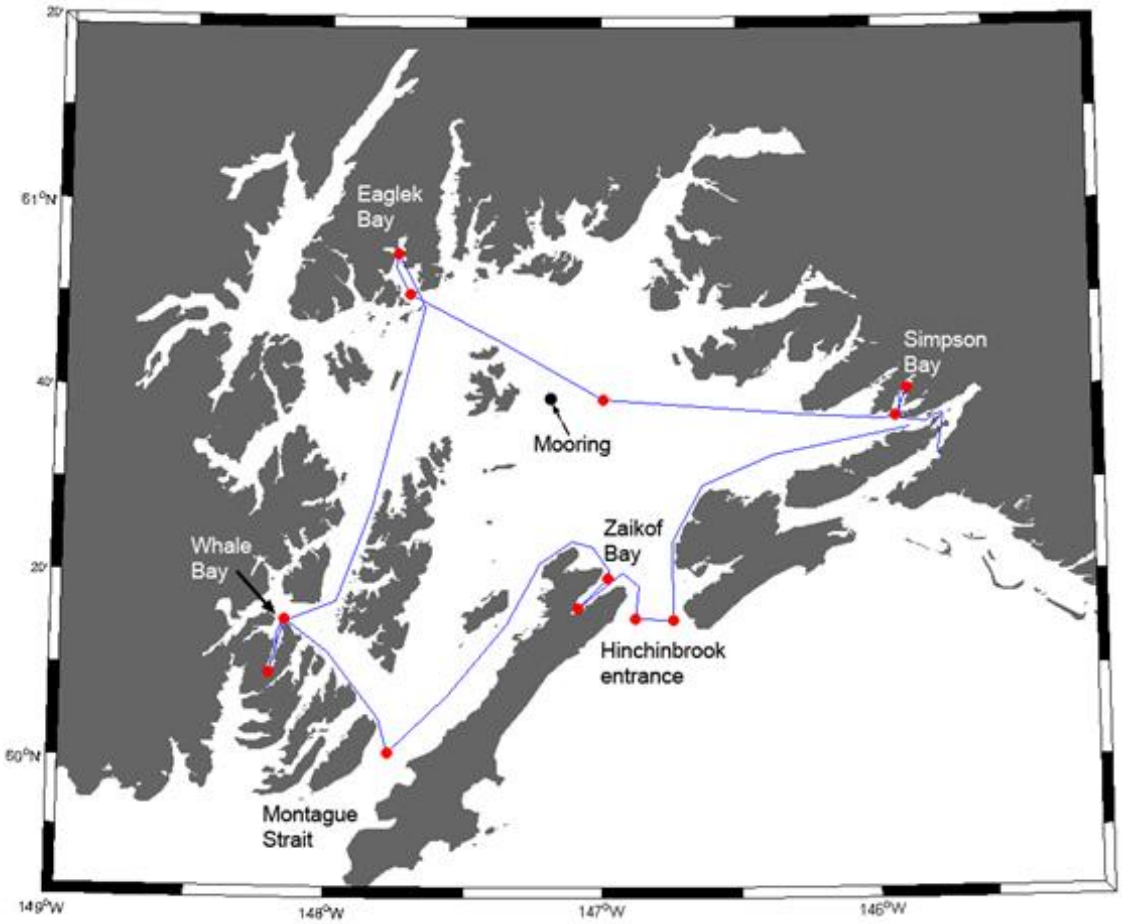


Figure I-1. Map of the standard cruise track and stations, and the location of the AMP mooring.

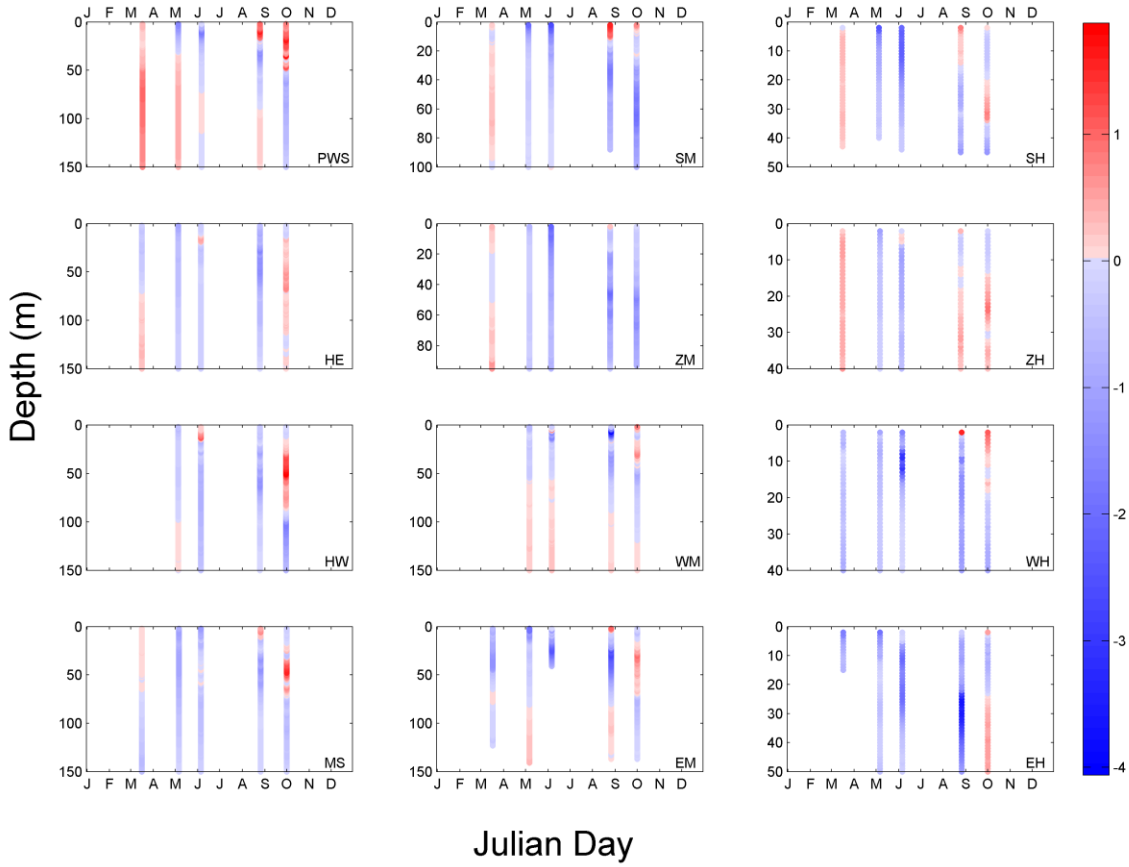


Figure I-2: Depth-specific temperature anomalies at the 12 standard cruise stations occupied during 2013. The plots are arranged columnwise, with the first column being more open water stations (central PWS, the east and west sides of Hinchinbrook Entrance, and Montague Strait (station codes at the bottom right of each panel should be sensible to the reader); the second column is stations at the mouth ("M") of the bays, and the third column is stations at the heads ("H") of the bays. Bays are denoted by the first letter of the code inside each plot (S = Simpson, Z = Zaikof, W = Whale and E = Eaglek). Note that the head of bay stations have different scaling on the ordinate. Anomalies were calculated on 1-m depth binned data by subtracting from the long term average for temperature at each geographical location and depth; the long term average is a second order cosine fit to a ~30 year database of CTD casts in the PWS region. A detailed description of the procedure is given in the report for the EVOSTC project which preceded the current project (10100132A: PWS herring survey: Plankton and oceanographic observations).

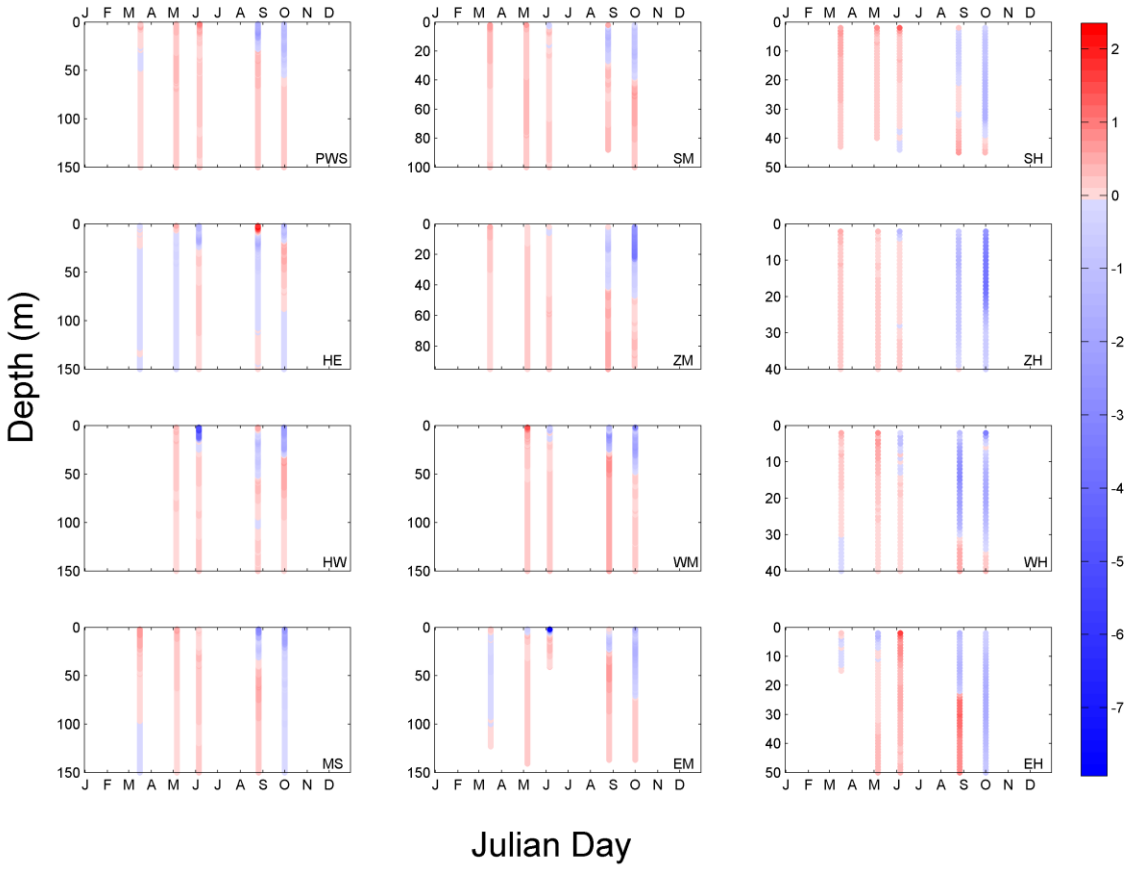


Figure I-3: Depth-specific salinity anomalies at the 12 standard cruise stations occupied during 2013. Station arrangement and anomaly calculation procedure are as described in fig. 2 for temperature.

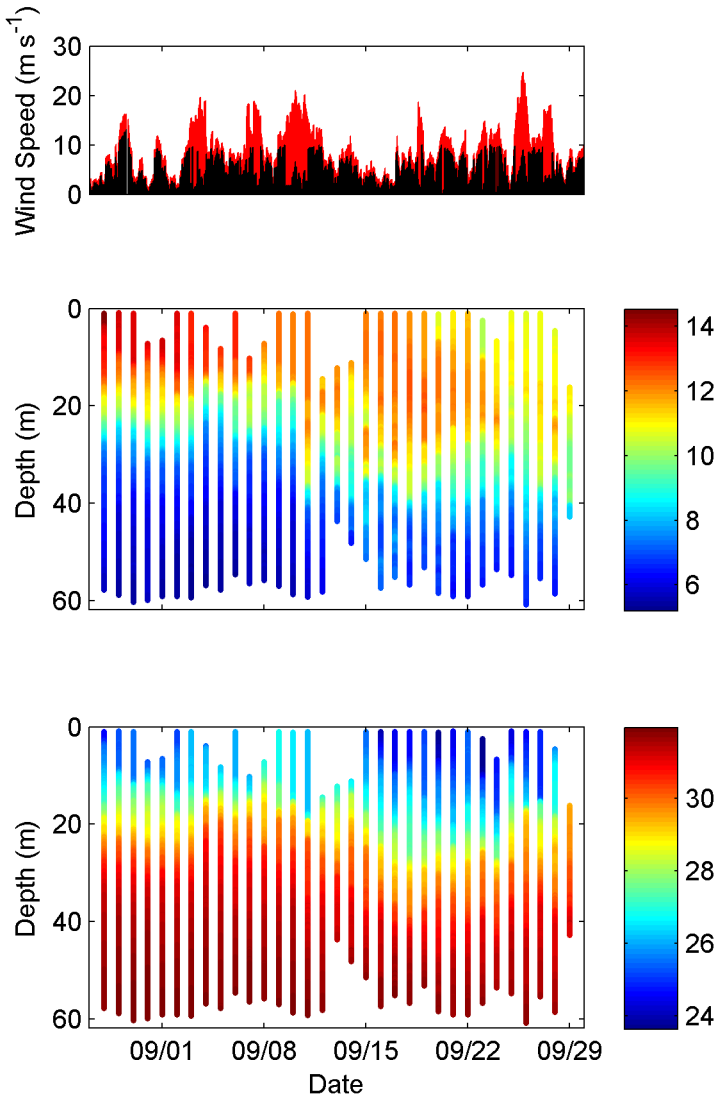


Figure I-4: Time series from the August-September deployment of the PWS AMP mooring. Top panel: sustained winds (black) and gusts (red) recorded at the mid sound buoy (buoy #46060). Middle panel: Temperature time series from daily casts. Bottom panel: Salinity time series from daily casts. Time scaling along the abscissa is the same among all the panels.

8. Information and Data Transfer: See, Reporting Policy at III (C) (8).

Campbell, R.W. 2013. PWS herring survey: Plankton and oceanographic observations. Presentation at EVOS Herring project PI meeting, March 2013, Juneau.

Campbell, R.W. 2014. State of the Sound: Trends in the surface oceanography of Prince William Sound. Poster presented at Alaska Marine Science Symposium, January 2014.

Joint presentation: Environmental drivers. Gulfwatch AK PI meeting, November 2013.

All CTD, chlorophyll-a, and zooplankton data collected in FY13 have been uploaded to the ocean workspace.

9. Response to EVOSTC Review, Recommendations and Comments: *See,* Reporting Policy at III (C) (9).

In its review of the 2013 work plan, the EVOSTC Science Panel expressed concerns about best practices for the treatment of physical oceanographic data. The LTM program team leads responded to those concerns in their response to the review, and need not be repeated here. Further to those concerns, the sampling protocol for this project (located on the data workspace) has been updated to include more detail on QA/QC procedures and best practices. The protocols used by PWSSC have been developed by several physical oceanographers on staff over the years (most recently by Claude Belanger, Mark Halverson, and W. Scott Pegau), and the protocol used by Campbell is based on that, as well as his training with oceanographers at the Canadian Department of Fisheries and Oceans , Dalhousie University, the University of British Columbia, and the University of Victoria. The Environmental Drivers component leads have been working together on a plan for archiving of the various CTD datasets produced by each sub-component. In the meantime, the CTD data collected by this project has been uploaded to the workspace in its entirety for each cruise, including raw data, processed data (with a subdirectory for each processing step), calibration files, and event logs (with scans of the paper logs, and in electronic format). The processing steps taken and file formats have been outlined in an appendix to the sampling protocol, and the format of the data file is consistent among cruises. Once the best format for archiving has been decided, code to translate the data into the appropriate format may be produced in very short order.

There was also concern expressed by the science panel about calibration frequency for the moored instrumentation, that the instrument should be calibrated prior to every deployment. We have consulted with the manufacturer's recommendations for Seabird CTDs[1] and UNOLS[2], and conclude that an annual service interval is appropriate. In addition, we take care to thoroughly clean all instruments and plumbing following deployment, and store them according to the manufacturer's recommendations. The plumbing system on the mooring additionally has antifouling devices ("kill cells") attached, and is plumbed with copper tubing (for straight runs) and black Tygon tubing (tight curved runs) in order in minimize biofouling. The on board fluorometer also has a copper-covered bio wiper to prevent biofouling and keep the optics clean. In addition, a CTD cast is done before and after every deployment of the profiler, to have data for cross-validation with a second instrument.

The Science Panel also questioned the various net meshes used by the various subcomponents for their plankton collections. This lead to a long and spirited discussion among the subcomponent leads at the November PI meeting on mesh size standardization. The consensus was that the various subcomponents have different logistical requirements and expectations, and standardization to a single net mesh will adversely impact the different time series. A white paper

[1] http://www.seabird.com/FAQs/FAQsService.htm#CalibrationSchedule
[2] http://www.seabird.com/FAQs/FAQsService.htm#CalibrationSchedule

on the topic was developed by Sonia Batten, and will be included as an appendix to her annual report. It was further decided (based on prior work by Russ Hopcroft) that the best way to standardize among projects is to use a high quality flowmeter mounted within the plankton nets, to measure the amount of water sampled by the net (which will vary with mesh size, smaller meshes being less efficient). This project has been using such a flowmeter (a calibrated Hydro-bios electronic flowmeter) since its inception. In addition, Campbell and Hopcroft will do some intercomparisons between their different gears and sampling depths at their central PWS stations in 2014.

10. Budget: *See,* Reporting Policy at III (C) (10).

Please see attached budget workbook.

J. Oceanographic Conditions in Kachemak Bay and Lower Cook Inlet, Doroff and Holderied (KBRR,NOAA , 12120114-G)

1. Project Number:

12120114G

2. Project Title:

Long-term monitoring of oceanographic conditions in Cook Inlet/Kachemak Bay to understand recovery and restoration of injured near-shore species

3. Principal Investigator(s):

Angela Doroff (Kachemak Bay National Estuarine Research Reserve), Kris Holderied (NOAA Kasitsna Bay Laboratory)

4. Time Period Covered by the Report:

February 1, 2013-January 31, 2014

5. Date of Report:

March 1, 2014

6. Project Website (if applicable):

www.gulfwatchalaska.org

7. Summary of Work Performed:

Field Sampling: Oceanographic and Plankton Surveys

Our oceanographic survey areas are located in lower Cook Inlet (Transects 3, 6, and 7) and in Kachemak Bay (Transects 4 and 9) (Figure J-1). We survey the outer Kachemak Bay and lower Cook Inlet transects quarterly with a chartered vessel and the mid-Kachmak Bay transect (Transect 9) monthly from our small boats. With the available charter vessel time in this project, the northern (Transect 3) and southern (Transect 6) lines are the primary sampling lines in lower Cook Inlet, with sampling also conducted on the middle line (Transect 7) when conditions allow. Oceanographic data is collected with vertical conductivity-temperature-depth (CTD) profiler stations (Figure J-1), using Seabird Electronics 19plus profilers. Plankton sampling is conducted at three of the stations along each transect. Figure 2 illustrates the along-transect bathymetry and station locations for each transect. Vertical zooplankton tows are conducted with 333 µm bongo nets and surface water is filtered through 20 µm nets for phytoplankton sampling. Oceanographic and plankton sampling, including instrument calibration, data collection, sample processing and data analysis, are conducted in accordance with the project sampling protocol (available on the Ocean Workspace). We are also coordinating oceanographic and zooplankton sampling protocols with other principal investigators (PIs) through Environmental Drivers component group meetings.

The sample collection dates and locations are summarized in Table J-1 for year one and two of this study. In 2013, we conducted 297 conductivity-temperature-depth (CTD) stations in lower Cook Inlet and Kachemak Bay. Monthly Kachemak Bay oceanographic and plankton surveys were conducted along Transect 9 from February 2013 through January 2014 with the exception of November 2013, when sampling was not conducted due to weather and boat issues. Quarterly lower Cook Inlet surveys were successfully completed in April and July 2013 but only the Kachemak Bay portion of the survey could be completed in February 2013 due to adverse weather conditions. An additional along-bay transect was completed in Kachemak Bay along with Transects 4 and 9. The fall quarterly survey was conducted over a two week period in late October and early November 2013, due to a long period of adverse weather conditions. Fall sampling was completed on all the primary transects (3, 4, 6 and 9), but we did not have enough charter vessel time to sample Transect 7. During summer 2013, we leveraged help for field work and data analysis from NOAA Hollings Scholar undergraduate summer interns at NOAA Kasitsna Bay Laboratory and additional funding from the NOAA Integrated Ocean Observing Program/Alaska Ocean Observing System. These partnerships allowed us to conduct additional intensive small boat CTD surveys during June and July, to assess tidal and spatial variability of marine conditions in Kachemak Bay.

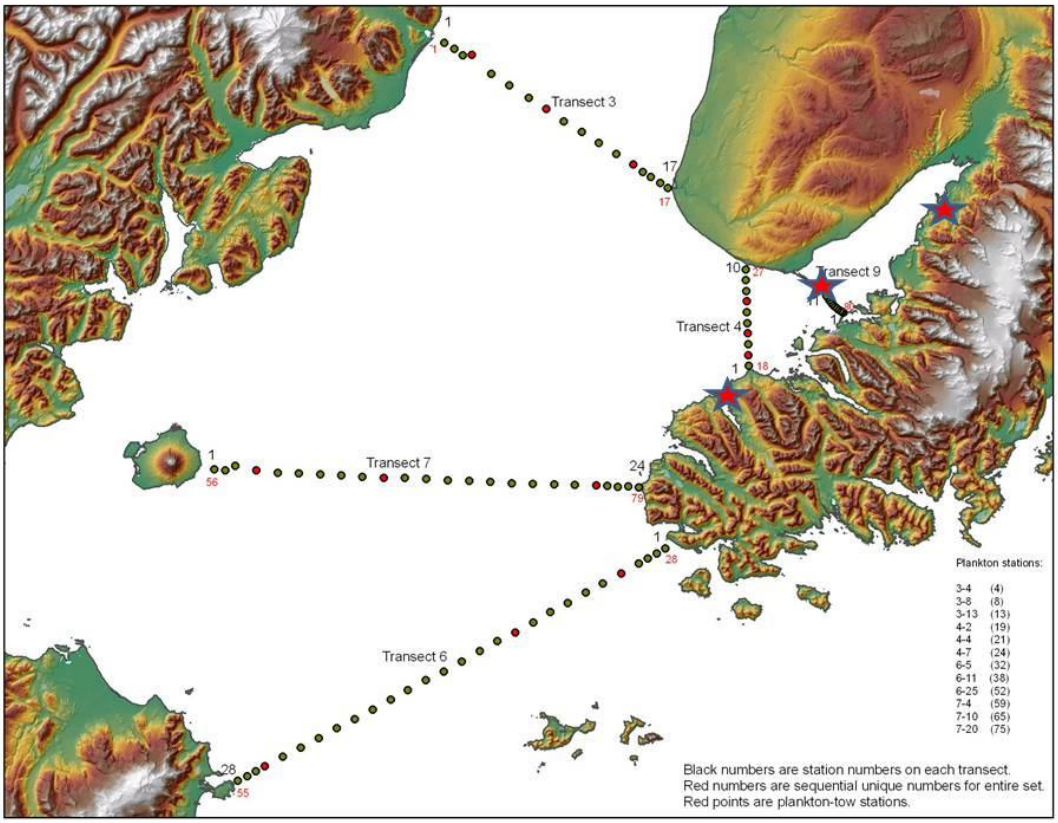


Figure J-1 Lower Cook Inlet and Kachemak Bay transects and sampling station locations for oceanographic sampling by CTD (all stations marked with dots) and phytoplankton and zooplankton sampling (red dots). Transects 3, 4, 6, and 7 are sampled quarterly and Transect 9 is sampled monthly. Stars indicate the location of water quality and nutrient monitoring stations in Kachemak Bay at the Homer and Seldovia Harbors and seasonally in Bear Cove.

Oceanographic monitoring:

Two SeaBird Electronics 19plus CTD profilers, from NOAA Kasitsna Bay Laboratory and KBNERR) are used to collect vertical oceanographic profiles in the monthly small boat and quarterly charter vessel surveys. The instruments are calibrated annually at SeaBird Electronics. Oceanographic profile data are processed with standard Seabird Electronics algorithms, with results exported to Excel spreadsheets and visualized in graphs of salinity/temperature/density profiles (see example Figure J-5), along-transect contour maps and anomaly time series plots. Anomalies from the oceanographic data are being compared to climate indicies, including the Pacific decadal oscillation (PDO), to biological data collected in the intertidal zone by other Gulf Watch Alaska researchers (Brenda Konar and Katrin Iken) and to oceanographic data collected along the Seward Line (Russ Hopcroft), at the GAK1 mooring (Tom Weingartner) and in Prince William Sound (Rob Campbell). Results have been presented at the Alaska Marine Science Symposium in January 2014 and Kachemak Bay Harmful Algal Bloom conference in February 2014. We are leveraging the CTD data collected as part of this study and the KBNERR water quality station monitoring data to validate hindcasts of the newly developed National Ocean Service (NOS) Coast Survey Development Laboratory Regional Ocean Circulation Model of Cook Inlet and Kachemak Bay. The detailed validation effort is being conducted by KBNERR and University of Alaska, Fairbanks with additional grant funding. The ocean circulation model was originally developed by NOS to produce a tidal energy assessment of Cook Inlet, in partnership with the Alaska Energy Authority. We are adapting the model to assess local circulation patterns in Kachemak Bay and to provide an updated circulation map for the region.

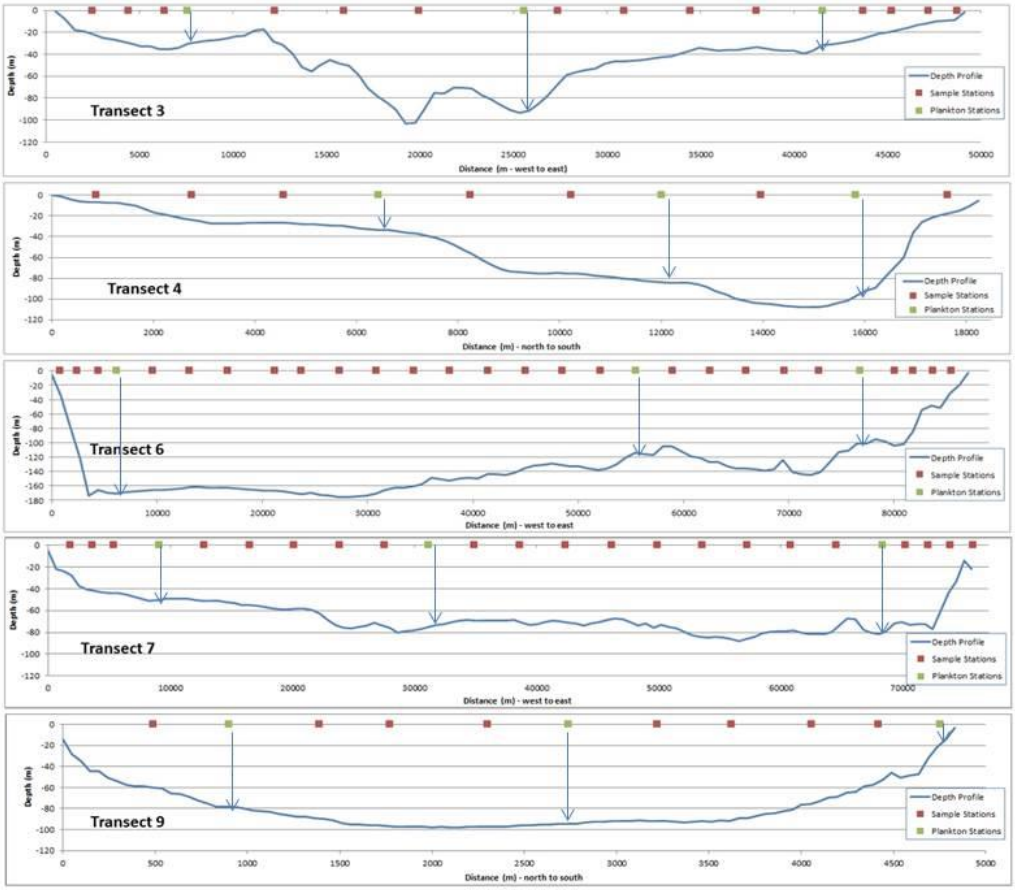


Figure J-2 Bathymetry of each transect sampled in the lower Cook Inlet and Kachemak Bay Gulf Watch Alaska project, with locations of CTD-only stations (red squares) and CTD, zooplankton and phytoplankton stations (green squares and arrows). Note that the horizontal distance (x-axis) and depth (y-axis) distance scales differ between the transect graphs.

Table J-1. Data and samples collected during 2012-2013 in lower Cook Inlet (transects 3,6, and 7) and in Kachemak Bay (transects 4,9) for the Environmental Drivers component of the Gulf Watch Alaska program.

Table 1. Data and samples collected during 2012-2013 in lower Cook Inlet (Transects 3, 6, and 7) and in Kachemak Bay (Transects 4 and 9) for the Environmental Drivers GulfWatch study.

		CTD					ZOOPLANKTON					PHYTOPLANKTON					OCEAN ACIDIFICATION				
		Transect No.					Transect No.					Transect No.					Transect No.				
Month	Year	3	4	6	7	9	3	4	6	7	9	3	4	6	7	9	3	4	6	7	9
April	2012					10					4					2					
May	2012	16	10	27	18	21	3	3	3	3	6	3	1	3	3	12					
June	2012					20					6					6					
July	2012	16	10	28	12	11	3	3	3	2	3	3	3	3	2	3			1		
August	2012					10					3										
October	2012	15	10	28	17	10	1		3	3	3	1		3	3	3		1	5	4	
January	2013					10					3					3					
	Σ=	47	30	83	47	92	7	6	9	8	28	7	4	9	8	29	0	1	6	4	0
February	2013		10			11		3			3		3			3		2			
March	2013					10					3					2					2
April	2013	16	10	23	24	10	3	3	3	3	3	3	3	3	3	2	2	1	4	3	1
May	2013					10					3					3					2
July	2013	16	10	28	23	10	3	3	3	3	3	3	3	3	3	3			4	4	
August	2013					10					3					3					
September	2013					10					3					3					
October	2013		10			10		4			3		7			9					
November	2013	16		20			3		3			3		3							
December	2013					10					3					3					
	Σ=	48	40	71	47	91	9	13	9	6	27	9	16	9	6	31	2	3	8	7	5

Water Quality Monitoring

Continuous data collection and reporting continued throughout the reporting period for the KBNERR System-wide Monitoring Program for meteorological, water quality, and monthly nutrient samples; all data are being quality controlled and archived through the NERR's Central Data Management Office. In year one, we purchased a YSI moored buoy system and deployed a data sonde to monitor water quality in Bear Cove; the system was up and running by mid July 2012 and was removed at the end of September 2012 for the winter and deployed again in March 2013 for the entire ice-free season. In 2012, all three surface water sondes were also upgraded to house a probe for continuous monitoring of chlorophyll-a (chl-a) in Kachemak Bay. Figure 3 illustrates results of chlorophyll-a monitoring in 2013, including continuous data from the probes and monthly data from water sampling. These graphs show only the results from the secondary NERRS QA/QC process, and not yet the final data review. This is important because it may illustrate likely fouling on the probe which produces "false peaks" in chl-a levels. Fouling was evident at all three sites this past year and we are working to clean up the data and identify the data gaps. However, we also had a couple large phytoplankton bloom events in July and late September/early October 2013. Water samples were collected and analyzed monthly for nutrients at each site throughout the monitoring period. The water quality sonde mooring in Bear Cove was telemetered to provide

researchers and local oyster farmers real-time access to the water quality data. We were able to provide local access to the data via the AOOS data portal.

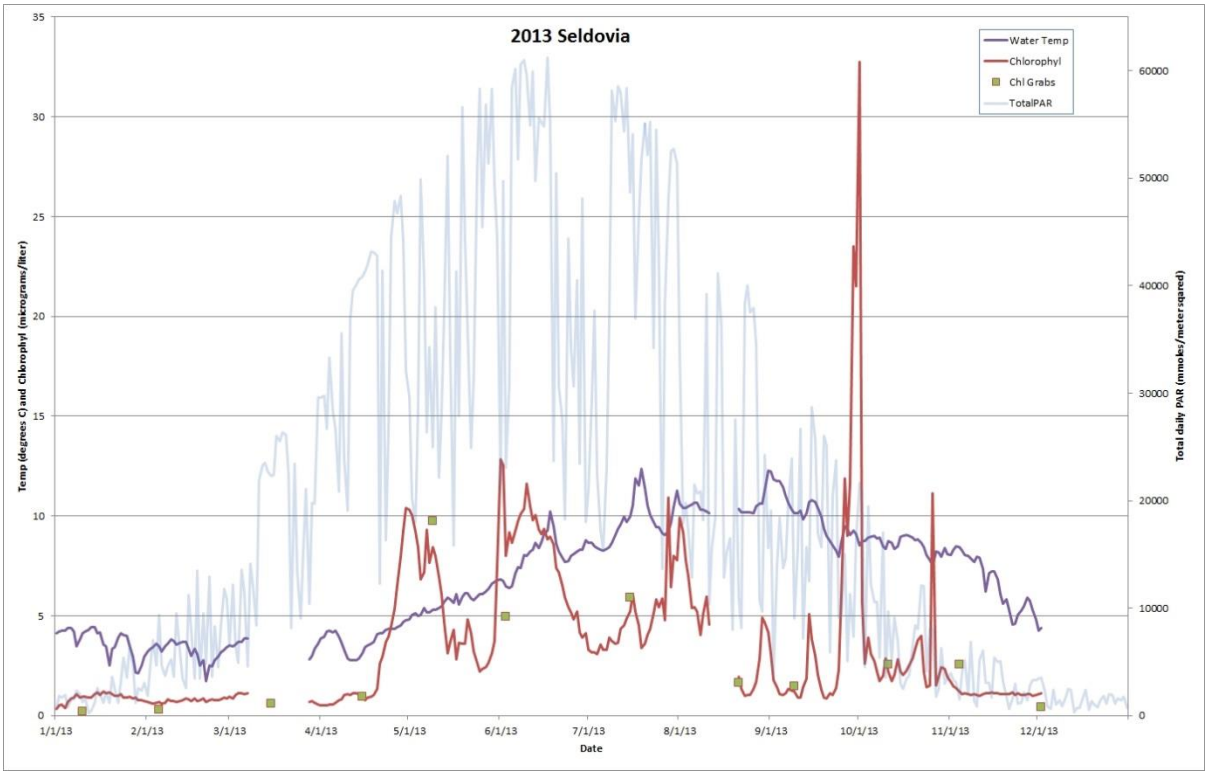


Figure J-3. 2013 data from the KBNERR water quality monitoring station at Seldovia harbor, including water temperature (dark blue line), photosynthetically available radiation (PAR – light blue line), continuous chlorophyll-a probe (red line), and monthly chlorophyll-a concentrations measured from filtered water samples (green squares). Chlorophyll probes are subject to fouling in the spring and summer months. The spike in late September may be evidence of fouling, but a widespread Karenia mikimotoi phytoplankton bloom also occurred in Kachemak Bay at that time.

Zooplankton Sampling

During this reporting period, 64 zooplankton samples were collected (Table J-1), preserved, and are being analyzed at the Prince William Sound Science Center. In Figure J-4, we show an example of the diversity of zooplankton in spring, summer, and winter in outer Kachemak Bay and the associated temperature and salinity profiles for Transect 4/Station4 (Figure J-5). All samples collected in 2012 have been analyzed at the Prince William Sound Science Center and our next steps with the data are to 1) complete sample analysis for 2013; 2) stratify the zooplankton samples by day and night time periods (Figure J-4); 3) categorize the zooplankton into broad groups that can be compared and contrasted across studies sites with other Gulf Watch Alaska projects such as the CPR data for lower Cook Inlet; 4) evaluate using a smaller mesh size to capture early life stages of small and large copepods; 5) evaluate water volume calculations for our samples under a variety of field conditions,; and 6) evaluate the sampling location along the transect for the

zooplankton samples with respect to potential convergence zones based on bathymetry (Figure J-2).

Biological samples collected in lower Cook Inlet and outer Kachemak Bay are subject to weather conditions and scheduling maximum efficiency for the ship charter time. As a result, samples are collected during both day and night time periods. Before we can examine zooplankton diversity and relative abundance of species, we need to stratify the data into day and night time collection periods. This is most typically done by sun rise and sun set tables, however, we also can use the ovalues for Kachemak Bay that can be correlated to sampling time. The majority of our zooplankton samples were collected during daylight hours and Figure J-6 illustrates the broad range of PAR values that we have during "day" time periods in our study area.

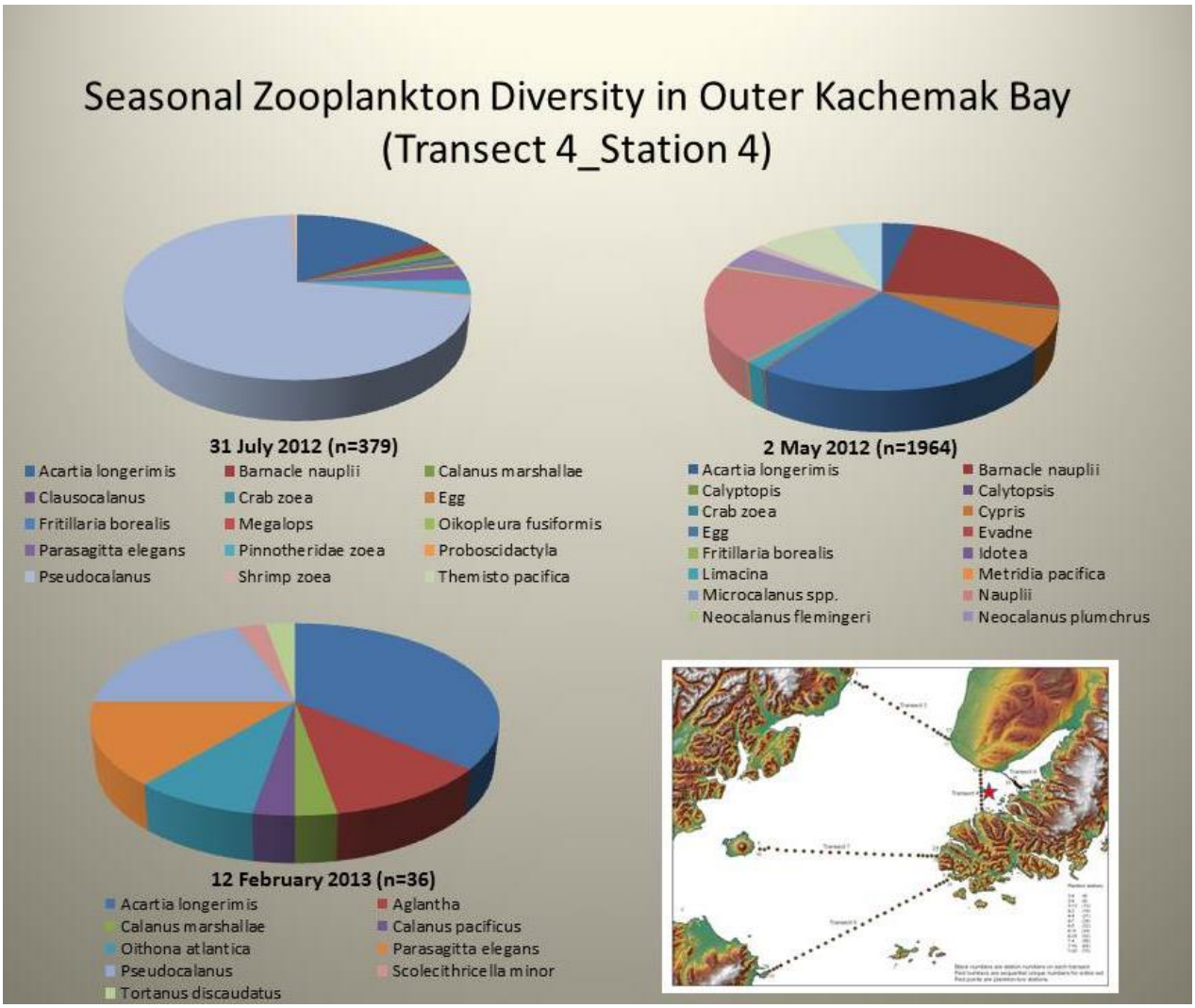


Figure J-4. Diversity of zooplankton in samples collected in outer Kachemak Bay, Alaska during spring (2 May 2012), summer (31 July 2012), and winter (12 February 2013) on Transect 4/Station4 with a bongo-style net (333µm mesh and vertical tow from 50m).

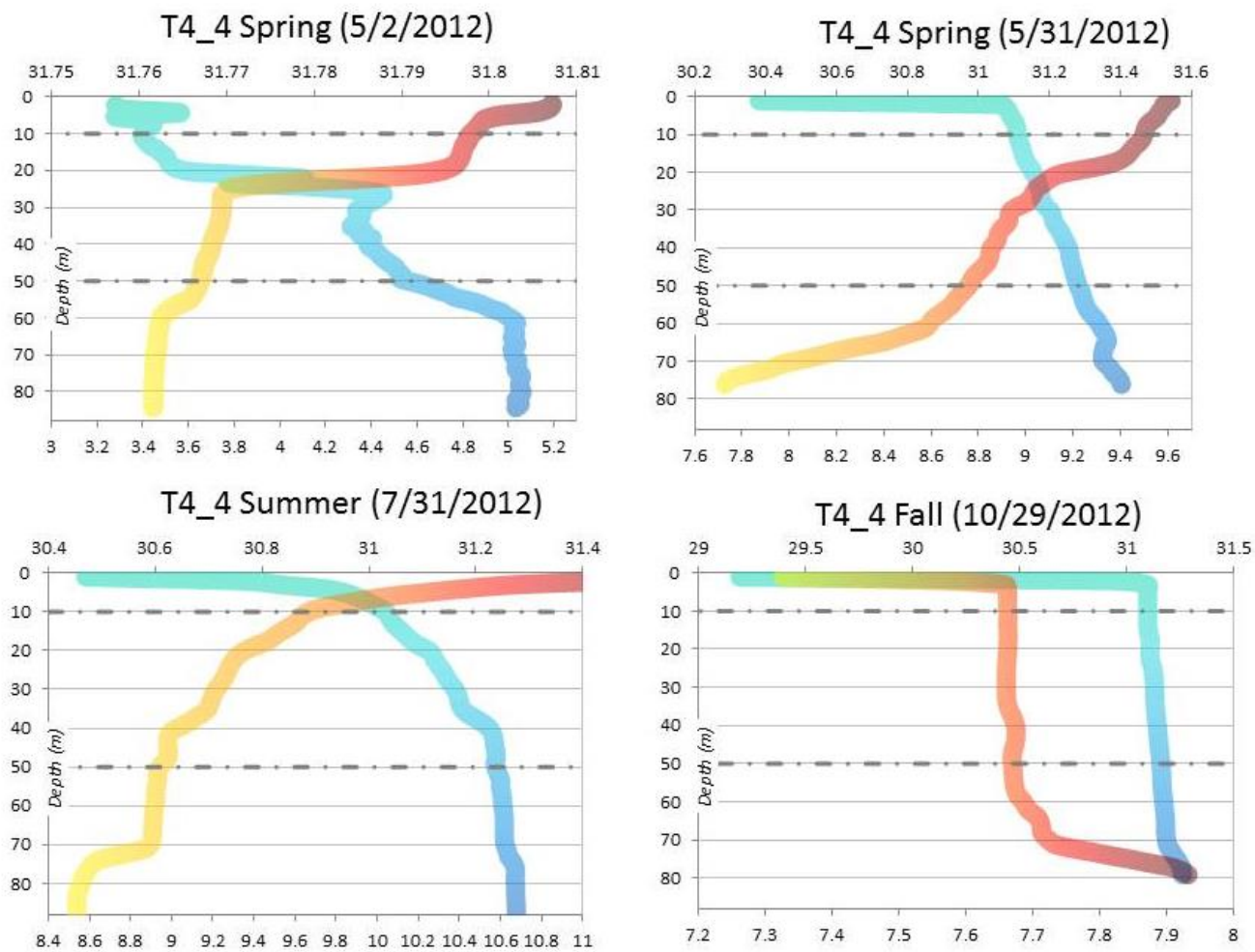


Figure J-5. Example vertical ocean water profiles of temperature and salinity from CTD stations along Transect 4 (outer Kachemak Bay) /Station 4 during spring, summer, and fall sampling periods during 2012. The yellow/red line is ocean temperature (degrees C, bottom axis) and the blue line is salinity (PSU, top axis). Depth in meters is on the y-azis. Increased stratification of the upper 10-20 meters is a persistent feature in Kachemak Bay and Cook Inlet, away from the convergence zones associated with tide rips, and can be seen in all profiles here, except in the fall.

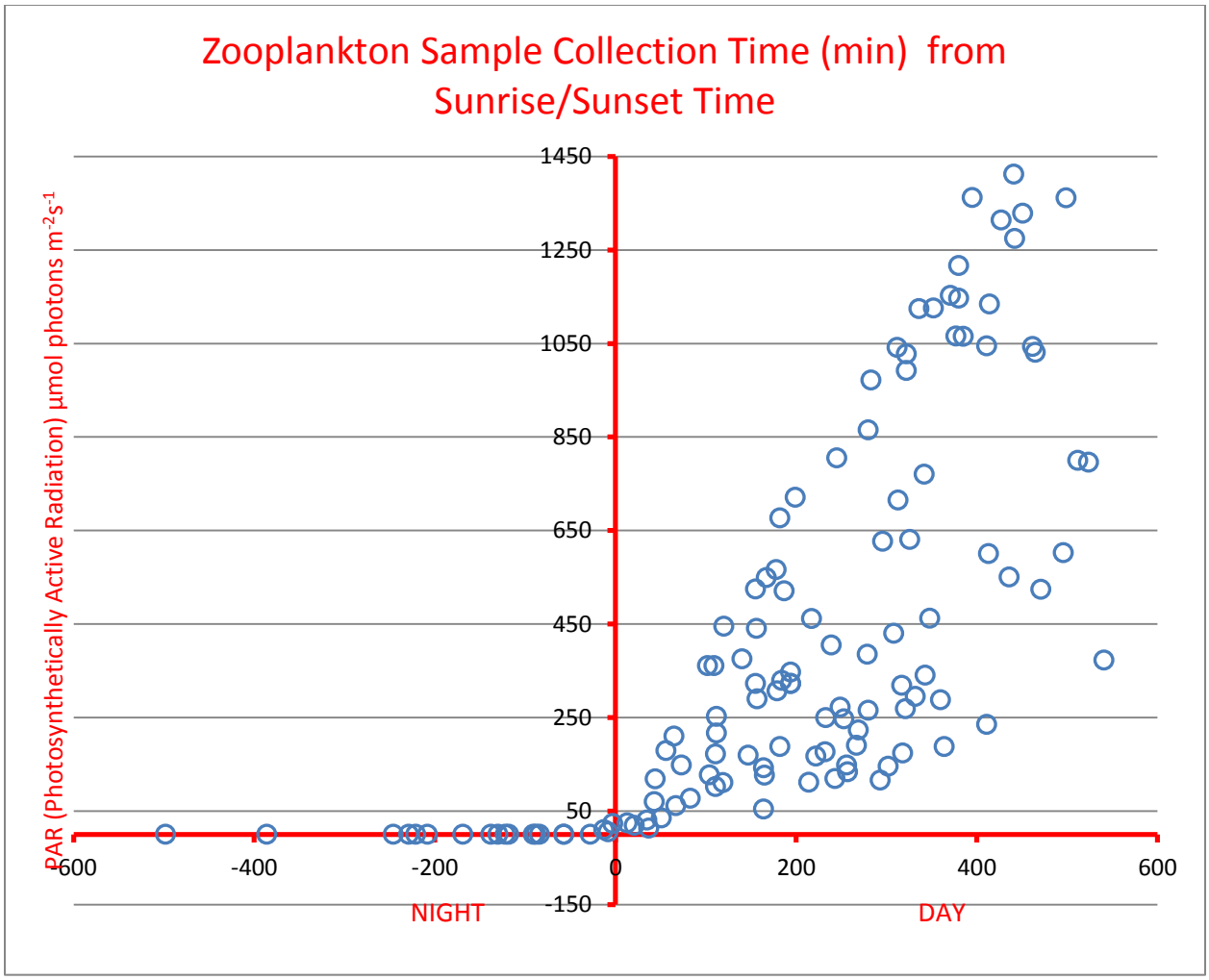


Figure J-6. Sample collection times for zooplankton are compared to photosynthetically available radiation (PAR) data that were obtained from the KBNERR Homer Spit weather station. PAR values are plotted relative to number of minutes from sunrise and sunset times (data were obtained on line from the U.S. Naval Observatory).

Phytoplankton Sampling

In 2013, we collected and processed 71 phytoplankton samples from filtered surface water samples collected, preserved, and analyzed during our sampling efforts in lower Cook Inlet and Kachemak Bay. Phytoplankton samples were collected during all monthly and quarterly shipboard surveys, at the same stations where zooplankton sampling was conducted. Phytoplankton samples were visually identified and enumerated using a light microscope and volumetric Palmer counting cells at Kasitsna Bay Laboratory. A subset of the samples was also analyzed at our sister NOAA/NOS/National Centers for Coastal Ocean Science (NCCOS) laboratory in Beaufort NC, using the more sensitive molecular technique of quantitative polymerase chain reaction assay (qPCR).

In addition to quantifying phytoplankton concentrations we also compared total cell abundances from two frequently sampled locations, the Kasitsna Bay Laboratory dock and Transect 9, with nutrient data obtained from the Kachemak Bay Research Reserve's System Wide Monitoring

Program (SWMP). The data are compared from early spring 2012 through fall 2013. Phytoplankton data from the Kasitsna Bay site were compared to nutrient data collected from the Seldovia harbor SWMP station and the nutrient data from the Homer ferry dock water quality station were compared to plankton data from Transect 9, Station 10, located near the end of the Homer Spit where the ferry dock is located. The Kasitsna Bay site shows that as phytoplankton abundances increase in early spring there is a drawdown in nutrients that persists through August when concentrations begin to drop and nutrient concentrations begin to rise, reaching their highest concentrations in December and January (Figure J-7). The same trend is seen in Figure J-8 for Transect 9, Station 10 (Sta. 9-10).

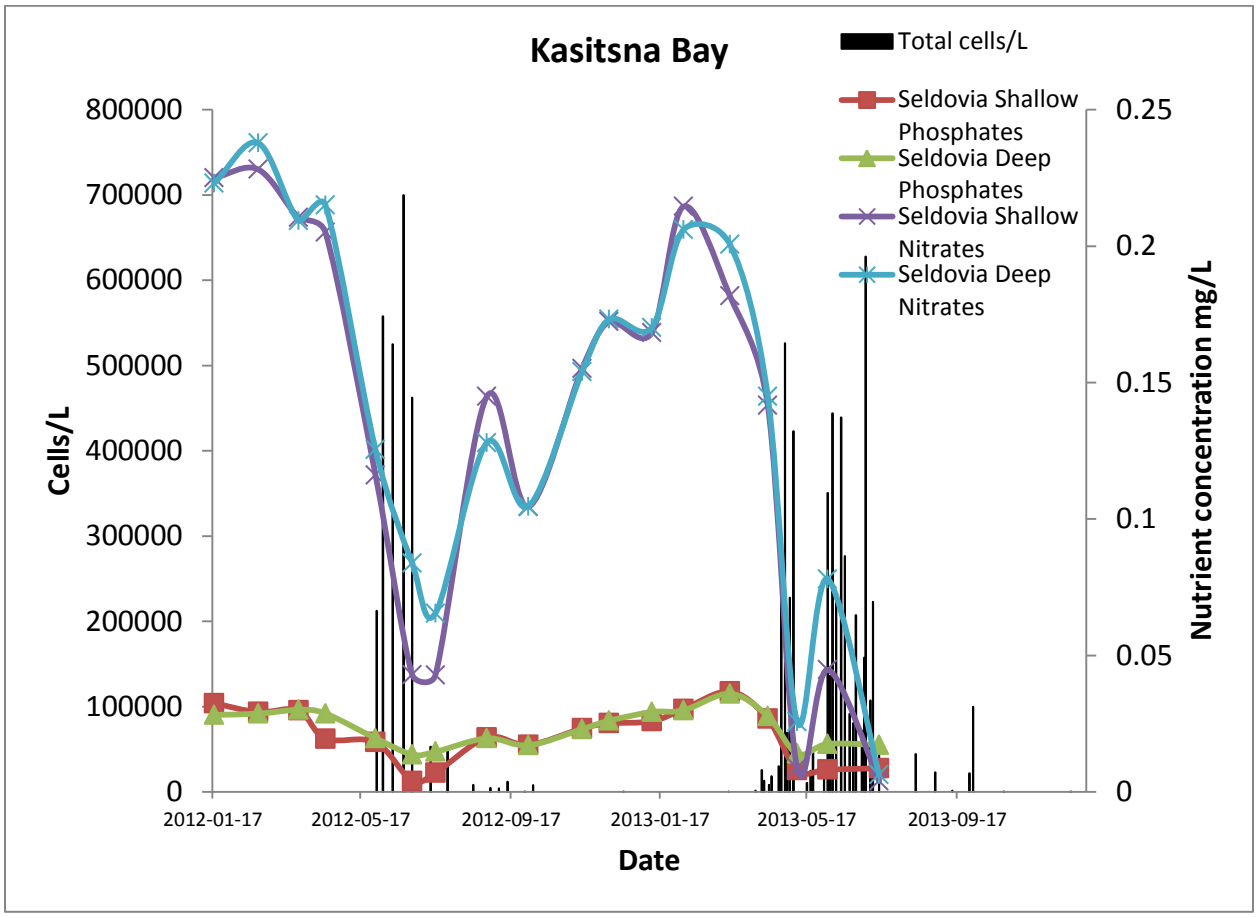


Figure J-7. A comparison of phytoplankton cell abundances measured at the NOAA Kasitsna Bay Laboratory dock with nutrient data from the Kachemak Bay NERR water quality station at Seldovia harbor, from January through November 2013. Total cell abundance (cells/liter) is shown in black and nutrient concentrations (milligram/liter) are shown in color.

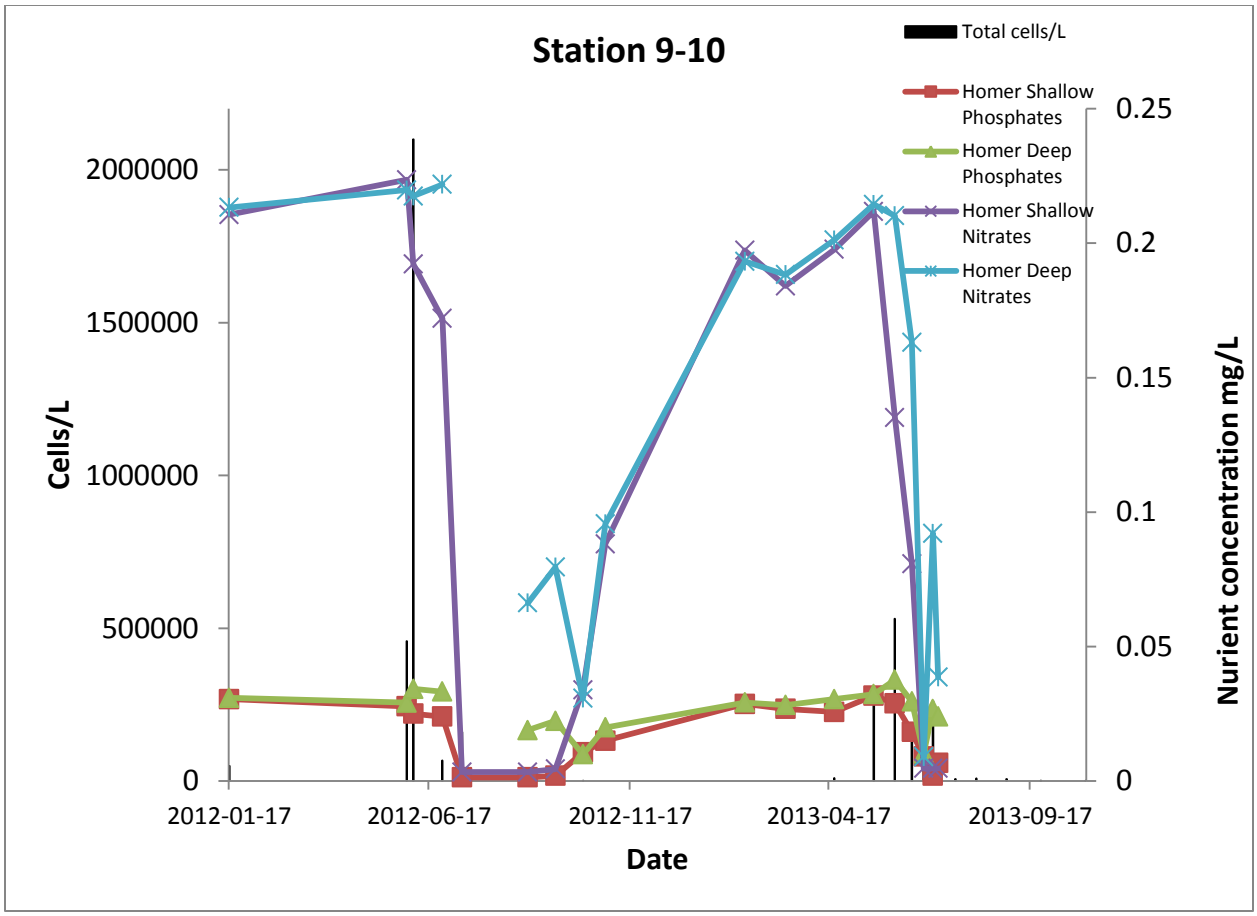


Figure J-8. A comparison of phytoplankton cell abundances collected at station 9-10 (north end of Transect 9 near Homer Spit) with nutrient data from the KBNERR SWMP station at Homer harbor, from Jan 2012 through fall 2013. Total cell abundance (cells/liter) is shown in black and nutrient concentrations (milligram/liter) are shown in color.

Coordination/Collaboration: We continue to coordinate our oceanographic and zooplankton sampling methods and analyses with other Environmental Drivers component PIs through component group meetings and individual discussions. At the November 2013 annual PI meeting we also began planning for component synthesis reports for the February 2015 EVOSTC science synthesis meeting. Zooplankton analyses are being done in collaboration with Rob Campbell at the PWSSC (funded on another Gulf Watch Alaska project). During the November 2013 PI meeting, we developed a strategy for making the zooplankton data comparable across all Gulf Watch Alaska programs; this will result in some changes in methods to our project for 2014. During all outer Kachemak Bay and lower Cook Inlet surveys, we were able to collect 25 water samples to support an ocean acidification sampling program done by NOAA Kasitsna Bay Laboratory in collaboration with the Alaska Ocean Observing System (AOOS) and University of Alaska Fairbanks. We hosted U.S. Fish and Wildlife Service staff from the At Sea Observer Program, who collected information on seabird and mammal distributions during the April and July 2013 seasonal surveys.

Community Involvement/TEK and Resource Management Application: We were able to acquire a KBNERR State Wildlife Grant to utilize data obtained in this study and other ongoing KBNERR monitoring programs to validate the NOAA National Ocean Service Cook Inlet ocean circulation model; we are still in the early phases of setting up the model code for validation. The enhanced chlorophyll-a monitoring done by our EVOSTC project during the summer months is providing additional information for a KBNERR-supported, community harmful algal bloom monitoring program. These data help community monitors and local oyster farmers interpret oceanographic conditions relative to phytoplankton blooms. Results from the first two years of this project were presented at the Kachemak Bay HAB monitoring workshop in February 2014, which brought together state, federal and university researchers, Alaska Department of Fish and Game shellfish managers, Alaska Department of Environmental Conservation public health officials, oyster farmers and community members. The assessment of ocean acidification variability in Cook Inlet and Kachemak Bay, which is supported by boat time from this project to collect water samples, is an area of local concern from oyster farmers and fishermen.

Table J-2. Status of project milestones for year 2

Deliverable/Milestone	Status
Monthly Kachemak Bay CTD & plankton surveys	Completed Feb-Oct 2013, Dec 2013, and Jan 2014 missed Nov 2013
Quarterly Lower Cook Inlet/Kachemak Bay CTD & plankton surveys	Completed, February (partial), April, July, Oct-Nov (partial)
Annual PI Meeting	Completed, November 2013
AMSS PI Meeting	Completed, January 2014

11. Information and Data Transfer: See, Reporting Policy at III (C) (8).

Information Transfer

No publications were produced during the reporting period. Quarterly updates on this project were made to the Kachemak Bay Research Reserve's Community Council and a poster presentation and a spoken presentation were made at the 2014 Alaska Marine Science Symposium (see titles and authors below). Public presentations using project data were also made in July 2013 by three NOAA Hollings Scholar interns in Seldovia, at the KBNERR Brown Bag Seminar Series in Homer and at the NOAA Office of Education Science and Education Symposium in Silver Spring, MD. During summer 2013, Doroff, Holderied, other project scientists and the Hollings interns provided science outreach for the general public and school groups at a KBNERR Discovery Lab on the Gulf Watch Alaska project.

Presentations:

Brainard, S. Jul 2013. So Much Data, So Little Time: Inter-Annual Ocean Circulation Trends in the Gulf of Alaska. Talks for Seldovia Library seminar series, KBNERR Brown Bag seminar series and NOAA Science and Education Symposium.

Ko, S. Jul 2013. Trends and Variability Between pH, Nutrients and Chlorophyll a in Kachemak Bay,

Alaska. Talks for Seldovia Library seminar series and KBNERR Brown Bag seminar series. Poster presentation at NOAA Science and Education Symposium.

Pickens, C. Jul 2013. Whatcha know about phytoplankton: Establishing a baseline in Kachemak Bay, AK. Talks for Seldovia Library seminar series, KBNERR Brown Bag seminar series and NOAA Science and Education Symposium.

Hondolero, D., K. Holderied, and C. Pickens. Jan 2014. Bloom and bust: monitoring phytoplankton populations in Kachemak Bay". Poster presentation at Alaska Marine Science Symposium

Data Transfer

- CTD data sets and associated metadata from 2012 have been uploaded to the AOOS Ocean Workspace and published on the Gulf Watch Alaska data portal.
- Zooplankton data and associated metadata that has been analyzed to date are available on the AOOS Ocean Workspace but have not yet been uploaded to the data portal.
- Water quality data from Bear Cove, Homer and Seldovia water quality data sondes and associated metadata have been uploaded to the Ocean Workspace and are published on the Gulf Watch Alaska data portal.

12. Response to EVOSTC Review, Recommendations and Comments: *See,* Reporting Policy at III (C) (9).

We are near the end of Year 2 of the 5-year program, with vessel contracts established through June 2014, and therefore cannot change the sampling design as suggested by the Science Panel, since much of the quarterly sampling has already been accomplished. We agree that it would be preferable to continue quarterly sampling in years 4 and 5 and have leveraged funding from other sources to be able to accomplish more sampling in years 4 and 5 than was originally proposed, while not increasing the requested funding from the Trustee Council. We reduced the sampling plan to fit within the overall budget limit for the program and still accomplish our primary goals. We decided to conduct quarterly sampling in lower Cook Inlet (in addition to monthly sampling in Kachemak Bay) in the first 3 years to improve assessment of seasonal variability, particularly of fall and winter conditions. We considered conducting less frequent sampling during the year to maintain consistency over 5 years, but determined that collecting data to assess seasonal variability was an important information gap to fill, particularly as we are interested in shelf-estuary exchange (in collaboration with Weingartner, Hopcroft and Batten projects), in regional comparisons with Prince William Sound conditions (in collaboration with Campbell project) and in providing

environmental data for the Benthic Monitoring efforts (Konar and Iken project) and for harmful algal bloom and ocean acidification research (separate NOAA and ADFG studies). We are fortunate to have captured a range of different forcing conditions (near record versus normal snow pack and normal summer precipitation/temperature versus dry/warm summer conditions) in the first 2 years of the project.

The monthly small boat sampling is maintained for all 5 years. While reducing the number of stations along each transect would not substantially reduce the vessel charter costs (due to length of time to conduct transects and relatively short time for CTD casts alone), we have also evaluated that option. However our initial data results demonstrate that current station spacing is needed to capture the strong horizontal gradients in Cook Inlet oceanographic conditions, particularly as those gradients are important for plankton, marine birds and other species.

As described in the original proposal and year 3 work plan, data QA/QC and instrument calibration for the water quality station instruments is conducted in accordance with the National Estuarine Research Reserve System-wide Monitoring Program, including a secondary review by the national NERR program's Central Data Management office. Additional information on water quality monitoring QA/QC can be found at http://cdmo.baruch.sc.edu/data/qaqc.cfm for Kachemak Bay. For conductivity-temperature-depth (CTD) profiler data, in addition to the processing steps described in the work plan, the final data formats are being coordinated with the data management team for consistency across the different oceanography projects. The Seabird Electronics 19plus profilers are sent to Seabird Electronics annually for sensor calibration. Additional information on calibration and data QA/QC for the oceanographic data is also available in the project's sampling protocol. The zooplankton data is collected using the same protocols as in the Campbell Prince William Sound project, and Campbell is conducting zooplankton identification and data processing.

As described in the Environmental Drivers overview in the original proposal and referenced in the year 3 work plan, the analysis of data from the first 2.5 years of this project, along with previous oceanographic sampling along the same transects, will be used in conjunction with data from the GAK1, Seward Line, and Prince William Sound oceanography projects to assess temporal and spatial variability in oceanographic conditions. The sampling design was planned to be complementary with the other projects and to build off previous Cook Inlet oceanographic sampling to create longer time series. We also discussed results of the first 18 months of sampling with our colleagues at the November 2013 PI meeting and are working with them to plan production of synthesis documents in 2014 for the February 2015 science meeting.

The Science Panel comments refer to the outer Kachemak Bay gyre and counter-gyre identified as potential subtidal circulation patterns by Burbank (1977), which is one of the reasons for sampling along Transect 4 in outer Kachemak Bay. While the GWA project is not funded to measure currents, Doroff and Holderied are involved in separately funded research to deploy drifter buoys in Kachemak Bay and develop an operational National Ocean Service ocean circulation model for Cook Inlet and Kachemak Bay. Those ocean circulation studies will provide new information on Cook Inlet tidal and subtidal circulation patterns and are an example of how we are leveraging other funding to enhance the GWA program.

13. Budget: *See,* Reporting Policy at III (C) (10).

See attached budget form for details.

- No line items exceeded 10% deviation on the proposed amounts by budget category for this FY of the project. There is a lag in spending due to leveraging of funding from other sources to allow more consistent Cook Inlet sampling through the entire 5-year project period and due to delays in transferring project funds between Federal fiscal years.

K. Continuous Plankton Recorder- Batten (SAHFOS, 12120114-A)

1. Project Number: *See,* Reporting Policy at III (C) (1).

12120114-A

2. Project Title: *See,* Reporting Policy at III (C) (2).

Continuous Plankton Recorder Sampling

3. Principal Investigator(s): *See,* Reporting Policy at III (C) (3).

Sonia Batten

4. Time Period Covered by the Report: *See,* Reporting Policy at III (C) (4).

February 1, 2013-January 31, 2014

5. Date of Report: *See,* Reporting Policy at III (C) (5).

March 1, 2014

6. Project Website (if applicable): *See,* Reporting Policy at III (C) (6).

www.gulfwatchalaska.org
and information on the whole North Pacific CPR survey available at:
http://pices.int/projects/tcprsotnp/default.aspx
www.sahfos.org

7. Summary of Work Performed: *See,* Reporting Policy at III (C) (7).

All six CPR transects were completed as scheduled in 2013 (Table K-1), with monthly spacing between April and September, see Table 1 below for sampling dates. Sample analysis and QC of the plankton data has been completed for the first 3 transects, while preliminary processing for the final 3 transects is finished and preliminary data are available, QC is ongoing. When the temperature sensor was downloaded after the first transect the data were found to be unreliable (unreasonably high temperatures were recorded on the last part of the transect). These data were discarded and a new sensor attached for the remainder of the year, which returned appropriate data.

Table K-1. Status of project milestones for year 2

Deliverable/Milestone	Status
February 2013 • Set up for start of field season, ship equipment to west coast ports	• Completed
April 2013	• Sampled April 11-14th, data available

• First transect	• Temperature data when downloaded seemed unlikely so sensor changed for next transect.
May 2013 • Second transect	• Sampled May 11-13th, data available
June 2013 • Third transect	• Sampled June 13-16, data available
July 2013 • Fourth transect	• Sampled July 14-15, preliminary data available
August 2013 • Fifth transect	• Sampled August 16-17, preliminary data available
September 2013 • Sixth transect	• Sampled September 15-16, preliminary data available

The graphs below (Fig. K-1) show summary plankton indices for the shelf region and into Cook Inlet based on preliminary data from 2013. Diatoms showed a strong spring peak in May and a secondary autumn peak in September, otherwise monthly values were slightly lower than average, but within the range seen before. Estimated mesozooplankton biomass was generally lower than average until September, while abundances were quite high in June and September. This suggests a bias towards smaller species, if biomass is low but abundance realtively high.

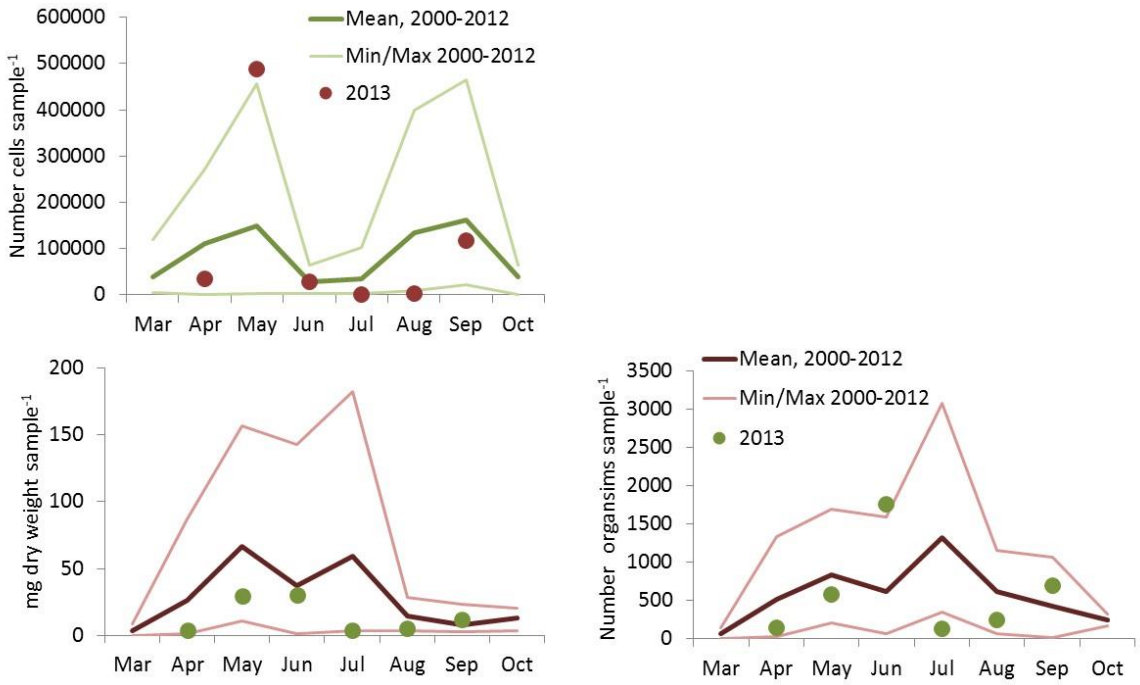


Figure K-1. Preliminary results from 2013 CPR sampling as monthly means overlaid on the long term time series of CPR observations from the Alaskan Shelf/Cook Inlet region. Upper graph shows mean diatom abundance, lower graphs show zooplankton biomass (left) and abundance (right).

Furthermore, warm water copepods appear to be more abundant than they have been for a few years. The graph in Fig. K-2 shows the mean annual sample abundance of a suite of four warm water species. Data for 2013 are preliminary at this stage; however, Figure 2 demonstrates that mean numbers were slightly above 2007 and greater than any year since 2005 in the Alaskan shelf/Cook Inlet region. Numbers of these copepods are still very small compared to the abundance of typical copepod species for the shelf, nevertheless, the strong relationship between their abundance and mean annual SST indicates a potential change in ocean conditions (SST data are not yet available to update this time series for 2013).

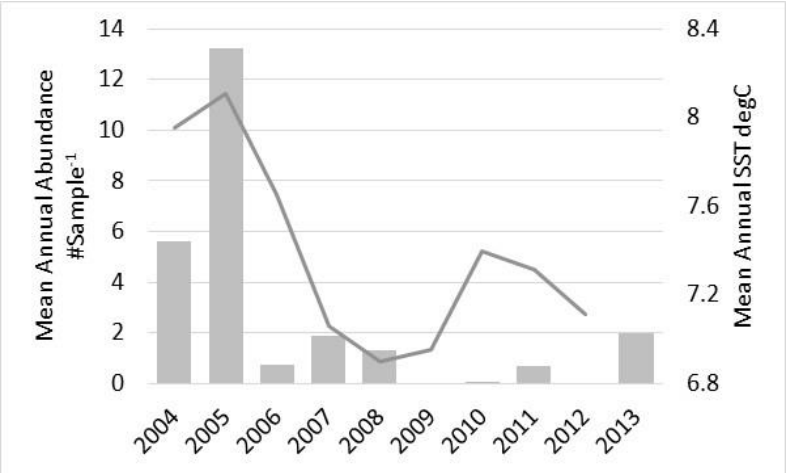


Figure K-2. Mean annual abundance of a suite of 4 warm water copepod species (bars) with mean annual SST for the region (Line) from http://las.pfeg.noaa.gov.

8. Information and Data Transfer: See, Reporting Policy at III (C) (8).

- Publications produced during the reporting period;

None completed.

- Conference and workshop presentations and attendance during the reporting period;

Dr. Batten gave 2 talks at the North Pacific Marine Science Organization (PICES) Annual Meeting, October 11-12th 2013, Nanaimo, BC, Canada. One talk was as an invited speaker, in session S9 (Cost-effective, cooperative ocean monitoring) entitled "*Ship of opportunity sampling of lower trophic levels*". Another science talk was given by Dr. Batten in session S4 (The changing carbon cycle of North Pacific continental shelves) entitled "*Variability in lower trophic levels on the Alaskan Shelf*".

Dr. Batten gave a poster at the January 2014 Alaska Marine Science Symposium entitled "*Zooplankton communities in the Gulf of Alaska*"

- Data and/or information products developed during the reporting period, if applicable;

Contribution to the NOAA Ecosystem Considerations report, http://access.afsc.noaa.gov/reem/ecoweb/index.cfm.

- Data sets and associated metadata that have been uploaded to the program's data portal.

Finalized 2012 plankton data were uploaded, together with the metadata (2013 will be uploaded later in 2014 when all 2013 data have been finalized).
2013 along-transect temperature data were uploaded.

- Collaborations (among the Gulf Watch Alaska program principal investigators)

Sampling zooplankton in an adequate way is notoriously complicated, with differing equipment, mesh sizes and sampling protocols all available. In total, likely years of effort have been spent in describing the issues and conducting inter-comparisons among gear types and regions to try to resolve them, and the end result can be summarized here as a quote taken directly from Owens et al., 2013:

"It is axiomatic in plankton research that no plankton sampler, or combination of plankton samplers, can provide a true estimate of abundance for all components of the plankton at anytime. Plankton vary in size from the microbic to large ctenophores and jellyfish, from robust to those extremely fragile and almost impossible to catch without damage. Plankton have extremely diverse behavioural patterns, daily and seasonal vertical migration, and different feeding, reproductive, survival and escape strategies. Even within the crustacean mesozooplankton abundances vary in four dimensions. Consequently, it has been necessary to develop numerous different types of sampling systems, and different mesh sizes have been used, in order to capture or observe the various components of plankton. Wiebe and Benfield (2003) listed more than 200 systems and that is not exhaustive. All systems underestimate parts of or all the plankton leading researchers to choose the system most suited to their study. The effects of different mesh sizes need to be considered as well using the same mesh on different systems to determine any differences due to mechanical design. Skojdal et al. (2013) is an important recent addition to this work and needs expanding. However, the study also demonstrated that significant resources and ship time are required for such an exercise and this is increasingly harder to fund."

As the last sentence indicates, the resources required to address the problem adequately are well beyond the scope of the GWA program so we are left with doing the best we can with what we have. Within the GWA program there are four zooplankton sampling groups, each with different sampling protocols and mesh sizes;

PWS, 202μm mesh, vertical tow from 50m (or near bottom) to surface, with flowmeter

CPR, 270μm mesh, horizontal tow at 7m depth, no flowmeter

Seward Line, 150μm mesh, vertical tow from 100m to surface, with flowmeter (daytime), and 505 μm stratified oblique Multinet tows (at night)

Kachemak Bay/Cook Inlet, 333μm mesh, vertical tow from 50m to surface, with flowmeter.

These mesh sizes, gear and sampling protocols were selected based on the existing time series practice prior to GWA (such as the lengthy Seward Line sampling) or the particular specifications of the gear as in the case of the CPR which cannot use a different mesh size and because it is towed behind commercial ships, cannot sample in any other way. Given that a major strength of GWA is the inclusion of historic data, it is clear that changes to existing time series methods should not be made, especially since, as described above, there is not one way to best sample zooplankton. There are also differing levels of taxonomic resolution employed by the four groups during sample

processing. These differences can be accommodated by grouping more highly resolved taxa prior to comparison, however the group will aim to improve on this comparability.

In our discussions at the PI meeting in November 2013 we resolved to use statistical approaches to intercompare the data (relative changes in seasonal cycles, annual anomalies for example), since this avoids the issue of comparing absolute numbers (and in any case we cannot accurately measure true plankton abundance in the water with certainty against which we can calculate the error of an estimate from a net sample). This doesn't negate the possibility of conducting gear inter-comparisons in the future should the opportunity arise.

The youngest time series is that of the Kachemak Bay/Cook Inlet sampling led by Angie Doroff which would be the least affected by switching to a different mesh size. This will be explored and if not feasible, it was also suggested that an additional small mesh net (150µm) could be used next field season with samples stored for now, in the hope that resources could be found to process them in the future and determine what the larger mesh net was missing.

The group also determined that it could make recommendations for any future GWA zooplankton sampling that may be initiated, to maximize the intercomparability with existing sampling and historic data, e.g. mesh size 200µm or less, vertical tow from near bottom (or at least 100m), at night, with a flowmeter fitted.

As an example of relevant inter-comparisons that have already been made, included in Appendix C, is an attachment summary of the comparison of CPR data with PWS data that was undertaken during EVOS TC project 10100624 (extracted from the Final Report currently under review). Note that most of the PWS data pre-dated GWA and was not well-resolved taxonomically, limiting the comparisons, however when this is revisited in the future with the more comprehensive sample analysis now being undertaken by Rob Campbell comparisons will be more extensive.

Literature Cited

Owens, N.J.P., Hosie, G.W., Batten, S., Edwards, M., Johns, D.G. and Beaugrand, G. (in press). All plankton sampling systems underestimate abundance: Response to "Continuous plankton recorder underestimates zooplankton abundance" by J.W. Dippner and M. Krause. Journal of Marine Systems, Available online 18 June 2013 http://dx.doi.org/10.1016/j.jmarsys.2013.05.003

Skjodal, H.R., Wiebe, P.H., Postel, L., Knutsen, T., Kaartvedt, S., Sameoto, D.D. 2013. Intercomparison of zooplankton (net) sampling systems: Results from the ICES/GLOBEC sea-going workshop. Progr. Oceanogr. 108, 1-42.

Wiebe, P.H, Benfield, M.C. 2003. From the Hensen net toward four-dimensional biological oceanography. Prog. Oceanogr. 56, 7-136.

9. Response to EVOSTC Review, Recommendations and Comments: *See,* Reporting Policy at III (C) (9).

N/A

10. Budget: *See,* Reporting Policy at III (C) (10).

There were no deviations from the predicted budget. Please see attached workbook.

L. DATA SYNTHESIS, ANALYSIS AND RECOMMENDATIONS FOR SAMPLING FREQUENCY AND INTENSITY OF NEARSHORE MARINE BIRD SURVEYS TO DETECT TRENDS UTILIZING EXISTING DATA FROM THE PRINCE WILLIAM SOUND, KATMAI AND KENAI FJORDS -COLETTI (NPS, 13120114-F)

1. Project Number: *See,* Reporting Policy at III (C) (1).

12120114-F

2. Project Title: *See,* Reporting Policy at III (C) (2).

Data synthesis, analysis and recommendations for sampling frequency and intensity of nearshore marine bird surveys to detect trends utilizing existing data from the Prince William Sound, Katmai and Kenai Fjords coastlines.

3. Principal Investigator(s): *See,* Reporting Policy at III (C) (3).

Heather Coletti

Collaborators: David Irons, James Bodkin, Brenda Ballachey, Tom Dean

4. Time Period Covered by the Report: *See,* Reporting Policy at III (C) (4).

February 1, 2013-January 31, 2014

5. Date of Report: *See,* Reporting Policy at III (C) (5).

March 1, 2014

6. Project Website (if applicable): *See,* Reporting Policy at III (C) (6).

www.gulfwatchalaska.org

7. Summary of Work Performed: *See,* Reporting Policy at III (C) (7).

A contract statement of work was finalized during June of 2013. Changes from previous versions of the proposal included determining which species to focus the analysis on. The species chosen were: harlequin duck, black oystercatcher and pigeon guillemot. These species represent various foraging guilds, are all nearshore reliant and occur in varying densities across habitats. The resulting proposal is summarized below.

The contract was submitted to the NPS contracting officials during July of 2013 and was put out to bid in early August of 2013. No bids were submitted. At this point, no funds have been committed and there has been further discussion on how to proceed. Re-advertisement of the bid is a possibility as well as completing the work within NPS by the SWAN biometrician or an interagency agreement with FWS to complete the analysis.

Summarized Proposal:

Initial analyses for NPS data (KATM and KEFJ) have shown high variability, making trend detection somewhat difficult. We recognize that variability is influenced by several factors including, but not limited to:

1. Individuals in groups are not independent

2. Imperfect detection

3. Habitat preferences by species. Habitat is treated as homogeneous across transects

4. Annual variation in distribution (i.e., availability) relative to our sampling area – By availability we mean birds present and subject to counts.

5. Within-season variation in distribution – birds may utilize home ranges that are larger than individual transects, and any individual that utilizes a given transect during the season may or may not be present and subject to being detected and counted at any given sampling occasion. Birds may also utilize home ranges that overlap multiple transects.

We anticipate that we will be able to detect large (>50%) changes in abundance for relatively common species, but have recently considered other questions of interest. We propose utilizing this data in an occupancy framework. Occupancy, defined here as the proportion of area occupied, may provide useful information regarding species distribution, habitat preferences or availability by species, and rates of extinction and colonization (species richness) by area (MacKenzie et al. 2006). As potential stressors to a system such as climate change, invasive species and other anthropogenic factors increase, understanding how a species or community is responding to those changes through changes in distribution may be informative for resource managers trying to assess park or regional resources and appropriate management actions.

While all species are identified and enumerated during the surveys, this current analysis will be done for three species, specifically harlequin duck, black oystercatcher and pigeon guillemot, that represent a range of abundances and distribution. We don't collect ancillary data that would allow us to account for imperfect detection in our survey methods. Occupancy modeling was developed to permit inference in the face of imperfect detection, so we propose an approach used by Hines et al. (2010) allowing the use of spatial replicates for occupancy modeling.

Hines, J. E., J. D. Nichols, J. A. Royle, D. I. MacKenzie, A. M. Gopalaswamy, N. Samba Kumar, and K. U. Karanth. 2010. Tigers on trails: occupancy modeling for cluster sampling. Ecological Applications 20(5) 1456-1466.

MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. A. Bailey, and J. E. Hines. 2006. Occupancy modeling and estimation. Academic Press, San Diego, California, USA.

In relation to this work, a marine bird subgroup was created during the November 2013 PI meeting and included both nearshore and pelagic representatives. The group is co-chaired by Dan Esler and Kathy Kuletz. Activities included a first conference call in December to lay out the goals of the group, review ongoing activities within GulfWatch, identify complementary work outside of GulfWatch, discuss significant issues, and generate action items to address. Specifically related to this analysis, there was broad recognition that approaches to quantification of these attributes are very different for nearshore versus pelagic species (e.g., nearshore benthivores occur in our study areas largely during winter and are concentrated in intertidal and shallow subtidal habitats, whereas pelagic bird abundance peaks during the breeding season and they occur across a range of nearshore to offshore habitats) and recognition that power analyses would help direct marine bird efforts across these programs. Our overall goal of the working group is to evaluate current activities

and consider whether there are more effective or efficient approaches to achieving desired outcomes, which are: quantifying marine bird numerical trends, distribution, and productivity, and subsequently linking those with spatial variation in habitat and temporal variation in ocean conditions, including prey. This proposal could be quite beneficial as a methods approach to a variety of programs within Gulf Watch Alaska.

We will continue to pursue avenues of analysis as described above and focus our efforts on three (3) nearshore species.

Other outcomes from the marine bird subgroup discussion:

- Recognition of need to conduct/expand winter surveys at some point
- Recognition that power analyses would help direct marine bird efforts; some have already been conducted; several data sets (both pelagic and nearshore) with multiple surveys of the same area (within and among years) were identified that are amenable to power analysis; action item is to review, combine, and conduct power analyses and create a report of findings for inclusion in the synthesis report next fall
- Linking variation in trends, distributions, and productivity to oceanographic features will require collaboration and synthesis with the Environmental Drivers group
- Products: generated a spreadsheet identifying all of the marine bird surveys, summarizing areas covered, timing (season and number of years), PIs and agencies, methodology and objectives, and plans for future

Table L-1. Status of project milestones for year 2

Deliverable/Milestone	Status
Finalized proposal (statement of work for contract)	Completed, June 2013
Contract Package submitted to NPS	Completed, July 2013
Contract Award	No bids were submitted for evaluation and award
Data collection	Annual summer surveys continue under the Benthic component (Ballachey et al.) in KATM and KEFJ. This data will be amended to existing data sets to strengthen analysis

8. Information and Data Transfer: See, Reporting Policy at III (C) (8).

Publications& Reports:

Coletti, H. A., T.A. Dean, K.A. Kloecker and B.E. Ballachey. 2013. Nearshore marine vital signs monitoring in the Southwest Alaska Network of National Parks: 2012. Natural Resource Technical

Report NPS/SWAN/NRTR—20XX/XXX. National Park Service, Fort Collins, Colorado. (anticipated release, February 2014).

Dean, T.A., J.L. Bodkin and H.A. Coletti. 2014. Protocol Narrative for Nearshore Marine Ecosystem Monitoring in the Gulf of Alaska, Version 1.1. Natural Resource Technical Report NPS/SWAN/NRTR—2014/756. National Park Service, Fort Collins, Colorado.

Presentation: Ballachey, B., L. Bowen, A.K. Miles, G. Esslinger, M. Lindeberg, K. Kloecker, H. Coletti. Gene transcription profiles in mussels from Prince William Sound, 2012 & 2013, as an indicator of ecosystem health. Poster presented at the Alaska Marine Science Symposium, Anchorage, Alaska, January 2014.

Meeting attendance: January 2014 Alaska Marine Science Symposium: Ballachey, Coletti, Doroff, Esler, Kloecker, Lindeberg, Monson, Shephard, Weitzman. November 2013 Gulf Watch PI meeting, Anchorage: Ballachey, Coletti, Dean, Doroff, Esler, Kloecker, Lindeberg, Monson, Shephard.

Data & metadata uploaded to data portal: In cooperation with the nearshore benthic group, marine bird and mammal survey data for KATM and KEFJ was uploaded to the workspace (raw count data and metadata in form of description of project and methods).

9. Response to EVOSTC Review, Recommendations and Comments: *See,* Reporting Policy at III (C) (9).

There were no recommendations for changes to this project component in the recent EVOSTC reviews.

10. Budget: *See,* Reporting Policy at III (C) (10).

Budget forms submitted separately. No funds have been allocated at this time. In July of 2013, because of contract cut-off deadlines, we modified the existing cost of the anticipated contract to $24,999 to award this fiscal year. This will leave us with a possible surplus of $5,001. However, because no award was given, we may have additional costs associated with the project that could use the additional $5,001.

M. Long-term Killer Whale Monitoring – Matkin (NGOS, 12120114-M)

1. Project Number: *See,* Reporting Policy at III (C) (1).

12120114-M

2. Project Title: *See,* Reporting Policy at III (C) (2).

Long-term killer whale monitoring in Prince William Sound/ Kenai Fjords

3. Principal Investigator(s): *See,* Reporting Policy at III (C) (3).

Craig O. Matkin

4. Time Period Covered by the Report: *See,* Reporting Policy at III (C) (4).

February 1, 2013-January 31, 2014

5. Date of Report: *See,* Reporting Policy at III (C) (5).

March 1, 2014

6. Project Website (if applicable): *See,* Reporting Policy at III (C) (6).

www.gulfwatchalaska.org, www.whalesalaska.net

7. Summary of Work Performed: *See,* Reporting Policy at III (C) (7).

February–April 2013. The current killer whale photographic reference catalogue was updated with 2012 field data. Matriline diagrams were updated as well. The updated catalogue was provided electronically to all tour boat operators and to the Kenai Fjords National Park. A publication on population dynamics of resident killer whales was completed, submitted and subsequently accepted by Marine Mammal Science. Preparation for field work also occurred in this period (see Table M-1 for summary of project milestones completed during this year).

May-October 2013. All fieldwork occurred during this period. During 63 days of fieldwork on the Natoa and 4 days on other vessels we logged 39 encounters with killer whales, 29 with residents, 4 with AT1 transients, 4 with Gulf of Alaska transients and 2 with offshores (Figure M-1).

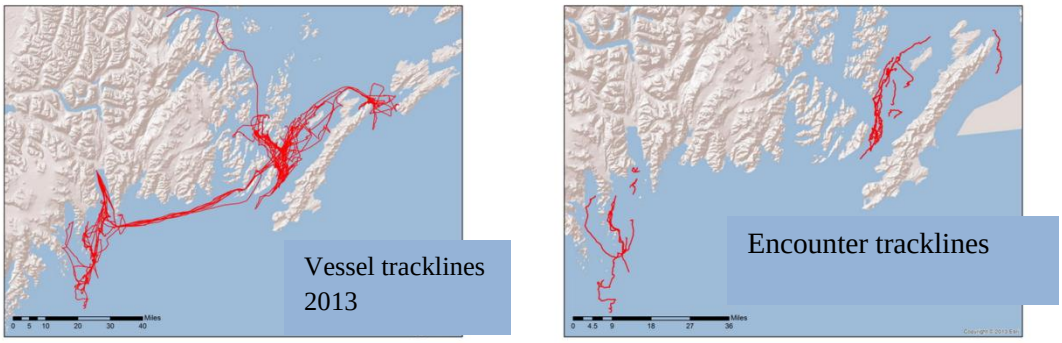


Figure M-1. Vessel and encounter tracklines for sampling in 2013.

Thirty five of the encounters were logged by the R.V. Natoa and 4 by other vessels with NGOS personnel on board. Effort was focused in the late season (September-October). AB pod was encountered on numerous occasions; however, the AB 17 matriline was not with them. Contributed photos of AB17 indicate the AB17 matriline was swimming separately from the rest of AB pod in 2013 although we did not encounter them. Also, AB45 a 23 year old male orphaned following the spill was also missing. The number of whales in AB pod remains at 20 pending confirmation of the death of AB45. The number of whales in the AT1 group remains 7 (Figure M-2).

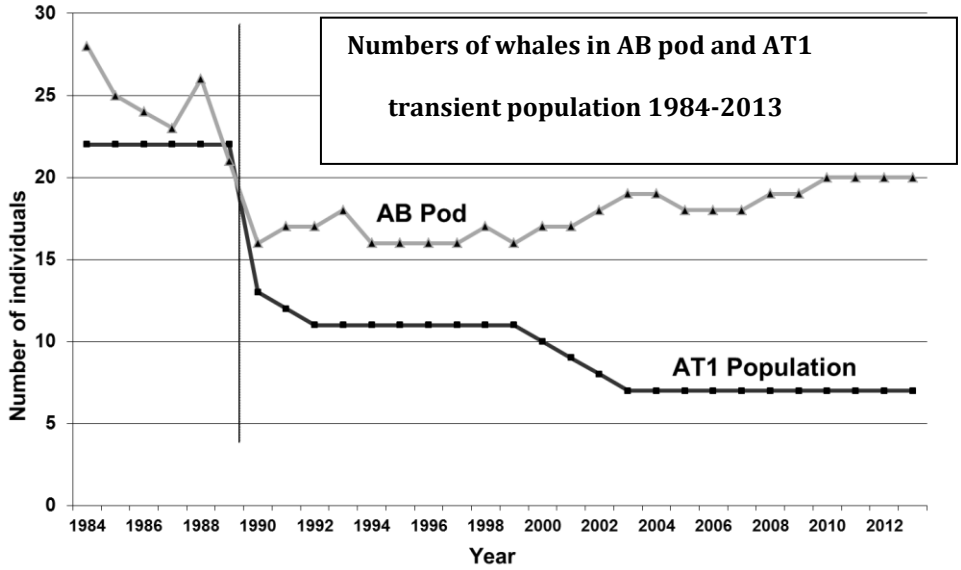


Figure M-2. AB and AT1 pod counts from 1984 to current.

We collected 6 biopsy samples for lipid, stable isotope and contaminant analysis during the fall field season. These samples were collected in parallel with our tagging effort in southwestern Prince William Sound and as part of our examination of feeding ecology at this time of year.

We attached tags to 3 whales in AJ pod during the September-October feeding aggregation in southwestern Prince William Sound. Tags deployed lasted an average of two weeks and were of the Mark 10 type (Wildlife Computers) which transmitted location and dive data. We are attempting to characterize feeding ecology during the crucial pre-winter period. Dive depths recorded by tags during feeding bouts were surprisingly consistent with the great majority at 200-280 meters (Figure M-3). The depths indicated feeding near the bottom. This has been a surprise as the putative coho salmon prey were not necessarily thought to swim at these depth, and suggests other prey, possibly king salmon. Sampling of prey was nearly impossible from the single vessel with two crew while completing other aspects of the study and in the future it may be necessary to use an additional inflatable vessel and personnel dedicated to prey sampling.

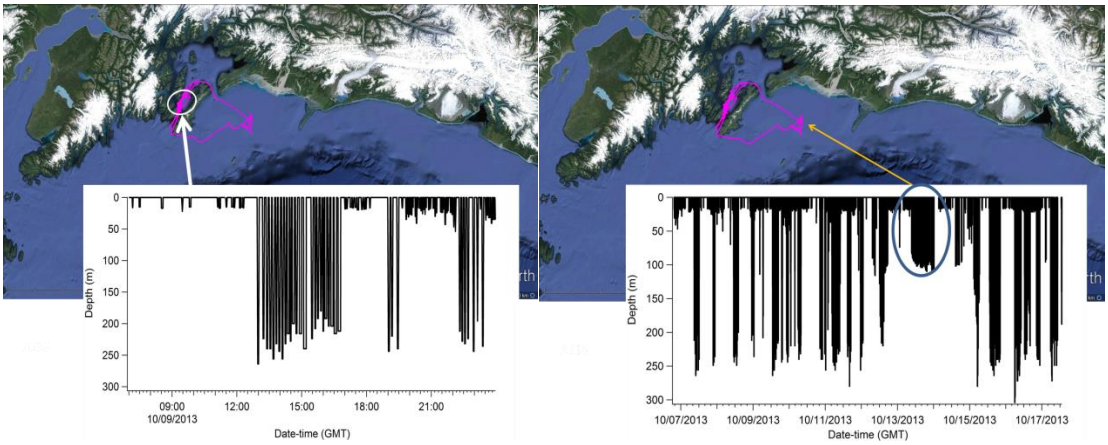


Figure M-3. In lower Knight Island Passage tagged AJ whales tended to dive to depths of 200-250m during feeding bouts while feeding boats offshore near Wessels reef were in the 100m range.

October 2013-January 2014. Photo analysis was completed during this period. A presentation was prepared and delivered at the annual Gulf Watch meeting in November. We updated numerous databases at NGOS with 2013 field data including survey and encounter access database and biopsy and tagging summaries. We filtered tagging data and constructed maps and tracks and associated dive data for tagged whales. Samples of tissue and scales were sent out for analysis. We supplied our humpback whale photo-identification and encounter data to Project 12120114-N(Humpback Whale Predation on Herring in Prince William Sound). Facebook and web sites were updated.

We followed our list of objectives as stated in the original proposal, although we are using the new time/depth recording Mark 10 tags instead of location only tags. With limited field time and the single vessel it was difficult to complete all aspects of project, especially sampling prey during deep diving bouts when prey and infrequently brought to the surface and the research vessel is involved in. We are considering the possibility of using an inflatable and additional personnel to sample prey in Prince William Sound. Outreach included the creation of a Facebook site for the North Gulf Oceanic Society that allows quicker posting of events and more direct interaction than the website.

Table M-1. Status of project milestones for year 2.

Deliverable/Milestone	Status
Prepare population dynamics manuscript	Accepted MMS, 30 April 2013
Update of photographic catalogue, population database, mapping database, lab analysis	Completed May 10 2013 (for 2012 data)
Field work: PhotoID, Biopsy, prey sampling, tagging.	15 May- 15 October 2013
Annual meeting Gulf Watch	November 2013

Alaska Marine Science Symp	January 2014

8. Information and Data Transfer: See, Reporting Policy at III (C) (8).

- Publication of book "Into Great Silence", by Eva Saulitis (Beacon press), the story of the AT1 transient population
- Presentations at NRDC (New York), Center for Coastal Studies, Wellfleet Audubon (Cape Cod) Maui Whale Fest, Kenai
  Fjords Tourboat Association, Pratt Museum, U of A Fairbanks, and U of A Juneau
- Cover article in spring 2013 "On Earth" magazine (NRDC)
- Publication of article on killer whales for Delta Sound Connections 2013 (PWSSC) in March 2013
- Complete rework of North Gulf Oceanic Society website by webmaster Eric Poncelet
- Initiated Facebook page and provide feedback to Facebook comments
- Gathering reports/photographs and daily web posting of whale sighting information in Kenai Fjords with
  feedback to participants

- Attendance of Alaska Marine Science Symposium (Jan 2014) and presentation of "Are recent changes in dietary patterns of Southern Alaska Resident killer whales leading to nutritional stress?"
- Data sets uploaded or updated on the Gulf Watch site in 2013 include Killer whale photo summary 2012, Killer whale matrilines 2012, Killer whale sat tag summary 2012, Killer whale GAT registry 2012, Killer whale biopsy summary 2012. Other summary data include AKW Master 2013, Orcadatabase 2012, GOA transient summary 2012, Killer whale vessel interactions 2012

9. Response to EVOSTC Review, Recommendations and Comments: *See,* Reporting Policy at III (C) (9).

We thank the reviewers for their positive remarks. This project did not receive direct recommendations from EVOSTC. We have responded to suggestions of staff regarding reporting.

10. Budget: *See,* Reporting Policy at III (C) (10).

Our budget and billing typically runs about 6 months behind the EVOS schedule because of our offset with fiscal year (the NGOS fiscal year ends June1). This has been the case for many years

Attached budget form reflects the notification and acceptance of changes in annual budget category amounts. There has been no change in total project budget. At this time there has not been more than 10% deviation in budget categories for FY13.

N. HUMPBACK WHALE PREDATION ON HERRING –MORAN AND STRALEY (NOAA, UAS, 12120114-N)

1. Project Number: *See,* Reporting Policy at III (C) (1).

13120114-N

2. Project Title: *See,* Reporting Policy at III (C) (2).

Long-term Monitoring: Pelagic Monitoring Component **-** Long-term monitoring of humpback whale predation on Pacific herring in Prince William Sound

3. Principal Investigator(s): *See,* Reporting Policy at III (C) (3).

John R. Moran (NOAA) and Janice M. Straley (UAS)

4. Time Period Covered by the Report: *See,* Reporting Policy at III (C) (4).

February 1, 2013-January 31, 2014

5. Date of Report: *See,* Reporting Policy at III (C) (5).

March 1, 2014

6. Project Website (if applicable): *See,* Reporting Policy at III (C) (6).

www.gulfwatchalaska.org

7. Summary of Work Performed: *See,* Reporting Policy at III (C) (7).

During the reporting period three whale surveys were completed (April 2013, September/October 2013, and December 2013). In addition to whale data, forage fish and zooplankton were collected during the fall and winter surveys, these samples will be analyzed for energy density and stable isotopes. QA/QC has been completed for all whale data collected to date. We will complete the final a whale survey of the 2013/2014 field season during April 2014. An additional five day whale survey is planned for the summer of 2014 with leveraged funds. See Table N-1 for a summary of project milestones and progress for this year.

Synopsis of field work:

April 2013

The whale total for the trip, was 33, three of these had been seen Kodiak. We observed large schools of staging and spawning herring as well as thick plankton layers in the Knowles Head/ Redhead Area. Several whales fed on a dense plankton layer in close proximity schools of herring. We completed a survey of the central-western part of Prince William Sound in addition to spending time in Ports Gravina and Fidalgo. We began in Port Fidalgo, traveled up inside Bligh and Busby Islands, then cut across Valdez Arm, around Glacier Island, and down to Naked Island. From there, we traveled south to between Knight and Montague Islands, anchoring for the night in Zaikof Bay. We saw no whales while on this run, and only a small number of other marine mammals; sea lions, otters, and a small group of Dall's porpoise.

September/October 2013

As in past years during the early fall surveys, whales were initially most numerous in southern Montague Strait feeding on herring but were moving into the sound as evidenced by finding the same whales on subsequent days in other locations along our route. Whales along Knight Island Passage and the mouth of Bainbridge Passage were feeding on krill although small herring (~10cm) were caught while at anchor at Shelter Cove, Evans Island. The weather for this trip was better than the past two years

December 2013

Fair weather and excellent sighting conditions occurred throughout the December 2013 humpback whale survey of Prince William Sound. Humpback whale distribution differed from previous surveys during December, probably the result of shifts in the prey field. Only seven whales were present in Port Gravina, bird numbers were also low. Whales were spread out in the tanker anchorage area south of Knowles Head, an area more typically occupied during Sept/Oct.

There were no whales from Zaikof Bay to Rocky Bay. Both bird and whale activity picked up from Little Green Island to the Needle and northeastern Latouche Island. These whales were scattered and moving fast.

One whale outside of Iktua Bay was seen near large schools of herring. The fish were breaking the surface, but no obvious sub-surface predators were seen. Four whales were photographed around the Pleiades.

Modeling

We have developed conceptual models to describe the movements and distribution of humpback whales in Prince William Sound (Figures N-1, N-2). These models will help us identify how, where, and when humpback whales impact the ecosystem, as well as gaps in data.

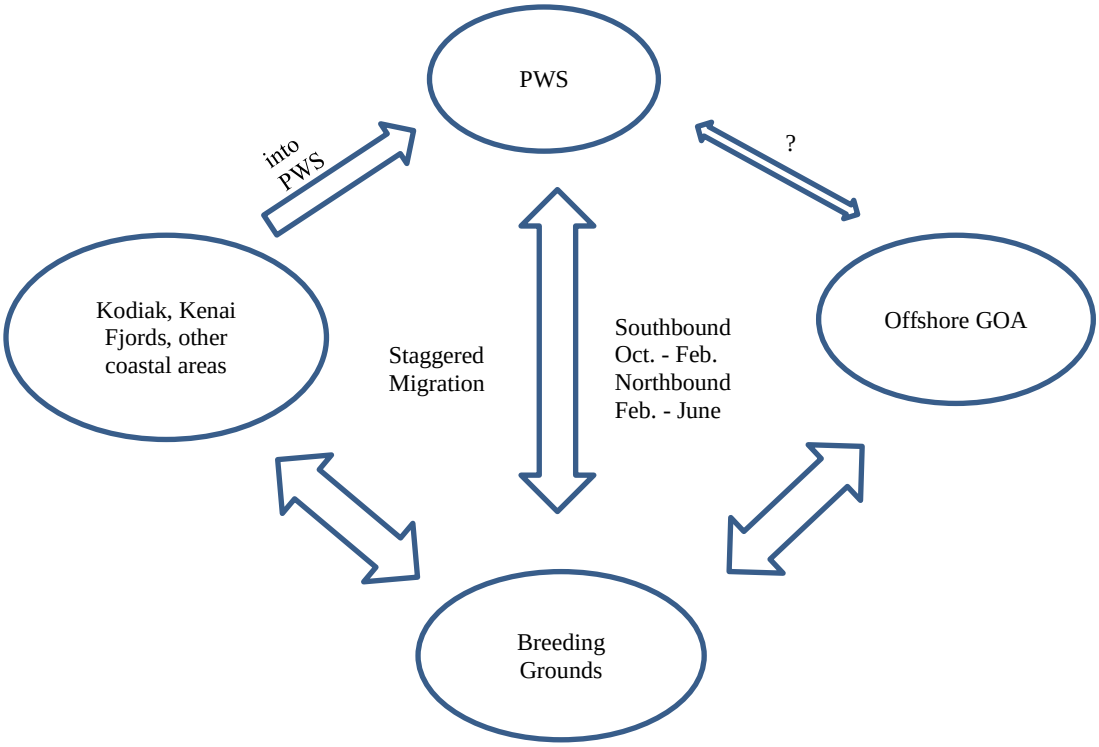


Figure N-1. A conceptual model of humpback whale distribution in the North Pacific relative to Prince William Sound.

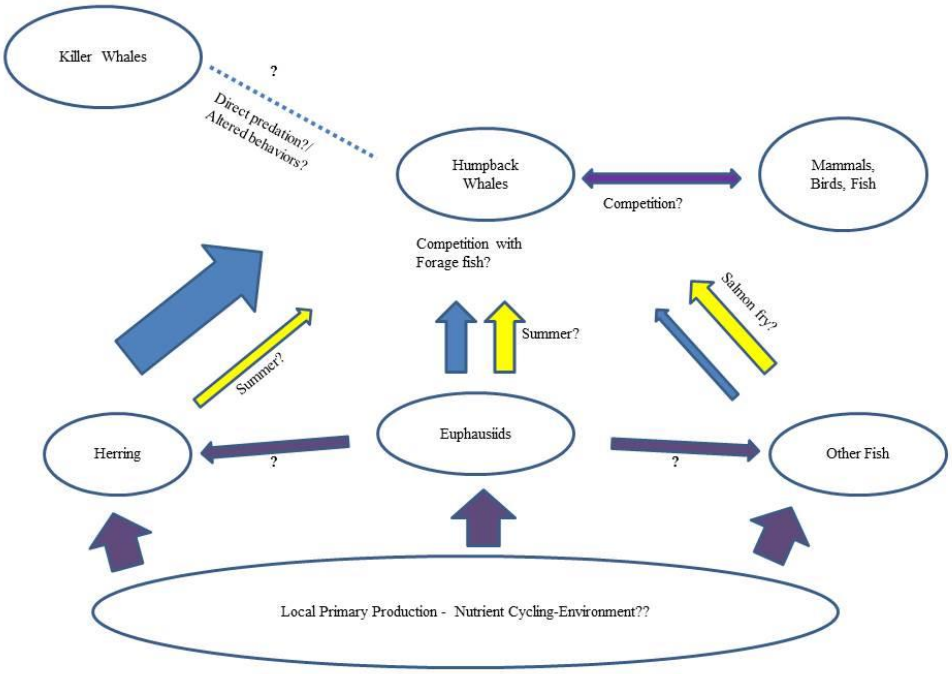


Figure N-2. A conceptual model of external factors influencing humpback whale movements into Prince William Sound. Humpback whale migrations and movements are strongly influenced by maternal and learned behaviors.

Table N-1. Status of project milestones for year 2

Deliverable/Milestone	Status
April PWS Whale Survey	Completed, 12 April, 2013
Sept. - Oct. PWS Whale Survey	Completed, 3 Oct., 2013
Dec. PWS Whale Survey	Completed, 8, Dec., 2013
Attend AMSS	Completed

8. Information and Data Transfer: See, Reporting Policy at III (C) (8).

- Three publications from last year are being revised for Fisheries Oceanography.
- Moran and Straley attended at the Alaska Marine Science Symposium and Gulf Watch PI Meeting in Anchorage. Moran gave presentations on humpback whales to the following groups: Marine Mammal Class guest lecturer for Heidi Pearson, UAS Biology Seminar Class guest lecturer for Sherry Tamone, University of Redlands lecture for Lei lani Stella, and the Sixth Annual Juneau Marine Naturalist Symposium. Straley provided information on

humpback whales on board the Wilderness Safari tour boat for a week during the summer 2013 and presented at the Craig Whale Fest.

- A fluke catalog of PWS humpback whales and associated metadata have been posted to the portal.
- We are current with data and metadata posting requirements.

9. Response to EVOSTC Review, Recommendations and Comments: *See,* Reporting Policy at III (C) (9).

- No recommendations were made for this project.

10. Budget: *See,* Reporting Policy at III (C) (10).

- In-kind contribution from NOAA - $25K/year in salary for Moran. An addition $58.5K in FY12 and $49.7K in FY13 of NOAA ship time was used to increase survey effort. The overall budget was within 10%, however, travel was 26.8 % higher than proposed due to the increased survey effort leveraged from NOAA ship funds. Personnel cost were lower by 16% (this represents only $700.00). Commodities were under estimated by 45%, this will likely balance out by the end of the project.

O. FORAGE FISH DISTRIBUTION AND ABUNDANCE- PIATT, ARIMITSU (USGS ASC, 12120114-O)

1. Project Number: *See,* Reporting Policy at III (C) (1).

12120114- O

2. Project Title: *See,* Reporting Policy at III (C) (2).

LTM Program – Monitoring long-term changes in forage fish distribution, abundance, and body condition in Prince William Sound

3. Principal Investigator(s): *See,* Reporting Policy at III (C) (3).

Mayumi Arimitsu and John Piatt

4. Time Period Covered by the Report: *See,* Reporting Policy at III (C) (4).

February 1, 2013-January 31, 2014

5. Date of Report: *See,* Reporting Policy at III (C) (5).

March 1, 2014

6. Project Website (if applicable): *See,* Reporting Policy at III (C) (6).

www.gulfwatchalaska.org

7. Summary of Work Performed: *See,* Reporting Policy at III (C) (7).

As originally proposed, the objectives of this work are to 1) identify robust indices for monitoring forage fish populations over time and devise a sampling strategy for long term monitoring of those indices, 2) assess the current distribution, abundance, species composition, and body condition of forage fishes (other than herring) in selected areas of Prince William Sound at selected times of the year, and 3) relate abundance and distribution of forage species to abiotic characteristics of the marine environment. See Table O-1 for a summary of project milestones completed this year.

During this reporting period we worked on 2012 data processing, and created metadata in Morpho. Datasets uploaded to the workspace include oceanography (water column temperature, salinity, chlorophyll *a*, water clarity, photosynthetically active radiation, oxygen), nutrients (nitrate, nitrite, ammonium, phosphate, and silica concentrations at two depths per station), zooplankton (species, stage, biomass per volume filtered), fish (species, abundance, length, weight by station), and predators (marine bird and mammal distribution and behavior). We began work on a project outreach website hosted by USGS that we expect to be ready for viewing soon. In July-August 2013, we conducted year two field work, which included a hydroacoustic-trawl and beach seine survey mainly in the eastern Sound. We also did exploratory work to investigate the feasibility of incorporating aerial spotting surveys in conjunction with the herring research program (i.e., Scott Pegau's aerial survey work with Mike Collins, a Cordova pilot). We spent four days validating aerial survey observations (species, age class, hydroacoustic measures of density and biomass). We also tested adaptive cluster survey design methods for placement of hydroacoustic transects in areas

with high density of target species, and opportunistically sampled forage schools when we encountered them (Fig. O-1).

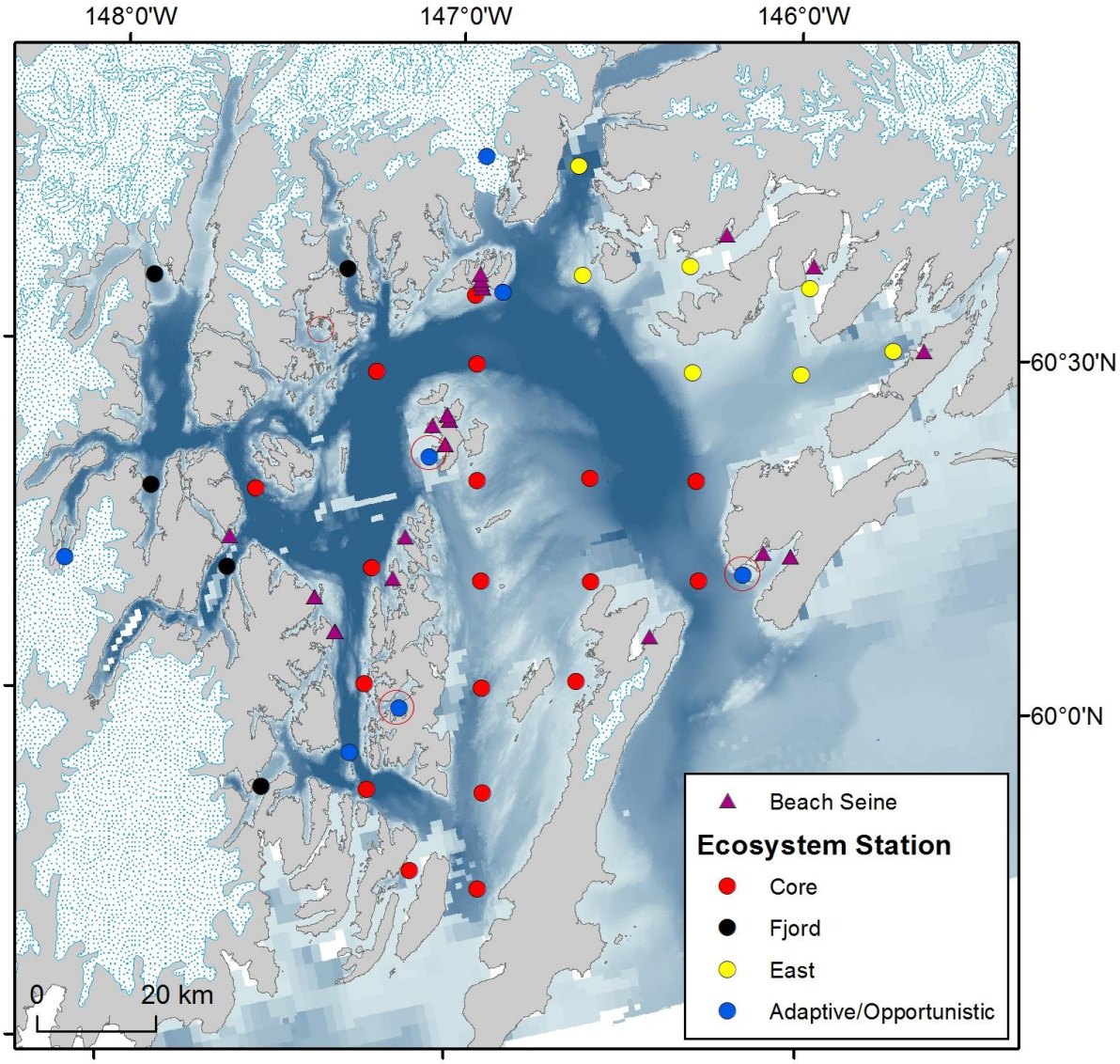


Figure O-1. . Fishing effort (trawl, beach seine) for forage fish in Prince William Sound during August 2012 -

Based on findings in our 2012 surveys in which we had a low encounter rate with target species, we proposed to make some improvements to the study design for the 2013 field season, with approval of Gulf Watch program managers and the EVOSTC. To increase our sampling efficiency, we devoted a significant portion of our 2013 effort to developing a strategy that incorporated nearshore aerial spotting to guide the boat-based hydroacoustic transects and net-sampling techniques. We continue to work towards this new approach, which has the benefit of facilitating broad spatial scale comparison of current and future data to previous work in the Sound (e.g., E. Brown, project 10100132-F). Moving forward, our project will focus on validating nearshore aerial survey observations with hydroacoustics and net sampling to quantify age class and biomass by species.

We are collaborating with Scott Pegau (PWSSC) on improving spatial referencing of existing protocols for juvenile herring surveys, coordinating with Michele Buckhorn (PWSSC) on hydroacoustic methods for assessing small-schooling fish, and collaborating with PI's on predator species (i.e., humpback whales – John Moran and Jan Straley, seabirds – Dave Irons) to ensure the forage fish surveys are spatially and temporally relevant to the larger GWA study.

Table O-1. Status of project milestones for year 2

Deliverable/Milestone	Status
Uploaded 2012 data to Ocean workspace	Completed, 3 July 2013
Uploaded project metadata (Morpho) to workspace	Completed, 3 July 2013
Conducted 2013 field work	July – Aug 2013
Submitted semi-annual report	August 2013
Annual PI meeting	Nov 2013
PI meeting at AMSS	Jan 2013

8. Information and Data Transfer: See, Reporting Policy at III (C) (8).

- John Piatt participated in a statewide Talk of Alaska radio interview on Nov 12, 2013. He described Gulf Watch Alaska's forage fish component, and highlighted ongoing efforts along with challenges to documenting important prey species in Prince William Sound (http://www.alaskapublic.org/2013/11/08/monitoring-in-the-north/)
- Mayumi Arimitsu presented a seminar for the University of Washington's Fisheries Acoustics Research Lab on Nov 1, 2013. She discussed survey design and improved efficiency through the combination of aerial-acoustic technologies in monitoring long-term changes in forage fish.
- 2012 datasets and associated metadata uploaded to the workspace during this reporting period include oceanography (water column temperature, salinity, chlorophyll *a*, water clarity, photosynthetically active radiation, oxygen), nutrients (nitrate, nitrite, ammonium, phosphate, and silica concentrations at two depths per station), zooplankton (species, stage, biomass per volume filtered), fish (species, abundance, length, weight by station), and predators (marine bird and mammal distribution and behavior).

9. Response to EVOSTC Review, Recommendations and Comments: *See,* Reporting Policy at III (C) (9).

In general, the review of the forage fish project proposal was positive. We appreciate that the team lead response identified the need for additional support for aerial surveys, a new component that we are working on with Scott Pegau, as we believe this is a critical component of the forage fish work in Prince William Sound.

10. Budget: *See,* Reporting Policy at III (C) (10).

Current expenditures of some line items exceed ± 10% deviation from the originally-proposed amount in cases where reporting accounts lagged behind actual expenses, inconsistency between federal and EVOS fiscal year start date, and because the USGS budget system categories (particularly commodities and equipment) differ from those shown in the EVOS proposal. However, all expenditures are all within keeping to our planned budget, despite significant changes to survey design (as discussed above). We expect to use all proposed funds by the end of the project.

P. Prince William Sound Marine Bird Surveys- Irons/Kuletz (UWFWS AK, 12120114-K)

1. Project Number: *See,* Reporting Policy at III (C) (1).

13120114-K

2. Project Title: *See,* Reporting Policy at III (C) (2).

Long-term Monitoring: Pelagic Monitoring Component - Continuing the Legacy: Prince William Sound Marine Bird Population Trends

3. Principal Investigator(s): *See,* Reporting Policy at III (C) (3).

David Irons and Kathy Kuletz

4. Time Period Covered by the Report: *See,* Reporting Policy at III (C) (4).

1 February 2013 – 31 January 2014

5. Date of Report: *See,* Reporting Policy at III (C) (5).

1 March 2014

6. Project Website (if applicable): *See,* Reporting Policy at III (C) (6).

www.gulfwatchalaska.org

7. Summary of Work Performed: *See,* Reporting Policy at III (C) (7).

This project had no field work scheduled in 2013. Progress was made on data analysis and summarizing of project results (Table P-1). Some of those findings were presented at the Alaska Marine Science Symposium in Anchorage, AK and the annual Pacific Seabird Group Meeting in Portland, OR.

Table P-1. Status of project milestones for year 2

Deliverable/Milestone	Status
Hire biologist to oversee 2014 survey	Awaiting approval of federal hiring waiver; to be hired by 31 March 2014
Uploaded 2012 data to Workspace	Completed, 21 January 2014

8. Information and Data Transfer: *See,* Reporting Policy at III (C) (8).

- Dan Cushing presented at the Alaska Marine Science Symposium in Anchorage, AK (January 2013) and the Pacific Seabird Group Meeting in Portland, OR. (February 2013). Dan discussed changes in abundance of Brachyramphus murrelets in Prince William Sound, Alaska, 1989-2012.

- 2012 marine bird survey dataset and metadata were posted to the Workspace during this reporting period.
- Irons and Kuletz attended the Alaska Marine Science Symposium and Gulf Watch Alaska PI meeting in Anchorage.

9. Response to EVOSTC Review, Recommendations and Comments: *See,* Reporting Policy at III (C) (9).

We appreciate the review of the marine bird population trends proposal and have considered the recommendations put forward. We also appreciated the LTM Program Team response that annual sampling would be preferred, but that is not feasible under the current program funding level. Additionally, regarding evaluation of the sampling design, the GWA program includes a project (Coletti, 13120114-F) which proposes to analyze historical marine bird survey data to assess the ability to detect trends in nearshore marine bird populations under a variety of survey time frames. The project has been delayed, but is expected to be complete in the summer of 2014 and the results will be used to inform GWA program decisions to recommend alternate marine bird survey frequencies to the Trustee Council.

10. Budget: *See,* Reporting Policy at III (C) (10).

Current expenditures are well within our planned budget; however, the federal hiring freeze initiated in March 2013 preempted the hiring of a Project Leader. We have submitted a hiring request waiver and intend to have the position filled in March 2014.

Q. Seabird Abundance in Fall and Winter – Bishop (12120114-C)

1. Project Number: *See,* Reporting Policy at III (C) (1).

12120114-C

2. Project Title: *See,* Reporting Policy at III (C) (2).

Long-term monitoring of seabird abundance and habitat associations during late fall and winter in Prince William Sound

3. Principal Investigator(s): *See,* Reporting Policy at III (C) (3).

Mary Anne Bishop, Ph.D.

Report prepared by: Jessica Stocking

4. Time Period Covered by the Report: *See,* Reporting Policy at III (C) (4).

February 1, 2013-January 31, 2014

5. Date of Report: *See,* Reporting Policy at III (C) (5).

March 1, 2014

6. Project Website (if applicable): *See,* Reporting Policy at III (C) (6).

www.gulfwatchalaska.org, http://pwssc.org/research/birds-2/seabirds/

7. Summary of Work Performed: *See,* Reporting Policy at III (C) (7).

Seabirds spend most of the year widely dispersed. At higher latitudes, late fall through winter are critical periods for survival as food tends to be relatively scarce or inaccessible, the climate more extreme, light levels reduced, day length shorter and water temperatures colder. Consequently daily energy requirements increase and birds have to forage for a large proportion of daylight hours. Of the seabirds that overwinter in Prince William Sound (PWS), nine species were initially injured by the *Exxon Valdez* oil spill. Long-term monitoring of seabirds in PWS during winter is needed to understand how post-spill ecosystem recovery and changing physical and biological factors are affecting seabird abundance and species composition, as well as their distribution and habitat use. The objectives of this project are:

1) Characterize the spatial and temporal distribution of seabirds in PWS during late fall and winter.
2) Relate seabird presence to prey fields identified during hydroacoustic surveys.
3) Identify critical biological and physical habitat characteristics for seabirds across PWS within and between winters.
4) Utilize increased temporal sampling resolution to improve our estimates of consumption of herring by seabirds during the winter.

For this FY13 report we provide preliminary results that address objectives 1 and 3 (Table Q-1). Objectives 2 and 4 will be addressed as hydroacoustic survey data becomes available from the juvenile herring surveys and expanded adult surveys. Four late fall and winter avian surveys were

performed during this reporting period, including one survey during the 2012/2013 winter and three surveys during the 2013/2014 winter. The same observer (J. Stocking) participated in all four surveys. Ships of opportunity used for our surveys included vessels surveying herring (PWS Science Center), shrimp (ADFG) and humpback whales (NOAA; Table 1; Figure Q-1). The October survey, previously conducted in conjunction with a NOAA humpback whale survey was replaced in 2013 by the ADFG shrimp survey. The ADFG shrimp survey is a preferable alternative because of a its broad-scale coverage of PWS as well as increased consistency in route due to the repeated visits to established sites.

Table Q-1. Status of project deliverables and milestones for year 2. No milestones were scheduled to be completed in FY 2013.

Deliverable/Milestone	Km surveyed (km)	Status
March PWS survey (PWSSC)	407	Completed, March 27-April 3, 2013; data available
October PWS survey (ADFG)	303	Completed, October 12-23, 2013; data available
November PWS survey (PWSSC)	254	Completed, November 6-14, 2013; data available
December PWS survey (NOAA)	237	Completed, December 2-8, 2013; data available

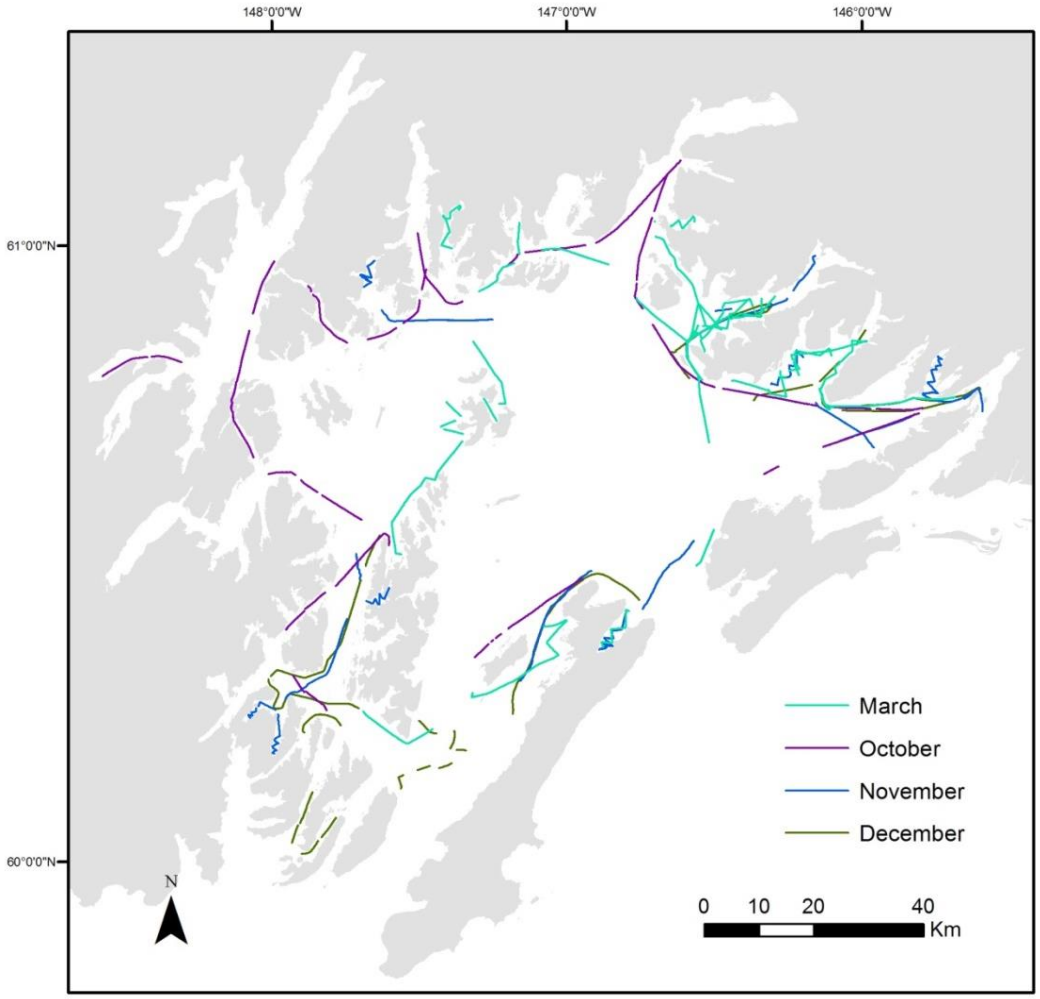


Figure Q-1. . Study area and tracklines for 2013 seabird surveys on ships of opportunity in Prince William Sound, Alaska.

All surveys employed established U.S. Fish and Wildlife Service protocols that have been adapted for GPS-integrated data entry programs (USFWS 2007). Species were identified to the lowest taxonomic level possible. Some common marine birds can be difficult to distinguish (e.g. Kittlitz's and Marbled Murrelets), and densities are typically calculated for groups of species (e.g. *Brachyramphus* murrelets) in this report (Table Q-2). Thirty species were observed during 1201 km of survey effort in 2013, with an average density of 10.2 ± 32.4 (sd) marine birds per kilometer of effort.

Table Q-2. Density (birds/km^2 ± se) of main species groups for year 2. Highest density values per avian species or group in bold.

Species or Species Group	March 2013	October 2013	November 2013	December 2013
Common Murre	0.163 (0.05)	1.576 (1.05)	0.733 (0.17)	**3.616 (0.61)**
Murrelets	0.514 (0.11)	0.111 (0.04)	2.088 (0.38)	**3.969 (0.77)**

Mergansers	0.103 (0.05)	0.040 (0.02)	**0.256 (0.10)**	0.212 (0.16)
Loons	0.934 (0.23)	0.394 (0.13)	0.598 (0.11)	**2.175 (1.25)**
Grebes	0.017 (0.01)	0.071 (0.03)	**0.232 (0.07)**	0.014 (0.01)
Cormorants	**1.234 (0.17)**	0.222 (0.05)	0.391 (0.09)	0.452 (0.13)
Scoters	**3.395 (0.71)**	0.010 (0.005)	0.287 (0.06)	0.078 (0.03)
Large Gulls	**2.134 (1.07)**	0.525 (0.11)	1.331 (0.20)	0.960 (0.20)
Small Gulls	0.120 (0.04)	0.384 (0.12)	**0.769 (0.13)**	0.593 (0.13)
Long-tailed Duck	**1.362 (0.80)**	0 (0)	0 (0)	0.099 (0.05)
Black-legged Kittiwake	**2.305 (0.63)**	1.182 (0.16)	0.586 (0.12)	0 (0)

Similar to previous winter surveys, we observed distinct temporal patterns by some of the most abundant species. Common Murre had highest densities in December and no discernable pattern of immigration or emigration (Table Q-2). This is contrary to previous evidence that murres are most common in Prince William Sound during March (Dawson *et al*. in review; Bishop and Kuletz 2013; 11110114-C 2012 Annual Report). The March 2013 survey, however, was much later (27 March - 3 April) compared with previous (mid-March) surveys. It may be that murres were already emigrating out of the Sound for their breeding grounds by late March. Similar to previous winters, murres were clustered in the northeast sound (Figure Q-2).

Murrelets were broadly distributed throughout the surveys. Murrelets had low numbers in March and October, increasing in November and peaking in December (Figure Q-3; Table Q-2), a pattern consistent with previous survey years (Dawson *et al*. in review; Bishop and Kuletz 2013; 11110114-C 2012 Annual Report). Similarly, loons had low densities in the early winter, peaked in December, and then were relatively low again in March (Figure Q-4; Table Q-2). Similar to Common Murres, observations of loons were clustered in the northeast Sound. Fork-tailed Storm-petrels and jaegers were only observed on the October trip, primarily in the southwestern corner of the study area (Table Q-2). Spatial and temporal patterns for both these species are consistent with Year 1 observations.

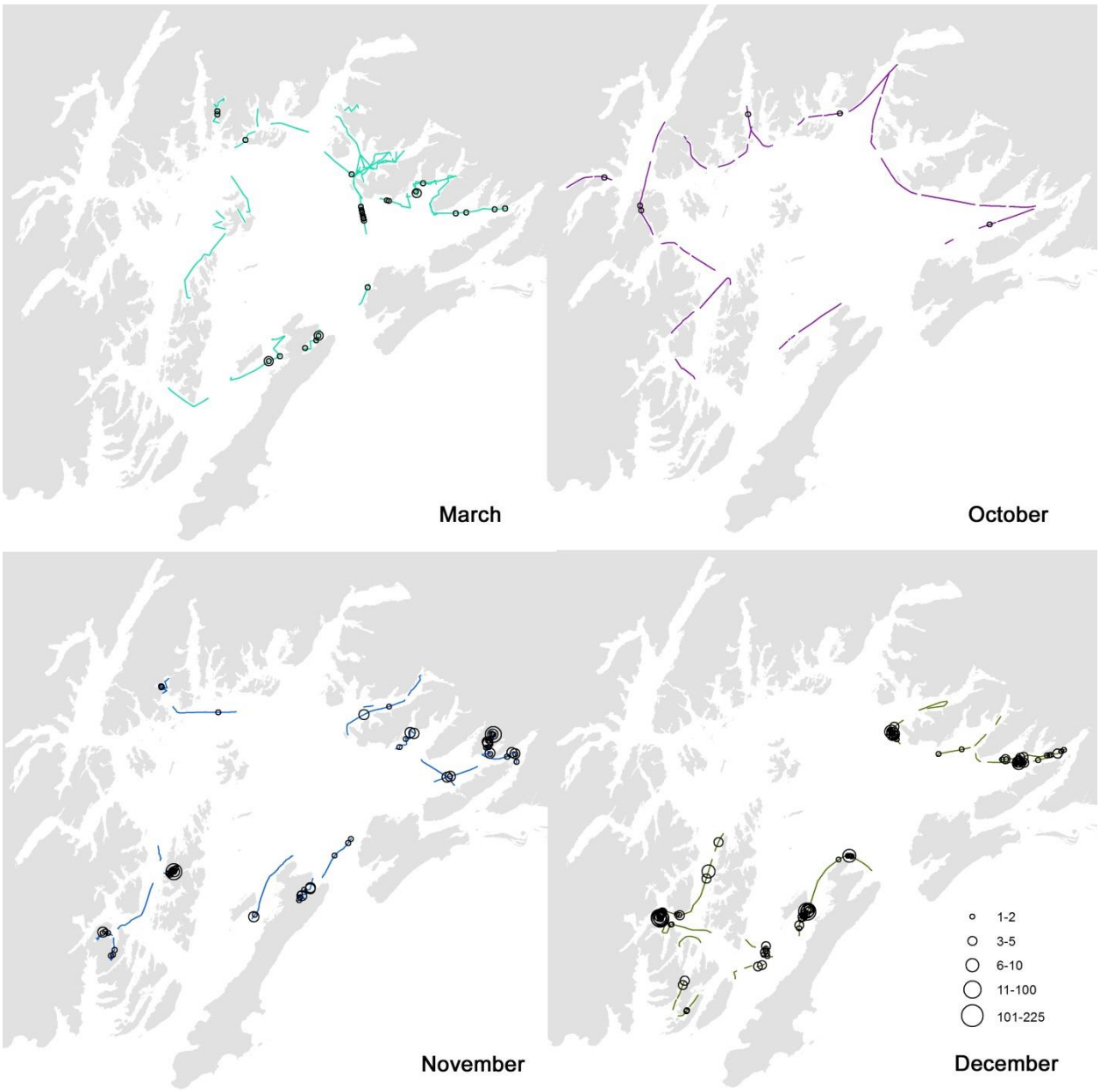


Figure Q-2. Distribution of Common Murre (*Uria aalge*), the most common bird observed during four winter surveys of in Prince William Sound in 2013.

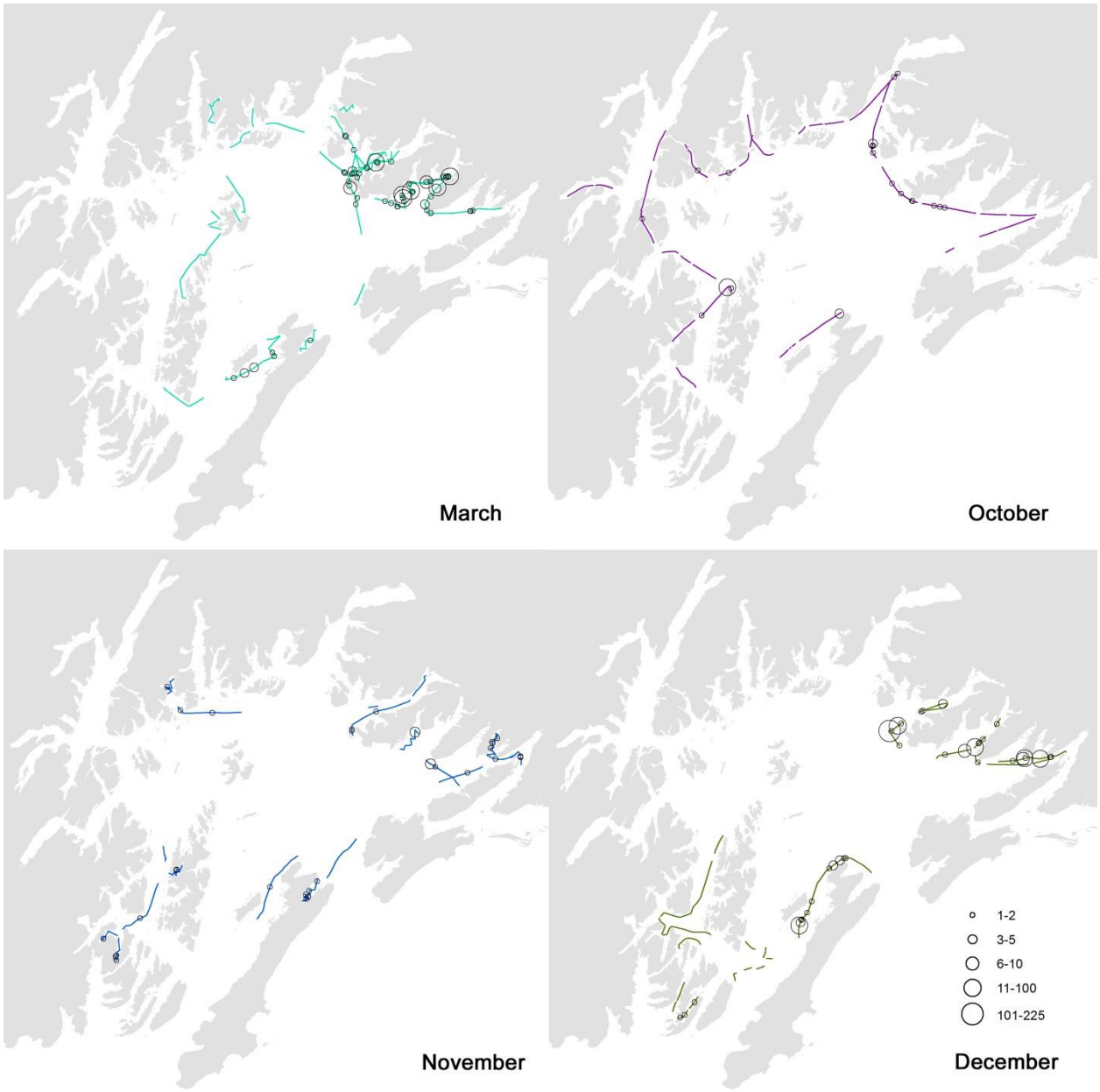


Figure Q-3. Distribution of *Brachyramphus* murrelet species (Kittlitz's Murrelet, *B. brevirostris* and Marbled Murrelet, *B. marmoratus*) in Prince William Sound during four winter surveys in 2013.

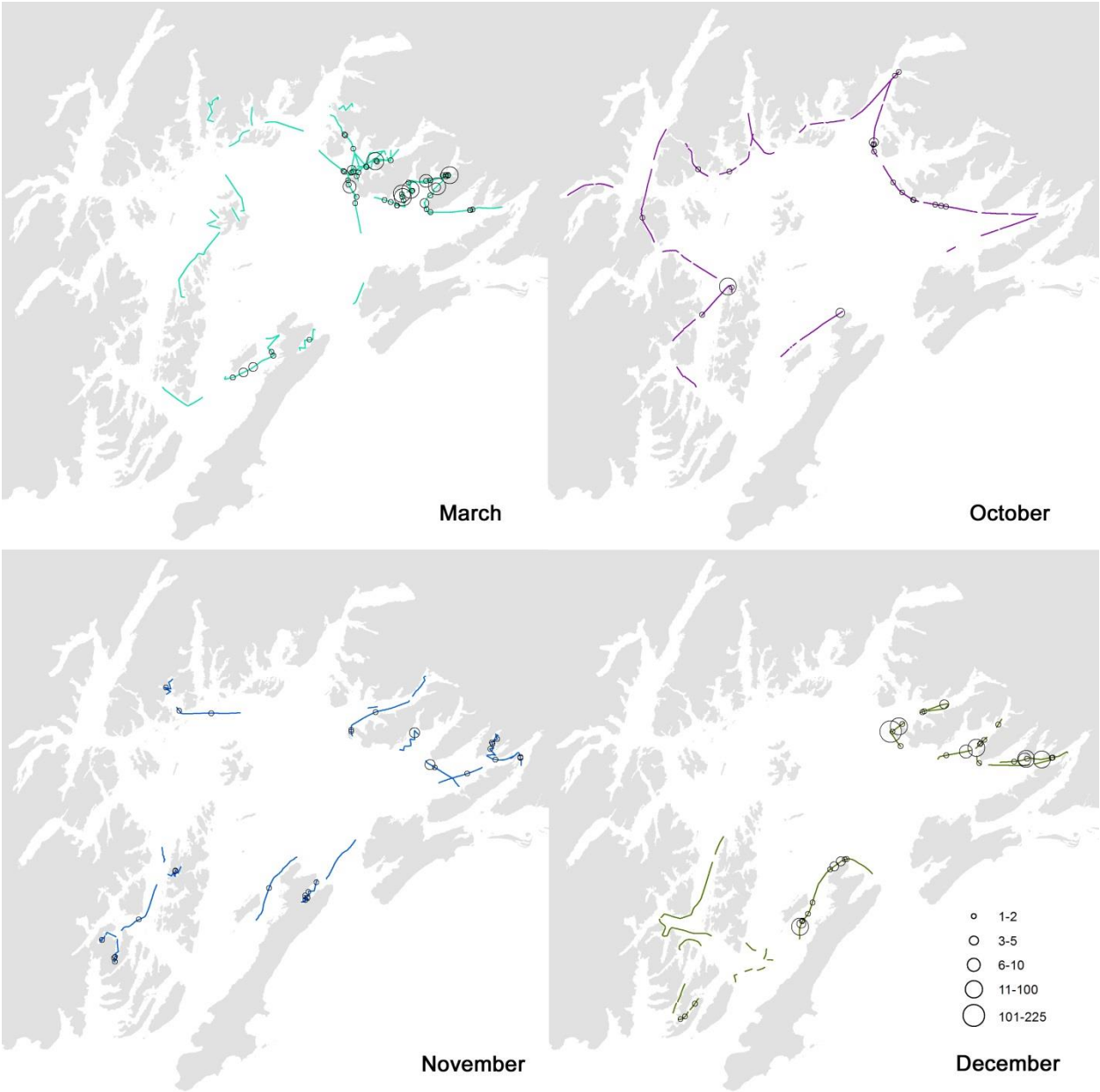


Figure Q-4. Distribution of loon species (Common Loon, *Gavia immer,* Pacific Loon, *Gavia pacifica*, Red-necked Loon, *Gavia stellata*, and Yellow-billed Loons, *Gavia adamsii*) in Prince William Sound during four winter surveys in 2013.

We completed a preliminary analysis of occupancy of major species groups in relation to environmental variables. We generated non-overlapping, one-kilometer segments along the length of surveyed trackline. Due to the non-random nature of the survey effort, we applied a model-based framework to describe distribution across time and space. Between 86% and 99% of segments had zero density estimates, depending on the species group. The number of non-zero observations (km^2 segments) were few enough for each species group to limit the possible covariate combinations, as 30 non-zero observations are recommended for each covariate included in a model (Zuur *et al.*, 2012). We therefore only modeled the response of six species groups: murres, murrelets, loons, cormorants, and small and large gulls (Table Q-4). Spatial autocorrelation was confirmed for observations of all species groups and was addressed in this report by inclusion of latitude and longitude as predictor variables. Distance to shore, sea surface temperature and month were also included. We fit species group occurrence using generalized additive models (GAMs) in "mgcv" package (Wood, 2006) in R (R Core Team, 2012) to accommodate possible non-linear effects of covariates on species occurrence (Clarke *et al*. 2003). For instance, non-linear relationships might be expected with effects of latitude and longitude over the extent of the Prince William Sound.

The full model explained 24% of the variability in distribution of murres, having little explanatory power for the other species groups (Table Q-3). Longitude was the most frequently significant predictor of bird presence. Latitude was only a strongly significant predictor for gulls; presence of small gulls increased toward the south, while the trend was nonlinear for large gulls. There was weak support for sea surface temperature influencing presence of murres, cormorants and loons, with generally linear positive associations for the two former and a negative relationship with loon presence. Distance to shore was strongly significant for cormorants, with birds more likely to be present closer to shore.

Table Q-3. Results of continuous variables in GAM occupancy models of 2013 winter seabird occupancy in the Prince William Sound, Alaska. DistShore = distance to shore (m); SST = sea surface temperature. Significance codes: 0 "*" 0.001 "**" 0.01 "*".**

Species Group	R^2	Latitude	Longitude	DistShore	SST
Murres	0.24	*	***	-	*
Murrelets	0.13	*	**	-	-
Loons	0.04	*	***	*	*
Cormorants	0.17	*	***	***	*
Small Gulls	0.11	***	*	-	-
Large Gulls	0.06	**	***	-	-

Future Work.

Beginning in 2014 we will conduct a February survey in conjunction with the annual servicing of the Ocean Tracking Network acoustic arrays across the major entrances and southwest passages of Prince William Sound (Figure Q-5). This cruise is currently funded for the next five years, with the possibility of continuation beyond that time. With the expanded adult herring survey occurring at the end of March when bird migration is already underway, this February survey will replace the March survey.

With increased numbers of non-zero density values, we will gain the opportunity to include more explanatory variables (e.g. exposure) and to select between *a priori* models explaining occupancy and abundance. We are also in the process of determining the most effective length of segments and scale of analyses so as to best maximize sample size while decreasing variance.

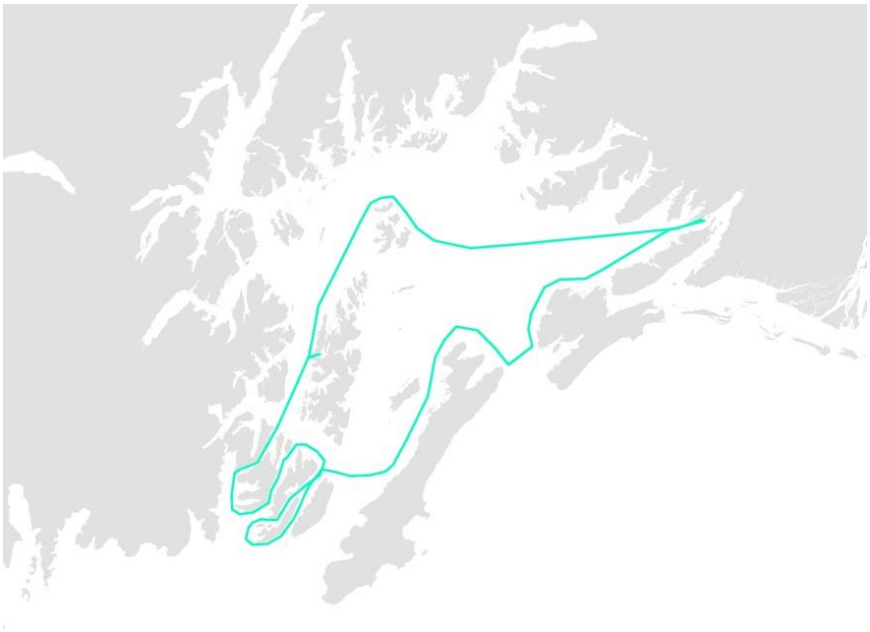


Figure Q-5. Approximate trackline for February 2014 [and annually ongoing] survey.

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8. Information and Data Transfer: See, Reporting Policy at III (C) (8).

- In September 2013 we were contacted by a consultant for the annual Prince William Sound shipper's drill. We provided information on seabird distribution and densities during October to inform the 7-9 October oil spill response drill.
- Data sets and associated metadata for October 2011 through December 2013 have been uploaded to the Gulfwatch portal. Both Bishop and Stocking, participated in the metadata (Morpho) training workshop
- A popular press article describing this project will be published during 2014 in *Delta Sound Connections* (circulation ~15,000). This annual newspaper published about the natural history of PWS and the Copper River Delta is distributed each May to airports and tourist areas in southcentral Alaska.
- We prepared time series graphs for the annual Gulfwatch meeting in Anchorage during October 2013. Principal Investigator Bishop attended the annual PI meeting in October 2013 as well as the January 2014 Gulfwatch PI meeting held during the Alaska Marine Science Symposium.
- Both Bishop and Stocking participated in marine bird working group the Dec 2013 teleconference.
- Publication status:

  Bishop, M.A., J. Watson, K. Kuletz, and T. Morgan. Pacific herring consumption by marine birds during winter in Prince William Sound, Alaska. *Fisheries Oceanography* Accepted, pending revisions.

  Dawson, N., M.A. Bishop, K. Kuletz and A. Zuur. *in review*. Winter habitat associations of seabirds in subarctic Alaska.

9. Response to EVOSTC Review, Recommendations and Comments: *See,* Reporting Policy at III (C) (9).

Please note responses to comments submitted to EVOSTC staff in September, 2013. In addition, we need clarification on the recommendation on seabird surveys, since the Science Panel comments appear to recommend combining two different surveys, one under the Pelagic component (Bishop, 14120114-C) and one under the Benthic component (Kuletz and Irons, 13120114-K). We reiterate that the Bishop project is specifically designed to collect information in late fall and winter to complement other summer seabird monitoring efforts. While other projects are addressing the nearshore birds such as black oystercatchers, harlequin, and goldeneyes our study is the only project monitoring pelagic marine birds (e.g. common murre, marbled murrelet, loons, cormorants) outside of the summer season. Our results show that there are consistent patterns of abundance and distribution of marine birds across winter, thus our surveys provide a more complete understanding of seabirds in PWS in winter, compared with March-only surveys.

The Bishop project is also conducted cost-effectively by leveraging vessel time provided by the following projects: EVOS Herring Research & Monitoring juvenile herring surveys, EVOS Gulfwatch humpback whale surveys, Alaska Department of Fish & Game shrimp surveys, and, as of February 2014, with the Ocean Tracking Network array cruise. Conducting additional summer surveys under the Kuletz and Irons project would require significantly more funding from the Trustee Council. In addition, as part of the first 5-year phase and in preparation for the 2015 joint Science Workshop, we are evaluating our sampling design.

10. Budget: *See,* Reporting Policy at III (C) (10).

Travel to the annual PI meeting and the Alaska Marine Science Symposium are now being charged to the project. These were not initially budgeted for. The delays in hiring personnel have been remedied.

R. NEARSHORE BENTHIC SYSTEMS IN THE GULF OF ALASKA- BALLACHEY AND DEAN (USGS ASC, 12120114-R)

1. Project Number: *See,* Reporting Policy at III (C) (1).

12120114-R

2. Project Title: *See,* Reporting Policy at III (C) (2).

Gulf Watch Alaska: Nearshore Benthic Systems in the Gulf of Alaska

3. Principal Investigator(s): *See,* Reporting Policy at III (C) (3).

B. Ballachey, J. Bodkin, H. Coletti, T. Dean, D. Monson, D. Esler; Co-PI's: K. Kloecker, M. Lindeberg, B. Weitzman, A. Doroff, M. Shephard

4. Time Period Covered by the Report: *See,* Reporting Policy at III (C) (4).

February 1, 2013-January 31, 2014

5. Date of Report: *See,* Reporting Policy at III (C) (5).

March 1, 2014

6. Project Website (if applicable): *See,* Reporting Policy at III (C) (6).

www.gulfwatchalaska.org

7. Summary of Work Performed: *See,* Reporting Policy at III (C) (7).

Summary of Work Performed

Our field work for year 2 (the 2013 field season, with field work from March through July) was completed with no problems or concerns, with project components completed on schedule (Table R-1). We conducted 6 field trips, including 1 to Katmai National Park (KATM), 2 to Kenai Fjords National Park (KEFJ), 2 to western PWS (WPWS), and 1 to northern PWS (NPWS). At Katmai, Kenai Fjords and WPWS, we visited and sampled sites that were established in previous years, and in NPWS, we established and sampled new sites. Work completed in all areas included monitoring of rocky intertidal, soft sediment and mussel sites, eelgrass beds, and black oystercatcher nests, as well as collection of sea otter forage data. We also completed a winter bird survey at Kenai Fjords, summer bird surveys in Katmai and Kenai Fjords, and sea otter carcass collections in WPWS, Katmai and Kenai Fjords. An aerial survey of sea otters was completed in WPWS. An aerial survey in Kenai Fjords was scheduled for completed August 2013 but due to several factors (primarily weather-related), we were not able to complete this survey. We have continued to coordinate our monitoring efforts with the intertidal work being done in Kachemak Bay (KBAY; K. Iken and B. Konar; Gulf Watch Alaska Nearshore Project 13120114-L). Mussels were sampled at 3 locations in northern PWS and were submitted to NOAA for contaminant analyses as part of their Mussel Watch program. A report entitled "*Intertidal Invertebrate and Algae Monitoring: Power to Detect Temporal Trends*" was submitted to NPS by WEST, Inc. in 2012. Currently, further work on these statistical analyses with WEST is being conducted with an anticipated completion sometime during the spring

of 2014 (funding for this component provided by NPS). We continued collections of nearshore species for stable isotope analyses and plan to establish priorities for future stable isotope sampling. Analyses of stable isotopes (carbon and nitrogen) in these samples are underway in the laboratory of Dr. S. Newsome. In addition, we are developing assays to evaluate gene expression and physiological status of mussels, as a tool for monitoring long-term health of the nearshore, in collaboration with Drs. L. Bowen and K. Miles (USGS-WERC) and T. Hollmen (AK SeaLife Center); a poster on this effort was presented at the 2014 Alaska Marine Science Symposium. A live oyster (*C. gigas*) was found during a sampling trip to Johnson Bay in WPWS in June 2013. The oyster was presumed to be at least 5 yrs old due to the perennial seaweeds growing on it as well as its size. No other oysters were found in the vicinity. A report on this finding was prepared by M. Lindeberg, and all appropriate agencies (including NOAA, ADF&G, and USGS) have been informed.

Here we present sample results from 3 components of our nearshore studies: (1) a summary of aerial surveys and ages-at-death of sea otters in western PWS, data through 2013, (2) rocky intertidal invertebrates and algae, presenting an synthesis of data from our study sites at KATM, KEFJ, WPWS and NPWS with data collected at KBAY study sites under Project Component 13120114-L, and (3) clam assemblages at sand/gravel sites in KATM, KEFJ, WPWS, and EWPS. A detailed description of the nearshore benthic component of Gulf Watch Alaska is presented by Dean et al. (2013) in the *Protocol Narrative for Nearshore Ecosystem Monitoring in the Gulf of Alaska*, updated in 2013 to reflect the joint effort of the NPS Southwest Alaska Vital Signs Monitoring Program and the EVOS Gulf Watch Alaska Long-term Monitoring of nearshore sites in the Gulf of Alaska. Additional data syntheses and analyses are presented in two recent reports: Coletti et al. (2014, http://science.nature.nps.gov/im/units/swan/publications.cfm?tab=2): SWAN and Ballachey et al. (2014, http://pubs.usgs.gov/of/2014/1030/) OFR. These three documents are provided as attachments to this annual report in Appendix C.

(1) Sea Otters: Aerial Surveys and Ages-at-death, WPWS

The *Exxon Valdez* oil spill (EVOS) caused significant sea otter mortality in western Prince William Sound (WPWS), and a variety of studies were conducted over the two decades to assess the recovery of sea otters, including aerial surveys to monitor abundance and annual carcass collections to assess patterns of ages-at-death. These efforts have been funded as part of the Gulf Watch Alaska nearshore benthic program since 2012, and analyses of these data sets, collected over two decades post-spill, are presented in a recent report (Ballachey et al. 2014). Here we provide a brief summary of the aerial survey and ages-at-death data through 2013.

Aerial survey methods were developed specifically for estimating sea otter abundance. Surveys have been implemented in the larger area of WPWS, and in the sub-area of the northern Knight Island archipelago in WPWS, where shorelines were heavily oiled in 1989.

In WPWS, by 2009 the estimated number of sea otters had approximately doubled relative to the 1993 estimate, although an accurate estimate of the pre-spill abundance at that spatial extent is not available for use as a recovery gauge. At northern Knight Island, which received heavy oiling of shorelines in 1989 and abundance was depressed for almost two decades relative to the pre-spill estimate (Fig. R-1). A return to pre-spill abundance was delayed for 2 decades at northern Knight

Island; however, by 2011, the number of sea otters there was comparable to estimated pre-spill numbers, and similar levels of abundance persisted through 2012 and 2013 (Fig. R-2).

Annual collections of sea otter carcasses from shorelines were initiated in WPWS in the 1970s. Based on teeth or skull morphology, it is possible to estimate the age at death, and this long-term data set provides a baseline for evaluating recovery from the spill. Pre-spill data indicate that mortality of sea otters typically was comprised largely of very young and older sea otters, with relatively few prime age (defined here as 2–8-year olds) otters dying each year (Fig. R-3). This pattern was altered after the spill when, for about two decades, annual carcass collections showed a relatively high proportion of prime-age otters dying each year. Starting in 2011, we observed a distinct change in the age-class proportions of dying sea otters, with a return to the pre-spill pattern of predominantly young and older sea otters recovered as carcasses. This pattern continued in 2012 and 2013, which we interpret as evidence that over the past few years, chronic exposure to lingering oil and/or chronic effects due to previous exposure have abated to the point where they are no longer factors constraining survival. A higher proportion of sea otters in oiled areas are again surviving to older ages, as documented in WPWS prior to the spill.

Based on the sea otter abundance and ages-at-death data through 2013, we conclude that status of sea otters in WPWS is consistent with the designation of recovery from the spill as defined by the Exxon Valdez Oil Spill Trustee Council (EVOSTC; www.evostc.state.ak.us/Recovery/status.cfm). Further data and discussion on aerial surveys and ages-at-death are presented in Ballachey et al. (2014).

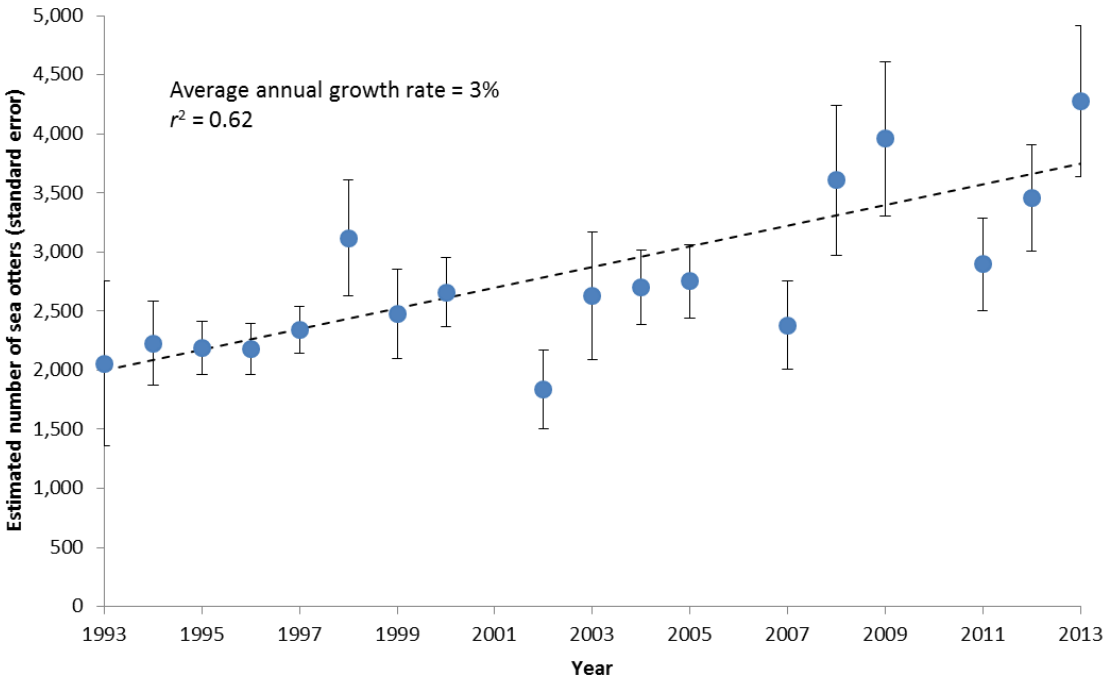

Figure R-1. Trend in sea otter abundance (± standard error) in western Prince William Sound, Alaska, 1993–2013.

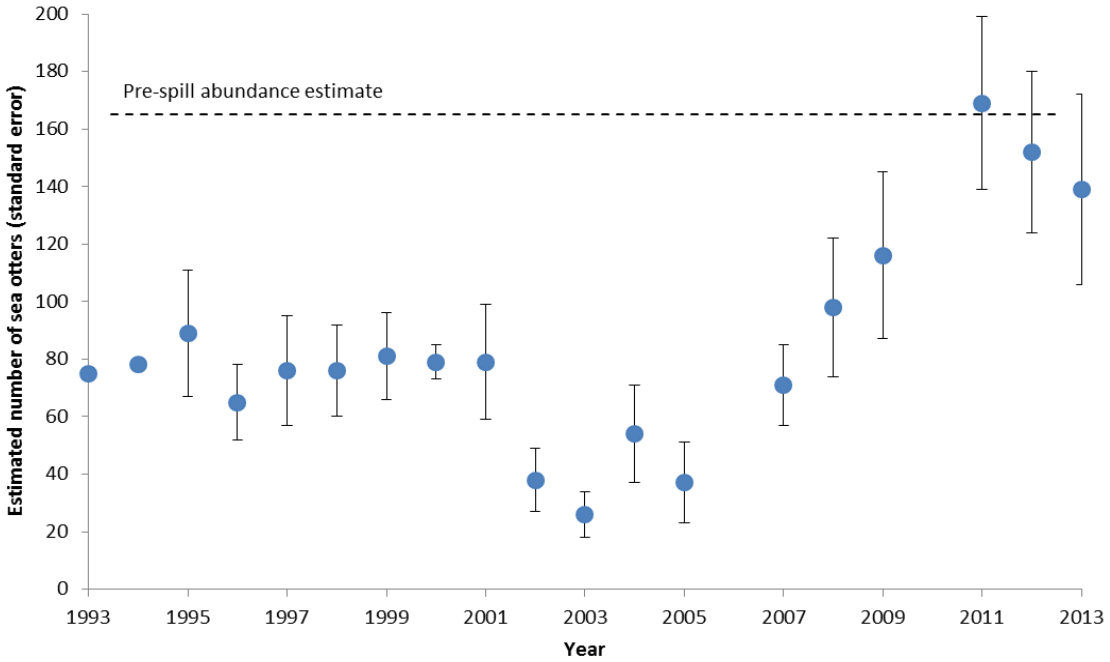

Figure R-2. Estimated numbers of sea otters (± standard error) at heavily oiled northern Knight Island, Prince William Sound, Alaska, 1993–2013 relative to a pre-spill abundance estimate

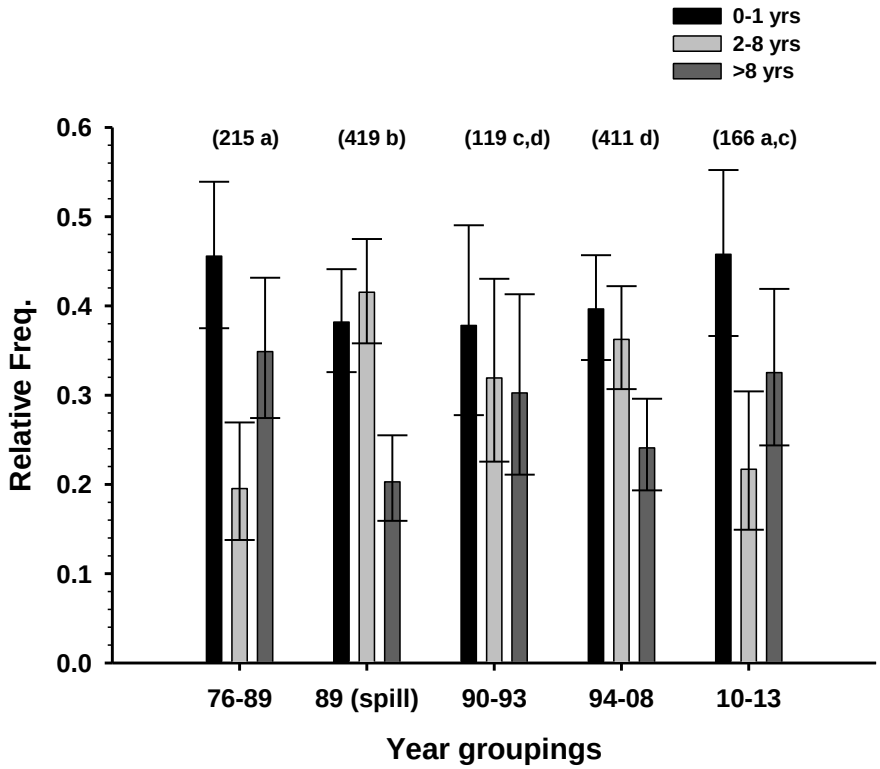

Figure R-3. Relative age distributions of sea otter carcasses collected on western Prince William Sound beaches from 1976 to 2013. All non-pup ages were estimated by tooth cementum analysis (Matson's Laboratory, Milltown, Mont.). Total numbers of carcasses collected are in parentheses above each grouping and distributions with the same letter do not differ significantly from each other.

(2) Rocky Intertidal – Synthesis of invertebrate and algae % cover data, KATM, KEFJ, WPWS, EWPS and KBAY.

To assess larger-scale spatial variability across the Gulf of Alaska, we are conducting an analysis of data on rocky intertidal community structure with our colleagues who are monitoring intertidal sites in KBAY (K. Iken and B. Konar, UAF, Gulf Watch Alaska Nearshore Project 13120114-L). This analysis incorporates sites from WPWS, EPWS, KATM, KEFJ, and KBAY. A multidimensional scaling plot of the communities in the mid and low intertidal strata collected in 2012 shows some regional differences in addition to site-specific differences within each region (Fig. R-4). For example, rocky intertidal community composition in KBAY (green triangles) separates distinctly from the other regions, but within KBAY, sites form two distinct groups based on three sites exposed to more oceanic conditions and two sites being more under glacial outflow influence. Similarly, three sites in KATM (light blue squares) group separately, likely due to stronger glacial influence at those sites compared to other KATM sites that are under greater Gulf of Alaska influence and are thus more similar to open coast, exposed KEFJ sites (red diamonds). Sites within Prince William Sound (WPWS, pink circles and EPWS, blue triangles) overall are relatively similar except for some sites with strong current and oceanic influences, which again are more similar to the KEFJ group. Hence,

local oceanographic differences seem to be a strong driver of community composition within each of the regions and can override regional differences. In continuing work, we will perform similar analyses for other sampling years, separately for different intertidal strata, and correlate community patterns with environmental conditions to identify the variables that most strongly drive rocky intertidal community composition.

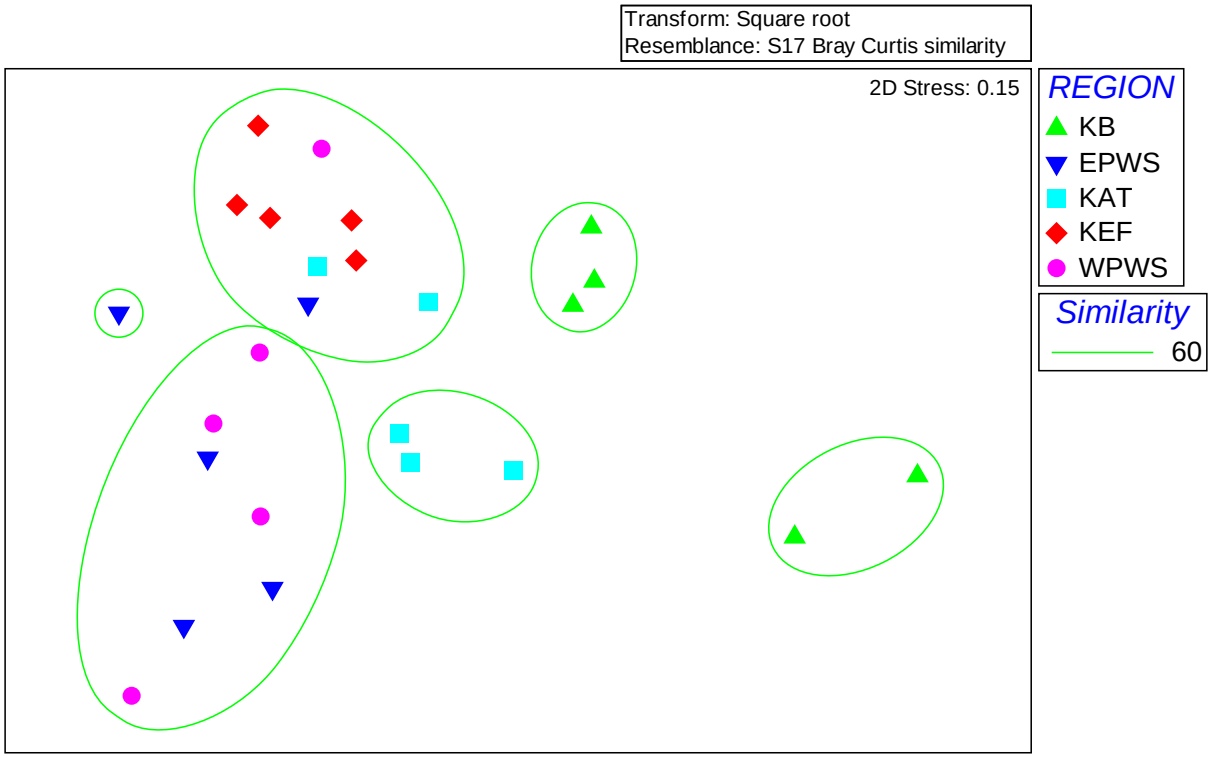

Figure R-4.Multidimensional scaling plot of community composition at rocky intertidal sites in the Gulf of Alaska, with cluster analysis grouping at the 60% similarity level. Regions are Kachemak Bay (KB), eastern PWS (EPWS), Katmai National Park and Preserve (KAT), Kenai Fjords National Park (KEF), western PWS (WPWS).

(3) Clam assemblages at sand/gravel sites, KATM, KEFJ, WPWS, and EWPS.

The intertidal environment in the Gulf of Alaska is vast and can be incredibly productive, supporting dense invertebrate populations that are important resources to humans for subsistence, sport, and commercial harvests and for many nearshore predators. In unconsolidated or mixed-gravel substrate (hereafter referred to as soft-sediment) the dominant resource is filter-feeding infaunal bivalves which are widely preyed upon by sea otters, sea and shore birds, bears, and other marine and terrestrial consumers. These resources often occur as patches or beds and recruitment can be highly variable over time. The intertidal environment is particularly susceptible to human disturbance including oil spills, harvesting activities, pollutants from terrestrial, airborne and marine sources, and shoreline development. Changes in the structure of the intertidal community serve as valuable indicators of disturbance, both natural and anthropogenic in origin.

The goal of the soft-sediment sampling of the Gulf Watch nearshore benthic component is to monitor bivalves and assess changes in size and density of assemblages over time. We compare between regions to assess trends in clam assemblage structure. Figure R-5 displays the mean available biomass over time at our sampling regions, including data from KATM, KEFJ, WPWS, EPWS, and NPWS collected during 2007-2013 (each point reflects the average of 5 sites per region). We find that there is variability in clam assemblages among regions and over time. The butter clam, *Saxidomus giganteus*, constitutes the highest biomass at most of our intertidal sites, except in KEFJ where *Macoma spp.* make up the bulk of the biomass. This represents an important distinction between areas, where one region may have fewer resources available to nearshore predators than another due to clam populations being of a much smaller size or at lower densities. In addition, we are able to monitor population trends like the decrease in *S. gigantea* at KATM, which may have important food web implications for sea otters and coastal brown bears. Observed trends are not consistent throughout our study range, but continued monitoring and integration of other nearshore benthic study components will provide insight into what is driving change in these resources throughout the Gulf of Alaska.

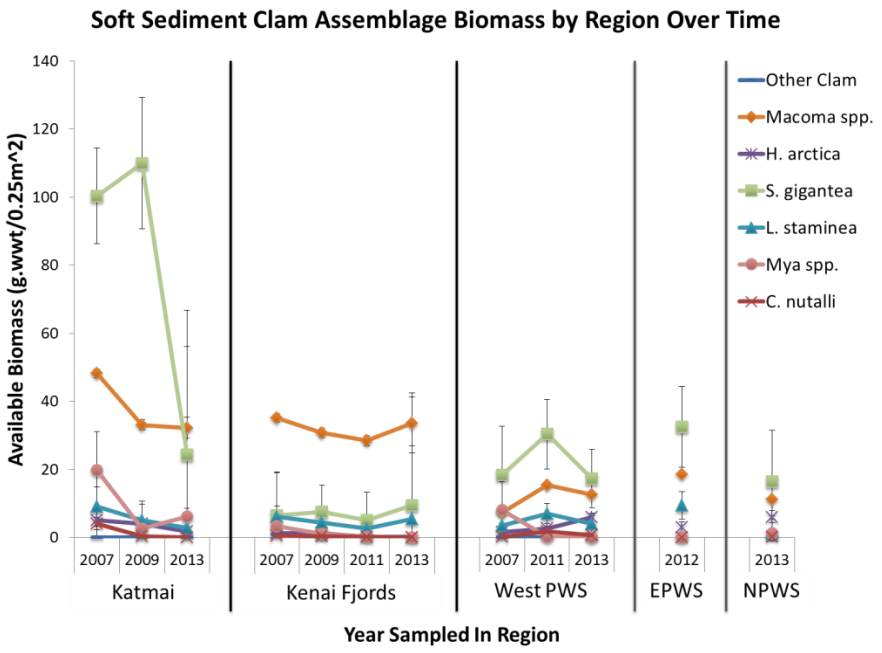

Figure R-5.Soft sediment (sand/gravel) clam assemblages at five regions in the Gulf of Alaska, presented as biomass within each region over time.

Table R-1. Status of project milestones for year 2

Deliverable/Milestone	Status
Field work (6 trips, multiple tasks per trip); Katmai, Kenai Fjords, WPWS, NPWS	Completed, March - July 2013
Aerial survey of sea otters, WPWS	Completed, June 2013
Upload 2012 data to project website	Completed, August 2013
PI's attend annual Gulf Watch meeting	Completed, November 2013

8. Information and Data Transfer: See, Reporting Policy at III (C) (8).

Publications& Reports:

Ballachey, B. E., J.L. Bodkin, and D.H. Monson. 2013. Quantifying long-term risks to sea otters from the 1989 *Exxon Valdez* oil spill: Reply to Harwell & Gentile (2013). Marine Ecology Progress Series 488:297-301. doi:10.3354/meps10498

Ballachey, B., D. Monson, G. Esslinger, K, Kloecker, J. Bodkin, L. Bowen and K. Miles. 2014. 2013 Update on Sea Otter Studies to Assess Recovery from the 1989 *Exxon Valdez* Oil Spill, Prince William Sound, Alaska.U.S. Geological Survey Open-File Report 2014-xxxx, 40 p., http://dx.doi.org/10.3133/ofr2014xxxx.

Bodkin, J.L., D. Esler, S.D. Rice, C.O. Matkin, and B.E. Ballachey. 2014. The effects of spilled oil on coastal ecosystems: lessons from the *Exxon Valdez* spill. Pp. 311-346 in B. Maslo and J. L. Lockwood, eds. Coastal Conservation.Cambridge University Press.

Coletti, H. A., T.A. Dean, K.A. Kloecker and B.E. Ballachey. 2013. Nearshore marine vital signs monitoring in the Southwest Alaska Network of National Parks: 2012. Natural Resource Technical Report NPS/SWAN/NRTR—20XX/XXX. National Park Service, Fort Collins, Colorado.(anticipated release, February 2014).

Dean, T.A., J.L. Bodkin and H.A. Coletti. 2014. Protocol Narrative for Nearshore Marine Ecosystem Monitoring in the Gulf of Alaska, Version 1.1. Natural Resource Technical Report NPS/SWAN/NRTR—2014/756. National Park Service, Fort Collins, Colorado.

Presentation: Ballachey, B., L. Bowen, A.K. Miles, G. Esslinger, M. Lindeberg, K. Kloecker, H. Coletti. Gene transcription profiles in mussels from Prince William Sound, 2012 & 2013, as an indicator of ecosystem health. Poster presented at the Alaska Marine Science Symposium, Anchorage, Alaska, January 2014.

Meeting attendance: January 2014 Alaska Marine Science Symposium: Ballachey, Coletti, Doroff, Esler, Kloecker, Lindeberg, Monson, Shephard, Weitzman. November 2013 Gulf Watch PI meeting, Anchorage: Ballachey, Coletti, Dean, Doroff, Esler, Kloecker, Lindeberg, Monson, Shephard.

Data & metadata uploaded to data portal: (1) Black oystercatchers: prey and nest site data, KEFJ, KATM, WPWS; (2) Rocky intertidal sites: percent cover of invertebrates and algae, nucella, katharina, & sea star counts, slope data; KEFJ, KATM, WPWS, EPWS; (3) Invertebrates on sand/gravel beaches: counts, species, sizes,KEFJ, KATM, WPWS, EPWS; (4) mussels: counts, sizes (if > 20mm), KEFJ, KATM, WPWS, EPWS; (5) Sea otters: carcass data, KATM, WPWS, forage data, KEFJ, KATM, WPWS, EPWS, aerial survey--metadata only; (6) Water quality: mussel contaminant data, KEFJ, KATM, WPWS, EPWS, temperature data (intertidal), KEFJ, KATM, WPWS; (7) Marine bird and mammal survey data, KATM, KEFJ (raw count data and metadata in form of description of project and methods).

9. Response to EVOSTC Review, Recommendations and Comments: *See,* Reporting Policy at III (C) (9).

There were no recommendations for changes to this project component in the recent EVOSTC reviews.

10. Budget: *See,* Reporting Policy at III (C) (10).

Budget forms submitted separately. Our overall budget expenditures are on target with the proposed expenditures, and are in keeping with the objectives of the project. However, our agency financial system codes categories somewhat differently than the EVOS categories, so that the total for each EVOS category sometimes varies between the proposed and the actual. Further detail, if needed, will be provided upon request.

S. ECOLOGICAL COMMUNITIES IN KACHEMAK BAY- IKEN, KONAR, DOROFF (12120114-L)

1. Project Number: *See,* Reporting Policy at III (C) (1).

13120114-L

2. Project Title: *See,* Reporting Policy at III (C) (2).

Long-term monitoring of ecological communities in Kachemak Bay: a comparison and control for Prince William Sound

3. Principal Investigator(s): *See,* Reporting Policy at III (C) (3).

Brenda Konar (UAF), Katrin Iken (UAF), Angela Doroff (KBRR)

4. Time Period Covered by the Report: *See,* Reporting Policy at III (C) (4).

February 1, 2013-January 31, 2014

5. Date of Report: *See,* Reporting Policy at III (C) (5).

March 1, 2014

6. Project Website (if applicable): *See,* Reporting Policy at III (C) (6).

www.gulfwatchalaska.org

7. Summary of Work Performed: *See,* Reporting Policy at III (C) (7).

Intertidal monitoring

Work during this period included intertidal field monitoring in Kachemak Bay, conducted 7-13 May 2013 (Table S-2). Monitoring included five rocky intertidal sites, four seagrass sites, and for the first time in this project also four mixed sediment clam beaches (Port Graham, Jakolof Bay, China Poot Bay, Bear Cove). Insufficient low tide level at Bishop's Beach and Bluff Point prohibited us from complete surveys of tidal levels at those sites. Limpet (*Lottia persona*) and mussel (*Mytilus trossulus*) size-frequency distributions were assessed at three rocky sites (Port Graham, Outside Beach, Cohen Island).

For all habitats and communities assessed, we found strong site-specific differences within Kachemak Bay in 2013. For several of these measures, such as rocky intertidal community structure, these differences are persistent over multiple years. Community structure is more similar among the three sites along the south shore of Kachemak Bay and along the two sites along the north shore with more pronounced differences between the two shores, likely driven by the stronger glacial influence on the nearshore system of the northern shore.

Among mussel collection sites in 2013, a very large recruitment peak was observed in Port Graham that did not occur at the other two sites (one order of magnitude larger at Port Graham). In collaboration with Dr. Suresh Andrew Sethi we assessed if mussels recruit annually into the system based on mussel size-frequency data obtained in 2012 and 2013. For this we calculated age distribution from size-frequency distribution based on published growth data for *Mytilus trossulus* (Millstein and O'Clair 2001). A cohort analysis was then applied to the age structure at the three

rocky intertidal sites in Kachemak Bay. Age population structure was then analyzed for cohorts. At all sites, mussels reached about 3 years of maximum age and the even distribution of age classes to overall population suggests that recruitment occurs every year in Kachemak Bay (for example see Fig. S-1). The reasons for the limited life span of mussels in Kachemak Bay is currently unknown but we will begin to compare these results to the otter scat and diet data (see below) to assess if predation pressure may be one of the causes.

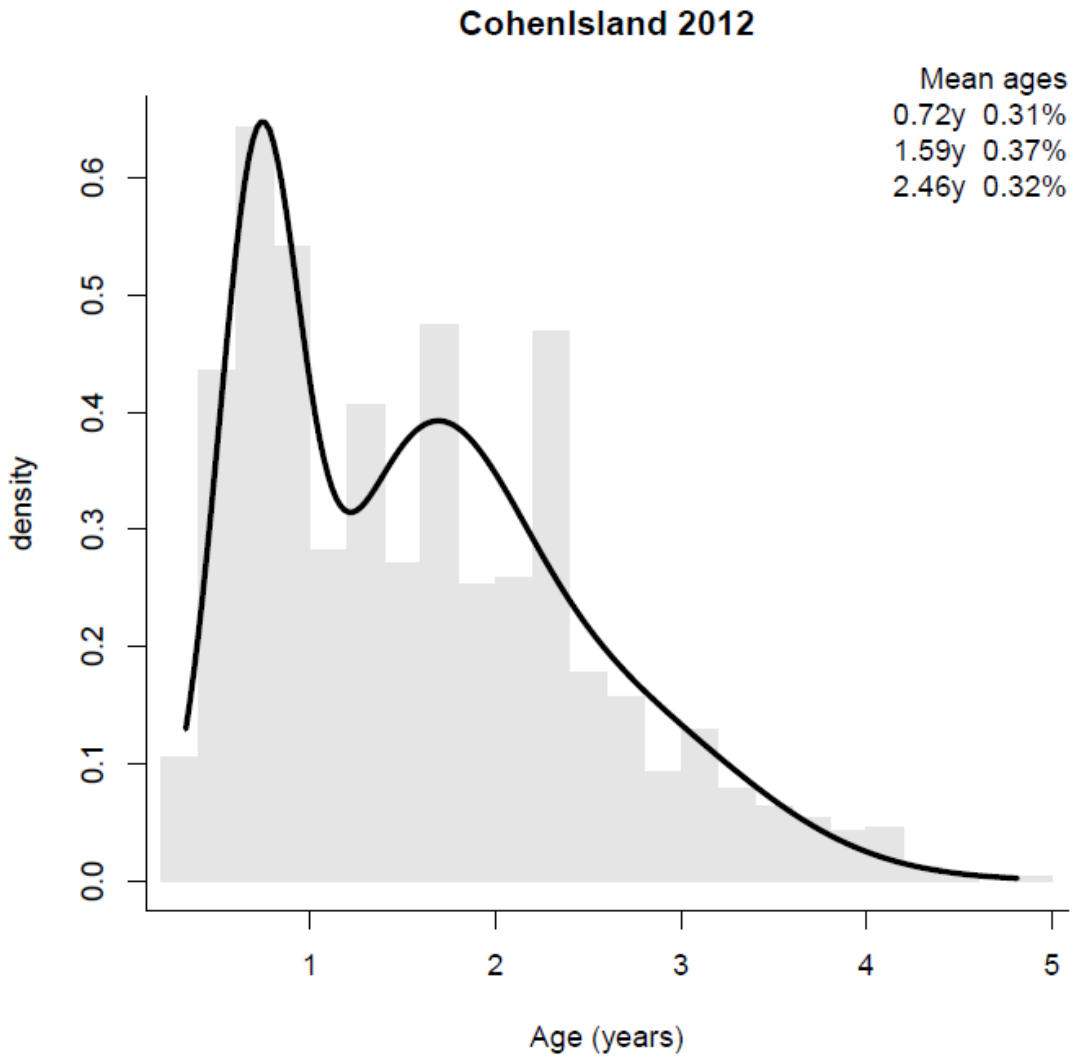

Figure S-1. Mussel age structure at Cohen Island in May 2012. The population comprises three age groups, each of which contributes a similar proportion to the overall population. This suggests relatively consistent recruitment in Kachemak Bay.

Clam species composition across sites was overall similar, although there also were site-specific differences in the relative contribution of the various species. Clam composition differed among sites and was often dominated by 1-2 taxa per site (Fig. S-2). *Macoma* spp. were dominant at Port Graham, Jakolof Bay and Bear Cove, while the butter clam, *Saxidomus gigantean,* dominated at China Poot. The Pacific Littleneck (*Leukoma staminea*) occurred in appreciable amounts only at Bear Cove, which also had the highest clam density of all sites.

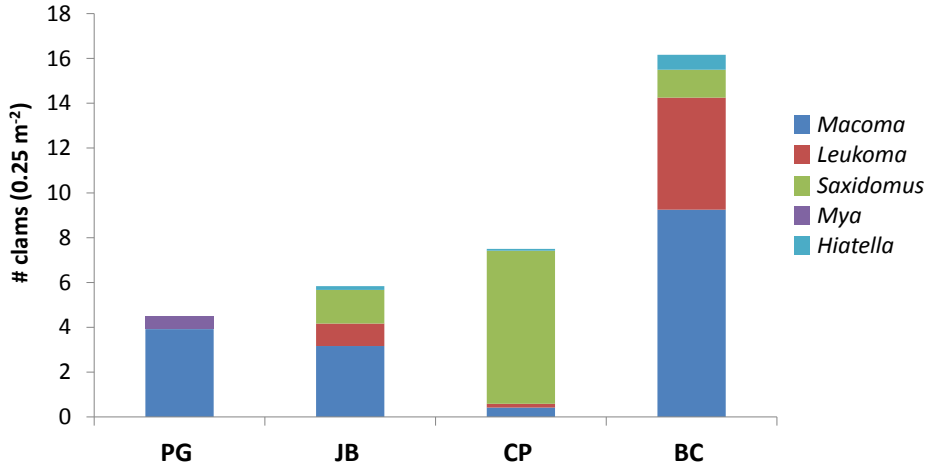

Figure S-2 Clam composition at soft sediment/gravel sites in Kachemak Bay.

The high site-specific community patterns observed in many of the nearshore habitats monitored in Kachemak Bay suggests that Kachemak Bay cannot be regarded as one homogeneous system but as a mosaic of communities that are experiencing varying environmental conditions. These conditions seem to contrast sufficiently to drive small-scale differences in the communities. Therefore, perturbations, such as those driven by climate alterations or human disturbances, may affect the same habitat type differently in different locations. Therefore, for successful monitoring, it is essential that communities are examined under various environmental influences within a larger system such as Kachemak Bay or the Gulf of Alaska.

To further assess larger-scale spatial variability, we started regional comparisons with our Gulf Watch Alaska colleagues from the USGS and the National Park Service who monitor rocky intertidal community structure in the Prince William Sound (eastern and western part), Katmai, and Kenai Fjords, compared to our Kachemak Bay region. A multidimensional scaling plot of the communities in the mid and low intertidal strata collected in 2012 shows some regional differences in addition to site-specific differences within each region (Fig. S-3). For example, rocky intertidal community composition in Kachemak Bay (green triangles) separates distinctly from the other regions, but within Kachemak Bay, sites form two distinct groups based on three sites exposed to more oceanic conditions and two sites being more under glacial outflow influence. Similarly, three sites in Katmai (light blue squares) group separately, likely due to stronger glacial influence at those sites compared to other Katmai sites that are more under Gulf of Alaska influence and are thus more similar to open coast, exposed Kenai Fjords sites (red diamonds). Sites within Prince William Sound (pink circles and blue triangles) overall are relatively similar except for some strong current and oceanic influence sites that again are more similar to the Kenai Fjord group. Hence, local oceanographic differences seem to be a strong driver of community composition within each of the regions and can even override regional differences. In future steps we will perform similar analyses

for other sampling years, separately for different intertidal strata, and we will correlate community patterns with environmental conditions to identify the variables that most strongly drive rocky intertidal community composition.

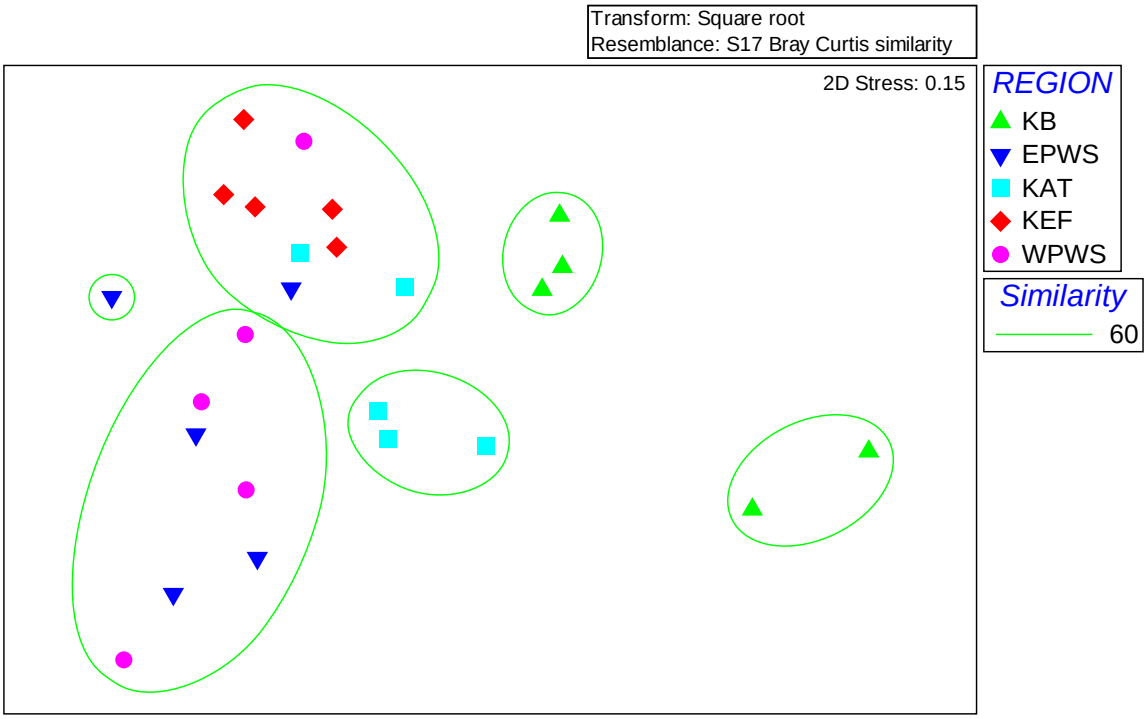

Figure S-3. Multidimensional scaling plot of rocky intertidal community composition in various regions of the Gulf of Alaska. Each symbol is a site, denoted by region. Sites are grouped on a 60% similarity level; sites closer together are more similar than sites farther apart.

Sea Otter Population Assessment

In 2012, U. S. Fish and Wildlife Service and U.S. Geological Survey completed three replicate surveys of Kachemak Bay in late summer. The adjusted population estimate was 5,927 ± 672 and in 2008, the population abundance was 3,596 ± 802 animals, reflecting an annual rate of increase of 0.13 yr^{-1} in abundance between 2008 and 2012 (USGS unpublished data; Gill et al. 2009). Methods were consistent between surveys and are detailed in Gill et al. (2009) and Bodkin and Udevitz (1999). The 2012 survey results were analyzed during the reporting period but are still preliminary and have not undergone formal review within U.S. Geological Survey. However, the increase in sea otter numbers is important and relevant to the community ecology within Kachemak Bay. The maximum annual population growth rate for a sea otter is estimated at 0.20 yr^{-1} (Riedman and Estes 1990) and the observed rate of population increase for Kachemak Bay may be due to high pup recruitment and survival rates in the region. During 2007-2010, sea otters were monitored by radio telemetry to assess a Marine Mammal Protection Act, Unusual Mortality event. Doroff and Badajos (2010) found that all female otters in the study ≥ 3 years of age produced a pup annually. It is also possible that there may be immigration from areas outside of the survey area.

Sea otters use different areas along the coast based on age, sex, and reproductive status. In 2007-2010, VHF radio transmitters were implanted in 44 animals (all sex/age classes) of sea otter in Kachemak Bay; sea otters used all habitats in the Bay and were frequently found in open water areas (> 1 km for shoreline) (Doroff and Badajos 2010). In Fig. S-4, we have generalized the habitat use areas by male and female pup rearing sites based on repeat locations of radio-marked sea otters and from personal observations (Table S-1).

Table S-1. Sea otter population abundance estimates from aerial-based sea otter surveys in Kachemak Bay Alaska 2002-2012. All surveys followed methods generated by Bodkin and Udevitz (1999).

Year	Estimated Abundance (Std Error)	Comments on the Surveys
2002	912±368	U.S. Geological Survey
2007	3,724±979	U.S. Geological Survey of lower Cook Inlet and Kachemak Bay; no replicate surveys
2008	3,596±802	U.S. Fish and Wildlife Service; Kachemak Bay only with replication
2009	*4,063*	A calculated estimate based on a 13% yr^{-1}rate of increase between survey periods
2010	*4,591*	A calculated estimate based on a 13% yr^{-1}rate of increase between survey periods
2011	*5,188*	A calculated estimate based on a 13% yr^{-1}rate of increase between survey periods
2012	5,927±672	U.S. Fish and Wildlife Service and U.S. Geological Survey ; Kachemak Bay only with replication

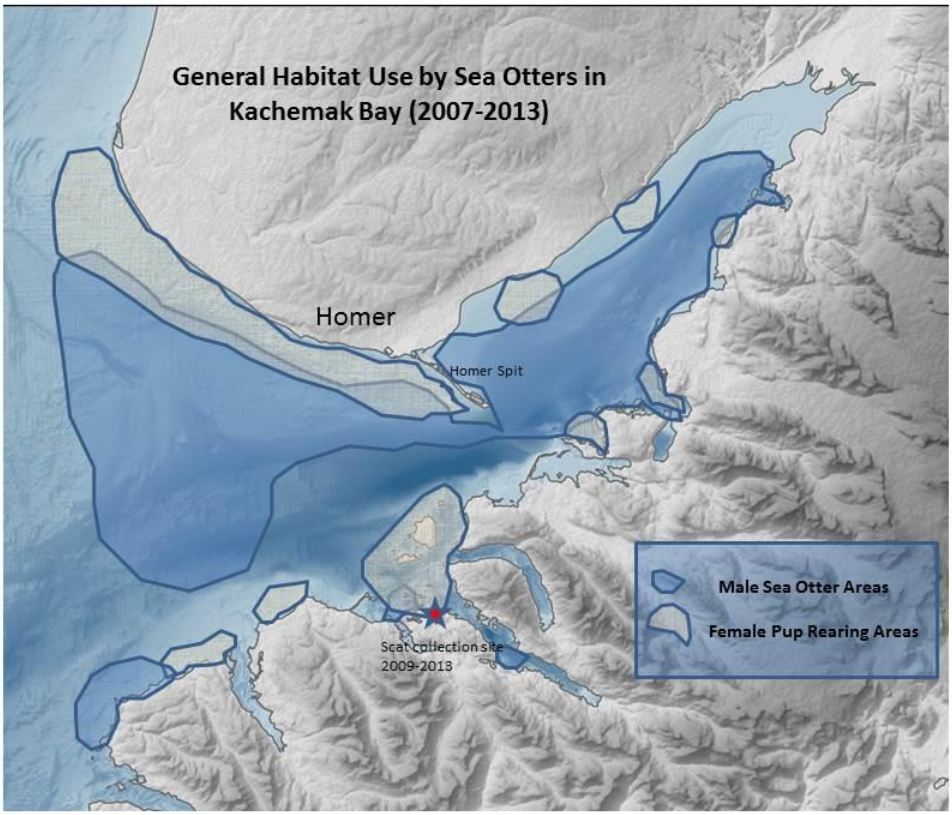

Figure S-4. Generalized habitat use of sea otter in Kachemak Bay, Alaska during 2007-2013 based on VHF radio telemetry studies and personal observations. This figure does not capture variations in habitat use by season.

Sea Otter Mortality

The Alaska Marine Mammal Stranding Network in Homer, AK in collaboration with the U.S. Fish and Wildlife Service, Marine Mammals Management Office has been collecting year-around data on sea otter carcass recovery, causes of mortality, and managing live strandings since the beginning of this study. The local marine mammal stranding network is voluntary and the following people have been instrumental in local response to sea otter strandings, Marc Webber, Debbie Tobin, and Rachel Rooney. Most of the strandings are reported along the Homer Spit and the Bishop's Beach area. The U.S. Fish and Wildlife Service have not published the data on the number of mortalities since the Unusual Mortality Event in 2006; however, they have continued to collect and manage data on sea otter mortality in this area.

In 2013, the U.S. Fish and Wildlife Service recovered 61 sea otter carcasses from Kachemak Bay; this is represents approximately 73% of the total recovered State-wide in the program. Sex/age classes were not reported for Kachemak Bay specifically; however, it appears that pups and prime-age adults make up the majority of the animals recovered. The USFWS conducts forensic-level necropsies on freshly dead sea otters from Kachemak Bay and Strep Syndrome is still a primary cause of sea otter mortality in the region (V. Gill, personal communications).

Sea Otter Prey Assessment

Visual Observations: All current and historical focal animal sampling data on sea otter diet were archived and sent to USGS to be included in the sea otter program's database for Gulf Watch; no independent assessments are provided in this report. Data from previous studies in Kachemak Bay can be found in this article: http://www.otterspecialistgroup.org/Bulletin/Volume29/Doroff_et_al_2012.pdf. It is important to note that the relative proportions of prey types identified in sea otter diet vary by the methods used to assess diet. Based on visual observations in Kachemak Bay we identified clam, mussel, and crab to make up 38%, 14%, and 2% respectively based on foraging dives where prey were identifiable (Doroff et al. 2012).

Scat Analyses: We continued to collect monthly sea otter scat samples in Little Tutka Bay, located along the south shore of Kachemak Bay, during the winter months of 2012-2013 (Fig. 4). The collection of these samples was accomplished through citizen science collaboration with the land/dock owners and the regularly scheduled mail delivery run in the area (see Doroff et al., 2012 for sample collection and methods). We collected 29 sea otter scat samples between October 2012 and December 2013, which were processed during this reporting period; sample collection is still ongoing for this winter. We worked with Dr. Deborah Tobin and Marc Webber at the UAA Kachemak Bay Campus and their students enrolled in a course on Marine Mammals to process the scat samples and summarize the data. Students and staff sorted each scat sample by prey type and assigned a percentage frequency method using a 1 – 6 ranking (1 = 1 – 5%; 2 = 5 – 25%; 3 = 25 – 50%; 4 = 50 – 75%; 5 = 75 – 95%; 6 = 95 – 100%). To summarize the categorical data on diet from scat samples, we used the median value for each category and averaged by sampling date (Fig. 5) and by winter period (Fig. 6).

The relative proportion of prey types were averaged by collection day (or event) since the beginning of the project in 2008. In spring 2008 and fall 2008-09, sample locations were diverse and sample sizes were higher until collections were standardized to one site (Little Tutka Bay, Fig. 1) and the collections limited to one per month of approximately one week's worth of sea otter scats per sampling event. In Figures 1 and 2, you can see the diet by scat becomes less diverse after 2009 when the sampling scheme was reduced to a single site and sample sizes were smaller. As discussed in Doroff et al. (2012), scat samples provide a good indication of prey items for which shell parts of marine invertebrates are ingested but provide no information for larger bivalve prey or prey where no shell materials are ingested. In these cases, fecal matter that contained no shell parts is categorized as unidentified prey (Fig. S-5, S-6). The two dominant prey types evident in the scat samples in this study were blue mussels (*Mytilus trossulus*) and crab. The relative proportion of crab quantified in the diet by season ranged from approximately 25% to 50% of all prey (Fig. S-5; excluding winter 2013 because sample collection is still ongoing). In 2011, we began to work with students to build a guide to the crab species found in sea otter scats, work that is still ongoing and crab identification from otter scat is still ongoing. Thus far, known species of crab include: helmet crab (*Telmessus cheiragonus*), pygmy rock crab (*Glebocarcinus oregonensis*), hairy crab (*Hapalogaster mertensii*), graceful kelp crab (*Pugettia gracilis),* graceful decorator crab *(Oregonia gracilis)*, and potentially Tanner crab *(Chionoecates bairdi).*

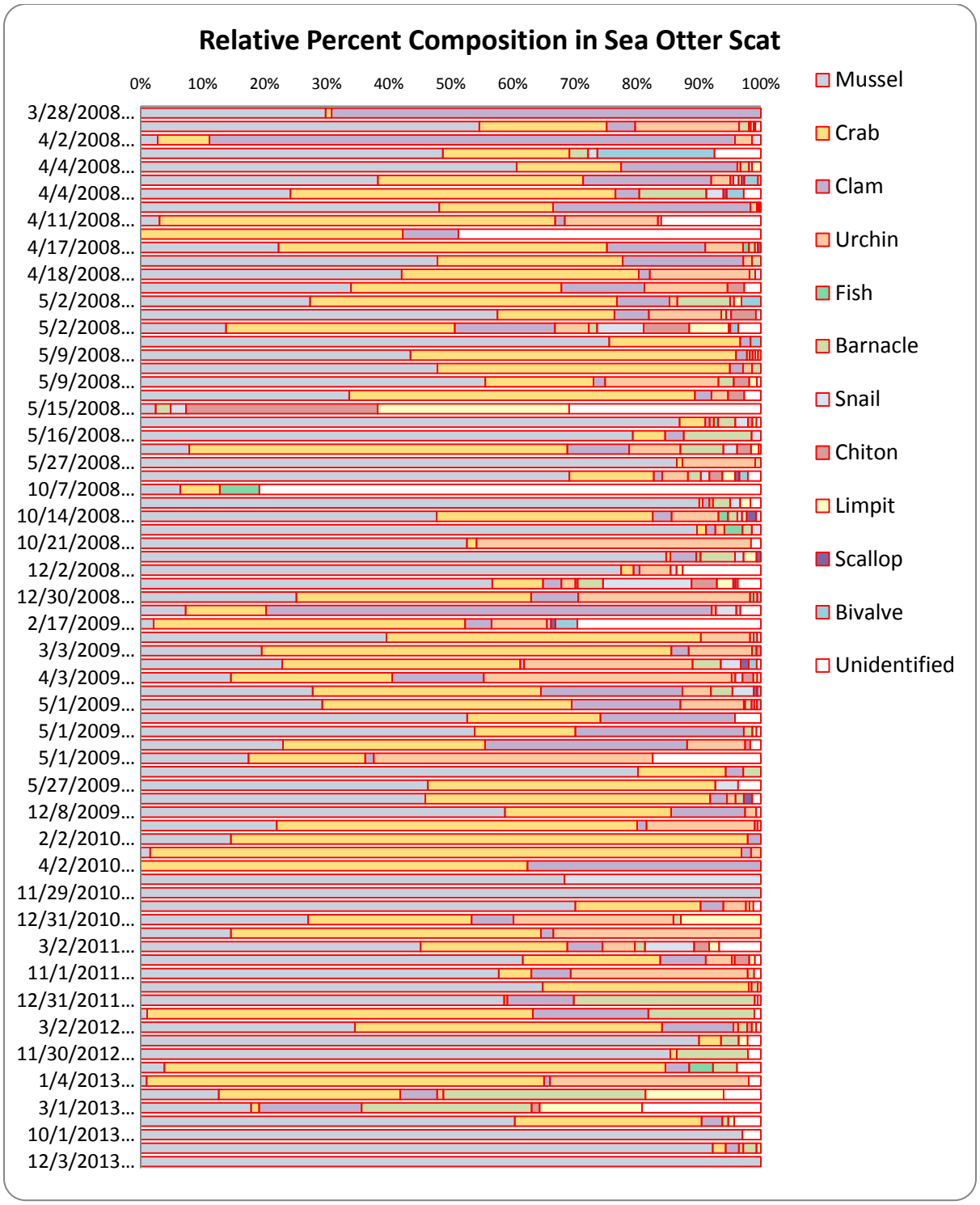

Figure S-5. During 2008-2013, individual sea otter scats were collected and processed to nearest identifiable taxon. The relative composition of prey found in sea otter scats was averaged for each sampling date. The unidentified category includes digested material from soft-bodied prey that contained no shell fragments.

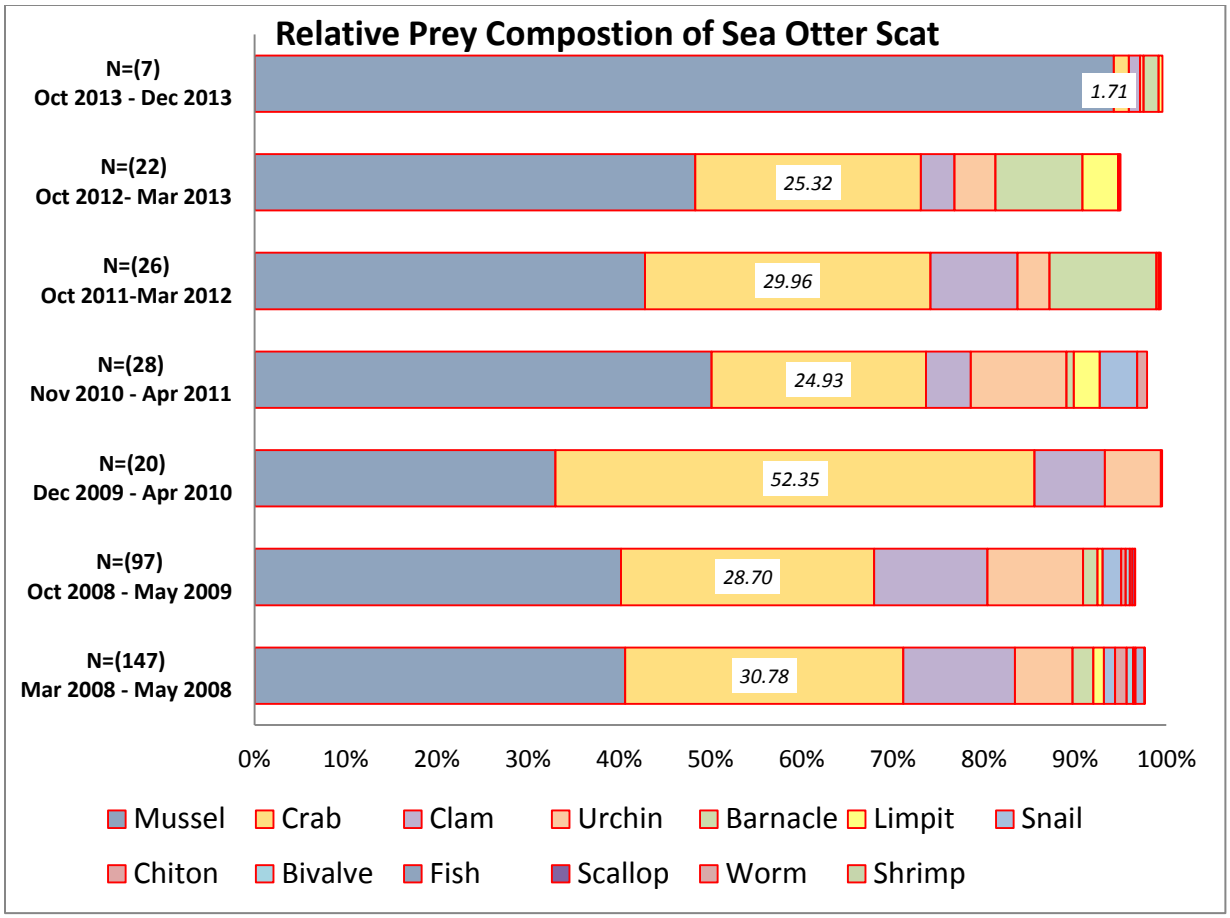

Figure S-6. Relative prey composition from sea otter scat collected during 2008-2013 during the winter months in Kachemak Bay, Alaska. Prey composition of individual scat samples was averaged by "winter period" and compared over time. In 2008-2009, scats were collected and processed from multiple sampling sites; however, 2009-2013 a single site was sampled monthly from late fall (October or November when sea otters began to haul out) through the spring (March or April when sea otters stopped hauling out).

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Bodkin, J. L. and M. S. Udevitz. 1999. An aerial survey method to estimate sea otter abundance.Pages 13-26 *in* G. W. Garner, S.C. Amstrup, J. L. Laake, B. F. J. Manly, L. L. McDonald, and D. G. Robertson editors. Marine Mammal Survey and Assessment Methods. A. A. Balkema Publishers, Rotterdam Netherlands.

Doroff A.M., O. Badajos, K. Corbell, D. Jenski, and M. Beaver. 2012. Assessment of Sea Otter (*Enhydra lutris kenyoni*) Diet in Kachemak Bay, Alaska (2008-2010). IUCN Otter Specialist Group Bulletin 29(1)2012.

Doroff A. M. and O. Badajos. 2010. Sea otter (*Enhydra lutris kenyoni*) survival and movement patterns in Kachemak Bay, Alaska 2007-2010. Final report to U.S. Fish and Wildlife Service Marine Mammals Management 1011 E.Tudor Rd, Anchorage, AK 99503. 63pp

Gill V.A., A.M. Doroff, and D. Burn. 2009. Aerial surveys of sea otters (E*nhydra lutris)* in Kachemak Bay, Alaska. 2008. U.S. Fish and Wildlife Service, Marine Mammals Management 1011 E.Tudor Rd, Anchorage, AK 99503. Final Report to Army Corps of Engineers, MIPR # WC1JUW80880784. 24pgs.

Millstein J., C.E. O'Clair. 2001. Comparison of age-length and growth-increment general growth models of the Schnute type in the Pacific Blue Mussel, *Mytilus trossulus* Gould. Journal of Experimental Marine Biology and Ecology 262: 155-176.

Reidman M. L. and J. A. Estes. 1990. The sea otter (*Enhydra lutris*): behavior, ecology and natural history. Biological Report 90(14). U. S. Fish and Wildlife Service, Washington D.C.

Table S-2. Status of project milestones for year 2

Deliverable/Milestone	Status
Sample intertidal communities in Kachemak Bay	Completed May 2013
Collect monthly sea otter scat samples	Completed April 2013
Conduct sea otter observations	Completed July 2013
Present work at Alaska Marine Science Symposium	Completed January 2014

8. Information and Data Transfer: See, Reporting Policy at III (C) (8).

Stewart NL, Konar B, Doroff A. Sea otter (*Enhydra lutris*) foraging in a heterogeneous environment in Kachemak Bay, Alaska. Bulletin of Marine Science. *In revision*

Iken K, Konar B. 2014. Strong local dynamics of intertidal communities in Kachemak Bay – a Gulf Watch project. Poster presentation at the Alaska Marine Science Symposium, January 2014, Anchorage AK

2012 rocky intertidal community data, 2012 mussel size-frequency data, seagrass shoot count data, 2012 limpet size-frequency data uploaded on workspace and linked to data portal. All files with project and dataset metadata.

9. Response to EVOSTC Review, Recommendations and Comments: *See,* Reporting Policy at III (C) (9).

n/a

10. Budget: *See,* Reporting Policy at III (C) (10).

See budget information attached.

Line item for “travel” is slightly overdrawn at this time. This is because no annual PI meeting travel was originally budgeted but occurs every year for two people. Currently, this is not a shift over 10% of total budget.

T. EVOS Oil Exposure of Harlequin Ducks and Sea Otters- Ballachey and Esler (USGS, 12120114-Q)

1. Project Number: *See,* Reporting Policy at III (C) (1).

12120114Q

2. Project Title: *See,* Reporting Policy at III (C) (2).

Gulf Watch Alaska: Monitoring Shorelines and Nearshore Vertebrates in Prince William Sound. Part II: Evaluating the chronic exposure of harlequin ducks and sea otters to lingering Exxon Valdez oil in western Prince William Sound.

3. Principal Investigator(s): *See,* Reporting Policy at III (C) (3).

B. Ballachey, J. Bodkin, D. Esler, K. Miles, L. Bowen

4. Time Period Covered by the Report: *See,* Reporting Policy at III (C) (4).

February 1, 2013-January 31, 2014

5. Date of Report: *See,* Reporting Policy at III (C) (5).

March 1, 2014

6. Project Website (if applicable): *See,* Reporting Policy at III (C) (6).

www.gulfwatchalaska.org

7. Summary of Work Performed: *See,* Reporting Policy at III (C) (7).

This study was implemented to evaluate recovery status of harlequin ducks and sea otters in PWS using biomarker assays to assess continuing exposure to lingering oil, and potential health consequences of contemporary or previous exposure. Sea otters were captured and sampled in western PWS in summer 2012, and blood samples from those otters were analyzed for biomarker and health assays using gene transcription analyses. A final report on the gene transcription results recently was completed, and is provided as an attachment to this report; highlights of associated sea otter studies through 2013 are included in the Nearshore Benthic Annual Report (Project component 12120114-R). Harlequin ducks were captured in PWS in March 2013 and liver biopsies collected for assays of cytochrome P4501A (CYP1A), a biomarker of exposure to oil; a summary of the findings from harlequin ducks over more than a decade of sampling in western PWS is provided below and in a final report to the EVOSTC. A summary of the project milestones completed is provided in Table T-1.

Induction of CYP1A in vertebrates occurs in response to exposure to a limited number of compounds, including polycyclic aromatic hydrocarbons such as those found in crude oil. Because CYP1A induction is both specific and sensitive, it has been used to evaluate exposure to inducing compounds in many cases of environmental contamination, including that of the *Exxon Va*ldez oil spill. Elevated CYP1A has been demonstrated in several species in areas of Prince William Sound oiled by the *Exxon Valdez* spill relative to unoiled areas, including harlequin ducks.

In this study, CYP1A induction was determined by measuring hepatic 7-ethoxyresorufin-O-deethylase (EROD) activity, which is a well-established method and is the same approach used in earlier *Exxon Valdez* studies and in similar studies of harlequin ducks and other sea ducks elsewhere. During March 2013, we captured 25 harlequin ducks in oiled areas of Prince William Sound and 25 in unoiled areas. Small liver biopsies were surgically removed from each individual, frozen immediately in liquid nitrogen, and subsequently shipped to the University of California Davis for EROD analysis.

We found that CYP1A induction was not related to area, with average (pmol/min/mg ± SE) EROD activity of 17.8 (± 3.0) in oiled areas and 27.7 (± 5.9) in unoiled areas. This represents the first occasion since sampling was initiated in 1998 that CYP1A induction was not statistically higher in oiled areas than unoiled areas (Fig. T-1). This critical result follows the observation during 2011 that, although CYP1A induction was higher on oiled areas, the magnitude of the difference was reduced relative to previous years (1998 to 2009). We also considered the incidence of elevated exposure (defined as the number of individuals with EROD activity ≥ 2 times the average on unoiled areas for that year); for 2013 samples, we found that 4% of individuals captured in oiled areas had elevated EROD, compared to 12% in unoiled areas (Fig. T-2). As in previous years, we found that attributes of individuals (age, sex, and mass) were not related to variation in EROD.

We interpret these results to indicate that harlequin ducks were no longer exposed to residual *Exxon Valdez* oil as of March 2013, 24 years after the spill. Additional sampling is planned for 2014 to confirm this finding.

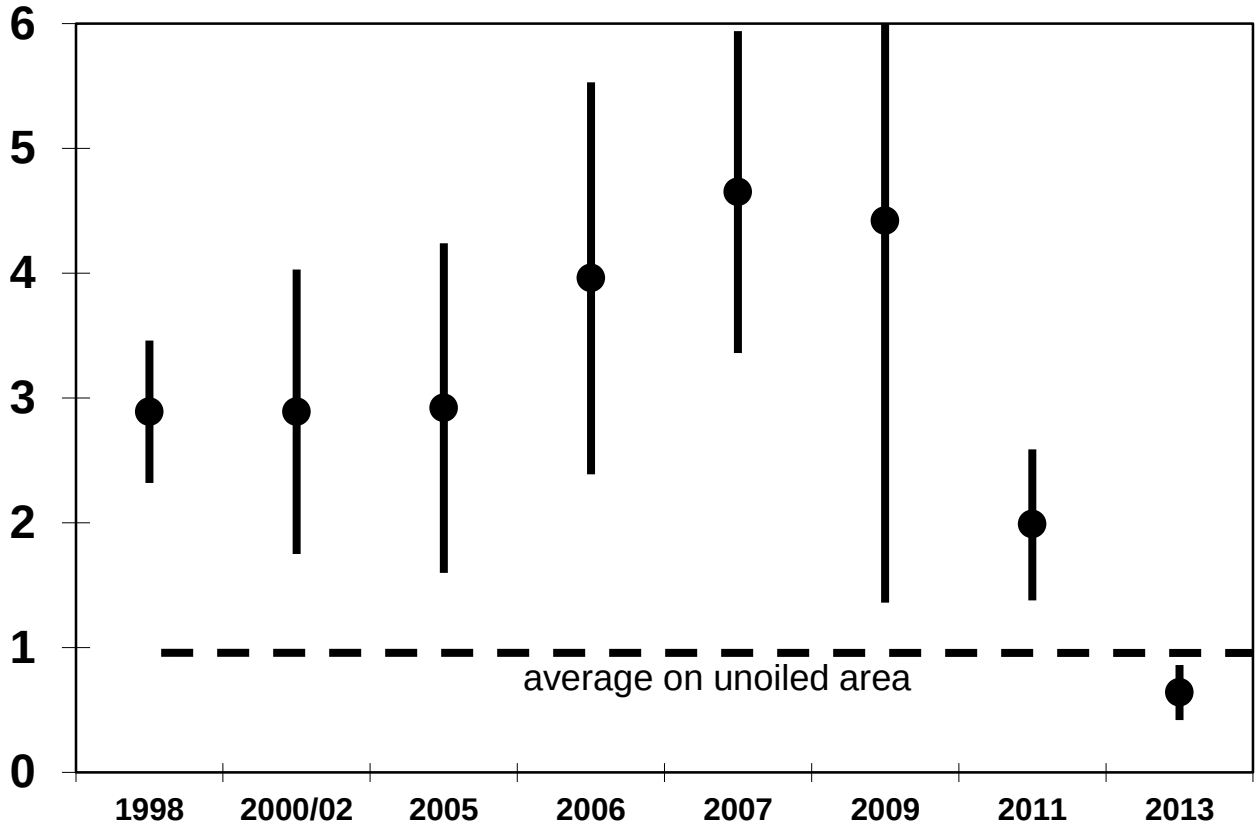

Figure T-1. Average (± 95% CI) scaled hepatic7-ethoxyresorufin-O-deethylase (EROD) activity of harlequin ducks (n = 50) captured in March 2013 in areas of Prince William Sound, Alaska oiled during the Exxon Valdez spill relative to nearby unoiled areas, contrasted with results from previous years. Results are scaled such that the average on unoiled areas for each year is set to 1; therefore, the data point for each year represents the multiplicative degree to which EROD is elevated on oiled areas (e.g., in 2011, EROD activity was approximately 2 times higher on oiled areas than on unoiled areas).

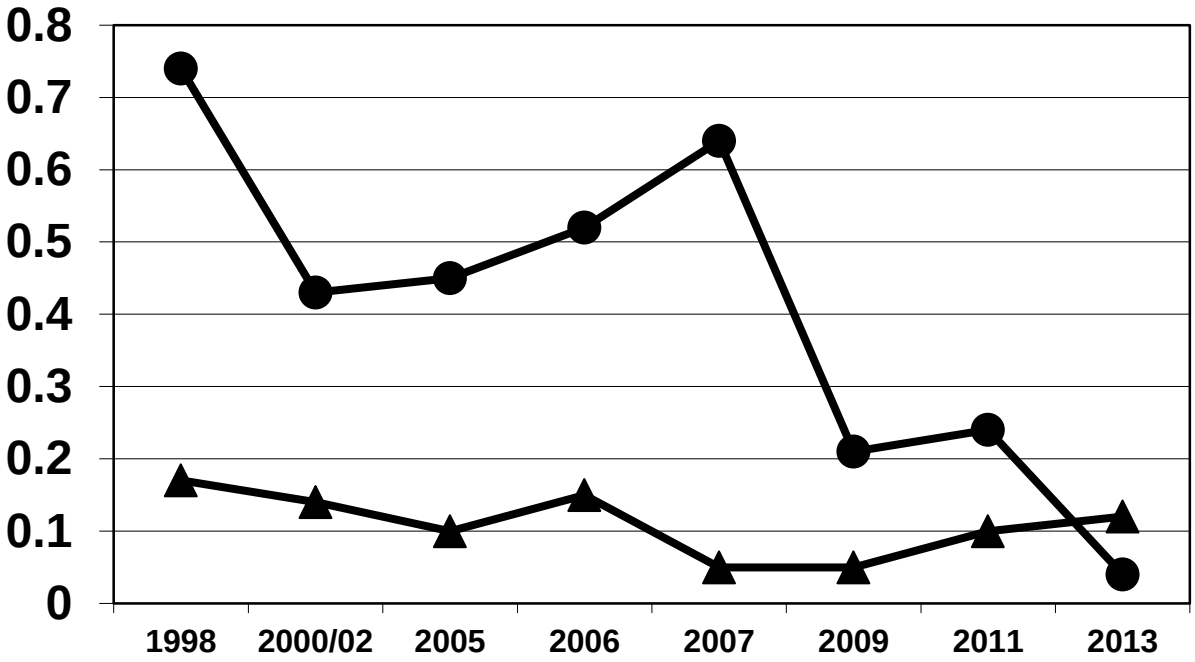

Figure T-2. Proportion (y-axis) of captured harlequin ducks with elevated hepatic7-ethoxyresorufin-O-deethylase (EROD) activity, defined as 2 times the average among birds from unoiled areas. Data include results from this study (March 2013) contrasted against findings from previous years.

Table T-1. Status of project milestones for year 2

Deliverable/Milestone	Status
Capture and sampling, harlequin ducks	Completed, March 2013
Data analysis, sea otter gene expression samples	Completed, May 2013
Sample and data analyses, harlequin ducks	Completed, May – July 2013
Report, harlequin ducks	Completed, August 2013
Report, sea otter gene expression results	Completed, January 2014

8. Information and Data Transfer: See, Reporting Policy at III (C) (8).

Publications & Reports:

Ballachey, B. E., J. L. Bodkin, and D. H. Monson. 2013. Quantifying long-term risks to sea otters from the 1989 *Exxon Valdez* oil spill: Reply to Harwell & Gentile (2013). Marine Ecology Progress Series 488:297-301. doi:10.3354/meps10498

Ballachey, B., D. Monson, G. Esslinger, K, Kloecker, J. Bodkin, L. Bowen and K. Miles. 2014. 2013 Update on Sea Otter Studies to Assess Recovery from the 1989 *Exxon Valdez* Oil Spill, Prince William Sound, Alaska.U.S. Geological Survey Open-File Report 2014-xxxx, 40 p., http://dx.doi.org/10.3133/ofr2014xxxx.

Bodkin, J. L., D. Esler, S. D. Rice, C. O. Matkin, and B. E. Ballachey. 2014. The effects of spilled oil on coastal ecosystems: lessons from the *Exxon Valdez* spill. Pp. 311-346 in B. Maslo and J. L. Lockwood, eds. Coastal Conservation.Cambridge University Press.

Esler, D. 2013. Long-term Monitoring: Lingering Oil Evaluating Chronic Exposure of Harlequin Ducks and Sea Otters to Lingering *Exxon Valdez* Oil in Western Prince William Sound. *Exxon Valdez* Oil Spill Trustee Council Restoration Project Final Report (Project 12120114-Q), Pacific Wildlife Foundation and Centre for Wildlife Ecology, Simon Fraser University, Delta, British Columbia, Canada.

Presentation: Esler, D., J. Bodkin, B. Ballachey, D. Monson, G. Esslinger, K. Kloecker, S. Iverson, K. Miles and L. Bowen. 25 years after the Exxon Valdez oil spill: Recovery timelines of harlequin duck and sea otter populations. Presentation at the Alaska Marine Science Symposium, Anchorage, Alaska, January 2014.

Meeting attendance: January 2014 Alaska Marine Science Symposium: Ballachey, Esler. November 2013 Gulf Watch Alaska PI meeting, Anchorage: Ballachey, Esler.

Data/metadata uploaded to data portal: Harlequin duck capture and EROD data.

9. Response to EVOSTC Review, Recommendations and Comments: *See,* Reporting Policy at III (C) (9).

There were no recommendations for changes to this project in the recent EVOSTC reviews.

10. Budget: *See,* Reporting Policy at III (C) (10).

Budget forms submitted separately. Our overall budget expenditures are on target with the proposed expenditures, and are in keeping with the objectives of the project.

U. Oil Level Weathering and Tracking- Carls (NOAA ABL, 12120114-S)

1. Project Number: *See,* Reporting Policy at III (C) (1).

12120114-S

2. Project Title: *See,* Reporting Policy at III (C) (2).

Long-term Monitoring: Lingering Oil - Extending the Tracking of oil levels and weathering (PAH composition) in PWS through time

3. Principal Investigator(s): *See,* Reporting Policy at III (C) (3).

Mark Carls, Mandy Lindeberg

4. Time Period Covered by the Report: *See,* Reporting Policy at III (C) (4).

February 1, 2013-January 31, 2014

5. Date of Report: *See,* Reporting Policy at III (C) (5).

March 1, 2014

6. Project Website (if applicable): *See,* Reporting Policy at III (C) (6).

www.gulfwatchalaska.org

7. Summary of Work Performed: *See,* Reporting Policy at III (C) (7).

Sample processing has focused on samples and data that contribute to long-term understanding of conditions in Prince William Sound and along the Gulf of Alaska. Hydrocarbon analyses and biomarker measurements have been completed for Gulf of Alaska samples and the draft report is in review (Project 11100112-B, Irvine et al), see Table U-1 for summary of project milestones. Measurement of hydrocarbons in three species of shrimp (pink, coonstripe and spot) from Prince William Sound is underway in the laboratory (PWSRCAC). Tissue processing is nearly complete and raw data are available for 91%. Sediment analysis will follow (10 samples). Data from the shrimp project (sediment and shrimp) will indicate whether benthic sediment is meaningfully contaminated with oil and if so, if those hydrocarbons are biologically available to macrofauna.

We have been hampered by the loss of three chemists due to NOAA downsizing and a major equipment malfunction (fire retardant discharge) that shut the lab down for about a month. The HPLC (high performance liquid chromatograph), critical for tissue processing, was in the hood where the discharge occurred was nonfunctional for several months but is now back in service.

Forensic analysis using geochemical biomarkers, developed in conjunction with a *Selendang Ayu* study and applied to the EVOS bioremediation study (Boufadel) is proving highly useful in a variety of studies, including the Irvine study and extending well beyond Prince William Sound and the Gulf of Alaska. Historic samples for biomarker analysis, including several alternative oil sources potentially found in Prince William Sound (Monterey crude oil, Constantine Harbor, Katalla, coal, and creosote) are in the queue and have been located. A major inventory of the stored collection was also completed and location information is now in the database. An EVO 2013 sediment

sample was collected for archival purposes from a historic lingering oil patch in the Knight Island area. This was a collaborative effort with the Gulf Watch Benthic component.

The updated hydrocarbon database is functional; it has undergone major revisions, data additions, and quality control. Quality control included linking key variables to detect errors, corrections as needed with verification against original records, and data insertions, a process coordinated among several people and that consumed many person-months of time. This process will likely remain intensive for several more months before the corresponding public version is available. We will provide GulfWatch a copy when it is ready by about March 1 with all Trustee-funded studies related to EVO included. The data include PAH, alkane, and biomarker concentrations and associated quality control tables. Sample information includes location, latitude, longitude, project name, date, investigator information, project codes, and sample type. We envision this data set as spatially explicity layers on the GulfWatch data porta (total polynuclear aromatic hydrocarbon concentrations in mussels and sediment by collection year).

Table U-1. Status of project milestones for year 2

Deliverable/Milestone	Status
Bioremediation data for Boufadel et al	Completed December 2012
Hydrocarbon data for Irvine et al	Completed May 2013. Numerical analysis and report writing is underway
Hydrocarbon database	New version was assembled in June 2013. Data additions and quality assurance work continues.
Additional bioremediation work was requested in Dec 2013	Pending.

8. Information and Data Transfer: See, Reporting Policy at III (C) (8).

- Draft report, Irvine GV, Aeppli C, Nelson RK, Reddy CM, Carls, MG, Holland LG, Mann DH, Minimally weathered *Exxon Valdez* oil persists on Gulf of Alaska beaches after 23 years: Using new methods to look at old stranded oil
- AMSS Conference, Jan 2014. Poster (Spilled oils: static or dynamic and bioavailable?)
- Hydrocarbon database; major structural revision and major review of data with corrections.
- The hydrocarbon database will be posted pending completion of immediate updates, ~ March 1.

9. Response to EVOSTC Review, Recommendations and Comments:

There were no comments from EVOSTC for this project.

10. Budget: *See,* Reporting Policy at III (C) (10).

Please see attached workbook.

APPENDIX B. PROJECT MILESTONES STATUS SUMMARY.

Project Lead	Project ID	Milestones	Progress
Hoffman and McCammon	12120114-B	Subaward contract management & monitoring of spending	Contracts issued and managed to six organizations for nine subaward projects. All spending monitored.
		Timely submission of narrative and financial reports	All reporting deadlines to EVOSTC and NOAA met in program year.
		Conduct annual audit	Completed at PWSSC in November 2013
		Attend annual PAC meeting	PAC meeting was cancelled due to government shutdown. We look forward to engaging with the PAC in future years.
		Formation of Science Review Panel	After communication between PMT and EVOSTC staff, delayed to Year 3 to maximize volunteer efficiency and influence.
		Administration of travel expenses for annual PI meeting	Fulfilled by PWSSC.
		Administration of expenses for activities directed by the Outreach and Community Involvement committee	Fulfilled by PWSSC.
		Conduct annual PI meeting	Coordinated and held in November 2013
		Attend AMSS	Robust attendance by GWA PIs
		Conference on community-based citizen science monitoring potential	Delayed to Year 3
		Develop data visualizations for website	Significant website updates completed and visualizations and data accessible through Gulf of Alaska Data Portal at http://data.aoos.org/maps/search/gulf-of-alaska.php
Bochenek	12120114-D	Continue to provide data management oversight & services, including data structure optimization, metadata generation & data transfer. Audit data and restructure and reorganize for public access.	Ongoing
		Continue to cultivate and support the functional capabilities of the AOOS Ocean Workspace to address GWA researcher needs.	Ongoing
		OImprove search capabilities of GWA projects in the GOA Data by exposing underlying file level metadata.	Completed, 15 January 2014
		Develop analysis & visualization tools	Identified future visualizations at Nov 2013 PI meeting.
		Organize & integrate historical datasets	Ongoing
		Integrate all data & metadata into AOOS GOA Data Portal.	Portal completed, 1 September 2013; then ongoing.
		Augment AOOS with DataONE services	Worked with NCEAS to incorporate current data and AOOS GOA portal as DataONE node with short-term solution: completed Feb 2014;.Long-term solution in planning.
		NCEAS synthesis	No activities

Jones	12120120	Assess/Validate year 1 datasets and metadata submitted through AOOS and NCEAS	Completed, April 2013
		Prototype data discovery and management tools demonstration	Completed, July 2013
		Participate in LTM program PI meeting	Completed, November 2013
		Complete integration of data salvaged into AOOS DM System for data collated from PIs via manual copy	Completed, November 2013
		Full release of data discovery and management tools (Released Metacat 2.2, 2.3, 2.4; Morpho 1.10.1; Historical Data portal)	Completed, January, 2014
Holderied	12120114-H	Assist in initial planning of joint Gulf Watch Alaska-Herring Research and Monitoring programs workshop	June comments provided, other planning and writing ongoing.
		Develop an example interactive data visualization tool in coordination with data management and conceptual ecological modeling teams.	Launched September 2013, ongoing updates.
		Submit year 3 work plan.	Year three work plans were prepared or edited as needed and were provided Sept. 3 to Trustee Council staff.
		Facilitate annual PI meeting	Planned, facilitated, and held November 2013.
		Conduct annual PI meeting	Meeting was planned with time series data workshop in conjunction. Meeting was held Nov.
		Attend Alaska Marine Science Symposium and provide update to GWA program	Kris Holderied presented an update to the GWA program at the symposium on Thursday, January 23. The program also held a short PI meeting.
		Submit report on synthesis of all available historical data from LTM projects	The NCEAS project is submitting a progress report on the historical data collection in conjunction with this annual report.
		Submit annual project report	This document constitutes report submission.
Hollmen	12120114-I	Conduct modeling workshop	Completed, November 2012
		Complete first interactive and data visualization tools for selected components	Completed, January 2014
		Design draft conceptual model	Completed, January 2014
		Attend annual PI meetings and Alaska Marine Science Symposium	Completed, November 2013 and January 2014
Weingartner	12120114-P	February CTD cast at GAK 1	Completed
		March mooring recovery and re-deployment at GAK 1	Completed
		March CTD cast at GAK 1	Completed
		April CTD cast at GAK 1	Completed
		May CTD cast at GAK 1	Completed

		June CTD cast at GAK 1	Completed
		August CTD cast at GAK 1	Completed
		September CTD cast at GAK 1	Completed
		November CTD cast at GAK 1	Completed
		December CTD cast at GAK 1	Completed
Hopcroft	12120114-J	2012 data delivered	Completed in full, fall 2013
		2013 May cruise	Successfully completed
		2013 September cruise	Successfully completed
Campbell	12120114-E	PWS Survey	Completed, 7 March 2013
		PWS Survey	Completed, 7 May 2013
		PWS Survey	Completed, 6 June 2013
		PWS Survey	Completed, 26 August 2013
		PWS Survey	Completed, 1 October 2013
		PWS Survey	Completed, 8 November 2013
		Process CTD data	Completed, 8 January 2014
		Enumerate Plankton samples	Completed, 15 January 2014
		Chlorophyll-a measurements	Completed, 15 January 2014
Doroff and Holderied	12120114-G	Monthly KBay CTD & plankton surveys	Completed Feb-Oct, missed Nov, and completed Dec 2013 & January 2014
		Quarterly Lower Cook Inlet/KBay CTD & plankton surveys	Completed, February (partial), April, July, Oct-Nov (partial)
		Annual PI Meeting	Completed, November 2013
		AMSS PI Meeting	Completed, January 2014
Batten	12120114-A	Feb-13, Set up for start of field season, ship equipment to west coast ports	Completed
		4/1/2013, First transect	Sampled April 11-14th, data available, Temperature data when downloaded seemed unlikely so sensor changed for next transect.
		May-13, Second transect	Sampled May 11-13th, data available
		Jun-13, Third transect	Sampled June 13-16, data available
		Jul-13, Fourth transect	Sampled July 14-15, preliminary data available
		Aug-13, Fifth transect	Sampled August 16-17, preliminary data available
		Sept-13, Sixth transect	Sampled September 15-16, preliminary data available
Coletti	12120114-F	Finalized proposal (statement of work for contract)	Completed, June 2013
		Contract Package submitted to NPS	Completed, July 2013

		Contract Award	No bids were submitted for evaluation and award
		Data collection	Annual summer surveys continue under the Benthic component (Ballachey et al.) in KATM and KEFJ. This data will be amended to existing data sets to strengthen analysis
Matkin	12120114-M	Prepare population dynamics manuscript	Accepted MMS, 30 April 2013
		Update of photographic catalogue, population database, mapping database, lab analysis	Completed May 10 2013 (for 2012 data)
		Field work: PhotoID, Biopsy, prey sampling, tagging.	15 May- 15 October 2013
		Annual meeting Gulf Watch	Nov-13
		Alaska Marine Science Symp	Jan-14
Moran and Straley	13120114-N	April PWS Whale Survey	Completed, 12 April, 2013
		Sept. - Oct. PWS Whale Survey	Completed, 3 Oct., 2013
		Dec. PWS Whale Survey	Completed, 8, Dec., 2013
		Attend AMSS	Completed
Arimitsu and Piatt	13120114-O	Uploaded 2012 data to Ocean workspace	Completed, 3 July 2013
		Uploaded project metadata (Morpho) to workspace	Completed, 3 July 2013
		Conducted 2013 field work	July – Aug 2013
		Submitted semi-annual report	Aug-13
		Annual PI meeting	Nov-13
		PI meeting at AMSS	Jan-13
Irons and Kuletz	13120114-K	Hire biologist to oversee 2014 survey	Awaiting approval of federal hiring waiver; to be hired by 31 March 2014
		Uploaded 2012 data to Workspace	Completed, 21 January 2014
Bishop	12120114-C	March PWS survey (PWSSC)	Completed, March 27-April 3, 2013; data available
		October PWS survey (ADFG)	Completed, October 12-23, 2013; data available
		November PWS survey (PWSSC)	Completed, November 6-14, 2013; data available
		December PWS survey (NOAA)	Completed, December 2-8, 2013; data available
Ballachey and Dean	12120114-R	Field work (6 trips, multiple tasks per trip); Katmai, Kenai Fjords, WPWS, NPWS	Completed, March - July 2013
		Aerial survey of sea otters, WPWS	Completed, June 2013
		Upload 2012 data to project website	Completed, August 2013
		PI's attend annual Gulf Watch meeting	Completed, November 2013
Iken and Konar	13120114-L	Sample intertidal communities in Kachemak Bay	Completed May 2013
		Collect monthly sea otter scat samples	Completed April 2013
		Conduct sea otter observations	Completed July 2013
		Present work at Alaska Marine Science Symposium	Completed January 2014

Ballachey and Esler	13120114-Q	Capture and sampling, harlequin ducks	Completed, March 2013
		Data analysis, sea otter gene expression samples	Completed, May 2013
		Sample and data analyses, harlequin ducks	Completed, May – July 2013
		Report, harlequin ducks	Completed, August 2013
		Report, sea otter gene expression results	Completed, January 2014
Carls	12120114-S	Bioremediation data for Boufadel et al	Completed December 2012
		Hydrocarbon data for Irvine et al	Completed May 2013. Numerical analysis and report writing is underway
		Hydrocarbon database	New version was assembled in June 2013. Data additions and quality assurance work continues.
		Additional bioremediation work was requested in Dec 2013	Pending.

APPENDIX C. INDIVIDUAL PROJECT REPORT ATTACHMENTS

ATTACHMENT TO DATA MANAGEMENT- BOCHENEK/MCCAMMON (AOOS, 12120114-D)

The long-term monitoring program of the Exxon Valdez Oil Spill Trustee Council

As of October 18, 2013

Note: This plan is a compilation of details provided in the original AOOS 5-year proposal for data management services submitted in May 2011 and approved by the Trustee Council in 2011, the Program Management Plan adopted by the Gulf Watch Alaska principal investigators in April 2012, and the AOOS data management plan.

Overall Approach

The overarching strategic plan for providing cost-effective data management services to the Exxon Valdez Oil Spill Trustee Council's Long-term Monitoring Program, also known as Gulf Watch Alaska, is to leverage the resources and capacity provided by the Alaska Ocean Observing System (AOOS) data system, including those described in more detail below in Section H.

AOOS is one of the 11 regional ocean observing systems funded through the national Integrated Ocean Observing System. The AOOS data system is developing as one of the largest regional data assembly center for Alaska's oceans and coasts, providing access to real-time sensor data, model data, satellite imagery and project-level data, as well as visualizations and integrated information products. The overall approach for managing data for the Gulf Watch Alaska Program is to use the AOOS Research Workspace to "stage" preliminary data and provide password-protected access to it for all program investigators and managers for use in synthesis and analysis activities. Once data are deemed "public" and metadata generated, they will be published to the Gulf of Alaska portal, which will serve as the primary public user interface and search catalogue for Gulf Watch Alaska data, historical EVOSTC datasets, and ancillary environmental data for the Gulf of Alaska region. The portal can be accessed via the GWA website: www.gulfwatchalaska.org, or via the AOOS website: www.aoos.org.

The Research Workspace is a tool developed by the AOOS data management team for the research community as a prototype, web-based software for assembling, storing and sharing data among members of the biological and physical oceanography communities. Ten research programs and about two hundred and fifty investigators are currently using the Workspace to manage and capture study data and metadata. AOOS has established separate Research Workspace accounts for the Gulf Watch Alaska Program and the Herring Research and Monitoring Program. The Workspace is password protected, and only available to project PIs and administrators. PIs are required to post their data and metadata in folders on the Workspace, as well as their sampling protocols (standard operating procedures – SOPs), according to protocols included in the Program Management Plan, adopted and signed by the program PIs. The data and metadata records are then available to all program investigators for use in synthesis, modeling and analysis efforts. Again,

according to the Program Management Plan, data can be published to the public AOOS Gulf of Alaska portal at the appropriate time.

Geographic Scope

The majority of this project will involve consolidating existing data, metadata, and other electronic resources related to oceanographic conditions, biological resources and human activities in the area affected by the 1989 oil spill. Specific areas of focus include those areas in Prince William Sound (PWS), Lower Cook Inlet, and Kodiak. The north, east, south, and west bounding coordinates of this area are 59.767, -145.837, 61.834, and -154.334.

Metadata Requirements

Per the adopted Program Management Plan, comprehensive metadata using FGDC or ISO standards are required for each dataset acquired through this project. These are considered minimal requirements, and PIs are encouraged to provide additional metadata fields. The Research Workspace incorporates easy-to-use metadata writing tools that are continually being enhanced. NCEAS, through its DataONE project, has provided training in the Morpho metadata-writing tool.

Information and data sharing protocols

The EVOSTC requires data sharing in its agreements among all principal investigators and program components. For this Program, all PIs shall adhere to these policies unless individual agency or legal requirements require restrictions contrary to these policies. The LTM Program Workspace account on the AOOS Research Workspace is password protected to ensure confidentiality among PIs.

- All data should be posted on the LTM Program Workspace as they become available following collection in order to promote internal integration and sharing within the project.
- These data should be replaced with QA/QC'd data when available.
- Comprehensive metadata using FGDC (or ISO) standards are required for each dataset.
- Monitoring data will be made available to the public as soon as it has been QA/QC'd or within 1 year following collection, whichever is sooner.
- Anyone making public use of another team member's data should contact the collector of the data and provide appropriate attribution and credit.
- The Science Coordinating Committee must agree to any deviations from these policies in advance.

As a program of the EVOSTC, all PIs and project managers are expected to adhere to EVOSTC policies regarding retention of all documents, correspondence (electronic and paper), samples and data per the terms of the EVOSTC court settlement.

Sampling protocols and QA/QC

Per the adopted Program Management Plan, each PI will document the key sampling standard operating procedures or protocols (SOPs) used for their monitoring component by June 1 2012 for posting on the Program website. If the PI of that component changes, the agreed upon sampling procedures must continue to be used by any new PI. The Science Coordinating Committee must agree upon any changes to standard protocols desired by the PI. Any changes must be noted at the annual PI meeting.

Individual investigators are required to document instrument calibration and data QA/QC procedures in these protocols and in project metadata.

Technical Design of AOOS Data System

Figure 1 below details the four logical technical tiers of the approach used in the Technical Design of the AOOS Data System. At the base (Tier 1) of the pyramid lie the source data produced by researchers, instruments, models, and remote sensing platforms which are stored as files or loaded within geospatial databases. Interoperability systems (Tier 2), such as Web Map Services (WMS) and Web Coverage Services (WCS), are then implemented and connected to these underlying data sources. The asset catalogue (Tier 3) connects to internal interoperability systems in addition to known external sources of interoperable data and populates a database describing the dimensional characteristics (space, time, measured parameter, and taxonomy) of each data resource. Also in this third tier are web services that provide access to the descriptive information contained in the asset catalogue database so that applications can more easily utilize data from multiple sources, formats, and types. The final technical level (Tier 4) is composed of the web-based applications and tools, which provide users access to data and products. Users sit at the top of the pyramid with all underlying systems working together to create a powerful and intuitive user experience. The intended result is the facilitation of rapid data discovery, improved data access, understanding, and the development of knowledge about the physical and biological marine environment.

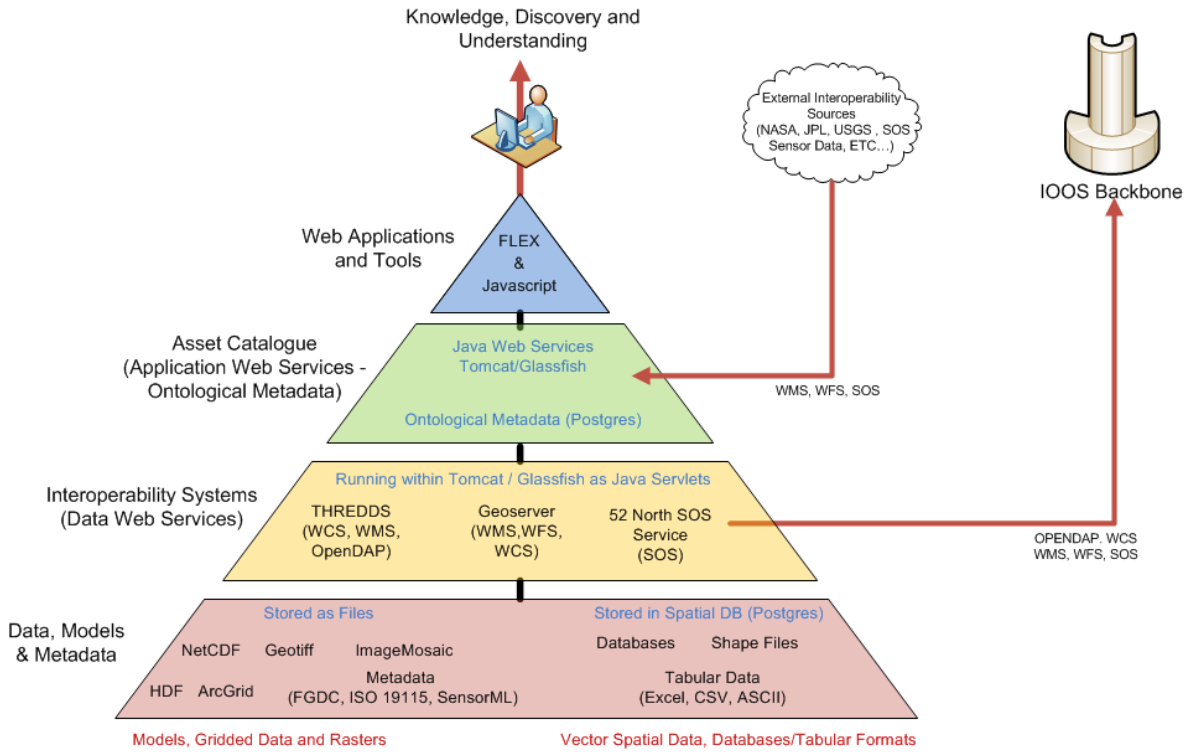

Figure 0-1. Data knowledge pyramid detailing the flow of data through logical technology tiers so that it can be consumed by users to enable discovery and understanding about the ocean environment.

Tiers are discussed in technical detail below.

- **Tier 1 (Data, Models and Metadata)** – At the base of the proposed data management framework are the datasets, metadata, and model outputs that provide the foundation for applications and user tools. These resources can be stored either in native formats or spatially enabled databases. The decision to choose one method over the other is dictated by the requirements of the interoperability system which will be serving the data. Data which has a tabular or vector form (Shapefiles, databases, Excel spreadsheets, comma separated values (CSV) text files, etc.) will be loaded into a PostgreSQL database and spatially indexed. GeoServer, an open source geospatial data server, will then connect to the PostgreSQL database and serve the data via WFS and WMS protocols. Imagery, raster, and model data will be stored in a file server in their native file formats. THREDDS and/or ncWMS will be used to serve NetCDF and HDF files which may contain two, three, four or higher dimensional gridded datasets. GeoServer or other OGC compliant mapping servers will be utilized to serve GeoTIFF, ArcGrid, ImageMosaic and other two dimensional imagery/raster data.

- **Tier 2 (Interoperability Systems)** – Various interoperability servers (GeoServer, THREDDS, ncWMS, 52 North SOS, etc.) will be implemented on top of source data. By design, these servers will expose a powerful set of interfaces for other computing systems and humans to extract, query, and visualize the underlying source data. These systems will facilitate all aspects of data delivery to users in addition to providing the muscle for the machine-to-machine data transfer to national data assembly systems as required. Because these systems have been developed using the Java programming language, they will run within a servlet container such as Tomcat or Glassfish.

- **Tier 3 (Asset Catalogue, Ontological Metadata and Services)** – The asset catalogue provides a description of known internal and external available data resources, access protocols for these resources (interoperability services, raw file download, etc.), and directives on how to ultimately utilize these data resources in applications. Because documentation and access methods vary widely between data sources, a system which catalogs data sources and reconciles these inconsistencies must be implemented if the data are to be used in an efficient manner.

  In addition to managing information about data availability and access methods, the asset catalogue will also contain an ontology that maps source data descriptions and metadata to a common set of internally stored terms with strict definitions. This mapping will allow users to easily locate related sets of information without having explicit knowledge of the internal naming conventions of each data-providing agency. The development of an internal ontology will also enable future endeavors to connect the asset catalogue to global ontologies in the semantic web. The following dimensions are to be stored in the database for mapping the heterogeneous characteristics of source data to common metrics:

    - **Source** – Service URLs and methods of interaction for these services.

- **Data formats and return types** – Data format returned by the service and how data can be equated between various formats.
- **Space (x, y, z)** – Spatial dimensions of dataset (1D, 2D, 3D). Upper and lower spatial bounds (bounding box or cube) stored in common projection (EPSG 4326).
- **Time (t)** – For data resources with a time component: document time span, whether time corresponds to a single moment or if it is representative of a time period. If data is in discrete periods, document individual available periods.
- **Taxonomy** – Taxonomic data mapped to International Taxonomic Information System (ITIS) codes.
- **Parameter** – Parameter(s) and units in the data resource and how they map to internally defined universal terms. For example: Datasets SST, AVHRR, and Sea_Surface all contain parameters that map to internal universal term Sea Surface Temperature.

Web services written in the Java programming language will be developed to connect to the asset catalogue and provide applications with access to the underlying descriptions of all known data sources. Because the asset catalogue contains a structured ontological definition of data sources and maps all known data sources to a common definition, applications can be developed which connect users to vast arrays of data through simple but powerful interfaces. The following is a list of example functionality that is possible utilizing this methodology:

- Users can load multiple data layers (potentially existing in different physical locations and being served by different systems) onto a single web based map. Users can also filter all layers simultaneously by time or request spatial and temporal subsamples of data that can be pulled from multiple sources and automatically packaged into a single download.
- All real time sensor feeds can be accessed and visualized on a single uniform user interface by parameter even though the sources of the sensor feeds may exist in a wide array of formats and service protocols.
- Users can query the asset catalogue to discover which data is available for an area, time period, parameter, and species.

- **Tier 4 (User Applications)** – Users interface with web based applications that bring together combinations of underlying data and allow users to make discoveries, improve understanding, and develop knowledge through visualization and data access. These types of applications would most likely be interactive map based data portals. Applications will also be developed which provide specific targeted functionality. These focused applications could include marine spatial planning tools, emergency response applications, and educational/outreach portals. Developed tools are designed to meet user needs and thus require user input into their initial design and periodic feedback to direct functional improvements for future design iterations.

Technical Design of AOOS Research Workspace

The AOOS data management team has designed and developed a web-based data management application for assembling, storing, and sharing data between members of scientific communities: the Research Workspace. Ten regional and national research groups currently use the Workspace, which has over 250 individuals sharing thousands of digital files. The Workspace provides users with an intuitive, web-based interface that allows scientists to create projects, which may represent scientific studies or particular focuses of research within a larger effort. Within each project, users may create topical groupings of data using folders and upload data and add contextual resources (e.g., documents, images and any other type of digital resource) to their project by simply dragging and dropping files from their desktop into their web-browser. Standard, ISO 19115-2 compliant metadata can be generated for both projects and individual files. Users of the Workspace are organized into groups, and everyone within a group can view the projects, folders and files uploaded by other group members. This allows preliminary results and interpretations to be shared by geographically or scientifically diverse individuals working together on a project or program before the data is shared with the public. It also gives program managers and other stakeholders a transparent and front-row view of how users have structured and described projects and how their programs are progressing through time. The Workspace has the following capabilities:

Secure group, user, and project profiles — Users of the Workspace have a password protected user profile that is associated with one or more disciplinary groups or research programs. The interface allows users to navigate between groups in which they are involved through a simple drop down control. Transfer of data and information occur over Secure Socket Layer (SSL) encryption for all interactions with the Workspace. The Workspace supports authentication through Google accounts, so if users are already logged into their Google account (e.g., Gmail, Google Docs, etc.), they can use the Workspace without creating a separate username and password.

Metadata authoring — Metadata elements currently available to researchers in the Workspace are common to the Federal Geographic Data Committee (FGDC) designed Content Standard for Digital Geospatial Metadata (CSDGM) and the ISO 19115 standards for geospatial metadata, extended with the biological profiles of those standards. Axiom also developed an integrated FGDC biological profile extension editor that allows users to search the ~500,000 taxonomic entities of the Integrated Taxonomic Information System (ITIS) and rapidly generate the biological profile component of the FGDC metadata record. Because the Workspace is a cloud-based service, researchers can move between computers during the metadata generation process in addition to allowing team members and administrators to simultaneously review and edit metadata in real time.

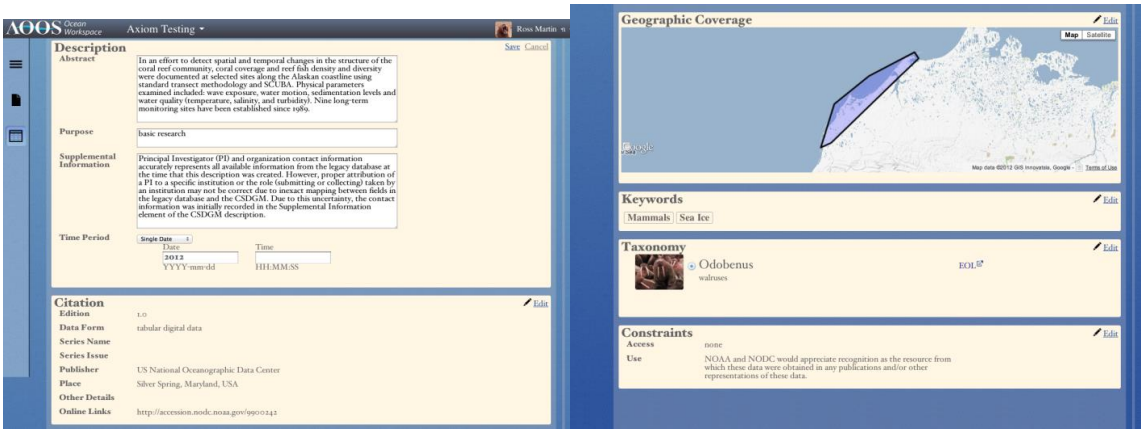

Figure 0-2. Screenshots of the Workspace metadata interface. The left screenshot shows the interface to author basic descriptive and citation metadata fields. The right screenshot displays a tool, which allows researchers to define the geographic extent of the project, keywords, FGDC biological profile and data constraints.

Advanced and secure file management — A core functionality of the Workspace is the ability to securely manage and share project-level digital resources in real-time with version control among researchers and study teams. Users of the Workspace are provided with tools that allow them to bulk upload files, organize those documents into folders or collections, create projects with predefined and user-created context tags, and control read and write permissions on files within projects. The Workspace also has the ability to track file versions: if a user re-uploads a file of the same name, the most current version of the file is displayed, but access is provided to past versions as well.

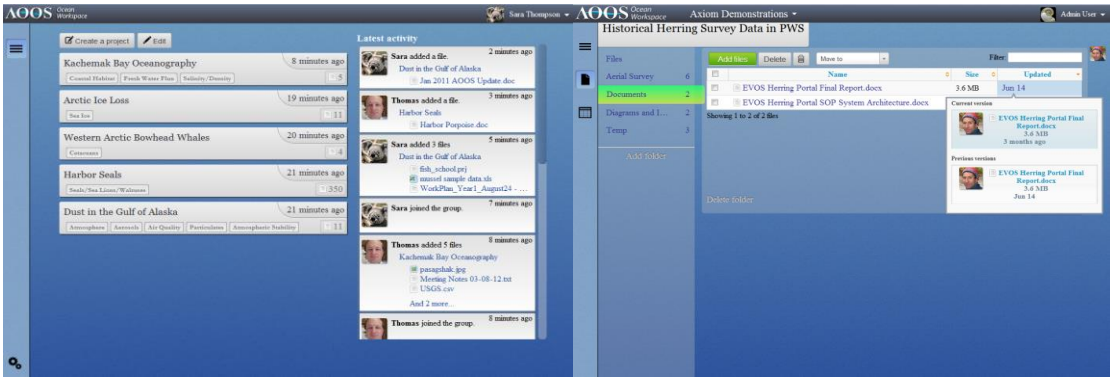

Figure 0-3. Screenshots of project and file management in the Workspace. The left screenshot shows a list of projects to which the example user has access rights. The right screenshot displays the interface a researcher would use to organize independentfiles into folders, and the way two versions of the same files are tracked by the workspace.

Specifically, the Workspace employs the following technological components:

- *Database systems* — PostgreSQL 9 is used for storage of tabular and relational data representations, and is extended with PostGIS for spatial data. All data uploaded to the Workspace is replicated across multiple database servers to provide redundancy and ensure high availability.

- *Object storage and schema-less data representations* — MongoDB is used as a persistent NoSQL storage and query system for file objects, tabular data (flat structures) and hierarchically structured data (generally XML). MongoDB allows horizontal scaling through sharding across physical devices and provides redundancy and high availability through replication. The MongoDB instance consists of a three node cluster, and each node maintains a complete replicate of the others. Data within each node is further redundant by virtue of RAIDed disk arrays.
- *Web tier* — The web services used by the Workspace are developed using Java and integrated into a web application framework called Play!, which provides a stateless architecture for Java and Scala development. The RESTful, stateless design allows services to be scaled across application nodes for load balancing, redundancy and horizontal scalability. The framework is also used to provide real time notifications browser clients to enable collaboration amongst users.
- *Caching and pub/sub* - Redis is used as an intermediary between the web and data tiers. It also serves as our pub/sub interface for managing communications between web tier nodes and serving real-time connections to browser clients in a scalable manner.
- *User interface* — The user interface of the Workspace is composed of several JavaScript and HTML5 libraries and integrates with server side modules wrapped into the Play! framework. The frontend uses a client-side MVC architecture in Backbone.js that synchronizes with its backend equivalent to provide users with a more responsive experience than is typically found in many web applications.

ZOOPLANKTON SAMPLING METHODS AND COMPARISONS

COMPARISON OF CPR AND PWS ZOOPLANKTON DATA, TAKEN FROM FINAL REPORT 10100624

AUTHOR: DR. SONIA BATTEN

Prince William Sound (PWS) has been sampled for zooplankton by several researchers (shown in parentheses below) since 2000, and they have generously made their data available for comparison with CPR data. The sampling method varied from the CPR method (horizontal tow at about 7 m depth with 0.27 mm mesh), and also varied between researchers and will be summarised here:

2000-2006 (Thorne): Zooplankton were sampled by ring nets, 0.335 mm mesh, towed vertically from 50m to surface. Six stations within PWS were sampled (Fig. 1) mostly 3 times a year (April, May, June), and normally more than 1 net tow was taken at each station.

2007-2008 (Kline/Campbell): The same mesh net was used but there were more stations, including some outside PWS, plus a flowmeter was fitted. Sampled in May and September/October each year.

2010-2012 (Campbell): Bongo nets with 0.202 mm mesh were used, with a flowmeter and again towed from 50m to surface. Sampling was carried out approximately monthly, and three stations within PWS most similar to the previous years were included here.

Zooplankton in PWS samples from 2000–2006 were only identified and counted into broad taxonomic groups, so for the subsequent years taxa were combined to form the same groups. Where more than one net was hauled at a station, a mean for that station was calculated, before calculating a mean for all stations inside PWS. Abundances were converted to numbers m^{-3}, and for the Thorne data, where a flowmeter had not been fitted, the mean efficiency from the 2007–2008 data with otherwise identical methodology (0.87) was applied to convert the abundances into numbers m^{-3}.

CPR data were divided into shelf and offshore using the 1000 m contour (Fig 1), and samples from within Cook Inlet were separated from the remaining shelf samples for this analysis. Abundances of the same broad taxonomic groups were calculated by averaging all CPR samples for each region per month. A seasonal mean was then calculated to match the PWS data, spring (April, May and June) and fall (September and October) for community composition comparisons. Monthly means were used to compare seasonal cycles of copepods.

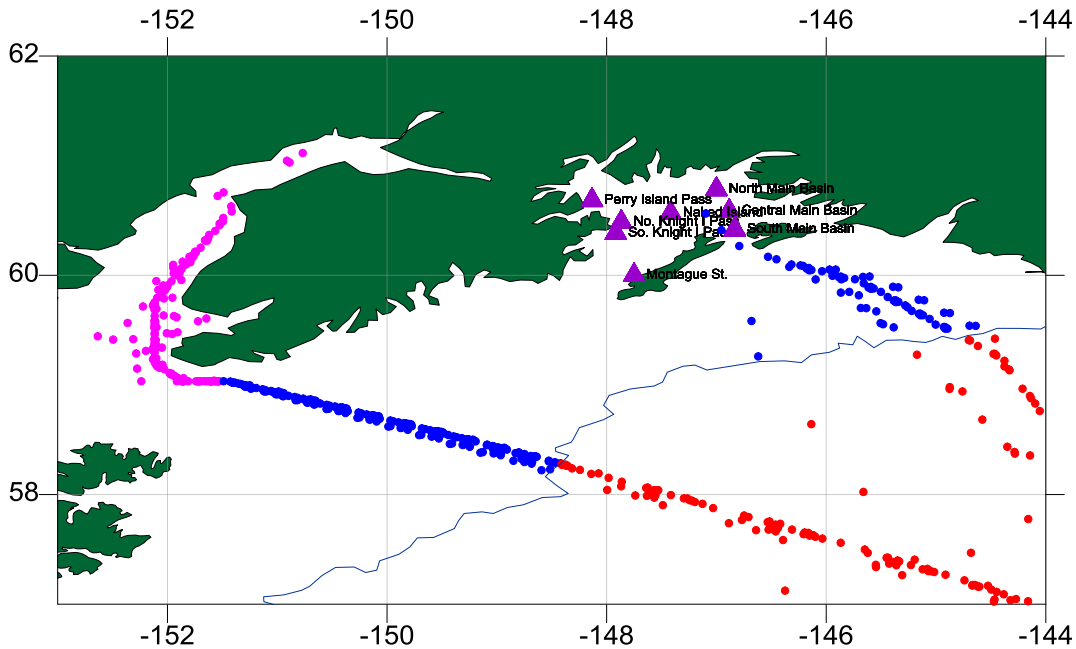

Fig. 1 CPR samples designated as Cook Inlet (purple), Shelf (blue), Offshore (red). PSW sampling locations (2000–2006 data only) shown as triangles.

Comparing interannual patterns was more challenging; most years of CPR sampling had one or more months where sampling did not occur (or failed), and most PWS sampling was restricted to a few months in each year, which made constructing annual means complicated. There were also the differing units in CPR and PWS sampling to accomodate. These limitations suggested that focusing on anomalies would make comparisons most straightforward. May was sampled in each year of 2000–2012, except 2009, by the PWS surveys, so we restricted the PWS anomalies to May only. For the CPR data, a mean spring abundance was calculated for each year (samples from March until June) and then anomalies calculated. Anomaly time series were created by calculating each annual anomaly as:

Log_{10}(year)/(geometric mean of all years)

Because the mesh size used in PWS sampling changed between 2008 and 2010, the two time periods were treated separately, with individual geometric means calculated for 2000–2008 and 2010–2012. The CPR data, because it included more months, should incorporate most changes in phenology (unless significant months were missing), while the PWS series is most sensitive to interannual variability in timing.

Community composition

CPR data were compared for spring and fall with the net sampling in PWS (Fig 2). The Thorne and Kline/Campbell datasets were combined for spring since they used the same net, though only 2007/2008 data were available for fall. The Campbell 2010-2012 data were treated separately as a smaller mesh was used and abundances were much greater.

Despite different sampling methodologies (CPR samples at 7 m with 0.27 mm mesh, nets sampled vertically to 50m with 0.335 mm or 0.202 mm mesh), the communities are broadly similar. Copepods dominate, with small copepods numerically dominant (but less so in terms of biomass). Large copepods were more important in most treatments in spring compared to fall, and the CPR showed them to be most important offshore and least important in Cook Inlet and PWS, with the shelf intermediate. The nets captured relatively more euphausiids in the fall, likely because of their deeper depth of sampling and larger mouth area. Pteropods were more common in CPR sampling in spring, while more common in nets in the fall, but this could be a bias caused by fewer years of sampling contributing to the net fall data – the decade of CPR sampling shows pteropods to have large interannual variability.

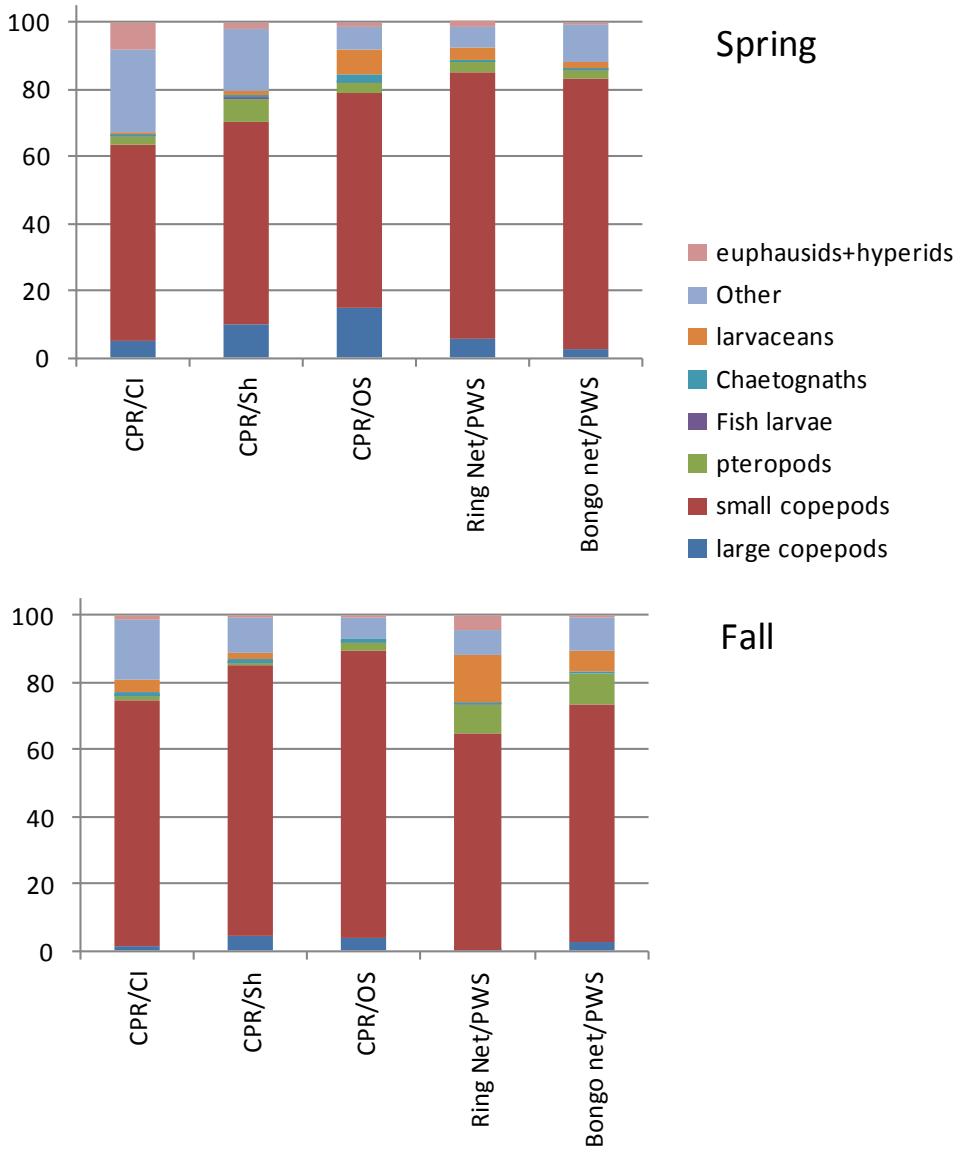

Fig. 2. Mean contribution (% of abundance) of each taxonomic group to the zooplankton community in spring and fall, as sampled by ring nets and the CPR. For CPR data; CI=Cook Inlet, Sh=shelf, OS = offshore.

Time series comparison

All datasets agreed that copepods were numerically dominant, so the comparison focussed on this group. Seasonal cycles of small and large copepods were compared (Fig. 3), with data for PWS coming only from the bongo net surveys by Campbell in the years 2010 to 2012 when monthly sampling was achieved and a seasonal cycle could be described.

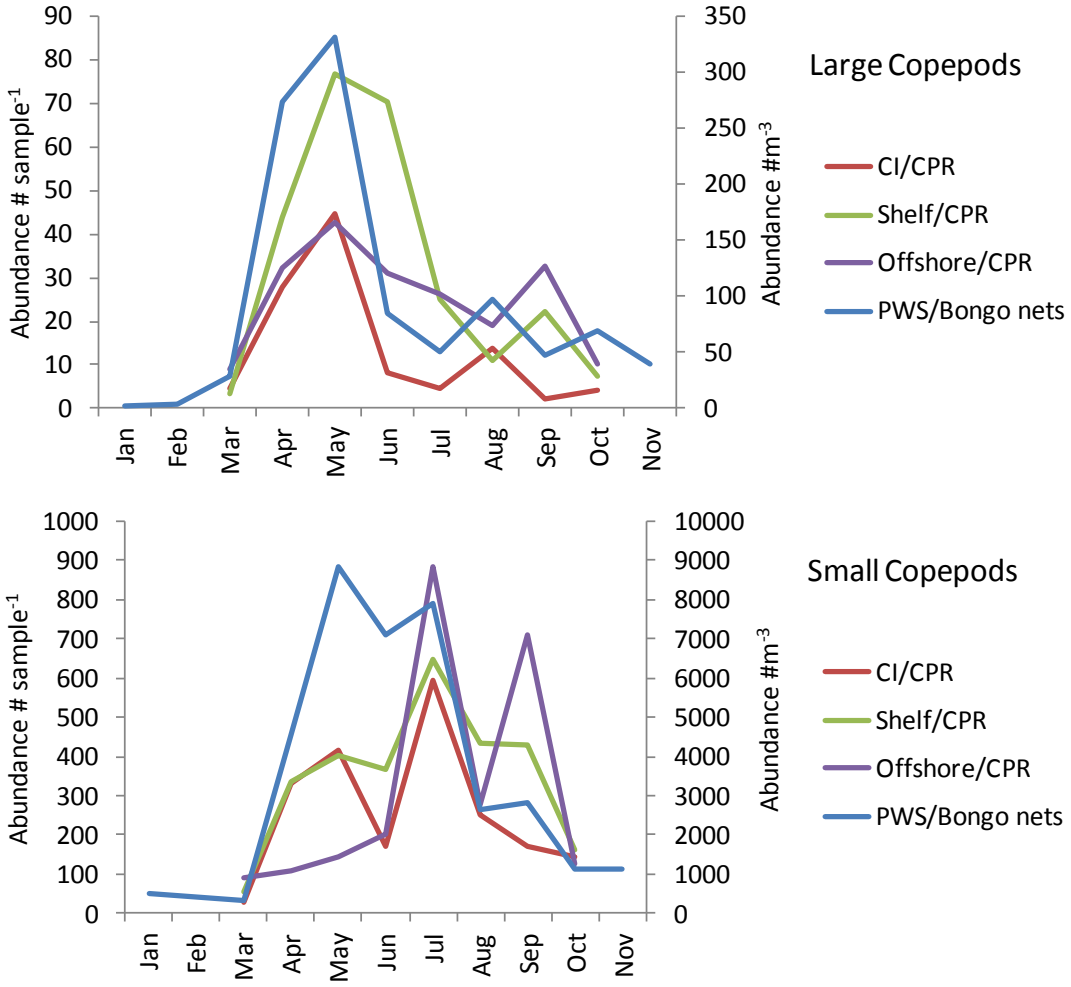

Fig. 3. Mean seasonal cycle of large and small copepods in 2010–2012 measured by Bongo nets in PWS and the CPR in Cook Inlet, the shelf and offshore regions as shown in Fig 1. CPR abundances are expressed as numbers per sample (approx 3m^3), Bongo net abundances as numbers m^{-3}.

With a smaller mesh size the bongo nets captured a higher abundance of both groups with a greater disparity in the small copepod counts, as expected. The CPR is also known to under-sample when compared to many net surveys (Clarke *et al*., 2001, John *et al*., 2001). However, the patterns shown by both sampling systems are very similar. The seasonal cycle of large copepods in PWS and in Cook Inlet are almost identical (correlation coefficient of 0.98); increasing from March to April, with a peak in May; dropping through June and July, with a small peak in August before declining in September. The wider shelf and offshore region also have peaks in May, but the decline through summer is less sharp

on the shelf and more gradual still offshore. Both these regions have a small second peak in September.

The small copepod results are less consistent between regions. The PWS copepods have an earlier peak from May through June, while the CPR-sampled regions rise through spring to a peak in July. This is most likely because the smaller mesh size of the bongo net is capturing the earlier juvenile stages that the CPR misses. In all cases, the small copepod peak is wider and later in the year than the large copepods.

Anomaly time series for each region are shown in Figure 4 and a table of correlation coefficients derived from comparisons of the time series (Table 1).

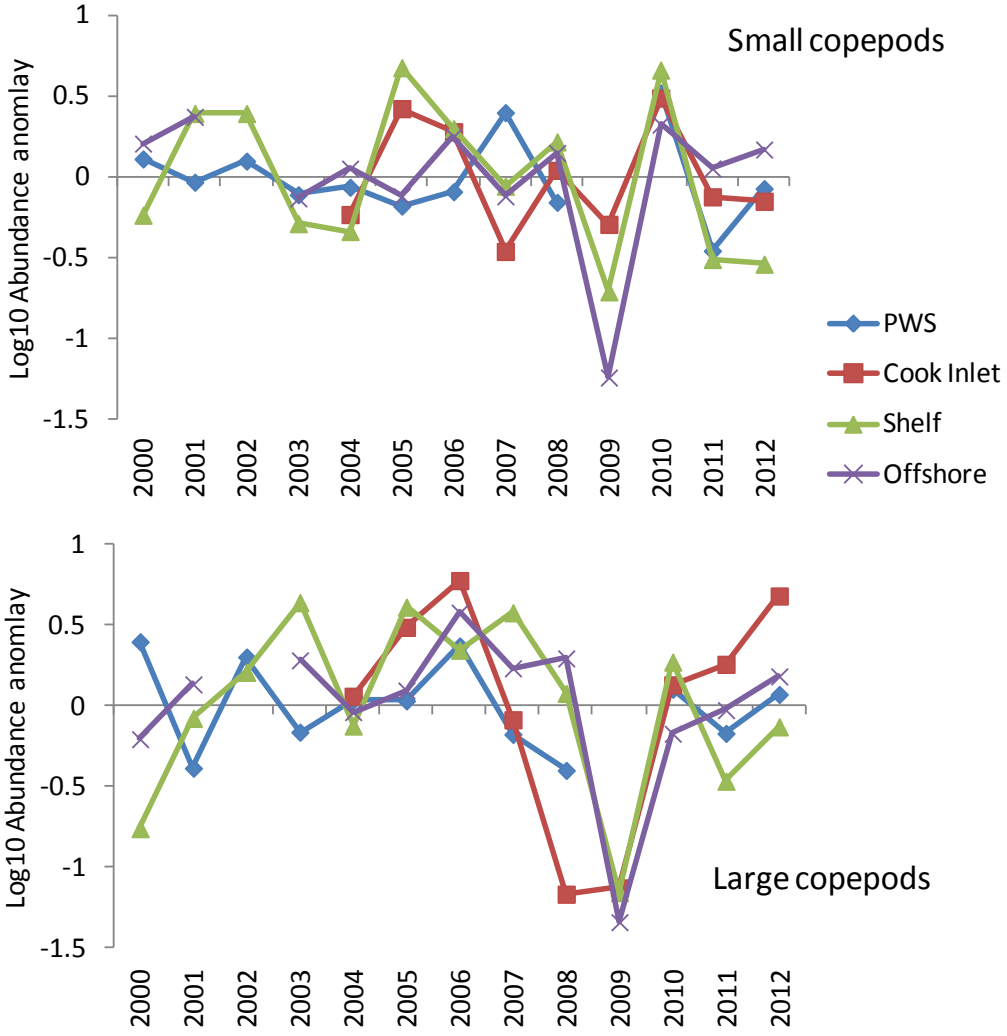

Fig. 4. Annual abundance anomalies of large and small copepods for each region (PWS not sampled in 2009, offshore not sampled adequately in 2002).

Table 1. Correlation coefficients for time series comparisons (those marked * are significant at p<0.05, those marked ** significant at p<0.01).

	PWS	Cook Inlet	Shelf	Offshore
Large *vs* small copepods	0.235	0.349	0.621*	0.788**
Small copepods PWS *vs*		0.064	0.370	0.201
Large Copepods PWS *vs*		0.837**	-0.160	-0.144
Small Copepods Cook Inlet *vs*			0.829**	0.445
Large Copepods Cook Inlet *vs*			0.489	0.565

All regions sampled by the CPR had a low anomaly of copepods in 2009, but unfortunately there were no data available for PWS in this year. The majority of the correlations are positive, suggesting a degree of synchrony across the wider region. Within a region, small and large copepods tend to have a similar pattern of interannual variability, but this was only significant in the shelf and offshore regions. Large copepods within PWS and Cook Inlet showed highly correlated interannual variability (p<0.01), as did small copepods within Cook Inlet and the wider shelf (p<0.01).

Conclusions

The comparison between CPR data from the wider region and plankton data from within PWS was limited in scope because early data from PWS were limited in seasonal coverage and taxonomic resolution. There was also a change in methodology between the three studies sampling between 2000 and 2012. The sampling program managed since 2010 by Dr. Campbell at the Prince William Sound Science Centre is more comprehensive than the earlier studies and, although at this time the comparison is limited to just 3 years, in the future more detailed studies will be possible as this program continues.

Comparisons between different plankton sampling systems are numerous. Each sampling system has strengths and weaknesses and normally, when making comparisons, a

systematic approach is preferred (Skojdal et al., 2013) that could not be followed here because the CPR was deployed outside of PWS and the nets inside it. The CPR is a unique sampler because it samples horizontally at a fixed depth over large distances in contrast to the nets which sample vertically on station. The different mesh sizes used in the nets before and after 2009 make comparisons within the time series of net data complicated, and all nets had a different mesh size from that used in the CPR. The CPR is not a perfect sampler either; it underestimates components of the plankton, e.g., large plankton such as euphausiids, delicate gelatinous plankton, and plankton smaller than the 270 µm mesh. Comparisons between the CPR and vertical net samplers have been undertaken in the past. Studies by Clark et al. (2001) and John et al. (2001) compared abundance estimates of the WP-2 net (with a 200 µm mesh) with CPR data, for a number of taxa of varying size. These comparisons were conducted over long time periods of 27 and 11 years, respectively, providing both long-term interannual comparisons and multiple seasonal comparisons. As would be expected, both Clark et al. (2001) and John et al. (2001) reported that the 200 µm mesh used in the nets caught substantially more plankton than the CPR 270 µm mesh. However, both studies showed that long-term and seasonal cycles in the CPR data were significantly similar to the data collected by the WP-2. In the comparison described in this report (Figs. 2, 3 and 4) a similar conclusion can be drawn even though the nets and CPR were not deployed in the same region; community composition at a broad taxonomic level was similar across sampling systems and, although the nets retained a higher abundance, similar large and small copepod seasonal cycles were evident (Fig. 3). By focussing on anomalies for the interannual comparison here, the differences in abundances retained by the sampling systems were not important and, as Table 1 indicates, there was a strong degree of synchrony across the region. PWS anomalies were also compared with the shelf and offshore at a 1-year lag, but the correlations were strongly negative. This suggests that any influence of zooplankton outside PWS on the populations within it happens within the year and not on longer time scales. The conclusion from this exercise is that, while each sub-region of the wider Alaskan Shelf and Gulf of Alaska will have local forcing and some variability from that, the shelf regions are also responding similarly to large-scale hydro-meteorological forcing. This is particularly true for the large copepods, which typically have an annual life cycle and therefore integrate the within-year variability, and whose interannual variability in the time series from Cook Inlet and PWS was almost identical.

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National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Protocol Narrative for Nearshore Marine Ecosystem Monitoring in the Gulf of Alaska

Version 1.1

Natural Resource Report NPS/SWAN/NRR—2014/756

ON THE COVER
Herring Bay, Prince William Sound
Photograph by: T.A. Dean

Protocol Narrative for Nearshore Marine Ecosystem Monitoring in the Gulf of Alaska

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Natural Resource Report NPS/SWAN/NRR—2014/756

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January 2014

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
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Revision History Log

All edits and amendments made to this document since its inception should be recorded in the table below. Users of this protocol should promptly notify the project leader of the marine nearshore monitoring program of recommended edits or changes. The project leader will review and incorporate suggested changes as necessary, record these changes in the revision history log, and modify the date and version number on the title page of this document to reflect these changes.

Revision History Log:

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #
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Add rows as needed for each change or set of changes associated with each version.

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Executive Summary

This document provides a comprehensive plan for long-term monitoring of nearshore marine resources in the Gulf of Alaska (GOA). The project is funded by the National Park Service's (NPS) Southwest Alaska Network (SWAN) and the Exxon Valdez Oil Spill Trustee Council (EVOS) Gulf Watch Alaska (GWA) programs. The objective of this plan is to assist managers in preserving nearshore resources by documenting changes to these resources over time and suggesting possible causes for these changes. The monitoring encompasses all major elements of the nearshore trophic web, from primary producers to apex predators, and focuses on six vital signs: kelp and seagrasses, marine intertidal invertebrates, marine birds, black oystercatchers, sea otters, and marine water chemistry and quality. Sampling will be conducted in Katmai National Park and Preserve (KATM), Kenai Fjords National Park (KEFJ), Prince William Sound (PWS) and to a lesser extent on the Lake Clark National Park and Preserve (LACL). Related projects that provide similar data from Kachemak Bay, Cook Inlet are not included here. Trends in different vital sign metrics (e.g. the number of sea otters) will be examined and the variation in the relative extent of change among different locations will be assessed.

Sampling will focus on estimating: cover by eelgrass and kelp; abundance (percent cover or density) of intertidal algae and invertebrates on sheltered rocky shores; density of infaunal invertebrates in gravel / mixed-sand gravel shores; size and density of Pacific blue mussels in mussel beds; abundance of marine birds; abundance, nest site density, and composition of prey provisioned to chicks for black oystercatchers; abundance, survival and diet of sea otters; and concentration of various organic and inorganic contaminants in mussels. In addition, temperature (both water and air) and salinity will be measured. All of these metrics will be examined within each of three core areas: KATM and KEFJ, and Western Prince William Sound (WPWS). Sampling within these core areas will generally be done at a frequency of once per year. Additionally, selected metrics will be examined less frequently in Eastern and Northern PWS (EPWS and NPWS) and LACL. Sampling of most metrics will be focused on randomly selected locations within each region.

Generalized guidelines on analytical methods to be used to detect trends in various vital sign metrics are provided. Also given are preliminary estimates of the extent of change that is deemed ecologically important and might trigger management action. In addition, guidelines for data management, management structure, operational requirements, and costs are provided.

Acknowledgments

The National Park Service, the Exxon Valdez Oil Spill Trustee Council, and the US Geological Survey supported this work. Special thanks to the NPS staff, and especially, Michael Shephard, Alan Bennett, Dorothy Mortenson, and Bill Thompson for their support and valued review comments. We would also like to thank Jim Estes and Kim Trust for their reviews.

1 Purpose and Background

1.1 Introduction

The purpose of this protocol is to provide a comprehensive plan to be used in implementing a long-term monitoring program of nearshore resources in the Gulf of Alaska (GOA). The goals of this program are to detect changes that may occur within the GOA nearshore system over the next several decades, to help identify potential causes for change, and to provide this information to resource managers and to the public in order in preserve nearshore resources. This protocol narrative provides an overview of design elements and procedures to be used in implementation of the protocol. Specifically, it provides:

- Background and rationale for marine nearshore monitoring
- A sampling design with rationale for its selection
- Metrics selected for sampling
- Specific sites to be used in sampling
- Proposed frequency of sampling and a proposed master schedule for plan implementation
- A structure for a database management system to be used in the nearshore
- Proposed guidelines for analysis of the data
- Proposed guidelines and schedules for review and modification of the design over time
- Estimated costs associated with implementation of the design

Details on how all aspects of the components described in the narrative will be carried out are provided in a series of Standard Operating Procedures (SOPs) provided in separate documents. Both this Protocol Narrative and SOPs were developed using guidelines established in Oakley et al. (2003).

1.2 Rationale for monitoring in the nearshore

The nearshore can be defined as that section of the marine ecosystem that extends from the high tide line, offshore to depths of about 20 m. The nearshore is considered an important component of the system because it provides:

- A variety of unique habitats for resident organisms (e.g. sea otters, harbor seals, shorebirds, seabirds, nearshore fishes, kelps, seagrasses, clams, mussels, and sea stars).
- Nursery grounds for marine animals from other habitats (e.g. crabs, salmon, herring, and seabirds).
- Feeding grounds for important consumers, including, killer whales, harbor seals, sea otters, sea lions, sea ducks, shorebirds, brown bears, and many fishes and shellfish.
- A source of animals important to commercial and subsistence harvests (e.g. marine mammals, fishes, crabs, mussels, clams, chitons, and octopus).

- An important site of recreational activities including fishing, boating, camping, and nature viewing.
- A source of primary production for export to adjacent habitats (primarily by kelps, other seaweeds, and eelgrass).
- An important triple interface between air, land and sea that provides linkages for transfer of water, nutrients, and species between watersheds and offshore habitats.

In addition, the nearshore is broadly recognized as highly susceptible and sensitive to a variety of both natural and human disturbances on a variety of temporal and spatial scales (Reviewed in Valiela 2006, Bennett et al. 2006, Dean and Bodkin 2006). For example, observed changes in nearshore systems have been attributed to such diverse causes as global climate change (e.g. Barry et al. 1995, Sagarin et al. 1999), earthquakes (e.g.

Baxter 1971), oil spills (e.g. Peterson 2001, Peterson et al. 2003), human disturbance and removals (e.g. Schiel and Taylor 1999), and influences of invasive species (e.g. Jamieson et al. 1998). Nearshore systems are especially good indicators of change because many of the organisms in the nearshore are relatively sedentary, accessible, and manipulable (e.g. Dayton 1971, Sousa 1979, Peterson 1993, Lewis 1996). Also, in contrast to other marine habitats, there is a comparatively thorough understanding of mechanistic links between species and their physical environment (e.g. Connell 1972, Paine 1974, 1977, Estes et al. 1998) that facilitates understanding causes for change. Lastly, the nearshore is the one habitat within which it is most likely that we will be able to detect relatively localized sources of change, tease apart human induced from naturally induced changes and, provide suggestions for management actions to reduce human induced impacts. Because many of the organisms in the nearshore are sessile or have relatively limited home ranges, they can be geographically linked to sources of change with a reasonable degree of accuracy.

1.3 Description of the GOA nearshore system

The following is a brief description of the nearshore system in the GOA. It is intended to provide an overview of what is generally perceived as important components and attributes of the system in order to provide background and context for sections that follow. More detailed descriptions of the GOA nearshore can be found in other more comprehensive resources (Peterson 2001, Mundy 2005).

The nearshore can be defined as that section of the marine ecosystem that extends from the high tide line, offshore to depths of about 20 m. It can be divided into the intertidal zone (between high-high water and lower-low water) and the nearshore subtidal (from lower-low water to depths of 20 m). The intertidal shorelines are geomorphologically diverse and vary from sheltered marshlands and beaches to steep rocky outcroppings subjected to high waves. The subtidal zone is a mix of cobble/ gravel, rocky outcroppings, and sand/silt. The subtidal substrate composition is only loosely correlated with that observed in adjacent intertidal zones.

Probably the most well recognized members of the nearshore habitat are the large mobile predators that reside in or spend some critical phase of their lifecycle within the nearshore zone. These include a variety of mammals (both terrestrial and marine), birds, and fishes. Among the most conspicuous marine mammals are sea otters, river otters, sea lions, and harbor seals (Lowry

and Bodkin 2005). Sea otters spend their entire life cycle principally within the nearshore zone and rely on intertidal and nearshore subtidal invertebrates (primarily clams and mussels) for food. River otters live and feed almost exclusively on nearshore fishes and invertebrates for food. In contrast, sea lions and seals are common inhabitants of the nearshore zone, but rely primarily on more pelagically derived sources for food (primarily pollock and fishes associated with more offshore environments). Terrestrial mammals including black and brown bears and deer occasionally forage in the intertidal. Birds commonly encountered include eagles, gulls, shorebirds, seabirds, and seaducks (Irons et al. 2000). Among those most closely linked to the nearshore are the black oystercatcher and several sea ducks (harlequin ducks and Barrows goldeneye) (Andres and DeZeeuw 1991, Robertson and Goudie 1999, Vermeer 1982, 1983, O'Clair and O'Clair 1998). Black oyster catchers are year-round residents that breed and rear young in the habitats adjacent to the nearshore and feed almost exclusively on intertidal mussels, limpets, and chitons. Harlequin ducks and Barrows goldeneye breed and nest in more upland habitats, but congregate in large numbers in the GOA nearshore (especially in winter) where they feed on mussels and other smaller epibenthic invertebrates in the intertidal and shallow subtidal zones. Pigeon guillemots breed on nearby offshore islands or on cliff faces and rely to a small extent on nearshore fishes for food. Other birds species (e.g. bald eagles, Northwestern crows, kittiwakes, and glaucous winged gulls) often feed in the nearshore, but rely more heavily on food resources derived from either terrestrial, watershed, or offshore sources (e.g. carrion from mammals, salmon, or pelagic forage fishes) (O'Clair and O'Clair 1998). Several commercially valuable fishes including Pacific halibut and salmon also rely on the nearshore. Halibut occasionally come to shallow water to feed on salmon and crabs. Some pink salmon lay eggs in the intertidal zone and both pink and Chum salmon rely on nearshore resources as food and shelter during outmigration (Simenstead et al.1980).

The important birds, mammals, and fishes represented in the nearshore, rely on a variety of habitats and species for critical life functions. Those habitats and assemblages of species are described as follows. The intertidal community on sheltered rocky shorelines is generally divided into three or four relatively distinct vertical zones characterized by different plant and invertebrate assemblages (Nybakken 1969, Feder and Kaiser 1980, O'Clair and Zimmerman 1986, Highsmith et al. 1994). The vertical extent, position with respect to tidal elevation, and species composition of each zone varies with physical characteristics of the site (e.g. substrate composition, slope, tidal range, and relative exposure) but can generally be characterized as follows. The upper zone is dominated by barnacles and generally occurs over a tidal range extending from about the mean tide level to mean high water (approximately plus 1 to plus 2 m, MLLW). It is bounded at the upper elevation by a thin crust of the black lichen *Verrucaria* spp. This zone generally has lower cover and a fewer number of species than the lower zones. Dominant organisms include barnacles (*Chthamalus dalli*, *Semibalanus balanoides*, and *Balanus glandula*), littorine snails (*Littorina scutulata* and *Littorina sitkana*), limpets (*Lottia pelta* and *Lottia persona*), and mussels (*Mytilus trossulus*). The next lower zone is dominated by *Fucus distichus* and generally extends from the mean tide level to just above mean lower-low-water (approximately plus 1 to plus 0.3 m, MLLW). The zone includes various algae (brown algae, *Fucus distichus* and *Pilayella* spp.; green algae, *Ulva* and *Cladophora* spp.; red algae *Palmaria*, *Neorhodomela* and *Odonthalia* spp.) as well as many of the same invertebrates as observed as dominant in the barnacle zone (e.g. barnacles, mussels, littorine snails, and limpets). On slightly more exposed sites, a narrow red algal zone is often seen just below the *Fucus* zone. This zone is dominated by various types of red algae, especially *Palmaria*, *Halosachion* and

Cryptosiphonia spp. This zone is less distinguishable at more sheltered sites where there is little wave action. The lower intertidal (generally below MLLW) is dominated by kelps (e.g. *Laminaria* spp.) or eelgrass (*Zostera marina*) and often extends into the subtidal zone.

Larger predatory invertebrates common in the intertidal include seastars (*Pycnopodia helianthoides*, *Pisaster ochraceus*, and *Evasterias troschelii*) and snails (*Nucella* spp. and *Lirabuccinum dirum*) that feed on barnacles, mussels, limpets, and littorines. Because these habitats are often exposed to the air, fish are relatively rare. However, several species of fish including the high cockscomb (*Anoplarchus purpurescens*) and the crescent gunnel *(Pholis laeta*) are commonly found under cobbles or boulders. In addition, Pacific Herring (*Clupea pallasil*) utilize the rocky intertidal as spawning habitat and in some localities deposit eggs in spring to create dense mats of eggs over several kilometers of shoreline.

In soft sediment intertidal habitats there are fewer conspicuous algae or invertebrates on the surface as most of the organisms are infaunal (buried below the surface). These infaunal communities are dominated by a variety of clams, small snails, annelid worms, and a variety of small crustaceans (primarily amphipods) (Feder and Keiser 1980, Driskell et al. 1996). Among the most abundant organisms (in terms of biomass) are littleneck clams (*Leukoma staminea*), butter clams (*Saxidomus gigantea*), *Macoma* spp., and cockles (*Clinocardium nuttallii*). Several clams (especially littleneck clams) are important subsistence foods and are also commercially harvested.

The subtidal zone is generally heavily vegetated by either kelps or eelgrass. Rocky bottoms are dominated by kelps including *Laminaria* spp., *Agarum clathratum*, and at more exposed shorelines *Nereocystis luetkeana* (Rosenthal et al. 1977, Dean et al. 1996a, 1996b). These kelps provide substrate for a variety of sessile invertebrates and a habitat for small crustaceans. Among the most common sessile invertebrates are bryozoans, hydroids, and the small mussel *Musculus* spp. The surfaces of rocks under the kelps are generally covered with coralline algae, fleshy red algae, and sessile invertebrates (bryozoans, sponges, and hydroids). The algae and sessile invertebrates harbor a rich fauna dominated by small crustaceans (shrimp and amphipods). These rock dominated communities are home to a variety of larger epibenthic invertebrates including several sea stars (e.g. *Pycnopodia helianthoides*, *Dermasterias imbricata*, *Evasterias troschelii*, and *Orthasterias koehleri*), crabs (especially the helmet crab, *Telmessus cheiragonus*), and sea urchins (*Strongylocentrotus droebachiensis*). Fishes common on rocky bottoms include greenlings (*Hexagrammos* spp.), a variety of sculpins, pricklebacks (especially *Stichaeus punctatus*), and juvenile Pacific cod (*Gadus macrocephalus*) (Rosenthal et al 1980, Dean et al. 2000). Along shorelines where herring spawn, eggs are often deposited on a variety of subtidal substrates to depths of several meters. A variety of rockfishes are also common along more exposed shorelines. While the seafloor is predominantly covered by rock in these habitats, there are often small patches of sand or silt interspersed that harbor a rich infaunal community including a variety of clams, annelid worms, and crustaceans (Dean and Jewett 2001).

Soft bottom subtidal habitats are often vegetated by dense stands of eelgrass (*Zostera marina*) (McRoy 1968, 1970, Rosenthal et al 1977, Dean et al. 1998). These are most common in relatively sheltered embayments fed by streams that supply silt, nutrients, and detritus. The eelgrass bed provides a substrate for a rich epifaunal community including small mussels (*Musculus* spp.) hydroids, and bryozoans (Rosenthal et al. 1977, Jewett and Dean 1977). Small

crustaceans and a variety of small snails are also commonly associated with eelgrass. Small harpacticoid copepods are particularly important as a food for outmigrating salmon fry and are very abundant within the eelgrass community. The community of large epibenthic invertebrates and fishes are less diverse than on rocky bottoms, but high densities of the sea stars (*Pycnopodia helianthoides* and *Dermasterias imbricata*), as well as helmet crabs (*Telmessus cheiragonus*) are often found in eelgrass beds (Rosenthal et al 1977, Dean et al. 1996b). Common fishes include cod, greenlings, and gunnels (Dean et al 2000). Juvenile Pacific cod (*Gadus macrocephalus*) are especially abundant. Herring utilize eelgrass as substrate to deposit eggs and in addition sandlance burrow into soft sediments in the nearshore subtidal (and lower intertidal) and both sandlance and capelin deposit eggs in the nearshore soft-bottom habitats (Robards et al. 1999). The infaunal community in eelgrass beds and in other soft sediment subtidal habitats is characterized by a diverse assemblage of small crustaceans, annelids, and gastropods (Feder and Jewett 1987, Jewett et al. 1999, Dean and Jewett 2001).

The food web in the nearshore system of the GOA is relatively complex (Figure 1). Most of the animals derive a large proportion of their energy from sources that can be traced to benthic based primary production from seaweeds (especially kelps), eelgrass, and unicellular algae (especially benthic diatoms). Some energy is also derived from offshore planktonic sources. Plankton and nearshore derived detritus are utilized as food by a large suite of filter and suspension feeding benthic invertebrates including clams, mussels, and barnacles as well as some crabs (especially hermit crabs). Other benthic invertebrates are herbivorous and feed primarily on diatoms or small encrusting algae (e.g. limpets, littorines, and some crabs) or larger seaweeds and eelgrass (e.g. sea urchins, helmet crabs, and some larger herbivorous snails). The predators comprise a large and diverse group that include sea stars, predatory snails, fishes, birds, sea otters, river otters, harbor seals and occasionally killer whales. Sea stars including *Pycnopodia helianthoides*, *Pisaster ochraceus*, *Evasterias troschelii*, and *Leptasterias epichlora*, feed primarily on barnacles, mussels, small snails, and clams.

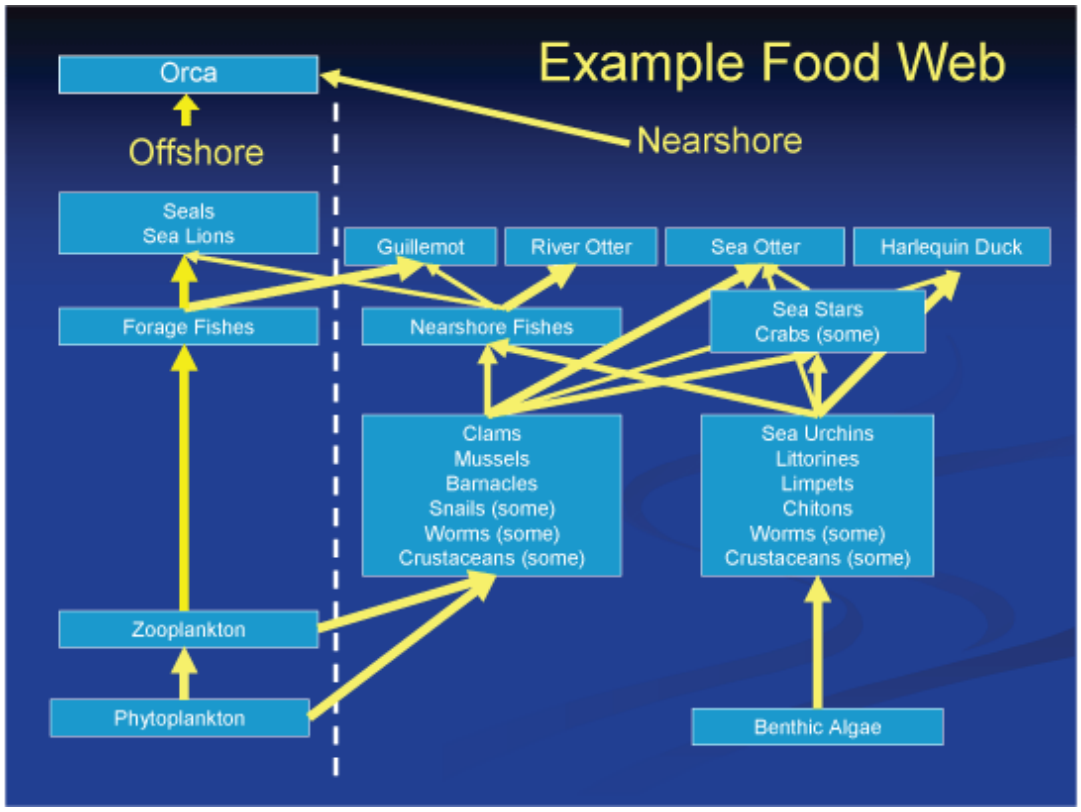


Figure 1. Simplified example of the food web for the nearshore Gulf of Alaska. The width of arrows indicates the degree of dependence on a particular food source. Also shown are links to offshore food.

The structure of algal and invertebrate communities of the nearshore GOA is largely governed by the same forces widely recognized as controlling the distribution and abundance of organisms in the more widely studied temperate rocky shores (reviewed in Peterson 2005). Important physical factors determining distribution and abundance include substrate composition, slope, temperature (both water and air), desiccation (for the intertidal), light, exposure to waves, the degree of fresh water input (i.e. salinity), currents, and ice scour. It is generally accepted that physical factors tend to limit the upper distribution of species in the rocky intertidal zone, and are generally more important higher in the intertidal. As one proceeds down slope to the lower intertidal and subtidal zones, the extremes in the physical environment generally diminish (i.e. less extreme variation in temperature and degree of desiccation, less influence of ice scour). As a result, biological processes (competition and predation) become increasingly more important with depth. In the absence of physical disturbance or predation, competition for space generally leads to dominance by one or a few superior competitors. However, predation and intermediate levels of physical disturbance (e.g. moderate ice scour or bashing of the intertidal by floating logs) often reduces competitive pressures and leads to more diverse assemblages. Of particular importance is predation by certain "keystone" predators that prey on potentially dominant species and thereby reduce competitive pressures and exert influence on community structure that is disproportionate to their abundance. In the GOA, keystone predators include sea otters (Estes and Palmisano 1974, Riedman and Estes 1990) certain sea stars (O'Clair and Rice 1985) black oyster catchers, (Power et al. 1996, Marsh 1986) and predatory snails (Carroll and Highsmith 1996). Changes in the abundance of these keystone species can produce intense direct and indirect effects that can cascade through the ecosystem. In one well documented

example in Alaska, reduction in sea otters led to an increase in the abundance of herbivorous sea urchins which in turn caused a reduction in the kelp upon which sea urchins graze.

While not well studied, it appears that physical factors are also important in structuring communities in soft bottom habitats as in rocky habitats. Sediment type and salinity have been shown to be key determinants of structure in soft sediment habitats. Predation (especially by sea otters) and competitive interactions are also known to influence soft sediment community structure as well (Kvitek et al.1992).

Variation in the timing and abundance of larvae can also exert a strong influence on benthic community structure in both rocky and soft sediment habitats (Connolly and Roughgarden 1999, Gaines and Roughgarden 1995, Gaines et al. 1995). Many of the sessile invertebrates and some algae rely on larvae or spores transported from distant populations for recruitment. Abundances of larvae are known to be highly variable in both space and time, and in more northerly latitudes like the GOA, can vary greatly from year to year (Estes and Duggins 1995, Connolly et al. 2001). In years when particularly large numbers of recruits are available, increases in abundance of a particular species can overwhelm the influence of predators and lead to larger than normal population sizes. In some cases, the effects of a particularly large year class can persist and have multi-year impacts on local community structure.

Factors structuring communities are often classified as either top down, or bottom up controls (Connolly and Roughgarden 1999). In the nearshore benthic community, the bottom up forces would include variation in larval recruitment and availability of food (for invertebrates) or light and nutrients (for plants). Top down forces include physical disturbance to higher trophic levels or predation. It is clear that in the GOA as elsewhere, both top-down and bottom up forces work to structure nearshore systems.

1.4 Historical causes for change in the GOA nearshore

While history is not necessarily a predictor of future events, it is none the less instructive to gain a historical perspective on changes that have occurred in the nearshore GOA over the past several decades and identify the causes for those changes. There have been three major events that have resulted in long-term change in the nearshore community in the GOA: The extirpation and subsequent re-colonization by sea otters, the 1964 earthquake, and the *Exxon Valdez* oil spill. Sea otters in the GOA were hunted to near extinction in the early part of the 20th century, leaving only a few isolated remnant populations. Based on more recent observations of the effects of more localized declines in sea otter abundance (Estes et al. 1998) and on observations of effects of sea otter range expansion (Estes and Palmisano 1974, Kvitek et al. 1992, Trowbridge 1995) it is clear that the near extinction of sea otters a century ago likely caused a dramatic shift in nearshore community structure. Declines in sea otter abundance likely resulted in increases in population densities of major prey items including sea urchins, clams, and crabs. As a result of increased sea urchin abundance, kelps on which sea urchins graze likely decreased in abundance. Since the cessation of large-scale human take of sea otters in the early 20th century, sea otter populations in the GOA have slowly recovered. The recovery has been characterized by decade or longer periods of low sea otter population density followed by relatively rapid increases in population size as the sea otters expanded their range and colonized previously unoccupied habitats. Expansion of sea otters into the Aleutian Islands led to a reduction in sea urchin abundance, an increase in kelp, and an increase in sea urchin predators including Common eiders

(Estes et al 1998). Over the past three decades there were also dramatic increases in number of sea otters in Eastern Prince William Sound (Trowbridge 1995) and Kodiak Island (Kvitek et al. 1992). The expansion of sea otters into new habitats led to rapid localized declines in crab and clam populations, and in PWS led to closure of the commercial crab fishery. Cascading effects on other parts of the system (e.g. a reduction in populations of animals that compete with sea otters for clam and crab resources) likely occurred but were not documented. With the exception of portions of Kodiak Island and Cook Inlet, sea otters now occupy most of the nearshore GOA from the Aleutians to Prince William Sound.

The magnitude 9.2 great Alaska earthquake in 1964 had its epicenter near Perry Island in Northern PWS (NRC 1971). The quake generated a tsunami that resulted in the loss of life and did extensive physical damage to towns and villages that border the Sound. Areas to the south of the epicenter were uplifted, with maximum uplift of nearly 10 m occurring on southwestern portions of Montague Island. Post quake surveys documented the complete destruction of the intertidal community in areas of maximum uplift as the land and associated attached fauna and flora was thrust upward into the supratidal zone (Baxter 1971, Haven 1971, Hubbard 1971). In addition, the quake caused an estimated 35% reduction in intertidal hard-shell clam populations in PWS (Baxter 1971). Other effects resulting from the tsunami, the spilling of fuel and oil from ruptured storage tanks, underwater land slides, the redirection of streams, the blockage of lagoon entrances, and the formation of new intertidal mudflats likely had a profound impact on the nearshore, but these impacts were not well documented. Recovery of some intertidal communities apparently occurred within several years or less, but it was estimated that recovery of some clam populations took considerably longer (Hubbard 1971).

The most recent event resulting in major changes to the nearshore in the GOA was the *Exxon Valdez* oil spill (EVOS). In March 1989, the T/V *Exxon Valdez* ran aground in Prince William Sound (PWS) spilling almost eleven million gallons of crude oil. The oil contaminated nearly 1,500 miles of coastline in the GOA region extending from PWS to Kodiak Island and killed hundreds of thousands of birds, mammals, and untold numbers of fishes and invertebrates (Spies et al. 1996). In addition, the spill and the associated cleanup of shorelines resulted in a major restructuring of the intertidal community. In areas heavily oiled by the spill, reductions of 50% or greater were noted for most of the dominant plants and animals in the mid and upper intertidal zone including barnacles, mussels, limpets, and *Fucus* (Highsmith et al. 1994). Shortly after the spill, the provision of un-colonized substrate led to increases in ephemeral algae that were on the order of 50 to 300%. Changes also occurred within the subtidal zone, where reductions in some crabs, sea stars, and sensitive infaunal organisms (primarily amphipods) were noted along with an increase in more stress tolerant species (Dean et al. 1996b, Jewett et al. 1999, Dean and Jewett 2001). While nearshore communities within much of the spill area recovered within several years, some impacts in heavily oiled portions of PWS persisted for 18 years or more. As of 2002, oil was still present in sediments (Short et al. 2006) and clams (Fukuyama et al. 2000) within the heavily oiled portion of western PWS, and there was evidence for ongoing effects of lingering oil on sea otters, sea ducks, and some fishes (Peterson et al. 2003). Exposure to lingering oil continued through 2005 for Barrow's goldeneyes (Esler et al. 2011) and through at least 2009 for harlequin ducks (Esler et al. 2010). For both sea otters and harlequin ducks, exposure to lingering oil was linked to lower survival rates, as population densities remained suppressed in heavily oiled portions of the Sound through at least 2007 for sea otters (Bodkin et al. 2011, Monson et al. 2011) and 2005 for harlequin ducks (Iverson and Esler 2011).

Over the past several decades there have undoubtedly been additional changes in the nearshore GOA that resulted from both human activities (e.g. logging activity, shoreline development, fishing pressure) and natural events (e.g. climate change associated with changes in the Pacific Decadal Oscillation). However, these have largely gone undocumented in the nearshore. We suspect that many of these changes have been more difficult to detect because they are less episodic in nature, or have occurred over smaller spatial and/or temporal scales than those related to re-colonization by sea otters, earthquakes, or the *Exxon Valdez* oil spill.

2.0 Goals and Sampling Design

2.1 Program goals

The goals of the nearshore monitoring program are to detect change; identify causes of change, and communicate these to the public and to resource managers to preserve nearshore resources. It is not possible to predict what changes might occur within the nearshore zone over the next several decades, and unforeseen changes that result from unforeseen causes, will almost certainly occur. However, hypothesizing what changes may occur, and what temporal and spatial scales they may occur over, is an important initial step in the development of an effective long-term monitoring program. We have developed a list of potential changes to the system based from a review of the changes that have occurred within the GOA over the past several decades, and a review of changes that have occurred in regions outside of Alaska where anthropogenic impacts have been more prevalent (Appendix A). This exercise suggests that changes may result from both natural and anthropogenic agents, and may occur over varying scales of time and space. One of the major challenges is to design a sampling program that can effectively detect changes regardless of their cause and the temporal and spatial scales over which they occur.

The monitoring program described here will focus on the portion of the Gulf of Alaska from Katmai National Park eastward to Prince William Sound. It is designed to detect changes that occur on spatial scales of 10 km of coastline or larger, and on temporal scales of one year or more. It is likely that changes over these scales of space and time will occur as the result of multiple causes. As indicated above, the monitoring program calls for detecting change based on synoptic sampling of a selected set of physical and biological variables (e.g. sea surface temperature or eelgrass distribution) over the entire study region, sampling of a suite of biological and physical parameters within the three core areas, or blocks (KATM, KEFJ, and WPWS), and sampling of a subset of biological and physical parameters throughout the study area on a less frequent basis. Details with respect to metrics sampled, number and location of sampling sites, and frequency of sampling are provided in the sections that follow.

The second goal of the monitoring program is to assign cause. As with most biological systems, changes will likely result from multiple causes and we anticipate that the responses to these will be complex. Most responses are likely to be non-linear and those resulting from multiple causes are likely to be non-additive. As a result, while it is likely that we will be able to suggest that changes are, in part, related to certain causative agents, quantitative assessments (the proportion of observed change attributable to a given cause) will be more difficult.

Possible causes for change will be assigned by first examining the spatial and temporal patterns of change that occur in relation to the expected patterns. For example, changes that occur over large spatial scales might be attributable to large-scale climate changes, but are unlikely to be caused by more localized coastal development. Second, we will conduct concurrent monitoring of biological responses and likely forcing agents. The forcing agents will include both top down (i.e. predators and physical disturbance) and bottom up (food or productivity related) factors. Possible correlations between responses and changes in forcing agents will suggest possible causation.

2.2 Vital sign metrics and objectives

This protocol focuses on sampling of several key members of the nearshore system in the GOA that are both numerically and functionally important to the system's health and on several key environmental drivers. These are termed "vital signs" and include kelps (and other marine algae) and seagrasses, marine intertidal invertebrates, marine birds, black oystercatchers *(Haematopus bachmani*), sea otters (*Enhydra lutris)*, and marine water chemistry and quality. The rationale for focusing on these vital signs is given in Bennett et al. 2006 and is summarized here.

Kelp, other algae, and seagrass are "living habitats" that serve as a nutrient filter, provide understory and habitat for planktivorous fish, clams, urchins, and a physical substrate for other invertebrates and algae. Kelps and other algae are the major primary producers in the marine nearshore and because they are located in shallow water they could be significantly impacted by human activities. These include spills of oil or other contaminants, dredging and disturbance from anchoring of vessels, and increased turbidity caused by runoff of sediments or nutrients.

Marine Intertidal Invertebrates provide critical food resources for shorebirds, ducks, fish, bears, sea otters, and other marine invertebrate predators, as well as spawning and nursery habitats for forage fish and juvenile crustaceans. Benthic invertebrates and algae are ecologically diverse in terms of habitat and trophic requirements; have a wide range of physiological tolerances; are relatively sedentary, and have varied life-histories. As a result, they are good biological indicators of both short-term (e.g. annual) and long-term (e.g. decadal scale) changes in environmental conditions.

Marine Birds are predators near the top of marine nearshore food webs. Marine birds are long-lived, conspicuous, abundant, widespread members of the marine ecosystem and are sensitive to change. Because of these characteristics marine birds are good indicators of change in the marine ecosystem. Many studies have documented that their behavior, diets, productivity, and survival changed when conditions change. Public concern exists for the welfare of seabirds because they are affected by human activities like oil pollution and commercial fishing.

Black Oystercatchers are well suited for inclusion into a long-term monitoring program of nearshore habitats because they are long-lived; reside and rely on intertidal habitats; consume a diet dominated by mussels, limpets, and chitons; and provision chicks near nest sites for extended periods. Additionally, as a conspicuous species sensitive to disturbance, the black oystercatcher would likely serve as a sentinel species in detecting change in nearshore community resulting from human or other disturbances.

Sea Otters are keystone species that can dramatically affect the structure and complexity of their nearshore ecological community. They cause well described top-down cascading effects on community structure by altering abundance of prey (e.g. sea urchins) which can in turn alter abundance of lower trophic levels (e.g. kelps). Sea otters generally have smaller home ranges than other marine mammals; eat large amounts of food; are susceptible to contaminants such as those related to oil spills; and have broad appeal to the public. Recent declines in sea otters have been observed in the Aleutian Islands. Currently declines are documented in areas to the western edge of our study area. As a result of these declines, the Western Alaska stock of sea otters (which includes populations in Katmai National Park and Preserve as well as Aniakchak

National Monument and Preserve), was federally listed as threatened on September 2005 under the Endangered Species Act.

Marine Water Chemistry and Water Quality**,** including temperature and salinity, are critical to intertidal fauna and flora and are likely to be important determinants of both long-term and short-term fluctuations in the intertidal biotic community. Basic water chemistry parameters provide a record of environmental conditions at the time of sampling and are used in assessing the condition of biological assemblages. Water quality (including water temperature, salinity, and levels of contaminants such as heavy metals and organic pollutants) are also critical in structuring nearshore marine ecosystems and can cause both acute and chronic changes in nearshore populations and communities.

Specific questions and objectives for each of the vital signs are:

Kelp and Seagrass

Question:

- What are the large-scale (GOA-wide, over decades) trends in the relative abundance and distribution of canopy forming kelps, intertidal algae, and eelgrass?
- What are annual trends in the abundance of canopy forming kelps, intertidal algae, and eelgrass?
- How do inter-annual changes in relative abundance of eelgrass differ among locations?

Objective:

- Estimate long-term trends in abundance and distribution of kelp and eelgrass at various locations.

Marine Intertidal Invertebrates

Questions:

- How are the composition and relative abundance of intertidal algae and invertebrates changing annually?
- How do inter-annual changes in relative abundance of intertidal algae invertebrates differ among locations?

Objectives:

- Monitor long-term trends in species composition and abundance of algal and invertebrate species at various locations.
- Document how the size distributions of limpets (*Lottia persona*), mussels (*Mytilus trossulus*), and clams are changing annually at various locations.

Marine Birds

Question:

- How is the species composition and abundance of birds (and especially those closely linked to the nearshore, such as harlequin ducks and Barrow's goldeneye) changing annually during summer and winter?
- How do inter-annual changes in the number of bird species present and the relative abundance of birds differ among locations?

Objective:

- Estimate long-term trends in the seasonal abundance of seabirds and seaducks at various locations.

Black Oystercatcher

Question:

- How are the relative density (pairs per linear kilometer of shoreline) of black oystercatcher nests and the nest site productivity (number of chicks or eggs per nest) changing annually?
- How is the composition of prey provisioned to black oystercatcher chicks changing over time?
- How do inter-annual changes in density of black oystercatchers and composition of prey provisioned to chicks differ among locations?

Objective:

- Estimate long-term trends in relative density and nest site productivity of black oystercatchers at various locations.
- Estimate long-term trends in black oystercatcher diet through collection of prey remains at various locations.

Sea Otter

Questions:

- How is abundance and spatial distribution of sea otters changing over time?
- How is age-specific survival of sea otters changing annually?
- How is the diet of sea otters changing annually?
- How do inter-annual changes in abundance, survival, and diet differ among areas?

Objectives:

- Estimate long-term trends in sea otter abundance and spatial distribution.

- Estimate and compare age-specific survival rates of sea otters among regions within the Gulf of Alaska.
- Estimate diet composition of sea otters at various locations.

Marine Water Chemistry and Quality

Questions:

- What is the daily, seasonal, and annual variation in intertidal water temperature and salinity and how are these changing over time?
- How is the concentration of contaminants in mussel tissue (an integrated index of contaminant concentrations in water) changing over time?
- How do inter-annual changes in water chemistry and contaminant levels differ among locations?

Objectives:

- Document daily, seasonal, and annual variability in temperature and salinity at various intertidal sampling sites.
- Monitor status and trends in the concentration of metals, PAHs (polycyclic aromatic hydrocarbons often associated with oil spill contamination), PCBs, pesticides, and metals in the tissues of mussels collected from various locations over time.

2.3 Sampling areas

The design focuses on examining each of these vital signs in the Katmai National Park and Preserve (KATM), Kenai Fjords National Park (KEFJ), Western Prince William Sound (PWS). Less frequent sampling of selected vital signs will be examined in Lake Clark National Park and Preserve (LACL), Eastern PWS (EPWS), and Northern PWS (NPWS) (Figure 2).

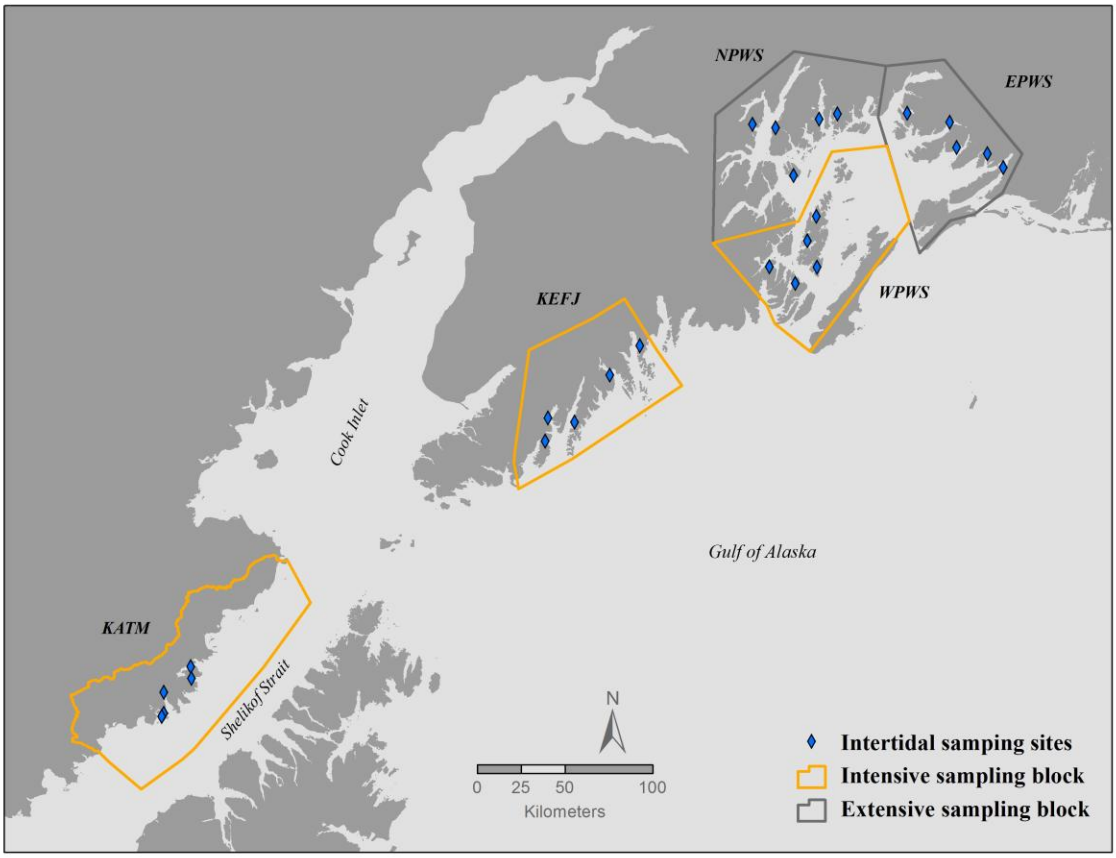


Figure 2. Areas for sampling within the Katmai National Park (KATM), Kenai Fjords National Park (KEFJ), and Western Prince William Sound (WPWS), Eastern Prince William Sound (EPWS) and Northern Prince William Sound (NPWS).

Various vital sign metrics are evaluated on an annual (or for some metrics less frequent) intervals within each location. Sampling frequency was determined based on the expected extent of inter-annual variation for a given metric as well as cost and logistical constraints. For example, the species distribution and abundance of intertidal invertebrates that are known to exhibit high inter-annual variation are to be sampled either annually or bi-annually whereas less variable contaminant levels in mussel tissue are to be monitored every 7 to 10 years.

The number and location of sampling units differ among metrics, but in general the design calls for sampling at multiple locations within each area. The number of sampling locations and the rationale for this are specified in vital sign specific SOPs, but in general were guided by preliminary estimates of effort required to detect ecologically meaningful levels of change. Sampling locations were selected to provide a random, spatially balanced distribution. The design allows for detection of large temporal or spatial-scale changes (e.g. changes that may occur over the entire region over time or among blocks). For some metrics (e.g. contaminants in mussels) the design will also allow for detection of changes that may occur on a more localized scale (e.g. at a site of heavy human influence).

2.4 Sampling method overview

Sampling in the core intensive sampling blocks (KATM, KEFJ, and WPWS) will consist of:

- Surveys of eelgrass and kelp canopy – The area covered by canopy forming kelps and eelgrass will be evaluated based on block-wide aerial surveys (Harper and Morris 2004) to be repeated on a ten to twelve year frequency. Changes in percent cover by eelgrass will also be evaluated in selected eelgrass beds on an annual basis. Selected sites will be areas of historical eelgrass cover (as documented by previous ShoreZone mapping conducted by Harper and Morris 2004) that are the nearest sites where intertidal and algal invertebrates are sampled. The boundaries of each bed will be located (either visually or using a fathometer and underwater camera) and positions recorded using a GPS.

- Sampling of intertidal plants and invertebrates on sheltered rocky shores - Sites on sheltered rocky shores will be selected and sampled annually to estimate the abundance and distribution of intertidal invertebrates and algae. Five to six sites will be sampled within each block. Metrics will include number of algal and invertebrate species, abundances of selected dominant taxa and size distributions of limpets.

- Sampling of infaunal invertebrates in gravel / mixed-sand gravel shores - Sampling of infaunal invertebrates will be conducted every other year at gravel/mixed sand-gravel sites in each block. Sampling will focus on bivalves that are relatively large, long-lived, and common (Lees and Driskell 2006). Metrics obtained will include abundances of selected clam species and size distributions of several dominant species. Sediment samples will be obtained from gravel / sand-gravel site for determination of grain size distribution (every 6 to 10 years).

- Sampling of Pacific blue mussels in mussel beds – The density and size distribution of mussels will be measured annually in 5 mussel beds in each w. The focus will be on larger mussels that are important prey for sea otters, sea ducks, and black oystercatchers. The selected beds will be the nearest beds to sheltered rocky intertidal sampling sites.

- Sampling marine bird and mammal abundance – Marine bird and mammal abundance will be estimated via boat annually in summer. Sampling in PWS will be done by under a separate contract to the US Fish and Wildlife Service (Irons et al. 2011). In addition, winter sampling will be conducted in KATM and KEFJ every two to three years. Counts will be made along shoreline transects using the methods of Irons et al. (2000). The focus will be on estimating the abundance of birds closely linked to the nearshore including harlequin ducks, Barrow's goldeneyes, and black oystercatchers (Webster 1941, Goudie and Ankey1986, Andres 1998). Surveys will be conducted in summer and winter so that abundance estimates can be obtained for birds with different seasonal patterns (e.g. harlequin ducks that are more abundant in winter and black oystercatchers that are more abundant in summer).

- Sampling of black oystercatcher nest site density and oystercatcher chick provisioning - The number of black oystercatcher nest sites will be surveyed annually along shoreline transects. The number of eggs and/or chicks present will be counted as an index of nest productivity. The species composition and relative abundance of oystercatcher prey

provided to chicks will be evaluated by sampling prey remains at oystercatcher nesting sites (Webster 1941, Andres 1998).

- Aerial surveys of sea otter abundance - Sea otter abundance will be estimated within each block in the summer of every second or third year using aerial survey methods described by Bodkin and Udevitz (1999). These methods have been used to conduct annual surveys to estimate the abundance of sea otters in Prince William Sound since 1993 (Bodkin et al. 2002), and on a less frequent basis elsewhere in the GOA. The metric obtained will be numbers of sea otters per block. Changes in the spatial distribution of sea otters will also be examined using boat based surveys in summer.

- Sampling of sea otter diets - The species composition and relative abundance of sea otter prey will be estimated annually using direct observation of sea otter feeding (Calkins 1978, Estes et al. 1981, Dean et. al 2002). These observations will provide an assessment of foraging efficiency (energy obtained per hour of feeding) as well as the composition of prey being consumed by sea otters. The latter will provide an indirect measure of the composition and relative abundance of representative intertidal and subtidal invertebrates that are difficult to sample directly.

- Coastline surveys for collection of sea otter carcasses - Specified beach segments will be walked annually for collection of sea otter skulls. The segments will be in areas where sea otter carcasses accumulate and will be based on preliminary surveys. A tooth will be extracted from each skull and sectioned to estimate the age of the sea otter (Bodkin et al. 1997). The data on the age distribution of dead sea otters will be used to evaluate changes in age-specific survival and to develop age-specific survival estimates based on an age-structured demographic model (Monson et al. 2000, Bodkin et al. 2002).

- Sampling of water/air temperature, salinity, and contaminants in mussels- Intertidal water/air temperature will be measured at each of the sheltered rocky intertidal sites. Temperature recording devices will be fixed at the 0.5 m tidal elevation in the intertidal zone and will record temperature every hour on a year round basis. Initially, salinity will be measured one to two sites in each intensive block. It is anticipated that more sites will be added if instruments prove reliable. The concentration of contaminants will be measured in mussels collected form rocky intertidal sites once every ten years.

In EPWS and NPWS, sampling will be limited to intertidal invertebrates and algae, eelgrass, mussels in mussel beds, infaunal invertebrates in gravel/mixed-sand gravel shores, water/air temperature, salinity, and contaminants in mussels. Sampling will be conducted as described above for intensive sampling areas but on a less frequent basis (every other year). Sampling within the LACL region will be limited to estimating abundance of infaunal invertebrates on gravel / mixed sand gravel beaches every 5 to 10 years. There is little rocky habitat within this region, and there are few sea otters or black oystercatchers.

A summary of the sampling design, with sampling sites and sampling frequency associated with each task, is given in Table 1.

Table 1. Summary of sampling design indicating sampling locations, number of sites sampled per location (if applicable) and frequency of sampling for each task.

Tasks	Sampling sites	Frequency
Kelp and eelgrass surveys	ShoreZone mapping over entire KATM, KEFJ, LACL, and PWS KATM, KEFJ, and WPWS -5 eelgrass beds per block EPWS and NPWS - 5 eelgrass beds per block	1 per 12 to 15 years 1 per year 1 per 2 years
Sheltered rocky intertidal invertebrates and algae	KATM, KEFJ, and WPWS – 5 sites per block EPWS and NPWS - 5 sites per block	1 per year 1 per 2 years
Limpet size distribution	KATM, KEFJ, and WPWS - 5 sites per block NPWS and EPWS - 5 sites per block	1 per year 1 per 2 years
Gravel / mixed sand gravel intertidal invertebrates	KATM, KEFJ, WPWS, NPWS, and EPWS - 5 sites per block LACL – 5 sites per block	1 per 2 years 1 per 5 to 10 years
Mussel size and density in mussel beds	KATM, KEFJ, and WPWS - 5 sites per block EPWS and NPWS - 5 sites per block	1 per year 1 per 2 years
Marine bird and mammal surveys - summer	KATM, KEFJ, and PWS[1]	1 per year
Marine bird and mammal surveys - winter	KATM and KEFJ	1 per 2 to 3 years
Black oystercatcher nest density and diet	KATM, KEFJ, WPWS - 5 sites per block	1 per year
Sea otter abundance (aerial surveys)	KATM, KEFJ, and WPWS	1 per 2 to 3 years
Sea otter diet	KATM, KEFJ, and WPWS	1 per year
Sea otter survival	KATM, KEFJ, and WPWS	1 per year

Tasks	Sampling sites	Frequency
Temperature	KATM, KEFJ, WPWS, EPWS, and NPWS – 5 sites per block	Year round
Salinity	KATM, KEFJ, WPWS, EPWS, and NPWS - 1 or more sites per block	Year round
Contaminants in mussels	KATM, KEFJ, WPWS, EPWS, and NPWS – 5 sites per block	1 per 5 to 10 years

[1]Bird surveys in PWS will be conducted by USFWS

Aerial digital video surveys of all shorelines (ShoreZone mapping) will be obtained approximately every 15 years using methods described by Harper and Morris (2004). The aerial video surveys are designed to characterize the geomorphology of shorelines within the region and to estimate large-scale spatial patterns of distribution and abundance for eelgrass, canopy forming kelps, and dominant benthic invertebrates and algae in the intertidal (e.g. brown algae and mussels). All of the shoreline within our study area has been surveyed in this manner over the past several years (Harper and Morris 2004). We also anticipate that satellite imagery describing sea–surface temperature and other physical chemical factors (e.g. surface chlorophyll) will be obtained and used as part of the nearshore program.

2.5 Design selection and alternatives considered

The GOA nearshore monitoring program described here grew from a lengthy developmental process involving extensive input and evaluation from the public, resource agencies, and the academic community. The initial program development for the National Park Service (Bennett et al. 2006) outlined the goals and objectives, identified vital signs, and outlined a process for future program development. In the same time frame, the *Exxon Valdez* Oil Spill Trustee Council sponsored a series of studies and workshops to develop a more geographically comprehensive program for monitoring changes in the nearshore over the region from Kodiak to Prince William Sound. The design presented here evolved from these earlier efforts that developed a conceptual design (Schoch et al. 2002), evaluated several design alternatives (Bodkin and Dean 2003), and provided a detailed nearshore monitoring and restoration plan (Dean and Bodkin 2006). The plan presented by Dean and Bodkin (2006) called for sampling within three blocks of approximately 10,000 km^2 within each of four regions: Kodiak archipelago, Alaska Peninsula, Kenai Peninsula, and Prince William Sound. A variety of metrics associated with the nearshore resources including sea otters, other marine mammals and birds, invertebrates, and algae were to be evaluated at various locations within each region. More frequent and comprehensive (in terms of metrics evaluated) sampling was to be conducted within one intensively sampled block per region. The sampling in intensive blocks was focused on detecting changes that may occur over larger spatial scales such as those associated with changes in climate. The plan also called for less frequent sampling at more widely dispersed sites within each of the 12 blocks that was aimed at detecting more localized changes such as those associated with point source discharges of contaminants.

A modified plan was initially implemented within KATM in 2006 and extended to KEFJ and LACL for the Southwest Alaska Network (SWAN) of the National Park Service as described in Dean and Bodkin (2011). The plan was based on the larger EVOS plan, but with several key differences. First, the SWAN nearshore vital signs program focused only on the three blocks that include KATM, KEFJ, and LACL. Second, only metrics that were identified as SWAN vital signs are to be measured. Finally, most of the emphasis was on intensive sampling within the KATM and KEFJ blocks aimed at evaluating large geographic-scale impacts. The plan was initiated on a limited basis in WPWS in 2007, and was fully implemented in WPWS, NPWS, and EPWS, starting in 2010 under funding from the Exxon Valdez Oil Spill Trustee Council (EVOS).

In the process of developing the SWAN and EVOS Nearshore monitoring programs we investigated most, if not all of the active nearshore monitoring programs along the west coast of North America (e.g. PISCO, MARINe, LIMPET, NAGISA, PSP, NOAA mussel watch). Where feasible we adopted and designed species and location specific procedures that would facilitate comparison of common metrics among existing and prior programs. For example, we employ point contact methods to estimate percent cover of intertidal invertebrates and algae that are similar to PISCO and MARINe methods and will facilitate comparison. We also estimate densities of large motile invertebrates (e.g. stars), that will be comparable to estimates from PISCO, MARINe, and other programs employing comparable techniques. In many instances species differences existed between existing nearshore monitoring programs in the contiguous US and Alaska requiring modification to available procedures. Where appropriate we adopted widely used and published methods to estimate marine bird densities (Irons et al. 2000) black oystercatcher abundance and diet (Andres 1998, Webster 1941) and sea otter abundance (Bodkin and Udevitz 1999), diet (Calkins 1978, Estes et al. 1981), and survival (Monson et al. 2000). There are however fundamental differences between some of the objectives of the GOA monitoring program described here and other nearshore monitoring programs. These include a GOA program objective to allow statistical inference to the entire region and therefore required a random component to site selection, rather than focusing on specific selected sites. Compared to other existing programs, GOA sites are remotely located and access is difficult and costly. As a result, our sampling frequency is generally equal to or greater than one year (with a few exceptions such as water quality), with limited ability to detect within year variation or trends. Furthermore, there are additional location-specific factors (e.g. a large tidal prism and high degree of disturbance due to ice and storms) that led us to different sampling designs than employed by other programs. Perhaps most importantly, the GOA program attempts to encompass all major elements of the nearshore trophic web: kelps and seagrasses as primary produces, benthic invertebrates as primary consumers, and the birds and mammals as apex predators (i.e. black oystercatchers, sea ducks and the sea otter). We know of no other nearshore monitoring program that incorporates this breadth of trophic interaction that will allow both “bottom-up” and “top-down” perspectives on causes of change in the nearshore marine ecosystem. This approach required adapting existing procedures where available and appropriate, and developing new ones as needed.

2.6 Selection of the sampling universe

As indicated above, sampling will be largely restricted to the KATM, KEFJ, PWS, and LACL coastlines, and will be concentrated in three blocks (KATM, KEFJ, and WPWS) (Figure 2). There are a wide variety of habitats within these regions. These are classified into ten

predominant geomorphologic types (Ford et al. 1996): fine-medium sand beaches, coarse sand beaches, mixed sand-gravel beaches, gravel beaches, exposed rocky shores, exposed wave-cut platforms, sheltered rocky shore, exposed tidal flat, sheltered tidal flat, marsh. For the purpose of the GOA monitoring program, we intend to restrict sampling of intertidal invertebrates and algae to sheltered-rocky shores and to gravel and mixed sand-gravel beaches. We selected these habitats because they represent over half (about 58%) of the shorelines within the region (Ford et al 1996); are biologically diverse; harbor both hard bottom (epibenthic) and soft bottom (infaunal) organisms; are tractable to sample, and have a wealth of historical data relative to other habitats. Thus, they provide excellent indicators of change. Of the other habitats, exposed rocky shores or exposed wave-cut platforms are the most represented. However, these are generally less accessible for sampling. The habitats that we do not intend to sample are clearly of ecological importance (e.g. tidal flats as critical habitats for birds), but focusing sampling efforts on a few representative habitats should produce a monitoring plan that is more sensitive and more likely to detect change.

Also, with the exception of sampling of eelgrass and indirect examination of subtidal invertebrates via sampling of sea otter diets, we have largely excluded sampling in the subtidal. While the subtidal is an important part of the system, cost considerations prohibited us from examining this habitat more closely.

2.7 Selection of the size and number of sampling units

The size and number of sampling units to be included for evaluation of each metric within a given sampling period are given in Table 2 and described in detail in specific Standard Operating Procedures. A sampling unit is defined as the smallest unit for which a particular metric is measured and expressed. For example, the number of sea stars will be counted within a 200 m^2 area and expressed as number per 100 m^2. For each metric, the size of the sampling unit and number of sampling units varies dependent largely on the behavior of the species associated with the vital sign being examined. In estimating abundance of larger, more motile species that have large and variable home ranges that can cover large portions of a block (e.g. sea otters), sampling will be conducted along relatively large random or systematically placed transects of several hundred meters or more that cover the entire block. For species that do not move about or have limited home ranges (e.g. many invertebrates) sampling will be conducted at discrete, permanently established sites within each block. A site is here defined as an approximately 50 to 100-m section of coastline and the water directly adjacent to it. For these smaller, less motile species, sampling will be conducted within quadrats or transects ranging in size from approximately 0.10 to 200 m^2 at each site. The number of transects or quadrats sampled per site will range from one (for larger invertebrates like sea stars) to 24 (divided equally between two vertical strata) for smaller invertebrates and algae. The intent is to sample a number of units that will provide sufficient statistical power to detect changes ranging from 20% to 80% (dependent on the metric, see section 2.9 below). These criteria were selected as ones that were both biologically meaningful and achievable given budgetary and logistical constraints.

Table 2. Overview of the sampling designs used in the evaluation of each vital sign.

Vital Sign	Primary metric	Sampling unit	Size of sampling unit	Number of sampling units per stratum & sampling period	Selection process for sample locations	Strata	Smallest spatial scale at which trends will be examined
Kelp and seagrass	Proportion of shoreline with canopy forming kelps and eelgrass	Block	Entire block shoreline	None	Not applicable	Blocks	Block
	Eelgrass bed area	Transect	Variable, ~ 200 m long	5 sites per block	Closest to rocky intertidal site	Blocks	Site
Intertidal invertebrates and algae – rocky shores	Sea stars abundance	Transect	200 m^2	5	GRTS	Blocks	Site
	Intermediate invertebrate (*Nucella* spp. and *Katharina tunicata*) abundance	Quadrat	2.0 m^2	12 quadrats per transect,10 transects per block (5 at each of 2 tidal elevations)	GRTS for transect, systematic with random start for quadrats within transect	Mid and lower intertidal transects, blocks	Tidal level of transect at a site (50 m long)
Intertidal invertebrates and algae – rocky shores	Sessile invertebrate and algae abundance	Quadrat	0.25 m^2	12 quadrats per transect, 10 transects per block (5 at each of 2 tidal elevations)	GRTS for transect, systematic with random start for quadrats within transect	Mid and lower intertidal transects, blocks	Tidal level of transect at a site (50 m long)
	Limpet density and size distribution	Quadrat	Variable based on density of limpets	120 per site, pooled from 6 quadrats	GRTS for site, systematic with random start for collection sites	Blocks	Site
Intertidal invertebrates – gravel/sand	Intertidal invertebrate abundance	Quadrat	0.25 m^2	12 quadrats per transect, 5 transects per block	Closest to rocky intertidal site, systematic with random start for quadrats [1]	Blocks	Site

Table 2 (continued). Overview of the sampling designs used in the evaluation of each vital sign.

Vital Sign	Primary metric	Sampling unit	Size of sampling unit	Number of sampling units per stratum & sampling period	Selection process for sample locations	Strata	Smallest spatial scale at which trends will be examined
	Clam size, by species	Quadrat	0.25 m^2	Variable, dependent on the number of clams per site	Closest to rocky intertidal site, systematic with random start for quadrats. [1]	Blocks	Site
Mussels in mussel beds	Density	Quadrat	Variable based on density ($\leq 1 m^2$)	10 quadrats per site	Bed closest to rocky intertidal site, systematic with random start for quadrats.	Blocks	Site
	Size distribution	Quadrat	Variable based on density ($\leq 1 m^2$)	10 quadrats per site	Bed closest to rocky intertidal site, systematic with random start for quadrats.	Blocks	Site
Marine birds and mammals	Density	Transect	Variable, 2.5 - 5 km long x 200-m wide	30-40	Systematic with random start	Winter/summer, Blocks	Block
Black oystercatchers	Nest density	Transect	Variable, ~ 20-km long	5-6	Centered on GRTS site	Blocks	Block
	Productivity – eggs and chicks per nest site	Nest site	Variable	Variable, dependent on nest density	Selected, dependent on nests sites	Blocks	Block
	Diet – Relative abundance of prey	Nest site	Variable, ~ 100 m^2	Variable, dependent on nest density	Selected, dependent on nests sites	Blocks	Block
Sea otter	Abundance (aerial	Transect	Variable, ~ 0.4	Variable, ~200	Systematic with	Blocks	Block

Table 2 (continued). Overview of the sampling designs used in the evaluation of each vital sign.

Vital Sign	Primary metric	Sampling unit	Size of sampling unit	Number of sampling units per stratum & sampling period	Selection process for sample locations	Strata	Smallest spatial scale at which trends will be examined
	survey)		to > 10 km		random start		
Sea otter	Diet – Relative abundance of prey, energy obtained per hour	Feeding bout	Not applicable	Variable, ~50	Selected, dependent on where feeding otters are observed	Blocks	Block
	Age at death	Individual carcass	Not applicable	Variable, ~ 30	Selected, dependent on where dead otters are found	Blocks	Block
Water Quality - Contaminants, temperature, and salinity	Concentration of contaminants in mussels	Site	Not applicable	60 per site, pooled from 12 quadrats per site	GRTS for site, systematic with random start for quadrats used for collection within site	Blocks	Site
	Temperature	Recorded every 30 minutes year round	Not applicable	1 recorder per site, 48 observations per day	GRTS for site	Block	Site
	Salinity	Recorded every 30 minutes year round	Not applicable	1 recorder per site, 48 observations per day	One or more GRTS sites	Block	Site

[1]At LACL, sites were selected using the GRTS process since rocky sites were not sampled.

2.8 Locations for sampling

For ShoreZone surveys (Harper and Morris 2004) of kelp canopy cover and eelgrass cover, the entire shorelines of each block are censused. Eelgrass beds used to estimate change in abundance annually were selected as the eelgrass bed closest to sites used for sampling of intertidal invertebrates (see below).

Discrete sampling sites used to sample intertidal invertebrates and algae on sheltered rocky shorelines were selected using a generalized random tessellation stratified (GRTS) sampling scheme (Stevens and Olsen, 2004). This design provides a random yet spatially balanced distribution of sites within block. A GRTS design also allows for expansion or contraction of the number of sites to be sampled over time by pre-selecting a large number of sites that are ordered with respect to priority. Thus, sampling sites can be added or deleted without compromising the statistical or spatial integrity of the design.

Rocky intertidal sampling sites were selected using S-Draw, a windows-based GRTS sampling software program developed by McDonald (2005) (the users guide (GRTS for the Average Joe: A GRTS Sampler for Windows) for downloading the program go to: http://www.west-inc.com/computer.php). First, shorelines representing sheltered rocky or gravel/mixed sand gravel geomorphologic types were identified using Geographic Information System (GIS) software. The shoreline classifications used were from Environmentally Sensitive Index (ESI) maps produced for each region (RPI, 1983a, 1983b, 1985, 1986). The shorelines for a given habitat type were then divided into 1-m long segments and a data file was produced which contained all segments within each block and their geographic coordinates. The S-Draw software was then used to produce an ordered list of 100 potential sampling sites within each block. A "pixelsize" of 1 m was used in the selection process to maintain a relatively widely dispersed array of sampling sites. In cases where two sites were in close proximity to one another (two or more within an embayment of a size roughly equivalent to 1 km^2) we eliminated the second site within that bay and chose the next site in the ordered list for sampling. This was done to maintain a relatively even spatial distribution. The actual sites sampled were not specified until an "on site" evaluation of habitat type was made. It was well known that there were misclassifications in the ESI index maps (Sundberg et al 1996) and in some cases selected sites were not of the appropriate habitat or were inaccessible. In these cases sites were either moved to appropriate habitat up to two hundred meters from the selected location, or if there was no appropriate habitat within two hundred meters, alternative sites within the same bay were selected from the GRTS list of sites. The location of sampling sites is given in Figures 3a through 3d.

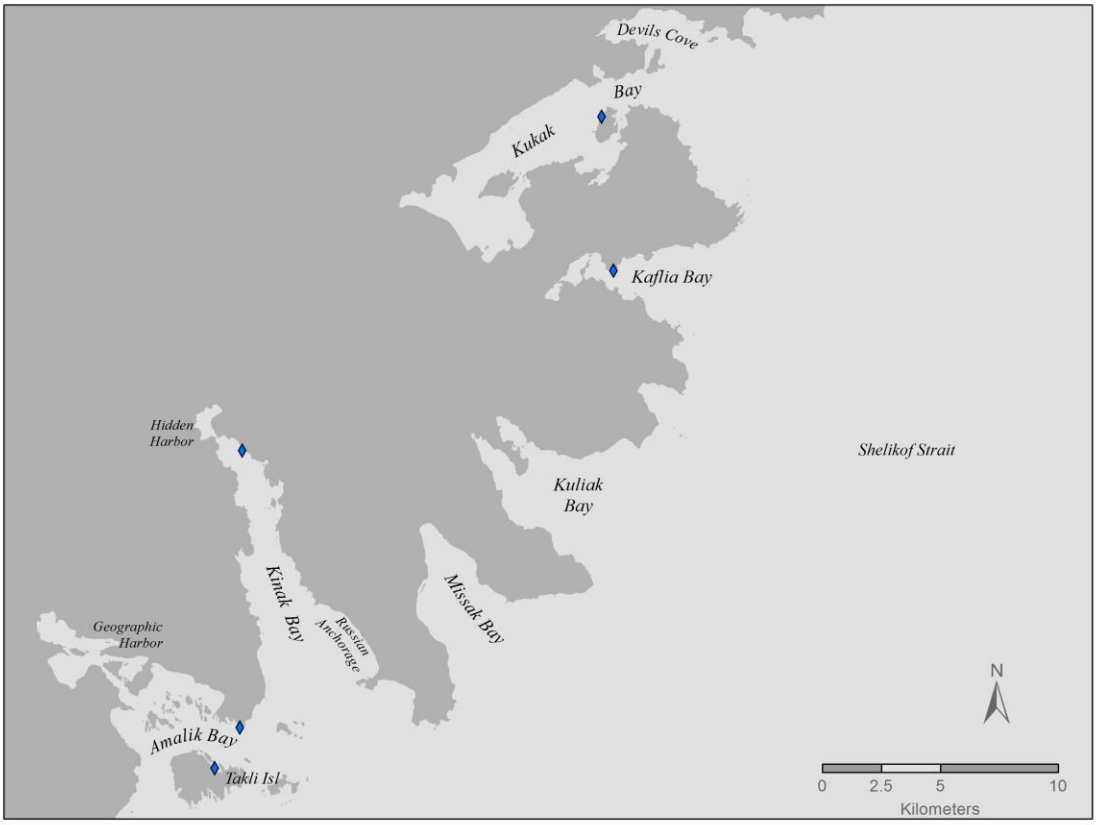


Figure 3a. Locations of intertidal invertebrate and algae sampling sites in Katmai National Park and Preserve.

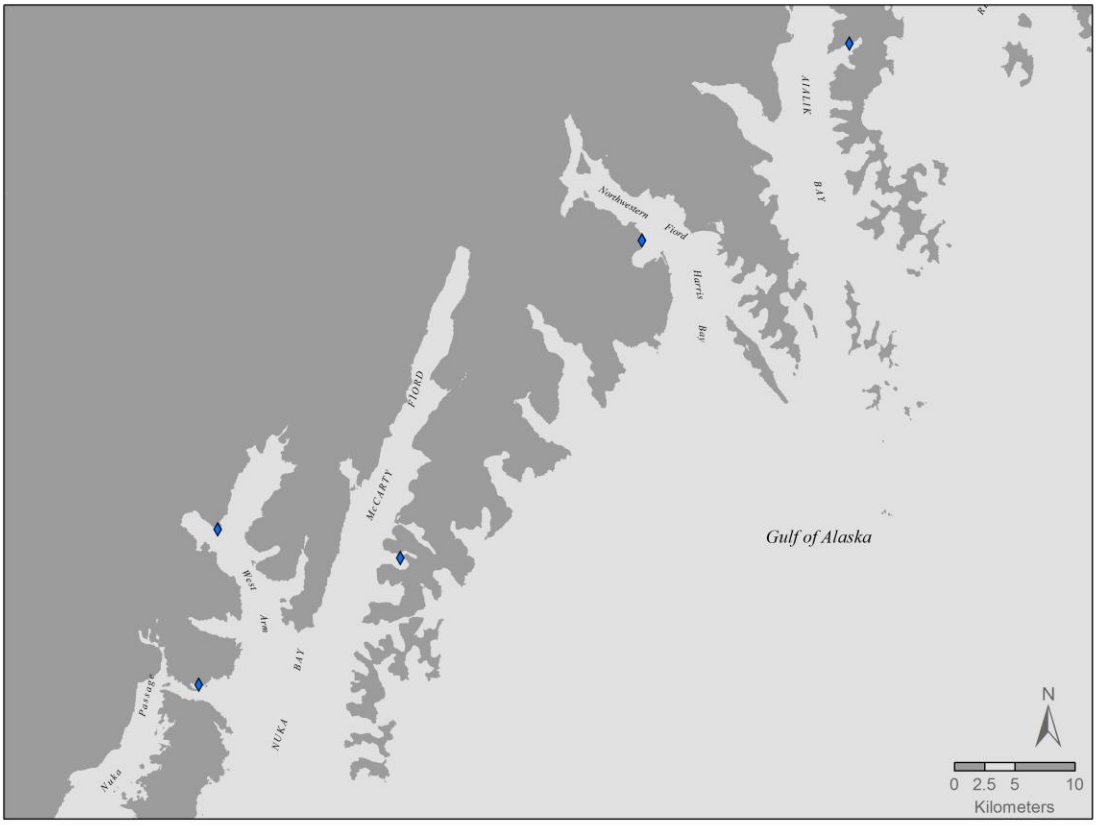


Figure 3b. Locations of intertidal invertebrate and algae sampling sites in Kenai Fjords National Park.

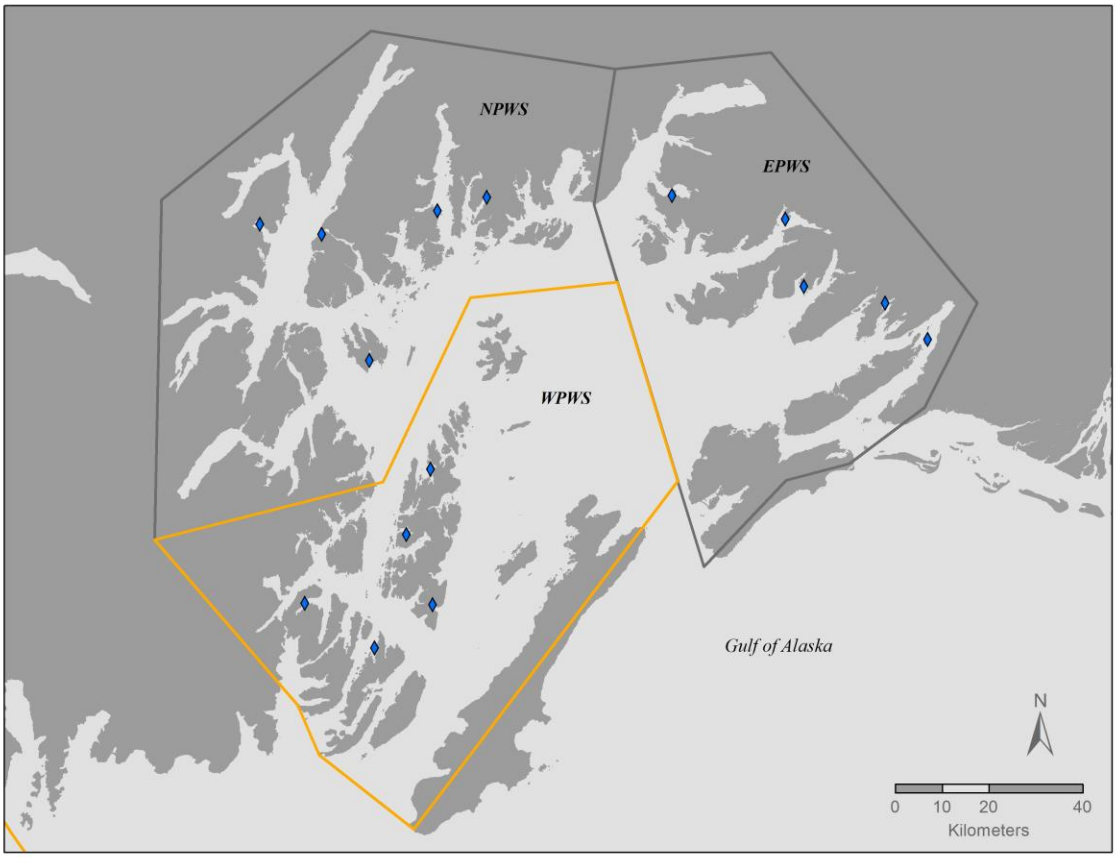


Figure 3c. Locations of intertidal invertebrate and algae sampling sites in Prince William Sound.

Figure 3d. Locations of intertidal invertebrate sampling sites in Lake Clark National Park and Preserve.

Transects for sampling clams and mussels were selected based on proximity to the GRTS rocky intertidal sampling sites. Clam and mussel sites were identified by appropriate habitats (unconsolidated sediments for clam and consolidated rocky for mussels) and the presence of clams and mussels. Transects used for sampling of marine birds and mammals were selected using a systematic selection with a random start point along the entire coastlines of each sampling block.

Transects used for estimating black oystercatcher density were centered on sites used to sample intertidal invertebrates on rocky shores. Nest productivity is to be estimated at each nest site located within these transects and prey composition is measured at any nest site where prey are observed.

Sea otter abundance (aerial surveys) is to be estimated using counts of sea otters along transects within defined sea otter habitat throughout each block that were selected systematically with a random start point. Sea otter foraging observations are to be made at sites wherever sea otters are seen foraging within a 5 km radius of invertebrate sampling sites. This radius roughly corresponds to the annual home range for sea otters. Sampling will be focused as close to the invertebrate sites as possible but will be dependent on the presence of sea otters required to obtain the minimum sample of 50 forage bouts per year. Carcasses of sea otter skulls are

collected from wherever skulls are found within each block, but will focus on specific locations where large numbers of sea otter carcasses have been found in the past.

Black oystercatchers are to be sampled on transects centered on the selected rocky intertidal sites. Sampling of intertidal invertebrates on sand/gravel beaches, mussels in mussel beds, and eelgrass will be sampled at sites of appropriate habitat type that are closest to the randomly selected rocky intertidal sites. We chose to focus samplings for these metrics around the randomly selected rocky sites rather than an independent set of randomly selected sites because of the logistical constraints (a reduction in travel time between sites) and because of a desire to geographically link sites for sampling of all metrics as closely as possible while still maintaining a random component. Water quality metrics (contaminants in mussels, temperature, and salinity) are to be measured at sites identified for sampling of intertidal invertebrates on rocky shores.

Temperature and salinity are to be sampled at the rocky intertidal sites and contaminants will be measured in mussels collected from either rocky intertidal or nearby mussel sites.

In addition to sites selected using the GRTS design, sampling may also be conducted at several sites that are selected based on their proximity to locations of probable future impact from shoreline development, sites with historical data of interest, or sites of special interest to local citizens. These sites will be selected based on their proximity to specific resources of interest (e.g. sites particularly important as bird nesting and feeding habitats), based on their proximity to sources of potential anthropogenic disturbance (e.g. near boat harbors or population centers), or sites that have been sampled in the past and can be utilized to capture historical data and extend historical data sets. A list of some potential selected sites is given in Table 3.

Table 3. Potential selected sampling sites.

Selected sites	Block	Reason for Inclusion
Ninagiak Island	KATM	Bird nesting site and sea otter foraging site.
Illiamna Bay	AP	Port site (mining logging)
Sukoi Bay	AP	Close to shipping lane

Data obtained from randomly selected sites that were chosen using the spatially balanced GRTS procedure can be used to make inference to the specific habitat and block with respect to the parameters measured at these sites. Data from selected sites cannot be used in this manner, but will likely be beneficial in detecting localized change. Sampling sites that are anticipated to be of high risk to anthropogenic disturbance or have historical data should enhance our ability to detect change and likely will provide early indicators of change that might trigger further studies.

2.9 Sampling frequency

The frequency of sampling will vary with metric (Table 2). In general, biological metrics will not be sampled at a frequency of more than once per year. Some physical measurements such as temperature will be measured more frequently in order to capture episodic events that may be determinants of changes in biological systems. Yet other metrics that are not as variable over time (e.g. shoreline geomorphology) will be measured less frequently than once per year, perhaps with additional sampling triggered by specific events such as an earthquake. As part of

the monitoring program, we also advocate hypothesis-driven process studies and more focused studies of events of particular importance (e.g. a large die off of a particular organism). We anticipate that funds for such studies may need to be obtained from agencies other than NPS or EVOS. We also anticipate that such studies will not be initiated until after the first 5 years or more of monitoring has been completed. This will allow identification of particularly compelling trends and development of hypotheses regarding causes for change, and will allow funding to be built to a sufficient level to support meaningful studies.

2.10 Power and the levels of detectable change

As indicated in Section 2.1 above, the objective of the sampling program is to assess how various metrics change over time and how those changes vary with respect to location and one another. The levels of change that we can expect to detect and the time and spatial scales over which they are to be detected vary with metric. The spatial scales over which trends will be examined range from a block (for large motile species like sea otters) to a site (for smaller, less motile species like mussels) (Table 2). In general, the goal for most biological metrics (e.g. abundance of sea otters, harlequin ducks, or dominant intertidal invertebrates like mussels) is to detect levels of change that are deemed to be of ecological importance (see section 4.2.6 for a discussion of determination of levels of change that are deemed ecologically important for each metric). In general, we intend to detect changes ranging from 20 to 80% (depending on the metric) at a given location (e.g. KATM or PWS). The ability to detect change can be expressed as power, the probability that a given level of change could be detected given the sampling design employed. Power analyses can also be used as a planning tool, to determine the sampling effort required to detect a given level of change with a prescribed power. As indicated in Section 5.0 below, it is anticipated that one of the primary methods used to detect change will conceptually take the form of mixed-model analyses (McCullouch et al. 2008) that examine, at a minimum, time (year) and location as the primary factors. The location factor consists of blocks (and in some cases sites nested within each block) with replicate samples within the block. Various mixed models would examine the extent of variation for a particular metric that could be attributed to location (e.g. block or sites within a block), time, and the interaction between these factors.

The power of a given design to detect a given level of change depends on the sample mean, sample size (n) and variances for a given metric. Variances of importance in determining power are among locations (to detect a time effect), among times (to detect a location effect), and in the relation between locations over time (to detect an interaction). Unfortunately, for most of the metrics of interest in the GOA program, data have not been collected over multiple years within each region. Therefore, variances needed to conduct the appropriate power analyses (those required to determine sample sizes required to detect reasonable levels of change for time, location, or time by location effects) are currently unavailable for most metrics.

It may be possible to make a reasonable approximation of power for each metric by estimating ranges of means and variances, based in part on data from elsewhere, and then performing simulations to estimate a range in levels of detectable change that might be expected. However, these have not been performed to date because such an effort is outside of the current scope of work. This is especially the case given the number of metrics that would need to be examined. Instead, it is suggested that the appropriate power analyses be performed as data are gathered (after five years, and at five year intervals thereafter) to determine the power to detect changes

and to modify sampling designs as required. These changes might suggest reducing sampling effort to achieve greater efficiency or increasing sampling effort in order to achieve reasonable power to detect change.

It is reasonable to assume that the power to detect a given level of change will increase over time as the number of surveys increases. This again stresses the need for conducting periodic power analyses to suggest modifications to sampling designs over time and to ensure efficiency in the sampling.

The power to detect a given level of change also depends on biases associated with a particular sampling regime (Tyre et al, 2003, Earnst et al. 2005). For example, these might include biases introduced by using different observers in aerial surveys of sea otters or birds or those associated with the inability to detect all individuals present. When possible, we will account for these biases in our analyses. For example, we will use COMDYN software (Hines et al. 1999) or similar procedures to account for potential biases resulting from differences in detection probabilities where appropriate (Nichols et al. 1998, see section 4.2 below). However, for some of the metrics we will examine, we have no easy means of accounting for biases (including those related to detection probabilities) and no corrections will be made. Specific methods used to account of undetected species or individuals, or the rationale for why this was not done are given in individual standard operating procedures.

3 Field Methods

Field methods used in the GOA nearshore monitoring program are outlined in specific standard operating procedures. In most instances, we rely on specific methods that have been field tested and used previously to successfully provide data for each metric.

It is a certainty that there will be technological advances over the coming years that will make for more efficient or more precise estimation of given metrics. Thus, it is anticipated that methods described in standard operating procedures will need to be modified over time. It is recommended that when new techniques are adopted, that there be a period when both new and existing protocols are conducted simultaneously. This will ensure that any protocol specific biases will be revealed and that the integrity of long-term data sets will be maintained.

4 Data Management

4.1 Purpose

Effective archival and communication of information can only be achieved through the use of a data management plan that provides a means of documenting and storing data and transferring information among scientists and the public. A comprehensive data management plan is currently under development with the assistance of NPS, USGS and EVOS staffs. It is anticipated that the plan will be developed under guidelines set forth for the larger NPS vital signs program (Mortenson 2006). The following outlines elements to be included in the data management plan and provides steps for implementation of the plan. The specific goals of the data management plan are:

Ensure accuracy and maintain integrity of the data as gathered by investigators.

1. Provide for an efficient exchange of information among investigators of the larger Gulf Watch Alaska (GWA) and SWAN monitoring program investigators, and between these investigators and NPS, USGS and EVOS staffs.
2. Provide a mechanism by which data and reports can be archived.
3. Provide a framework by which analyses presented in reports can be traced to methods used to collect data and to the underlying data obtained during the initial data collection.
4. Provide a mechanism by which managers and the public can gain access to the information obtained.

There are several keys to the successful implementation of such a plan. First, the plan must be a written document. Second, there must be a management framework that clearly defines responsibilities for the plan's implementation. Third, all scientific investigators and their staffs must be trained to ensure that all data are obtained and transferred as specified by the plan.

Here we provide a framework by which a more complete plan can be produced and implemented as the project progresses. The complete plan will include the standard operating procedures, data sheets to be used in data collection, a complete description of all metrics included in the data,

and an outline of the database structure. Standard operating procedures will include field data sheets and examples of raw data files. A final database structure and design is yet to be completed. Also, the details of procedures and mechanisms for information storage and transfer have not been fully developed.

The data management plan is intended to be a "living" document that will change as procedures are modified. While we have attempted to anticipate all of the possible permutations, there are almost always changes required. One seldom is able to anticipate all of the potential problems associated with field studies, and the subtleties of the data being gathered.

4.2 Data managers and information flow

The data manager for the program will be a staff member who is responsible for the overall design and maintenance of NPS vital signs and Gulf Watch Alaska databases. After collection and timely review, all data files will be submitted by investigators to the data manager for inclusion in the vital signs (NPS), USGS and Gulf Watch Alaska databases. It will also be the responsibility of the data manager to ensure that hardware and software are provided for the transfer and archiving of information, and for the development of transfer protocols. It will also be the responsibility of the data manager to maintain the central database, to maintain an updated index or metadata database, and provide a means of disseminating information in the database to the other investigators, and the public.

It will be the responsibility of each investigator to ensure that the data presented to the data manager is in an appropriate, pre-determined format, and is an accurate representation of the data as collected. The investigators will designate specific persons on her/his staff who have authority to submit data or request data from the data manager.

4.3 Written documentation

Written documentation will primarily be provided in the form of the monitoring protocol provided here, standard operating procedures, and reports. All procedures, including field operations, laboratory analyses, data management, data distribution, report production, and the archiving of files will be provided in SOPs. All SOPs will contain the author's name, the draft number, the effective date of the SOP, a brief statement of its purpose, and the specific training required to use the SOP. The format will follow that outlined by Oakley et al. (2003). SOPs are to be reviewed every year and updated as required. New SOPs are to be written as new procedures are adopted.

4.4 Training

Before an SOP can be used, all of those persons who will utilize the procedure must be trained. The level of training will be dependent on the procedure and will be at the discretion of the principal investigator in charge of that particular task. At a minimum, all users will be required to have read the SOP, and to have demonstrated their understanding of it. More elaborate training procedures involving hands on training and proficiency testing may be required in some instances and will be defined in individual SOPs.

4.5 File structure and databases

An outline for a suggested file structure for the nearshore data management program is given below. Files are to be organized under major file-folder headings and subfolder headings including the following:

Administrative

Protocols

Bibliography_Documents

Graphics

Photos: not site ID photos

Data_Sampling (data used for site/transect selection process

Data_Collection: Data is organized by the data collection method and year. Once the data has been deemed clean, a copy is made for the 540_Data_QAQC directory.

\SOP1_Coastline_Surveys (sea otter carcasses)

\SOP2_Sea_Otter_Forage

\SOP3_Mar_Bird_Mammal_Surveys

\SOP4_Inverts_Rocky_Shores

\SOP5_Sea_Otter_Aerial_Surveys

\SOP6_Inverts_Gravel_Sand_Beaches

\SOP7_Black_Oystercatcher

\SOP8_Mussels_Beds

Data_Analysis

Data_QAQC: validated & verified seasonal data. (Staging area prior to import into master datasets).

Data_Master: master datasets. Lookup tables as well as field data.

Data_Design: Staging area for developing database applications.

Samples_Collected: Sample tracking database for collection, storage, analysis….

Reports_and_Presentations:

\Field trip

\Annual

\Final

\Presentations

\Posters

Field or laboratory data that are initially recorded in 'hard copy' form and later transferred to electronic form should be maintained by individual investigators. Raw data files are access, excel or similar files that may be entered and edited hard copy field or laboratory data sheets. Analysis files are those used to manipulate or provide summaries of statistical analyses of the raw data. Metadata files describe the contents of each raw or analysis file. With the exception of hard copy raw data files, all files are to be in electronic format and are to be maintained by the data manager.

Analysis flow diagrams describe procedures used to obtain a particular result (figure, table, or descriptive result) given in a report. Any presentation of data in a report will be accompanied by an appendix that lists an analysis flow diagram that describes the steps taken in producing the table or figure. This flow chart will allow one to trace the summary presentation back to field or laboratory data sheets and allow for efficient data audits. The diagram will indicate all the names of any intermediate databases used in the production of the final table or figure, as well as the names of all analysis files.

Sampling locations are to be described using latitude and longitude (degrees, decimal degrees) and the NAD 83 datum.

4.6 Acronyms and abbreviations

The database management system will use the following standardized abbreviations and acronyms:

Vital Signs:

- KELP = Kelp & Eelgrass
- MAII = Marine Algae and Intertidal Invertebrates
- MBM = Marine Bird & Mammals (live)
- BLOY = Black Oystercatcher
- SEOT = Sea Otter
- MADE = Marine Debris
- MACA = Marine Carcasses
- MAWQ = Marine Water Quality

Location Codes:

- KATM = Katmai
- ANIA = Aniakchak
- KEFJ = Kenai Fjords
- LACL = Lake Clark
- WPWS = Western Prince William Sound

- EPWS = Eastern Prince William Sound
- NPWS = Northern Prince William Sound
- SWAN = Southwest AK Network
- GWA = Gulf Watch Alaska

Status Codes

- Raw = raw
- Draft = draft
- QAQC = ready for import into a final database, verified, validated
- Final = final product (image, illustration, analysis, etc)
- InProg = a step or steps up from Raw, but QAQC not completed yet (data files), basically a 'work in progress' for other file types.

Files and directories are to be named according to the following naming standards. File names will use date for versioning as YYYYMMDD. Names are to be kept as short as possible, using abbreviations or acronyms as indicated above where applicable. Spaces and unusual characters (e.g. % or &), or reserved words (e.g. DATE) are to be avoided in both folder and file names. Conventions for commonly used file types are as follows:

Reports

AuthorLastNameFirst Initial_YEAR_CODE_Title_YYYYMMDD.doc
(e.g. BodkinJ_2004_AK_Forage_Depths_SeaOtters_200401.doc)

SOP Files

SOPNum_VitalSign_Method_Title_YYYYMMDD.doc
(e.g. SOP01_SeaOtter_Forage_DataCollection_200603.doc)

Field Data Sheets

SOPNum_VitalSign_Num_Title_YYYYMMDD.doc
(e.g. SOP01_SeaOtter_Forage1_FieldDataSheet_200603.doc)

Spreadsheets, Analysis Files (SAS Programs, Sigmastat, etc), GIS Files, etc:

SOPNum_VitalSign_Num_Title_Status_YYYYMMDD.xxx
(e.g. SOP01_SeaOtter_Forage1_Block10_ForageData_RAW_20061025.doc)

Images (non-data):

Code_YYYY_Description_###.jpg
(e.g. KATM_2006_BrownBear_and_Cub_001.jpg)

4.8 Metadata

Metadata will be created per Executive Order 12906 (1994) requiring the creation of metadata for all data sets as well as allowing metadata to be available to the public. Metadata structure will follow the Biological Data Profile of the Content for Digital Geospatial Metadata or the Metadata Profile for Shoreline Data for FDGC CSDGM standards, depending on data type. FDGC CSDGM standards as well as the above mentioned profiles may be found at the following website: http://www.fgdc.gov/metadata/geospatial-metadata-standards. Metadata databases will be developed to facilitate access to information in raw files, intermediate databases, and analysis files. Separate metadata databases will be developed for geospatial data (GIS coverages) and for non-geospatial data. These will contain at least the minimum requirements described in the FDGC CSDGM standards which are: Identification information (contains data entry fields that ask for citations, spatial domain, keywords, access constraints and analytical tool use) and Metadata Reference Information (contains data entry fields that ask for metadata date, metadata contact, metadata standard name and metadata version). Geospatial and non-geospatial metadata will be created using ArcCatalog (ESRI), Metavist, or similar software. Creation of metadata will allow for efficient searching of data not only for the proposed project participants, but for ease of data distribution and collaboration across disciplines and reduce the possibility of duplication. Investigators will be responsible for updating metadata information sheets associated with each file and forwarding these to the data manager.

It is anticipated that the data will be housed and served in a web accessible form. A website for this purpose has yet to be developed, but it is anticipated that this website will serve the following functions.

1. Provide general project information to other scientists and the public. This would include contact numbers, project descriptions, biographies of key personnel, a schedule of events, descriptions of new and exciting findings, and access to reports.
2. Provide a web-based server that will house all of the nearshore data, documents, etc. and will provide a means of accessing the data by project personnel as well as non-project persons. It is anticipated that some files (e.g. raw data files or certain correspondence files) will be accessible only to investigators. Others will be publicly available.
3. Provide a means of accessing the data in a linked and searchable fashion. For example, provide a means of obtaining information relating to a specific location such as: data on mussel abundance at a particular site, maps of the site based on GIS coverages, and shoreline aerial video of the site. Other important aspects include providing linkages between a particular data set with an SOP under which the data were collected or linking numerical data with images.
4. Create and maintain records of edits to data files and archive older versions of files.
5. Create a “community forum” bulletin board where members of coastal communities can record observations of significance. These might include observations regarding particular events such as when and where the first herring spawn occurred in a given year, unusual weather, or unusual occurrences of dead animals in the nearshore.

5 Analysis of Monitoring Data

5.1 General guidelines

It is important in developing a monitoring plan to determine how the data generated might be analyzed to detect change and how results of these analyses might be interpreted. Specific types of analyses to be performed will vary with metric and are detailed in specific standard operating procedures. The following provides a generic discussion of types of analyses to be used. In large part, the discussion focuses on changes (primarily declines) in the density or other important demographic measures (e.g. survival or size structure) of species that are currently relatively abundant. However, our sampling designs (especially for intertidal algae, intertidal invertebrates, and marine birds) are inclusive of both rare and abundant species. Therefore, we should also be able to detect increases in rarer species that may occur over time.

5.2 Selection of primary metrics

The number of potential metrics to be used in the evaluation of vital signs is large and not all metrics provide the same degree of information with respect to insights as to trends in vital sign resources. For example, over 70 taxa of invertebrates and algae were identified in 2006 and 2007 surveys of sheltered rocky intertidal sites at KATM. However, the majority of these are relatively rare and indices of abundance for many are highly variable over time. As a result, indices of abundance for most of the taxa encountered are not suitable as vital sign indicators. Therefore, we have chosen to limit the number of primary metrics used to evaluate various vital sign resources on a routine basis. In general, we selected metrics that were deemed to be of ecological importance and that could provide reasonable power to detect trends over time. A preliminary list of these metrics is given in Table 4 and the rationale for their selection is given below. Other “secondary” metrics will be maintained in the databases and used on an ad hoc basis to evaluate change. For example, the sudden dominance by an intertidal invertebrate species in surveys of rocky shorelines or in the diet of sea otters might be deemed important and evaluated as an indicator of change in the future.

Table 4. Primary vital sign metrics to be analyzed to detect changes in the nearshore system on a routine basis. Also given are preliminary guidelines for degree of change deemed ecologically important (as discussed below).

Vital sign	**Metric**	**Degree of change deemed ecologically important**
Kelps and seagrass	Km of coastline with canopy forming kelp (based on ShoreZone surveys)	50% reduction
	Km of coastline with eelgrass (based on ShoreZone surveys)	25% reduction
	Area with eelgrass present	25% reduction
Intertidal communities-rocky	Number of algal and invertebrate species	30% change
	Percent cover bare substrate	80% change
	Percent cover barnacles	80% change
	Percent cover *Fucus distichus*	80% change
	Percent cover *Alaria* sp.	80% change
	Percent cover *Neorhodomela/Odonthalia* spp.	80% change
	Density of *Nucella* spp.	80% change
	Density of *Katharina tunicata*	80% change
	Density of sea stars	80% change
	Density of *Evasterias troschelii*	80% change
	Size distribution of *Lottia persona*	50% change
Intertidal community- soft	Density of *(Leukoma staminea)*	80% change
	Density of *Saxidomus gigantea*	80% change
	Density of *Macoma* spp.	80% change
	Size distribution of *(Leukoma staminea)*	50% change in mean size
	Size distribution of *Saxidomus gigantea.*	50% change in mean size
	Size distribution of *Macoma* spp.	50% change in mean size
Intertidal Community – mussel beds	Density of *Mytilus trossulus* >20 mm	80% change
	Total biomass of *Mytilus trossulus* >20 mm mussels	50% change
Marine birds	Number of bird species - summer (including rates of local extinction, colonization, and turnover)	50% reduction

Table 4 (continued). Primary vital sign metrics to be analyzed to detect changes in the nearshore system on a routine basis. Also given are preliminary guidelines for degree of change deemed ecologically important (as discussed below).

Vital sign	Metric	Degree of change deemed ecologically important
	Number of bird species – winter (including rates of local extinction, colonization, and turnover)	50% reduction
	Abundance of harlequin ducks in winter	50% reduction
	Abundance of Barrow's goldeneye in winter	50% reduction
	Abundance of black-legged kittiwakes in summer	50% reduction
	Abundance of glaucous-winged gulls in summer	50% reduction
	Abundance of pigeon guillemots in summer	50% reduction
	Abundance of cormorants in summer	50% reduction
	Abundance of scoters in summer	50% reduction
	Abundance of harlequin ducks in summer	50% reduction
Black oyster catcher	Density of active nest sites	50% reduction
	Number of chicks or eggs per nest site	50% reduction
	Species composition of prey remains (proportion of *Mytilus trossulus* , *Lottia persona, Lottia scutum,* and *Lottia* spp.)	Not determined
	Size distribution of remains of dominant prey (*Mytilus trossulus* and *Lottia persona*)	Not determined
Sea otter	Abundance (number per region based on aerial surveys)	40% change
	Proportion of dominant prey in diet (proportion of clams, mussels, crabs, and "other")	35% change
	Hours required to obtain energy required for maintenance.	20% increase; 33% decrease
	Proportion of carcasses in young, prime age, and aged age classes	40% change in any class
Water quality	Mean yearly air temperature, water temperature, and salinity	None
	Average daily range in air temperature, water temperature, and salinity	None
	Minimum and maximum air temperature, water temperature, and salinity	None
	Concentration of PAHs, PCBs, DDTs, Chlordanes, Total HCH (organopesticides), and	Concentrations that exceed the mean of all sites sampled in the U.S.

Table 4. Primary vital sign metrics to be analyzed to detect changes in the nearshore system on a routine basis. Also given are preliminary guidelines for degree of change deemed ecologically important (as discussed below).

Vital sign	Metric	Degree of change deemed ecologically important
	selected heavy metals in mussel tissue.	mussel watch program (see Table 5 below).

Kelp and seagrasses – Monitoring of kelp and seagrass (eelgrass) requires estimation of changes on several different spatial scales. We will examine larger temporal- and spatial- scale changes in the distribution of canopy forming kelps and eelgrass by examining the changes in the km of shoreline occupied by kelps and eelgrass based on ShoreZone mapping surveys (Morris and Harper 2004) conducted approximately every 15 years. For eelgrass, we will estimate the area covered by eelgrass and categorical estimates of eelgrass density in selected eelgrass beds annually.

Intertidal community - Algae and Invertebrates on sheltered rocky shorelines – For intertidal invertebrates and algae, we will examine number of species present and rates of local extinction, colonization, and turnover based on the presence or absence of species (Nichols et al. 1998) using COMDYN software (Hines et al. 1999). We will also examine changes in abundance of selected species. Species selection was based on surveys conducted at 5 sites in KATM in 2007 and 2008 (Bodkin et al 2007, 2008), at KEFJ in 2008 (Bodkin et al. unpublished data), and at PWS in 1989-1991 (Highsmith et al. 1994). In these surveys, over 70 taxa of invertebrates and algae were identified, but most were rare and offer little power to detect changes in their abundance over time. As a result, we choose to limit the number of metrics we will examine as vital sign indicators to the percent cover of bare substrate (indicating the absence of sessile invertebrates and algae), the total number of sessile and small motile species encountered, the total number of sea stars species, and the percent cover or number per unit area of several relatively abundant and ecologically important taxa. Indices of abundance (either based on percent cover or density) will be evaluated for five taxa of sessile invertebrates and algae: barnacles, *Mytilus trossulus*, *Fucus distichus* susp. *evanescens*, *Alaria* sp., and *Neorhodomela/Odonthalia* spp. These taxa are widely distributed, dominate the intertidal in terms of percent cover (together contributing over 90% of cover), and are important as the primary structural and energetic components in the rocky intertidal community. For larger motile invertebrates, we will evaluate the abundance of 4 sea star species (*Evasterias troschelii*, *Pisaster ochraceus*, *Pycnopodia helianthoides*, and *Dermasterias imbricata*), the large chiton *Katharina tunicata*, and the predatory snail *Nucella* spp. *Katharina* is an important grazer in this community (O'Clair and O'Clair 1998) and sea stars and *Nucella* spp. are important keystone predators (O'Clair and Rice 1985, O'Clair and Zimmerman 1987, Carroll and Highsmith 1996, O'Clair et al. 1999). We will also examine size distributions of *Lottia persona* that are abundant and are important prey for higher trophic levels (especially black oystercatchers) (O'Clair and O'Clair 1998).

Intertidal community - Invertebrates on sand-gravel beaches - For intertidal invertebrates on sand/gravel beaches, we will examine changes in abundance and size distribution of selected species. Species selection was based on surveys conducted in KATM and KEFJ (Lees and Driskell 2006, Coletti et al. 2009) that focused on the abundance, size distribution, and diversity of clams. A total of over 25 species were found, most of which were rare (fewer than 10 individuals in 12 – 0.25 sq. m. quadrats per site) and offer little power to detect change in their abundance over time. As a result, we choose to initially limit the number of metrics we will examine as vital sign indicators to the density and size distribution of three dominant taxa (*Leukoma staminea*, *Saxidomus gigantea*, and *Macoma* spp.). The three taxa selected for consideration are also important prey for sea otters (Calkins 1978, Estes et al. 1981, Kvitek et al 1992, Dean et al. 2002). While we will focus on these more abundant species at present, all larger bivalves are counted and measured and could be included in future analyses should their abundance increase over time.

Intertidal community- mussel beds – We define mussel beds as sites with relatively high densities of Pacific blue mussels, *Mytilus trossulus*. Specifically, mussel beds are defined as areas with greater than 10% cover by mussels within contiguous 1 m^2 quadrats over areas of 100 m^2 or greater. Metrics used to evaluate changes in mussel beds will include the average density of large mussels (greater than 20 mm in length), and the mean biomass of mussels greater than 20 mm in length (the minimum size generally taken by black oystercatchers and sea otters). Biomass will be estimated based on density and size distribution data gathered at each site, and on previously established relationships between size and biomass (O'Clair et al. 1999).

Marine birds – Evaluation of marine birds rely primarily on summer and winter boat based surveys that provide indices of density for each species encountered. We will examine the number of species present and rates of local extinction, colonization, and turnover based on the presence or absence of species in each season (Nichols et al. 1998). We will also examine changes in estimates of abundance of selected species chosen based on their relative abundance and ecological importance in the nearshore. In summer surveys conducted in KATM and KEFJ in 2006 and 2007, more than 30 species of birds were identified and counted. Most of these were rare. While we may include these species in our analyses should they become more abundant over time, we will focus only on relevant species that currently provide more statistical power to detect changes in abundance over time. The taxa selected for evaluation include three that nest in the nearshore and feed primarily on schooling fishes (black-legged kittiwakes, glaucous-winged gulls, and pigeon guillemots) and five that are more reliant on nearshore benthic food resources (harlequin ducks, goldeneye, mergansers, cormorants, and scoters). We elected to examine genera instead of species for some birds (goldeneyes, mergansers, cormorants, and scoters) because of occasional difficulty in distinguishing between closely related species within these genera during field surveys. Previous boat-based surveys in Prince William Sound (Irons et al 2000) found that abundance estimates for all of these taxa provided reasonable power to detect changes (greater than 50% power to detect a 50% reduction or a doubling in abundance between oiled and unoiled areas based on a sample size of 123 transects).

Black oystercatchers – Oystercatcher density will be estimated in marine bird surveys (see above) and in specific summer boat-based surveys. We will also estimate nest site density and will use this as a primary vital sign metric. In addition, we will evaluate nest site productivity as estimated based on the average number of eggs or chicks per nest, and will evaluate the

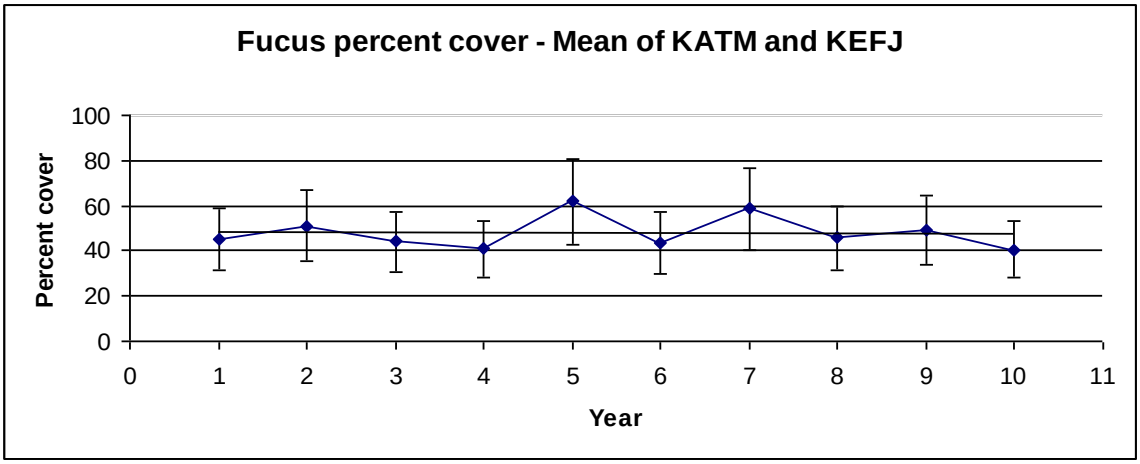
composition of remains of prey brought to nest sites. Metrics to be evaluated for prey composition will include the proportion of the predominant prey items (primarily mussels, chitons and several limpet species) as well as the size distributions of predominant prey.

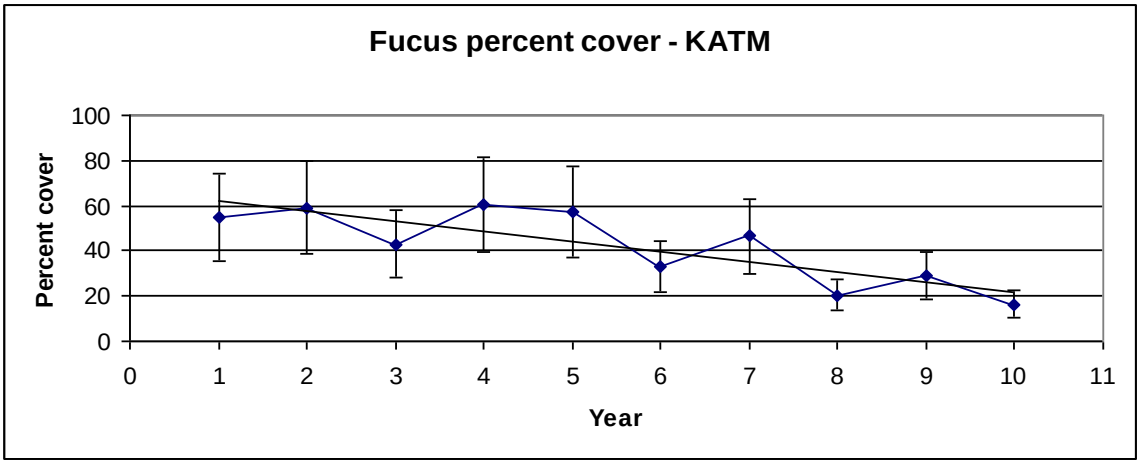
Sea otters – We will examine changes in number of sea otters (based on aerial survey estimates) as a primary metric of interest in evaluating changes in sea otter populations. However, sea otters are relatively long-lived marine mammals (generally reaching 15 years of age or greater) with relatively low birth rates and changes in abundance may not be the most sensitive indicator of long-term trends in abundance. Nor will changes in abundance offer any clues as to the causes for change. As a result, we will also evaluate trends in age-specific mortality rate (as indicated by the proportion of carcasses in each of three age classes: 0 to 3, 4 to 8, and >8 years of age). In addition we will evaluate changes in diet over time. Metrics to be evaluated will include the proportion of predominant prey items in sea otter diets (proportion of mussels, clams, crabs, and other prey). We will also estimate the total prey energy obtained per hour of feeding by sea otters. The latter is used to estimate food availability (Dean et al. 2002) and incorporates data on the composition and sizes of prey as well as dive times and intervals between dives.

Marine Water Chemistry and Water Quality – Water quality will be evaluated by measuring temperature and salinity in the intertidal zone and the concentration of various metal and organic contaminants in the tissue of mussels. For temperature and salinity, we will evaluate changes in yearly mean, mean daily range,, and minimum and maximum yearly values. We will focus on ranges and extreme values because these are often important disturbance events that can regulate community structure of intertidal algal and invertebrate communities (e.g. Carroll and Highsmith 1996). A total of over 120 organic compounds or isomers and ten metals are measured in the tissue of mussels. For organics, we will evaluate several summary metrics including total PAHs, total chlordanes, total DDTs, total PCBs, and total HCHs) as indicators of exposure to contaminants in the nearshore.

5.3 Routine annual analyses

Annual reports will include primarily descriptive analyses that present means and confidence intervals for each primary metric over various spatial scales. The plots of means over time will be made to examine trends over the spatial scales of the region (means for KATM, KEFJ, and WPWS), within a block (e.g. KATM) and in the case of metrics in which multiple sites are examined, for sites within a block (Figure 4).





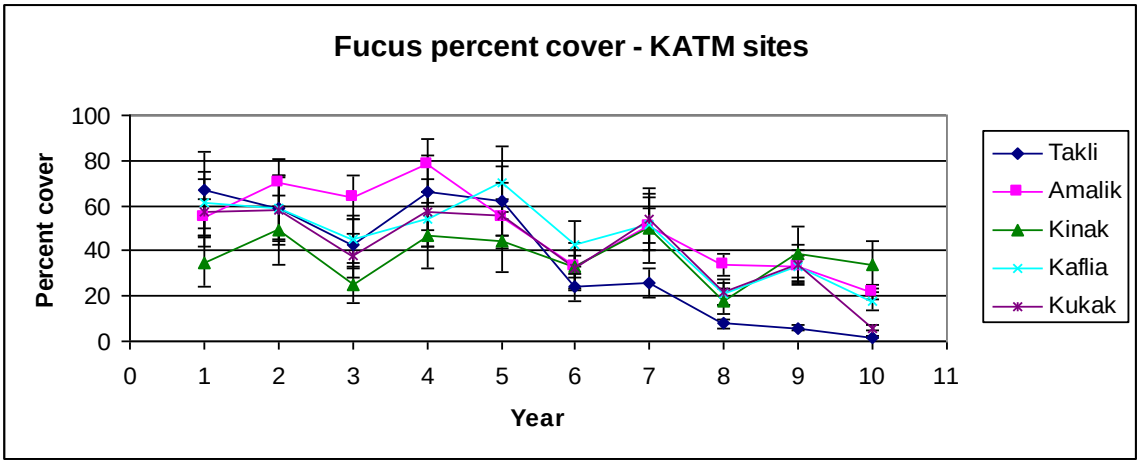


Figure 4. Example plot of mean and confidence intervals over time for hypothetical data for percent cover of Fucus for regions, blocks (e.g. KATM), and sites within blocks..

5.4 Analyses to detect trends

Analyses to detect trends in the data will be conducted after five years of data have been collected for a given metric and at 2 to 5 year intervals thereafter. The specific analyses

performed will depend in part on the metric and on any patterns or observed trends. The following provides a general discussion of types of analyses that are being considered.

Different types of analyses may be required if trends are gradual and occur at a relatively consistent rate over time or are episodic (e.g. extreme shifts in a given year based on an extreme event such as an earthquake or particularly hard freeze). Trends that result from extreme events will be modeled using either change-point or segmented regression (Seber and Wild 1989, Küchenoff and Carol 1997). More gradual changes will be examined using linear or log-linear regression models.

The general approach to be used in trend analysis is as follows. Several hypotheses (models) will be selected a priori that might provide reasonable explanations of trends in the observed data, and we will use information-theoretic (I-T) criteria to rank these models based on their relative support and select the best-fitting model to generate our trend estimate (Burnham and Anderson 2002, 2004; Lukas et al. 2007). If more than one model is reasonably supported, we will use model averaging to generate our estimates (Burnham and Anderson 2002). In the simplest form, models used to examine trends in various vital signs (e.g. sea otter abundance) will include explanatory variables of time (e.g. survey year), location (e.g. block), and the interaction of time and location. (This would result in the simultaneous testing of 6 models with parameters of year; location; year and location; year and the interaction of year and location; location and the interaction of year and location; and year, location, and the interaction of year and location.) Where appropriate, models examined will include terms that might account for potential biases in the data, such as the years of observer experience or observer identity for a given sea otter aerial survey. Terms that might further explain trends over time (e.g. mean annual temperature, location relative to a particular local disturbance, or time period relative to a particular disturbance event) may also be included where appropriate. Terms such as observer identity that are likely to lack independence in influencing dependent variables in successive years be will be treated as random effects. The regression analyses are to be performed using the Proc Mixed function in SAS (SAS 2000) or comparable software.

5.5 Analyses to provide insights as to causes

Causes for observed environmental changes can only be determined by use of specific experimental designs. However, we can gain some insights as to possible causes for change using two primary analytical methods. First, the spatial and temporal patterns of change, and the scales over which they occur, will be examined using the analytical tools described above. The temporal and spatial scales of change should help to suggest possible causes. For example, a change that occurs over decades and is roughly of equal magnitude at all locations (a time effect of ecological importance, but no location or time by location effect) would suggest that the change was due to some large-scale event (e.g. global climate change or PDO), rather than a more localized one (e.g. a release of a toxicant from boat harbors). Second, inclusion of explanatory variables in models might also suggest cause. For example, if inclusion of the concentration of contaminants in mussels helps to provide a better fit of temporal trends in black oyster catcher abundance, then this might suggest that a decline in oyster catchers was related to an increase in contaminants.

It should be stressed that we will not be able to definitively assign causes for changes based solely on the data generated in this monitoring plan. Assigning cause will rely heavily on further

process studies that are designed to test hypotheses regarding specific cause and effect relationships. These process studies cannot be designed or carried out until there is sufficient observational or correlative evidence produced to detect a change and suggest a possible cause.

5.6 Ecological thresholds and management trigger points

The objective of the GOA nearshore monitoring program is to examine trends in various metrics that are indicative of changes in the health of the nearshore community. However, the ultimate goal of the program is to provide resource managers with the tools that will allow them to take actions to protect resources. Therefore, in addition to identifying trends, it is also necessary to provide some guidance as to what levels of change are ecologically important and to identify "trigger points" that warrant consideration of action on the part of managers (Nichols and Williams 2006).

Determining when a trend is ecologically important is not a straightforward process. There is currently no standard by which to measure ecological importance, and there are no clear guidelines to determine "trigger points" for action by resource managers. Various models have been proposed to evaluate threats to threatened or endangered species (e.g. IUCN 2002), but these are generally not appropriate for our use. Few of the species we are monitoring as vital signs are in danger of extinction, and our hope is that we can identify trends of ecological importance and inform managers so that actions can be taken to protect resources prior to reaching the status of threatened or endangered. Furthermore, the geographic scale of concern is different. For example, it is possible to have declines in abundance of a particular species that is of concern to resource managers, but relatively insignificant to the continued survival of the species. There is currently a NPS funded study to help identify a process that may help to determine these trigger points based on structured decision making and on models of system behavior (Nichols et al. 2007). Our intent here is to provide some interim guidance for ecologically important trends for each metric we are considering. We stress that these are preliminary. While such values are needed to guide analyses and interpretation of results, there is little precedent for establishing ecological thresholds. It is anticipated that these will be modified over time based on further empirical and theoretical analyses.

Our preliminary guidance on possible trigger points is based largely on our understanding of the species within the nearshore system of the GOA and interactions between these species. In general, we deem important changes that are likely to have system-wide effects through predator –prey interactions, for example. This is based largely on our conceptual understanding of the system and not on a more rigorous systems model. Where possible, we will rely on two types of data to help identify trends of ecological importance. The first is the range in natural variation that has been observed in what are considered healthy populations. These variations represent the bounds to be placed on any reasonable trigger point. The second is the range in variation, generally expressed as a level of change that has been considered ecologically important in past studies of impacts to nearshore ecosystems, and especially those that have been shown to have larger system-wide effects. We will rely heavily on observations made following the *Exxon Valdez* oil spill, since the spill is widely recognized as having significant long-term impacts on

the nearshore ecosystem. The spill affected nearshore communities in KATM, KEFJ, and more strikingly in PWS, was widely studied over a period of several decades. In some cases, there is an absence of data on levels of natural variation in healthy systems or examples of the levels of change that have proved to be of ecological importance. In these cases we make use of our best professional judgment to estimate levels of natural variation and levels of change that may be of ecological importance.

It is unlikely that we will ultimately rely solely on any single metric to evaluate the health of the nearshore system. Instead, we will likely rely on change in a suite of metrics viewed in the context of a community or systems model. For example, reductions in intertidal mussel populations coupled with a reduction in mussels as a component of the diet in sea otters and black oyster catchers would provide stronger evidence of an important ecological change than would reductions in mussels alone. However, it is important to provide trigger points for each metric as an initial step in this process.

The guidance provided is given in terms of absolute levels of change from current conditions. However, in some instances it may be appropriate to also examine trends in the relative levels of change at one location compared to others. Tracking relative change may be important in identifying locations that are changing in response to a site specific disturbance event, especially in cases where there are larger geographic-scale temporal changes that are occurring in response to normally occurring climatologic or oceanographic change. For example, relatively small absolute declines in abundance at a given location might be deemed important if abundances elsewhere are increasing, and relative changes at that given location are large in relation to other locations. We assume that the magnitude of relative change that is ecologically important is the same as the level of absolute change. For the sake of simplicity, we discuss only absolute changes below. However, it should be recognized that relative levels of change may be of interest and will be similarly evaluated.

The actions that might be undertaken by mangers when a trigger is exceeded cannot be determined and will be resource and event dependent. Actions might range from continued or more detailed study to more specific conservation measures such as limiting of visitation to sites where declines are observed or removing potential sources of contamination. It is likely that future consideration of possible management decisions will be made based on a weight of evidence provided.

Preliminary guidance on changes deemed to be of ecological importance for each vital sign metric is as follows:

Kelps and seagrasses – The natural variation in the cover of canopy forming kelps in the Gulf of Alaska is largely unknown. However, kelp canopies in the GOA and elsewhere are known to fluctuate in response to oceanographic conditions (e.g. storm activity, water temperature, light, and nutrient availability), grazing, competition, and human disturbance (North 1964, Neushul 1981, Dayton 1985, Foster and Schiel 1985). Therefore, we will recognize only relatively large (greater than 50%) reductions in canopy cover within a block (based on aerial ShoreZone mapping) to be of ecological importance.

Dramatic changes in the abundance of eelgrass have been observed over the past several hundred years (Costa 1988, Short and Wylie-Echeveria 1996). Changes are generally associated with disease and human disturbance. While some eelgrass beds along exposed coastlines are subject to high inter-annual variability due to storms, those in more sheltered habitats (like most in KATM, KEFJ, and PWS) display relatively little variation from year to year (Costa 1988, Short and Wylie-Echeveria 1996, Ward et al. 1997). Longer-term (5 to 10 yr.) declines in beds of 25% or more, in these types of sheltered habitats are generally attributable to human disturbance and are considered to be of ecological importance. We have few data on the trends in abundance of eelgrass at KATM, KEFJ, or PWS, but based on the relative lack of annual variation made in sheltered eelgrass beds elsewhere in Alaska (Ward et al 1997), we consider reductions of 25% or greater in the km of coastline occupied by eelgrass, or in the area covered by eelgrass at selected eelgrass beds, to be of ecological importance.

Algae and invertebrates on sheltered rocky shorelines -Inter-annual patterns of abundance of intertidal invertebrates and algae on rocky shores are highly variable. Most of the species have high mortality rates due to intense grazing or predation and because of their susceptibility to natural disturbances including wave action, freezing, and desiccation. In what are regarded as healthy systems in the Gulf of Alaska, it is not unusual to see inter-annual changes in estimates of percent or abundance of dominant intertidal invertebrates and algae that are 50% or greater (Highsmtih et al 1994, Skalski et al. 2001). At sites impacted by the *Exxon Valdez* oil spill, only larger changes (on the order of 80 to 90%) were deemed to be of ecological importance. Based on these results, we consider changes in abundance of selected dominant taxa of 80% or greater be of ecological importance. Changes in the number of species present are somewhat less variable, and inter-annual variation in the number of species detected is generally less than 20%. Impacts from the *Exxon Valdez* oil spill caused changes in number of species of algae detected that were on the order of 30% or greater. We consider changes of 30% or greater ecologically important. Based on 3 years of data from KATM, size distributions of limpets, *Lottia persona*, appear to vary relatively little over time. Median sizes at any one site varied less than 20% over the three year period. We have no data on longer-term changes in limpet size, but suspect that changes in median size on the order of 50% or greater may be ecologically important.

Invertebrates on sand-gravel beaches – In the Gulf of Alaska, there are relatively few data regarding the normal range of variability in clam assemblages on sand-gravel beaches or on levels of change that are ecologically important. Additionally, the sampling methods are by necessity destructive and preclude sampling at high frequency. As a result variation in mean density values within clam beds over time are generally high. Within clam beds sampled in multiple years in Glacier Bay, mean densities of dominant species varied by as little as 10% and as much as 300% (J. Bodkin, unpublished data). Similarly, Houghton et al. (1996) found relatively high inter-annual variability in clam densities in PWS (at sites unaffected by the Exxon Valdez oil spill). Because of the lack of data from many of our sampling sites (especially KATM and KEFJ) and the anticipated high spatial and temporal variance, we will use values for clam densities of 80% to represent changes that are deemed ecologically important. Reductions on the order of 80% or greater were observed at sites that were washed after the Exxon Valdez spill and were deemed ecologically important (Houghton et al. 1996). We also lack size data for dominant intertidal clams from KATM or KEFJ, but

expect variation in mean sizes to vary much less than density. As a consequence we expect a 50% change in mean size of dominant intertidal clams to be ecologically important.

Intertidal community- mussel beds – Little is known about the persistence of beds of Pacific blue mussels (*Mytilus trossulus*) or changes in density, sizes, or biomass of mussels within beds over time. A two-year study in Price William Sound indicated that year to year variations in density and biomass were as high as 50%. Longer-term studies of two closely related species, California mussels (*Mytilus californianus*) and blue mussels (*Mytilus edulis*) suggest that mussel beds can persist for decades but that the boundaries of the bed and changes in biomass of mussels within a bed can change appreciably. Studies indicate that while beds can persist for a decade or more, occasional episodic large disturbance events (storms associated with El Nino events or ice scour associated with extremely cold winters) can cause local extinctions of some beds (Paine et al 1985, Seed and Suchanek 1992, Petraitis and Dudgeon 2004). Without specific information on the persistence and inter-annual variation in beds of Pacific blue mussels, it is difficult to set meaningful boundaries on changes that might be considered ecologically important. Until more data are provided we consider block-wide (e.g. within KATM, KEFJ, or WPWS) changes of 80% or greater in the average density and 50% change in the biomass of mussels to be ecologically important.

Marine birds –After the Exxon Valdez oil spill, Irons et al. (2000) found significant reductions in several bird species that were on the order of 50% or higher and were deemed of ecological importance. We will consider similar reductions (on the order of 50% or greater) as ecologically important. However, for many species of birds, inter annual variation is quite high, and it is likely that we only be able to detect somewhat higher reductions. For example, in Glacier Bay National Park, inter-annual variation for commonly observed species varied between 15 and 60%, (Drew et al. 2008) and even somewhat higher inter-annual variation was observed at KATM between 2006 and 2008 (Coletti et al. 2009).

Black oystercatchers - Black oystercatchers are long-lived, have high nest site fidelity and appear to have relatively stable nest site densities and productivity over time in the absence of major disturbance events (Andres 1997, Coletti et al. 2009). Following the Exxon Valdez oil spill in Prince William Sound, comparisons of changes in black oystercatcher density and productivity at oiled and unoiled areas after the spill implied that there was greater than 60% reduction in active nest density in areas impacted by the spill and an 80% reduction in nest productivity in areas disturbed by cleanup operations. Both were considered of ecological importance. Here we consider reductions in nest density or productivity that are 50% or greater to be of ecological importance. Changes in diet, including both changes in prey frequency and sizes of select prey within the black oystercatcher chick provisioning diet, are metrics we are using to assess black oystercatcher status. There are no prior studies to suggest what specific levels of changes in diet might be of ecological importance. In surveys conducted in KATM between 2006 and 2008 there were large changes in the diets of black oystercatchers over time (a 71% and 47% reduction in the proportion of *Lottia persona* and *Mytilus trossulus* respectively and a greater than 200% increase in the proportion of both *Lottia scutum* and *Lottia pelta*). However, there were no appreciable changes in either nest density or productivity of black oystercatchers over this period (Coletti et al 2009) and no obvious changes in the intertidal community at large. Therefore it is unclear as to the magnitude of change in prey size would be considered ecologically important. Thus, we will

continue to monitor both prey composition and prey size to help us understand possible changes in community dynamics, but we cannot establish ecological thresholds for these metrics at present.

Sea otters – Estimates of abundance of sea otters based on aerial surveys are somewhat imprecise and in general 95% confidence intervals around the estimated population size in any given year are on the order of 20-30% of the mean. As a result of this imprecision and natural variation, population estimates for what are considered "healthy" sea otter populations that are relatively stable can vary by as much as 30% from one year the next. However, longer-term changes on the order of 40% or larger are thought to represent changes of ecological importance. Following the *Exxon Valdez* oil spill, reductions in the sea otter population in western Prince William Sound were on the order of 50% and were clearly considered to be of ecological importance. We will use a reduction of 40% or larger in sea otter abundance as our level of change considered as ecologically important. Also following the *Exxon Valdez* oil spill, increases of 60% in the proportion of prime age sea otters found beach-cast (17 to 28%) with corresponding decreases in the proportions of juvenile and aged adults (44 to 42%, and 40 to 31%, respectively) were considered biologically significant, contributing to a protracted period of recovery from the spill (Monson et al. 2000). Because these proportions are not independent, we will use a change of 40% in any of the three age groups as biologically significant, assuming a minimum total sample size of 100 ages at death. Sea otter diet appears relatively consistent over long time scales at some locations. For example the proportion of clams in the diet of sea otters in Prince William Sound in the 1970's was similar to the 1990's (about 70-80%, Calkins 1978, Bodkin et al. 2002). We will consider changes in dominant prey (those contributing 35% or more to the diet) of 35% or more to be biologically significant and indicative of change in the prey base. The estimated number of hours that sea otters must spend feeding in order to obtain sufficient energy for maintenance is generally on the order of 9-10 hours per day in stable and healthy populations. Increases in feeding time required for maintenance that excede 11 hours (20%) or decreases to less than 8 hours (33%) are considered to be of ecological importance.

Water quality: Temperature and salinity – Variations in temperature and salinity are potentially important drivers of ecological change. Therefore, we will measure and analyze temperature and salinity on a routine basis. Variations in temperature, and especially in temperature extremes, are known to vary greatly from year to year. Less is known regarding variations in salinity, but these too are expected to vary considerably in the nearshore zone that is highly influenced by the degree of freshwater runoff. However, longer-term variations in both temperature and salinity in the nearshore (and especially the intertidal zone) are largely unknown, as are the levels of change that are of ecological importance. Furthermore, no managerial action is anticipated even if ecological meaningful changes in these metrics are observed. Therefore, we set no thresholds for these metrics.

Water quality: Contaminants –Levels of contaminants in mussel tissue have been widely studied as an indicator of water quality. These data are used to indicate relative "hot spots" where concentrations of given contaminants are of potential concern. Relationships between concentrations of contaminants and adverse biological responses are less clear and no "threshold concentrations" indicative of adverse biological effects have been established. Therefore, we provide estimates of concentrations that are of ecological importance based on

comparisons to those found elsewhere in the US. Specifically, we consider concentrations to be of ecological importance when mean for a given site exceeds mean values of all sites sampled in the US as part of the NOAA mussel watch program (O'Connor et al. 1996). We have chosen to use the mean rather than "high" values (those equivalent to one standard deviation above the mean based on log-transformed data) because the majority of sites sampled in the mussel watch program are from highly industrialized sites that are generally considered ecologically degraded relative to those in our sampling universe. Both means and "high" values for each contaminant are given in Table 5.

Table 5. Mean concentration and "High" values (those that exceed one standard deviation of the mean for log-transformed data) of contaminants in oyster and mussel tissue samples taken from sites (generally in industrialized urban areas) throughout the United States between 1986 and 1993. For silver, copper, zinc, lead and chromium values are for mussel tissue only. All others are for oysters and mussels. Data are from O'Connor et al. (1996).

Chemical	**Mean**	**"High"**
Metals (concentrations in µg/g)		
Arsenic	10	17
Cadmium	2.7	5.7
Mercury	0.094	0.24
Nickel	1.7	3.3
Selenium	2.5	3.5
Silver	0.17	0.58
Copper	8.9	11
Zinc	130	190
Lead	1.8	4.3
Chromium	1.7	3.0
Organics (concentrations in ng/g)		
tPCB	110	470
tDDT	37	120
tCdane	14	31
tPAH	260	890

5.7 Interpretation of results

For the biological metrics, we consider changes to be of ecological importance if a trend is established and if the trend is such that the threshold of ecological importance has been exceeded. Trends will be deemed to be established if the 90% confidence intervals about the time coefficient in trend analysis models do not include zero. Whether that trend is of ecological importance will be determined by examining the confidence intervals in relation to the threshold levels established (Alderson 2004) (Figure 5). For example, for sea otter abundance, we deem a 40% reduction of the population estimate to be a threshold. If the mean percentage change in the population estimate (as determined by the adjusted time coefficient in trend analysis over any given time interval) is less than 40% and the lower confidence interval about that mean does not include 40%, then no effect of ecological importance would be indicated. If the confidence intervals about the mean (either upper or lower) include a 40% reduction, then the results would be considered inconclusive. If the mean decline is greater than 40% and the upper confidence interval does not exceed the 40% level, then an ecologically important decline in the sea otter population would be indicated.

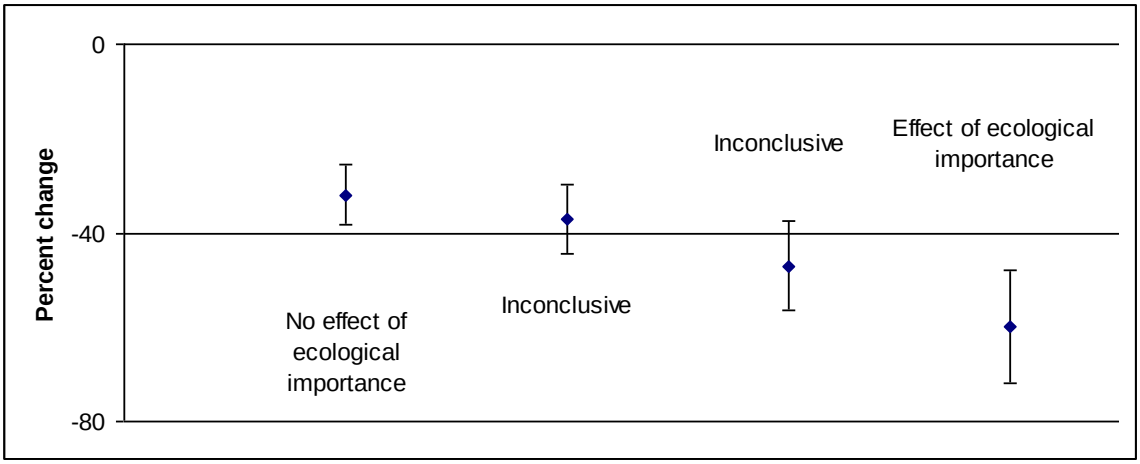


Figure 5. Interpretation of thresholds for consideration of action given means percentage change observed and 90% confidence intervals about those means. The horizontal line of no effect (-40%) is the threshold level of change deemed ecologically important.

6 Reporting

Three different levels of reporting are to be conducted. The first are annual reports that describe the activities for the previous year, summarize results in the form of annually updated figures and tables, highlight any unusual events or trends in the data, and describe activities to be conducted in the upcoming year. More comprehensive reports will be produced every five years that provide complete statistical analyses of data gathered to date, conduct power analyses as appropriate to examine possible changes to sampling designs, suggest changes to sampling designs, and suggest possible topics for process studies needed to examine causes for change or evaluate new sampling techniques. Also, it is anticipated that there will be special reports produced on an as needed basis that address patterns of observed change that require some immediate action such as increased sampling effort, initiation of process studies, or possible regulatory intervention. Special reports might also summarize the results for a particular time specific task such as evaluation of a potential modeling effort or a synthesis of results.

7 Management Structure, Personnel Requirements, and Training

7.1 Management structure and key personnel

This project is one of several conducted as part of the SWAN and Gulf Watch Alaska monitoring programs (Bennett et al. 2006, *www.aoos.org/**gulfwatchalaska***). The nearshore program described here will be jointly managed by leads from NPS and USGS. Data management functions will be directed by the NPS Data Manager. Other staff will be provided by NPS, USGS, NOAA, and private contractors.

7.2 Personnel requirements

The list of required staff (including contractors) and a brief description of their responsibilities and qualifications are given in Table 6.

7.3 Training

The level of training required for each of the project personnel will depend in part on their level of experience. At a minimum, training will consist of familiarization and demonstrated proficiency in safety procedures, data management procedures, and in implementation of standard operating procedures as required by the position. Required proficiencies for each task are outlined in standard operating procedures.

7.4 Schedule of activities

The following table (Table 7) summarizes the annual schedule for activities to be conducted in nearshore vital signs program.

Table 6. Anticipated staffing requirements and salary estimates for the GOA nearshore monitoring program. All salary estimates are given in 2013 dollars and include benefit and overhead costs.

Position and number required	Responsibilities	FTEs Required	Approximate Annual Salary
Lead Scientists (USGS and NPS)	Oversee project staff, budgets, scheduling, contracts, analysis, preparation of reports, and coordination with other contractors	1.6	$180,000
Lead Analyst	Oversee analysis of data. Assist in planning, field efforts, and report preparation	0.7	$90,000
Senior Scientists	Oversee field sampling. Assist in organization of data, maintenance of data bases, and report preparation.	0.8	$85,000
Biologists	Assist in preparation for field sampling, field sampling, data base maintenance, and data analysis	0.7	$80,000
Biologists - Technical support	Assist in field logistics, field sampling, data entry, and data base maintenance	1.1	$90,000
Data manager	Provide data management support, build and maintain data bases	0.2	$20,000
Seasonal field support technicians	Assist in field sampling	0.1	$10,000
Total		5.2	$ 555,000

Table 7. Summary of tasks completed through 2012 (in black) and tasks planned for 2013 and 2014 (in red) as part of the GOA nearshore monitoring program.

Metric	Area	2006	2007	2008	2009	2010	2011	2012	2013	2014
Eelgrass percent cover in	KATM			x	x	x		x	x	x
selected beds	KEFJ			x	x	x	x	x	x	x
	WPWS			x	x	x	x	x	x	x
	EPWS							x		x
	NPWS								x	
Invertebrate and algal	KATM	x	x	x	x	x		x	x	x

Table 7 (continued). Summary of tasks completed through 2012 (in black) and tasks planned for 2013 and 2014 (in red) as part of the GOA nearshore monitoring program.

Metric	Area	2006	2007	2008	2009	2010	2011	2012	2013	2014
abundance and limpet size	KEFJ			x	x	x	x	x	x	x
	WPWS		x			x	x	x	x	x
	EPWS							x		x
	NPWS								x	
Intertidal invertebrate	KATM		x		x		x		x	
abundance and clam size	KEFJ		x		x		x		x	
	WPWS		x				x		x	
	LACL				x					
	EPWS							x		x
	NPWS								x	
Mussel abundance	KATM			x	x	x		x	x	x
and size	KEFJ			x	x	x	x	x	x	x
	WPWS					x	x	x	x	x
	EPWS							x		x
	NPWS								x	
Bird density	KATM	x	x	x	x	x		x	x	x
- summer	KEFJ		x	x	x	x	x	x	x	x
Bird density	KATM				x			x		
- winter	KEFJ			x		x			x	
Black oyster catcher nest	KATM	x	x	x	x	x		x	x	x
density	KEFJ		x	x	x	x	x	x	x	x
	WPWS		x			x	x	x	x	x
Black oyster catcher	KATM	x	x	x	x	x		x	x	x
- prey relative	KEFJ		x	x	x	x	x	x	x	x

Table 7 (continued). Summary of tasks completed through 2012 (in black) and tasks planned for 2013 and 2014 (in red) as part of the GOA nearshore monitoring program.

Metric	Area	2006	2007	2008	2009	2010	2011	2012	2013	2014
abundance										
	WPWS					x	x	x	x	x
Sea otter abundance –	KATM			x				x		
aerial survey	KEFJ		x			x			x	
	WPWS	x	x	x	x	x		x	x	x
Sea otter diet – Prey	KATM	x	x	x	x	x		x	x	x
relative abundance	KEFJ		x	x	x	x	x	x	x	x
	WPWS					x	x	x	x	x
Sea otter age at death	KATM	x	x	x	x	x		x	x	x
	KEFJ		x	x	x	x	x	x	x	x
	WPWS	x	x	x	x	x	x	x	x	x
Contaminants in mussels	KATM			x					x	
	KEFJ			x					x	
	WPWS							x		
	EPWS							x		
	NPWS								x	
Temperature	KATM	x	x	x	x	x	x	x	x	x
	KEFJ			x	x	x	x	x	x	x
	WPWS					x	x	x	x	x
	EPWS							x	x	x
	NPWS							x	x	x
Salinity	KATM		x	x	x	x	x	x	x	x
	KEFJ		x	x	x	x	x	x	x	x
	WPWS					x	x	x	x	x
	EPWS							x	x	x
	NPWS							x	x	x

8 Operational Requirements and Cost Estimates

8.1 Operational requirements

Operational requirements for specific tasks are outlined in standard operating procedures. More generic operational requirements are given here.

Facilities and Office Equipment

- Office facilities for 6 staff
- Computers for above staff
- Central server for data storage and website (specifications and location to be determined)
- Software for data management, statistical analysis, geographic information system, and office management

Field Equipment

- 3 Inflatable vessels and associated power and safety equipment
- 16 to 24 ft vessel and associated power, electronic, and safety equipment
- 5 High power scopes for sea otter foraging observations
- 5 Ruggedized laptop computers for entry of field data
- 40 Temperature recording devices
- 6 GPS units
- 4 Digital cameras
- 6 Binoculars
- 10 salinity recording devices
- 2 Down-looking sonar recorders

Charter Vessels and Aircraft

- Minimum 50 ft vessel for charter with accommodations for 6 scientific staff
- Aircraft for aerial surveys for of sea otters
- Helicopter for access to the LACL sites

It is anticipated that many of the field equipment needs could be met using existing equipment, thereby eliminating the need for large initial capital expenditures.

8.2 Cost estimates

Cost estimates for the monitoring program are summarized in Tables 8. The cost estimates include in kind support from USGS and NPS for salaries and vessel charters. Not included is in kind support for facilities and existing equipment.

Table 8. Estimated annual budget for the GOA nearshore monitoring program. All costs are in 2013 dollars. Future costs require inflation adjustment.

Category	Annual cost estimate	Comments
Salary	$555,000	Detailed in Table 6. Includes salaries for USGS, NPS, NOAA, and contract personnel.
Vessel charter	$120,000	Includes costs for 4 summer and 1 winter cruise
Equipment purchase	$7,000	Computers, vessels, and field instruments
Travel	$8,000	Travel to meetings and to field
Commodities	$10,000	Includes fuel, software, field supplies
Contracts	$29,000	Includes contracts for aircraft and for chemical analysis
Agency overhead	34,000	
Total	$763,000	

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Appendix A

Possible agents of change in nearshore systems of the Gulf of Alaska over the next several decades, their physical effects, biological effects, and temporal and spatial scales on which impacts are likely to occur.

Agent of Change	Physical Effect	Biological Effect	Temporal and Spatial Scale[1]
Natural			
ENSO - El Nino	• Temperature increase • Decreased upwelling • Increase storm activity	• Decrease in primary production • Northerly range extension of southern species • Increase in some diseases	Years/Region
ENSO – La Nina	• Temperature decrease • Increased upwelling	• Southerly range extension of northern species • Increase in primary production •	Years/Region
PDO	• Temperature increase (in warm cycle) • Decreased upwelling (in warm cycle)	• Decrease in primary production • Northerly range extension of southern species • Increase in some diseases	Decades/Region
Extreme cold	• Freezing in intertidal • Extreme cold air temp	• Death of Inverts/algae and some vertebrates	Days (though effects may last years) /Area (with greater effects in northerly exposures)
Extreme heat	• Heat/desiccation in intertidal (especially if coincident with spring tide)	• Death of inverts/algae	Days (though effects may last years) /Area (with greater effects in southerly exposures)
Storms	• Waves/debris increase • Salinity decrease	• Death of inverts/algae and some vertebrates	Days (though effects may last years) /Area (with greater effects in more exposed locations, locations with movable substratum, or nearer stream mouths)
Disease	•	• Increased death rate or reduced reproductive rate	Largely unknown
Earthquakes	• Uplift or downthrust • Sediment shifting and shifting of stream	• Killing of inverts and algae	Minutes/Hours (though effects may last years) /Area (with greater effects in areas of

Agent of Change	Physical Effect	Biological Effect	Temporal and Spatial Scale[1]
	mouths		greatest uplift/downthrust
Volcanoes	• Increased sedimentation in intertidal	• Smothering of inverts and algae	Minutes/Hours (though effects may last years) /Area (with greater effects in areas most exposed to ash
Glacial activity	• Increased / decreased sedimentation and calving	• Smothering of inverts and algae (on advance) or increase in exposed bottom/intertidal inverts and algae and decreased glacial feeding by birds (on retreat)	Decades/Location or Sites
Anthropogenic	•	•	
Global warming	• Increased temperature • Increased UV radiation • Reduced salinity	• Northerly shift in species distribution • Reduced photosynthesis of kelp • Reduction in marine stenohaline spp.	Years/Region
Ocean acidification	• Reduction in pH of ocean waters	• Reduction in abundance of mollusks, echinoderms, and other organisms that rely on calcium carbonate for skeletons	Years/Region
Introduction of exotic spp.	• None	• Reduction in abundance of competitors/prey	Years/Area
Fishing	• None	• Reduction in targeted stocks • Reduction in predators of those stocks, possible habitat destruction	Years/Area or Location
Aquaculture (especially intertidal clam)	• None	• Intertidal habitat loss • Reduction in intertidal inverts/algae with possible reduction in their predators	Years/Area or Location
Coastal development	• Increased sedimentation and eutrophication • Introduction of contaminants	• Reduction in fish spawning habitat • Reduction in inverts and algae intolerant to stress	Years/Sites

Agent of Change	Physical Effect	Biological Effect	Temporal and Spatial Scale[1]
		• Increases in stress tolerant spp. • Increased contaminant levels in animals • Increased death rate or reduced reproductive rate especially in higher trophic levels.	
Recreational use	• None	• Disturbance to mammals/birds • Entanglement of birds/mammals with trash • Reduction in intertidal inverts/algae due to trampling	Years/Sites
Watershed development	• Increased sedimentation • Increased eutrophication • Introduction of contaminants	• Reduction in fish spawning habitat • Reduction in inverts and algae intolerant to stress • Increases in stress tolerant spp. • Increased contaminant levels in animals • Increased death rate or reduced reproductive rate especially in higher trophic levels.	Years/Sites (especially at stream or river mouths)
Contamination from distant sources	• Increased levels of metals and other chemicals	• Increased contaminant levels in animals • Increased death rate or reduced reproductive rate especially in higher trophic levels.	Years/Region or Areas
Logging activity	• Increased sedimentation and eutrophication • Introduction of contaminants	• Reduction in fish spawning habitat • Reduction in inverts and algae intolerant to stress • Increases in stress tolerant spp. • Increased contaminant levels in animals • Increased death rate or reduced reproductive rate especially in higher trophic levels.	Years/Sites

Agent of Change	Physical Effect	Biological Effect	Temporal and Spatial Scale[1]
Oil or chemical spills	• Increased levels of contamination	• Reduction in inverts and algae intolerant to stress • Increase in stress tolerant spp. • Increased contaminant levels in animals • Increased death rate or reduced reproductive rate especially in higher trophic levels.	Days (although impacts may last years or decades) /locations or sites

[1] Definition of spatial scales (with approximate shoreline extents)

Region – Gulf of Alaska (1,000 plus km)

Area – Prince William Sound, Kenai Peninsula, Kodiak archipelago, and Alaska Peninsula) – (200 km)

Location – Subareas on the order of Western Prince William Sound 50-100 km

Site - E.g. Herring Bay, Orca Inlet, Jakalof Bay, etc. (5-10 km)

Spot – 10s to 100s of m

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Nearshore Marine Vital Signs Monitoring in the Southwest Alaska Network of National Parks

2012

Natural Resource Technical Report NPS/XXXX/NRTR—20XX/XXX

ON THE COVER
Black oystercatcher in the intertidal – KATM
Photograph by: Sue Saupe

Nearshore Marine Vital Signs Monitoring in the Southwest Alaska Network of National Parks

2012

Natural Resource Technical Report NPS/XXXX/NRTR—20XX/XXX

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Abstract

In 2012, we successfully completed another year of field sampling for the Southwest Alaska Network's (SWAN) Nearshore Vital Signs monitoring program and the Gulf Watch Alaska Program in accordance with standard operating procedures set forth for the six vital signs: marine intertidal invertebrates, kelp and seagrass, marine water chemistry and quality, marine birds, black oystercatcher, and sea otter. All analyses in this report are descriptive and no statistical tests were used in any comparisons across regions or time for this entire report.

Summer sampling in 2012 represented the sixth year of data collection at Katmai National Park and Preserve (KATM) and Kenai Fjords National Park (KEFJ) and the fourth year of sampling in western Prince William Sound (WPWS). Sampling did not occur in KATM in 2011 or in WPWS in 2008 or 2009. We anticipate continued annual sampling in the SWAN parks as well as WPWS for the vital signs: intertidal invertebrates, kelps and seagrasses, water chemistry and quality, marine bird surveys (only KATM and KEFJ), black oystercatcher diet and productivity, and sea otter diet. Data from WPWS are presented here in anticipation that all three areas (KATM, KEFJ and WPWS) will continue to be sampled and analyzed together in order to provide a larger spatial context to the analyses. In addition to WPWS, monitoring sites area being added in eastern and northern PWS and will be included in future analyses.

No modifications were made to the rocky intertidal sampling protocol from previous years and the protocol and SOPs have been finalized. Hobo water temperature sensors are currently deployed at five rocky intertidal sites in each area (KATM, KEFJ and WPWS). In addition, salinity loggers are co-located at rocky intertidal sites at KATM, KEFJ and WPWS. We implemented a fifth year of mussel bed and eelgrass bed sampling and a final SOP for sampling mussel beds is near completion and will be sent out for peer review in 2013-2014. Modifications for eelgrass bed monitoring are being made and a new draft SOP will be sent for review.

Marine bird surveys in KEFJ and KATM continued with little modification in 2012. For marine bird surveys, we recommend that the survey effort continue until further analysis can be completed. The existing SOP for marine bird surveys is final.

Black oystercatcher abundance, nest density, productivity and diet data should continue to be collected with little revision. Sampling at the current intensity should allow us to detect trends in changes of nest density, productivity and diet (especially prey size) of the black oystercatcher. The SOP for black oystercatcher monitoring is also final.

A sea otter aerial survey was completed in KATM during August of 2012. This was the second aerial survey completed along the KATM coastline. An aerial survey was previously flown in 2008. Survey methodology followed Bodkin and Udevitz (1999) and accounts for imperfect detection. The survey took three days to complete. The estimated sea otter abundance for KATM is 8,644 individuals, with an overall density of 5.95 otters/km^2. The 2008 abundance estimate was 7,095 individuals with an estimated density of 4.89 otters/km^2.

Sea otter foraging data was collected in KATM and KEFJ in 2012. Clams (multiple species) and mussels (*Mytilus trossulus*) dominated sea otter diets across all years of data collection (2007-2012), together comprising over 80% of the diet. Annually there has been little observed change in the predominant prey category at any area, although sea otters observed at KEFJ in 2012 consumed more clams and fewer mussels. A sea otter forage database has been completed. Database completion will

ease data entry both in the field and office as well as optimize data analysis. Carcass collection continues in all areas, although to date we have not recovered enough carcasses from KEFJ to employ age-specific mortality analyses.

In the spring of 2014 we will finalize data entry and data management procedures for the sea otter foraging, mussel and soft sediment SOPs. We will continue to sample nearshore vital signs at KATM, KEFJ and WPWS in 2014.

In 2014, the protocol narrative for the cooperative SWAN and Gulf Watch Alaska monitoring program was updated through an external peer review process. http://science.nature.nps.gov/im/units/swan/assets/docs/reports/protocols/nearshore/DeanT_2014_SWAN_NearshoreProtocolNarrative.pdf

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Intertidal Invertebrates and Algae Sampling

Introduction

Intertidal invertebrate and algal communities provide an important source of production; are an important conduit of energy, nutrients, and pollutants between terrestrial and marine environments; provide resources for subsistence, sport, and commercial harvests; and are important for recreational activities such as wildlife viewing and fishing. The intertidal is particularly susceptible to human disturbance including oil spills; trampling by recreational visitors; harvesting activities; pollutants from terrestrial, airborne and marine sources; and shoreline development. Changes in the structure of the intertidal community serve as valuable indicators of disturbance, both natural (e.g. Dayton 1971, Sousa 1979) and human induced (Barry et al. 1995, Lewis 1996, Keough and Quinn 1998, Jamieson et al. 1998, Shiel and Taylor 1999, Sagarin et al. 1999, Peterson 2001, and Peterson et al. 2003).

Intertidal invertebrates and algae (including intertidal kelps) were sampled annually at KATM beginning in 2006; however no sampling occurred in KATM in 2011. Sampling began in KEFJ in 2008. WPWS sampling began in 2007 and then again from 2010-2011. Sampling of intertidal invertebrates and algae at these sites is designed to detect changes in these communities over time as part of the NPS SWAN Vital Signs Program and Gulf Watch Alaska Monitoring Program. The specific objectives of this sampling on rocky shores are to assess changes in: 1) the relative abundance of algae, sessile invertebrates, and motile invertebrates in the intertidal zone, 2) the diversity of algae and invertebrates, 3) the size distribution of limpets (*Lottia persona*) and mussels (*Mytilus trossulus*), 4) the concentration of contaminants in mussel tissue, and 5) temperature (either sea or air depending on tidal stage). In this section, we present results of sampling conducted in 2006-2011. The metrics to be examined are: 1) abundance estimates for dominant taxa of sessile invertebrates and algae, and the size distribution of the limpet *Lottia persona*.

Methods

Sampling was conducted at five sites in sheltered rocky habitats within KATM, KEFJ and WPWS. Descriptions of the study sites and methods used to sample intertidal algae and invertebrates are available in Dean and Bodkin (2011b). Sites were chosen using a generalized random tessellation stratification (GRTS) procedure (Stevens and Olsen, 2004) that provided a spatially balanced yet random selection of sites. The following is a general description of the methods employed. Sampling of abundance and species composition for algae and invertebrates was conducted along two 50 m linear transects at each site along the 0.5m and 1.5m tidal elevations. The percent cover of algae and sessile invertebrates was estimated within 12 evenly spaced ¼ m^2 quadrats placed along transects that ran parallel to the shoreline and originated at permanent markers, respectively. Quadrats were placed at random start points and at equally spaced intervals thereafter. In addition, a minimum of 120 individual limpets (*Lottia persona*) were measured at each site for estimation of size distributions.

The analyses presented here focus on estimates of abundance of dominant taxa at each tidal elevation, and on size distributions of limpets. Means and 95% confidence intervals are reported for each park in each year.

Results

Mean percent cover (and 95% confidence intervals) are reported for each site at KATM, KEFJ and WPWS in Figures 1 through 9. Relative abundance varied by region and tidal elevation, but *Fucus distichus. evanescens*, barnacles, and *Alaria marginata* were generally the most abundant. *Alaria marginata* does not occur at the higher tidal elevation (1.5 m) and does not generally occur in WPWS. *Alaria marginata* occurs along coastlines with more exposure than those found in WPWS. Notable differences between regions were observed at the lower (0.5 m MLLW – mean low low water) tidal elevation, with a greater percent cover of *Fucus* at KEFJ. The only notable trend over time was an increase in cover by *Fucus* at the 1.5 m tidal elevations at KEFJ between 2008 and 2011. No differences between regions were noted for the mean size of the limpet *Lottia persona* (Figure 10).

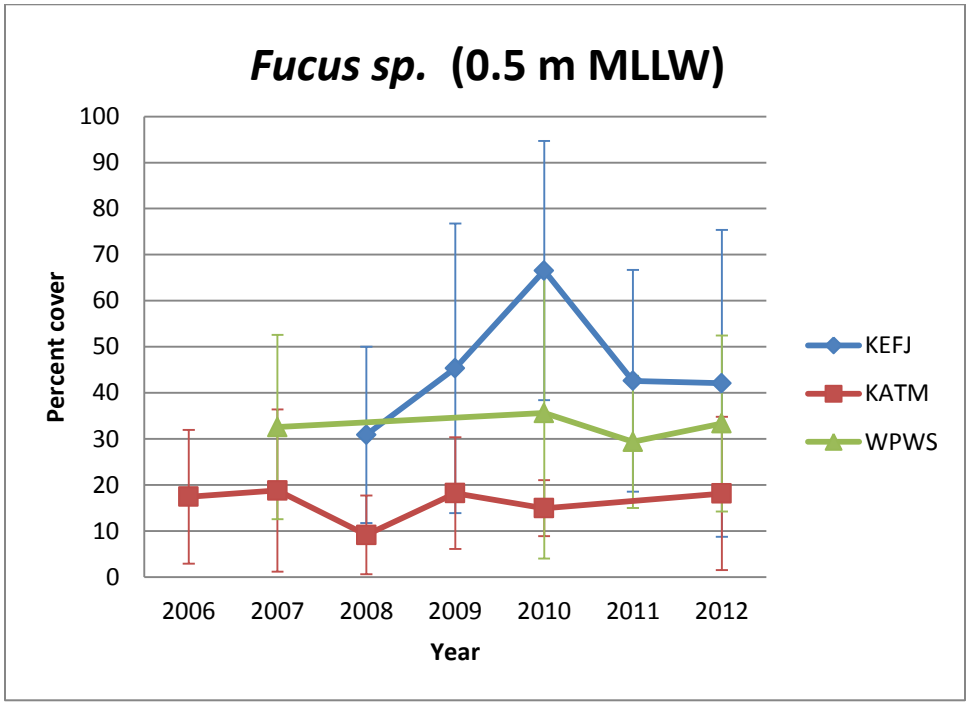


Figure 1. Percent cover of *Fucus* at the 0.5 m MLLW in KATM, KEFJ, and WPWS, 2006-2012. Error bars indicate 95% CI.

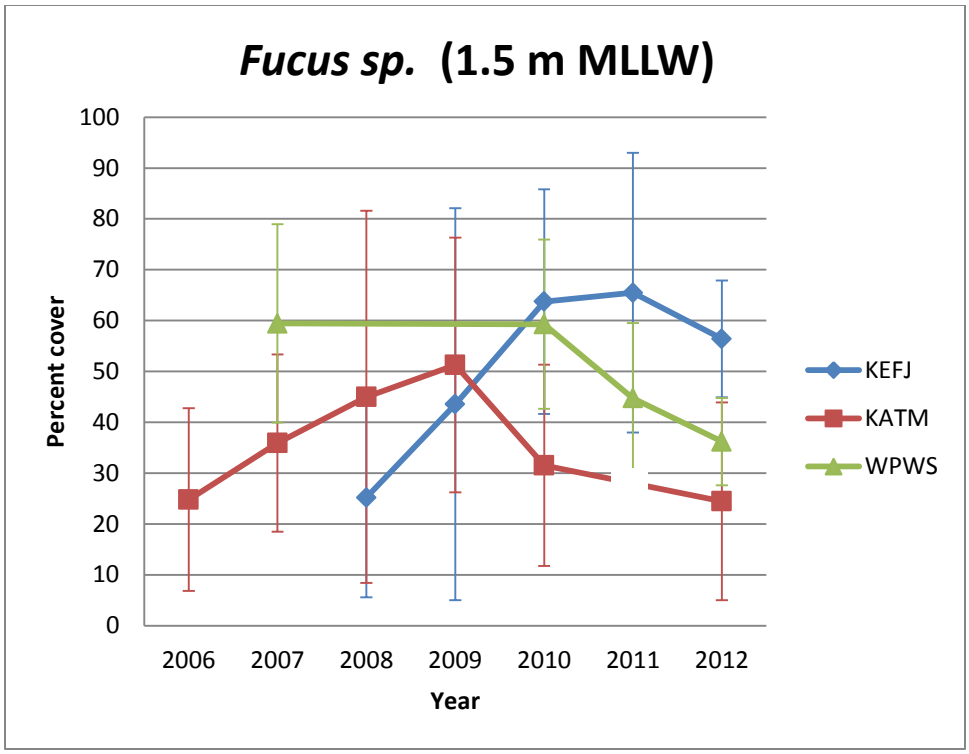


Figure 2. Percent cover of *Fucus* at the 1.5 m MLLW in KATM, KEFJ, and WPWS, 2006-2012. Error bars indicate 95% CI.

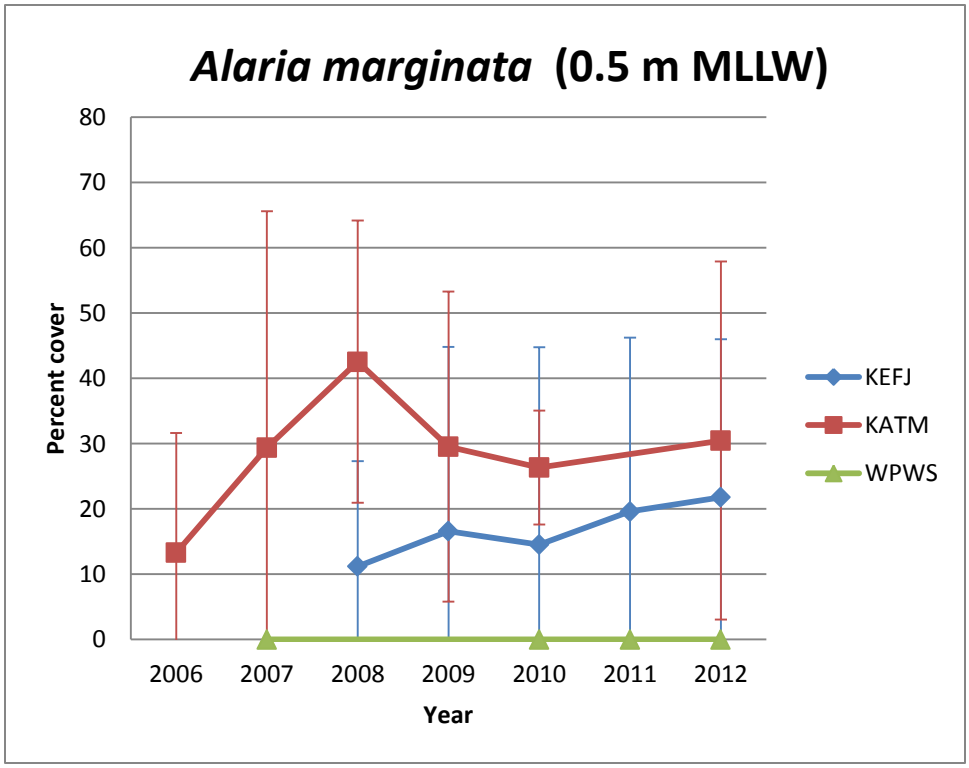


Figure 3. Percent cover of *Alaria* at the 0.5 m MLLW in KATM, KEFJ, and WPWS, 2006-2012. Error bars indicate 95% CI.

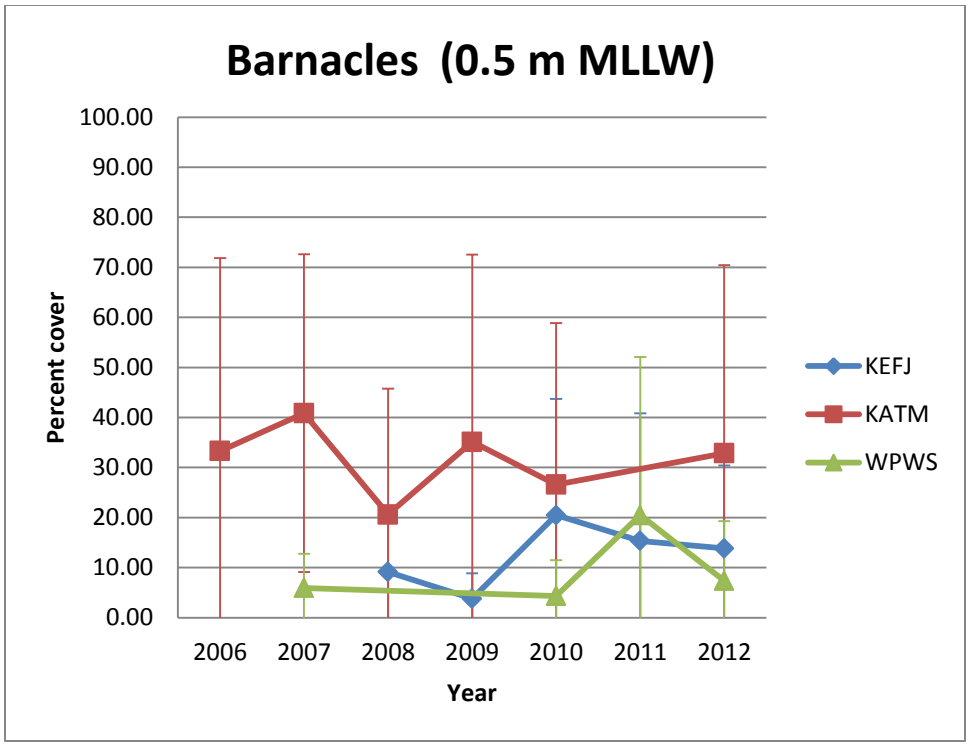


Figure 4. Percent cover of barnacles at the 0.5 m MLLW in KATM, KEFJ, and WPWS, 2006-2012. Error bars indicate 95% CI.

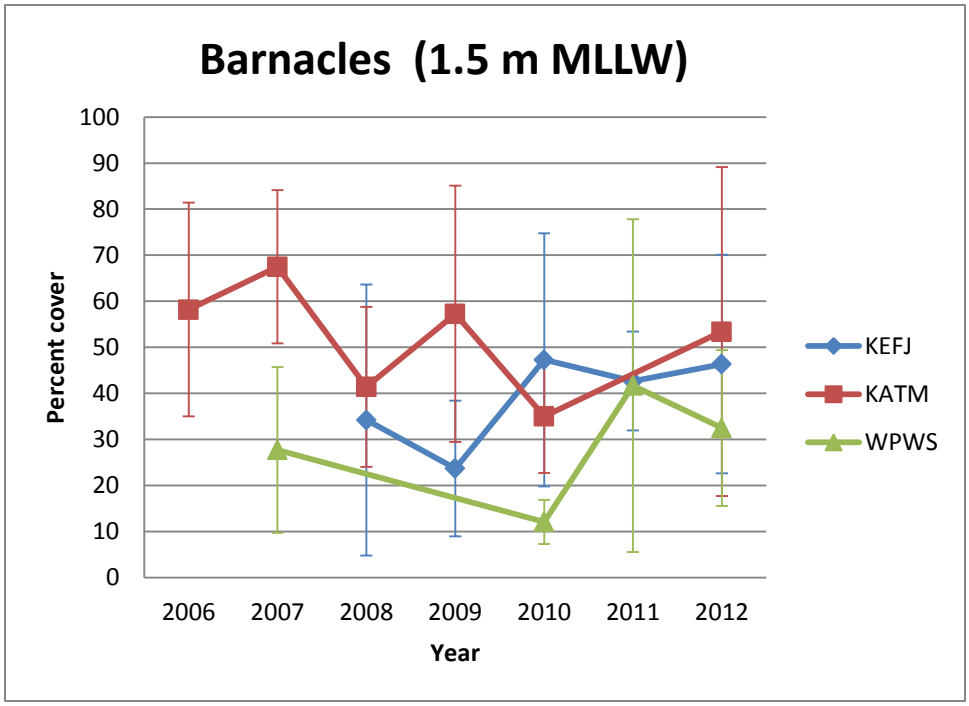


Figure 5. Percent cover of barnacles at the 1.5 m MLLW in KATM, KEFJ, and WPWS, 2006-2012. Error bars indicate 95% CI.

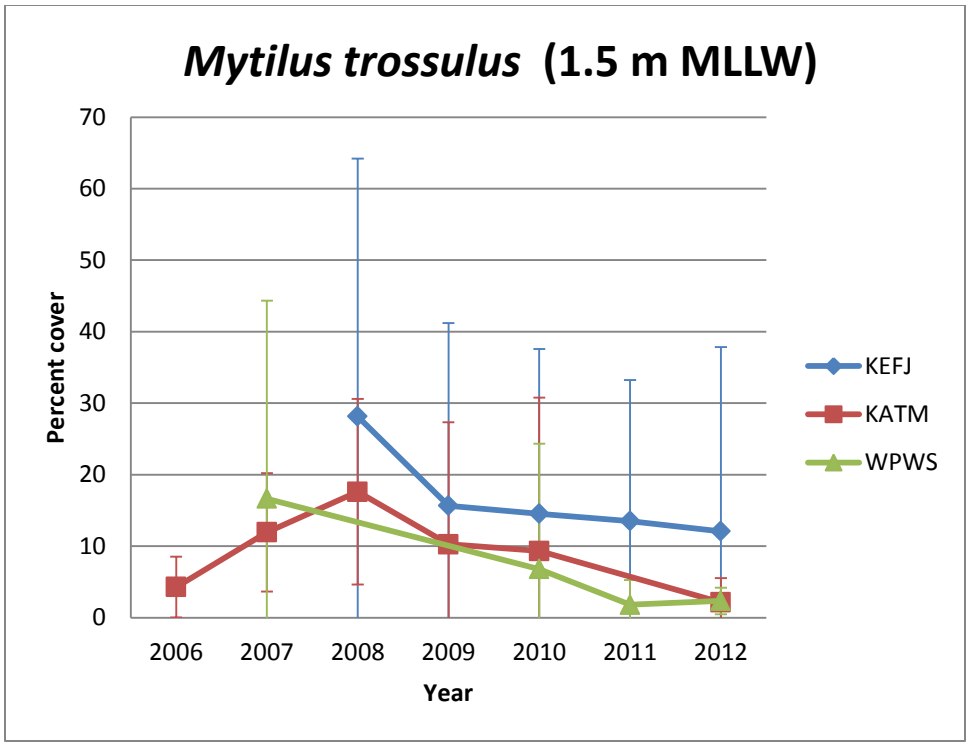


Figure 6. Percent cover of *Mytilus* at the 1.5 m MLLW in KATM, KEFJ, and WPWS, 2006-2012. Error bars indicate 95% CI.

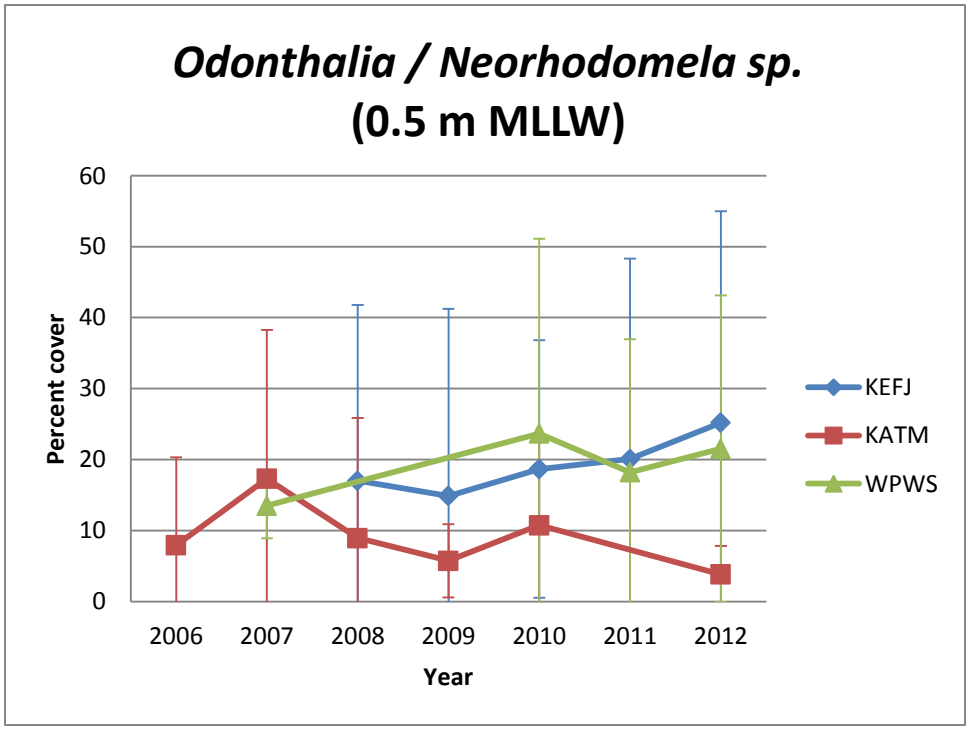


Figure 7. Percent cover of *Odonthalia / Neorhodomela* at the 0.5 m MLLW in KATM, KEFJ, and WPWS, 2006-2012. Error bars indicate 95% CI.

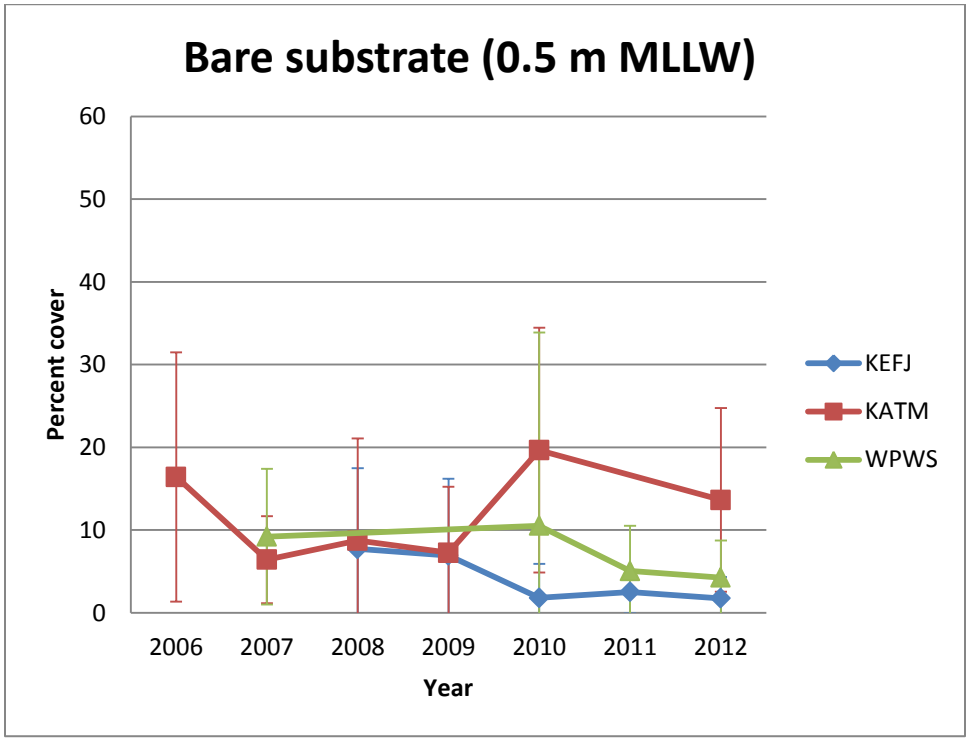


Figure 8. Percent cover of bare substrate at the 0.5 m MLLW in KATM, KEFJ, and WPWS, 2006-2012. Error bars indicate 95% CI.

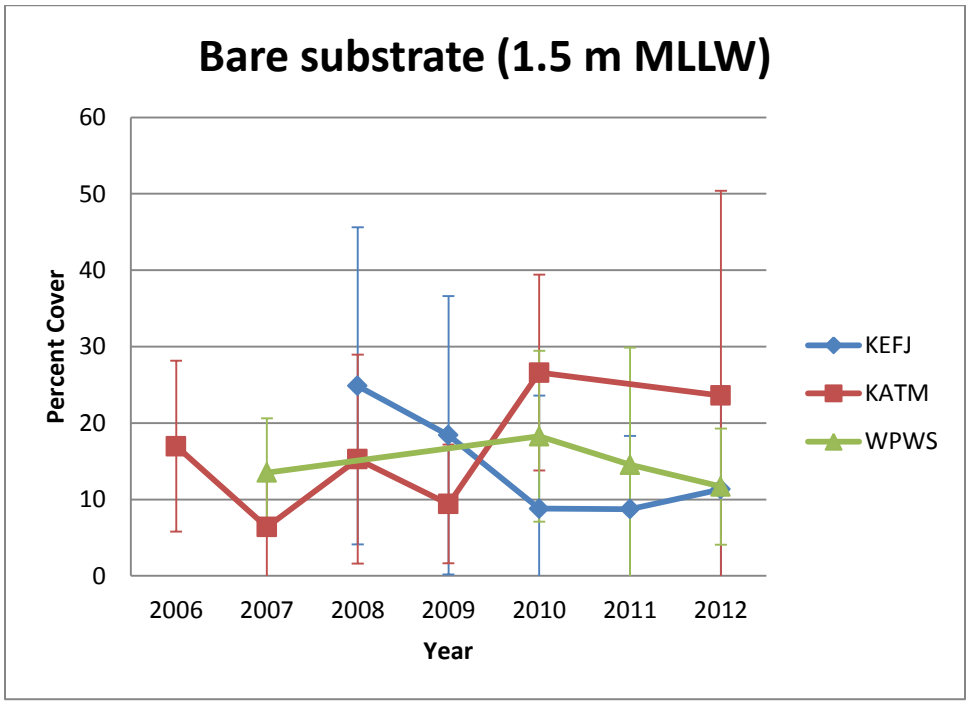


Figure 9. Percent cover of bare substrate at the 1.5 m MLLW in KATM, KEFJ, and WPWS, 2006-2012. Error bars indicate 95% CI.

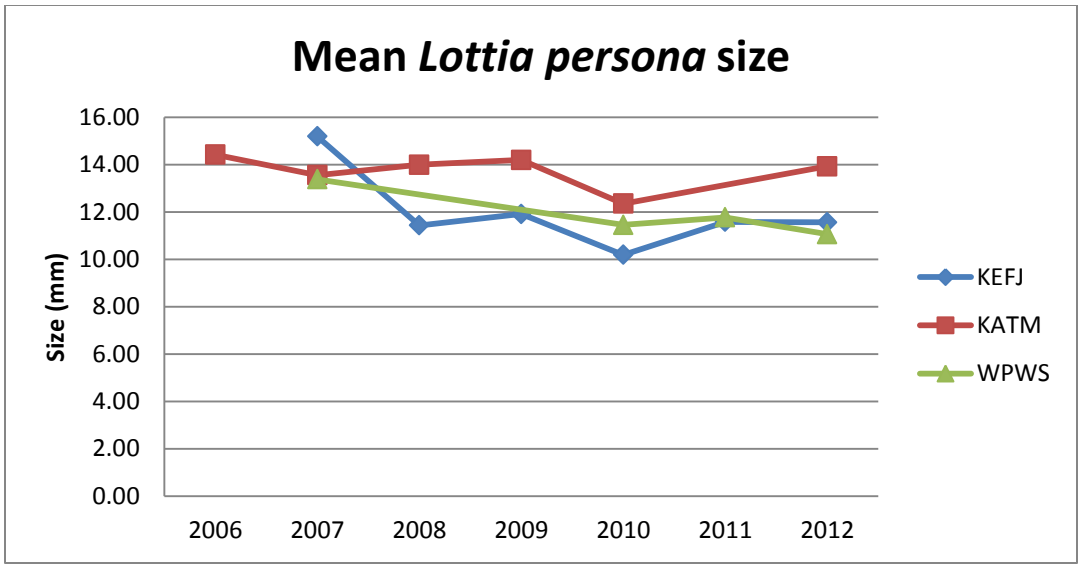


Figure 10. Mean size (mm) of *Lottia persona* in KATM, KEFJ and WPWS, 2006-2012. Error bars indicate 95% CI.

Discussion

Sampling provided estimates of the abundance of intertidal invertebrates and algae (including intertidal kelps) at sites within each region. We anticipate that the methods employed will detect ecologically meaningful levels of change in the future. Existing data will allow the program to conduct trend analysis for several metrics and build simulations to estimate the number of samples and sample frequency required to detect a specified trend or change with some level of confidence for selected metrics, specifically the rocky intertidal algae and invertebrate vital sign. The rocky intertidal invertebrate and algae vital sign has eight metrics that have several years of data to conduct simulations to determine the power to detect change. The levels of change or trend to be detected have already been specified by the investigators (Dean and Bodkin 2011a, Dean et al. 2014). The Vital Signs Monitoring Plan for SWAN (Bennett et al 2006) explicitly states the use of hierarchical models to estimate trends. The work proposed here is to assist the National Park Service in the modification of the protocol for its monitoring program.

Recommendations

Based on these results, we recommend continued estimation of percent cover by sessile invertebrates and algae using random point counts and continued estimation of sizes of limpets.

Mussel Bed Sampling

Introduction

Pacific blue mussels (*Mytilus trossulus*) are a dominant and ubiquitous invertebrate in the intertidal zone and are critically important prey for a variety of organisms including sea otters (*Enhydra lutris*), black oystercatchers (*Haematopus bachmani*), harlequin ducks (*Histrionicus histrionicus*), Barrow's goldeneyes (*Bucephala islandica*), and several species of sea stars (O'Clair and Rice 1985, O'Clair and O'Clair 1988, VanBlaricom 1988, Andres and Flaxa 1995, Esler et al. 2002, Bodkin et al. 2002). Mussels are widely distributed in many intertidal habitats, but also form relatively monotypic stands of larger individuals that are termed mussel beds. The goal of mussel bed sampling is to assess changes in the size of beds and in the size of mussels within those beds over time. These data are used primarily as an indicator of mussel abundance as prey for various predators (sea stars, sea ducks and sea otters). Specifically, the objectives are to estimate: 1) the density of mussels within a bed, 2) the density of large mussels (greater than or equal to 20 mm in length) within a bed, and 3) the size distribution of the large mussels within a bed (those generally consumed by black oystercatchers, sea ducks and sea otters). We define mussel beds as sites with relatively high densities of mussels. Specifically, mussel beds are defined as areas with greater than approximately 10% cover by mussels within contiguous 0.25 m^2 quadrats over areas of 100 m^2 or greater. Metrics used to evaluate change over time will include the area of individual mussel beds (in m^2), average density of large mussels, and the mean size of large mussels. In this report, we include results of sampling mussels at sites in KATM, KEFJ and WPWS.

Methods

Sampling sites are defined as 50 m of coastline with contiguous mussel beds. These sites were selected following intensive searches in 2008 for the presence of mussel beds adjacent to the randomly selected rocky intertidal sites (see intertidal invertebrates and algae section). The closest mussel bed to the randomly selected rocky intertidal site was selected for sampling.

A transect 50 m in length was established through the mid-point of the bed, relative to tidal elevation, and at the left end of the bed, as observed from the water. A permanent bolt was placed at this location and at approximately 5 m intervals along the 50 m length of the horizontal transect to establish the site for future sampling. Ten vertical transects were then established at systematic intervals based on a random start point (a different random start point is used each year) along the horizontal transect length, and the distance from the upper most margin of the bed to the lower margin (or the 0 m tidal elevation) was measured for each vertical transect.

Estimates of mussel density are made within quadrats that are randomly located along each vertical transect. Quadrat dimensions are dependent on the density of mussels $\geq$ 20 mm within 1 m of the predetermined random point along the vertical transect, and determined at the time of sampling. The quadrat size can range from .0025 m^2 to 1.00 m^2 (5 cm to 100 cm on a side) with the size dependent on obtaining a collection of at least 20 mussels $\geq$ 20 mm in length. This results in at least 200 mussels to estimate size distributions of large mussels at a site. All mussels $\geq$ 20 mm are collected from within the quadrat and later counted and measured, and densities of large mussels are

calculated. Densities of all mussels (of a size that is visually detectable, approximately 5 mm and greater) are estimated from a 2.54 cm radius (20.27 cm^2) core located at the same random number that defined the vertical quadrat, but on the opposite side of the tape from the origin of the large mussel quadrat.

Results

In 2012 we estimated the abundance and size of mussels at five mussel bed sites at five sites each in KEFJ and KATM for the fifth year in a row, and at WPWS for the third year in a row. Results for each area are represented here. In general, mussel density is greater in KEFJ than in KATM or WPWS for all mussels including the large mussels (Figures 11 and 12). Mean sizes of mussels ≥20mm are similar across all three areas (Figure 13). The proportion of large mussels appears to have decreased in KEFJ and KATM from 2010 to 2012, but remained relatively stable in WPWS (Figure 14).

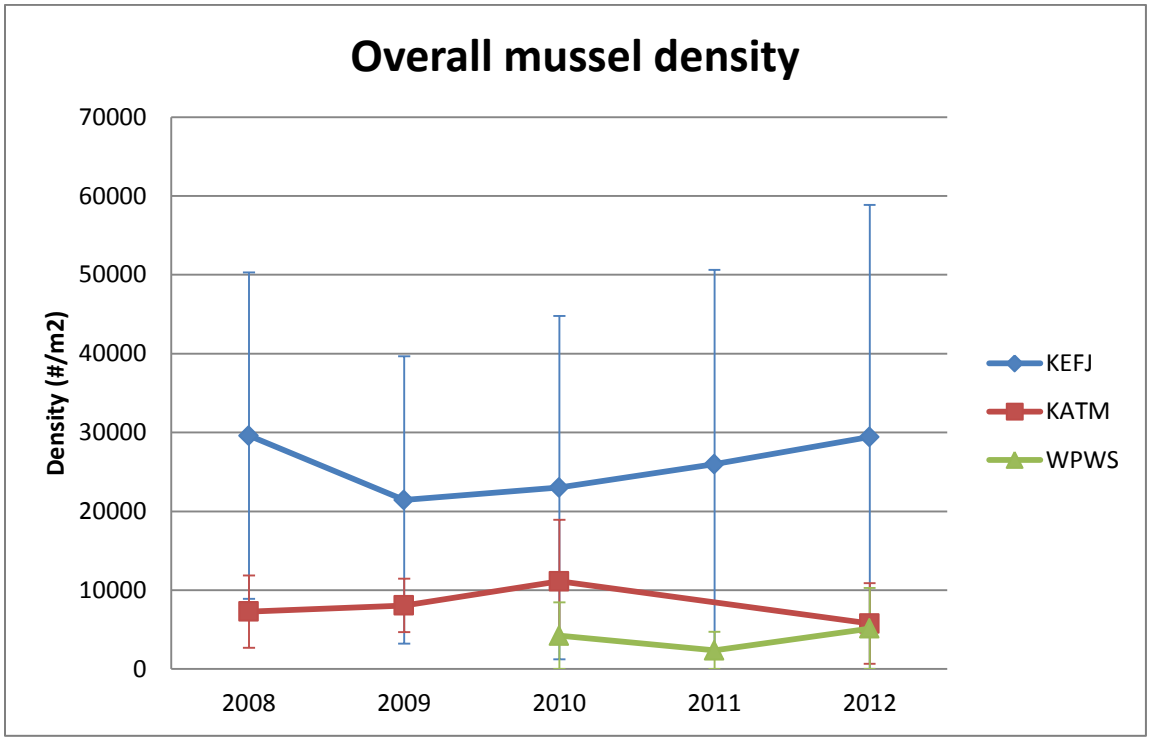


Figure 11. Overall mussel density (#/m^2) in KATM, KEFJ and WPWS, 2008-2012, based on core samples. Error bars indicate 90% CI.

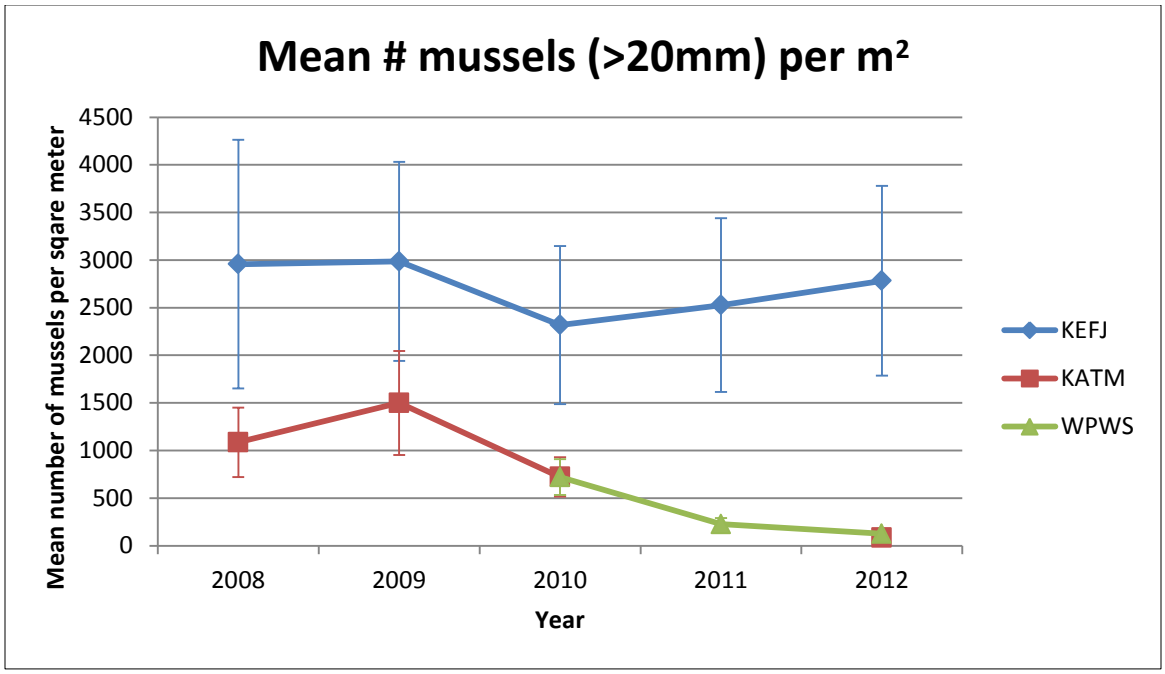


Figure 12. Density (#/m^2) of mussels ≥ 20 mm in KATM, KEFJ, and WPWS, 2008-2012. Error bars indicate 95% CI.

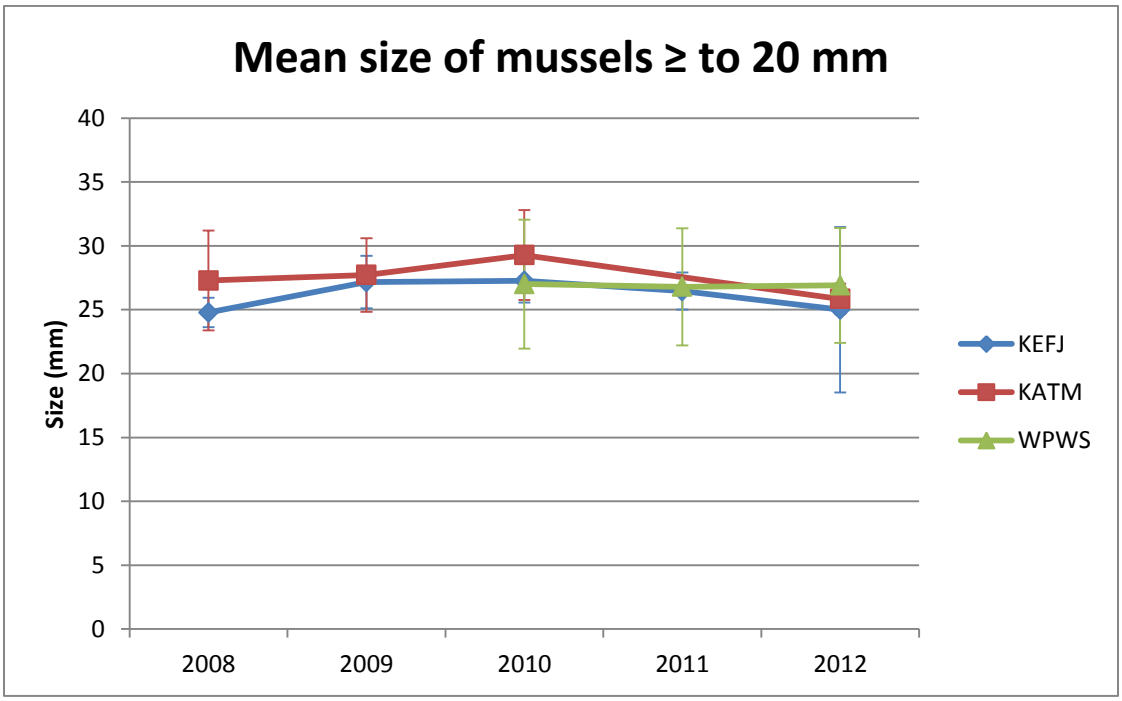


Figure 13. Mean mussel size in KATM, KEFJ, and WPWS, 2008-2012. Error bars indicate 95% CI.

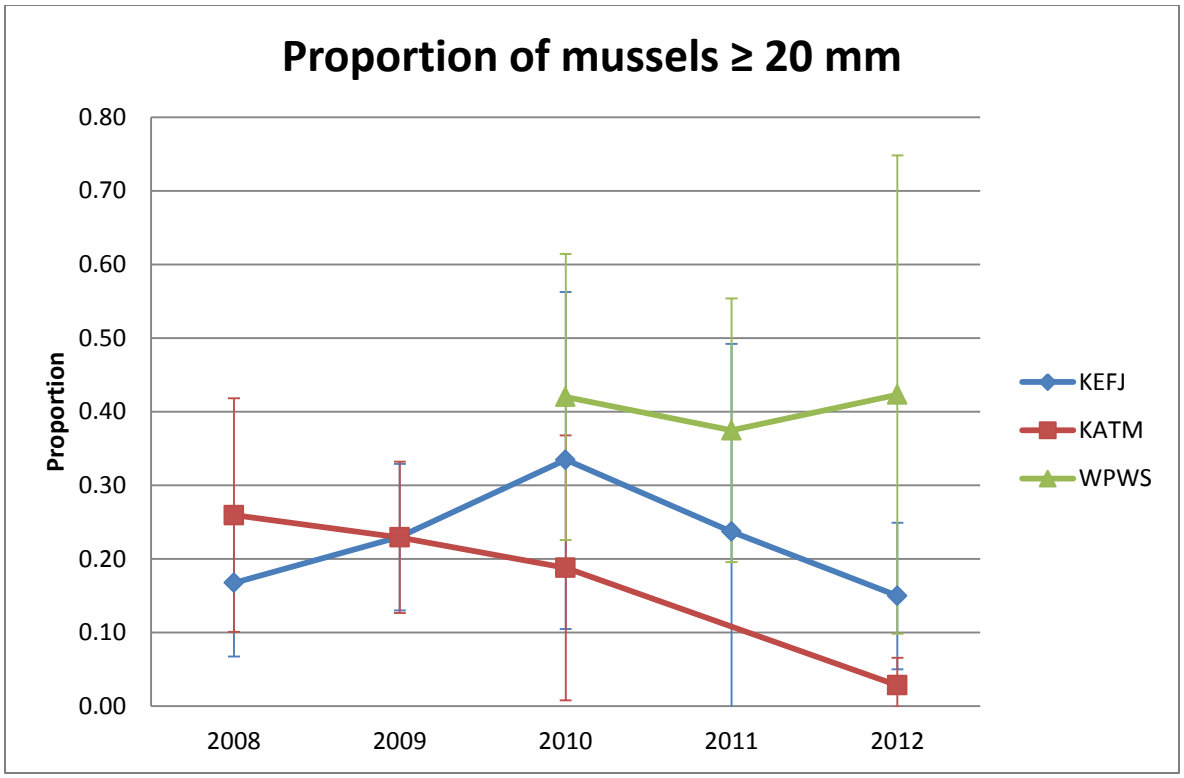


Figure 14. Proportion of mussels ≥ 20 mm in KATM, KEFJ, and WPWS, 2008-2012. Error bars indicate 90% CI.

Discussion

Using the methods briefly described above, we were able to estimate densities of mussels, the size distribution and density of large mussels (≥ 20 mm), and the proportion of large mussels. Mussel densities varied greatly between parks, both in terms of all mussels and large mussels. Mean sizes of large mussels were relatively uniform among all sites, indicated by the smaller error bars. The high uniformity in mean sizes and low variance among sites suggests common mechanisms structuring the sizes of mussels across all areas. While evaluating variance estimates of mussel densities and sizes for sensitivity to detect change will require additional years of data, the relatively low variation in mean sizes of large mussels across sites continues to suggest that mussel size may provide a statistically powerful metric to detect change over time.

Recommendations

Our fifth year of descriptive analysis indicates that sizes of mussels may provide a metric sensitive to change both among and within sites. We recommend the continuation of annual mussel bed sampling. Similar to the algae analysis discussed in the previous section, existing mussel bed data will allow the program to conduct trend analysis for several metrics and will be used in simulations to estimate number of samples and sample frequency required to detect a specified trend or change with some level of confidence for selected metrics, specifically the rocky intertidal algae and invertebrate vital sign. The levels of change or trend to be detected have already been specified by

the investigators (Dean and Bodkin 2011a, Dean et al. 2014). The Vital Signs Monitoring Plan for SWAN explicitly states the use of hierarchical models to estimate trends. The work proposed here is to assist the National Park Service in the modification of the protocol for its monitoring program. The SOP for mussel bed sampling will be finalized in 2014.

Eelgrass Bed Sampling

Introduction

Eelgrass (*Zostera marina*) is the dominant native seagrass in protected waters of the Gulf of Alaska and is broadly distributed in sheltered embayments, especially in habitats dominated by soft sediments where they often form “beds” or relatively monotypic stands that can cover much of the shallow (0 to 5 m depth) subtidal zone (McRoy 1968, 1970). Eelgrass is an important "living habitat" that serves as a nutrient filter, provides shelter for fish and a variety of invertebrates, and provides physical substrate for invertebrates and algae (Thayer and Phillips 1977, Jewett et al. 1999, Dean et al. 2000, Bostrom et al. 2006). Eelgrass is a major primary producer in the marine nearshore (McConnaughey and McRoy1979) and because it is located in shallow water, is susceptible to oil spills and other human disturbances (Short and Wiley-Eschevaria 1996, Dean et al. 1998, Duarte 2002, Larkum et al. 2006, Short et al. 2006). Eelgrass is especially susceptible to dredging, anchor scars, and events that reduce light penetration into the water column such as runoff (increased turbidity) or nutrient addition (Walker et al. 1989, Oleson 1996, Hauxwell et al. 2003, Neckles et al. 2005, Terrados et al. 2006).

The purpose of this sampling is to assess changes in the extent of eelgrass over time. In this report, we examine results from sampling eelgrass cover in KATM, KEFJ, and WPWS. The sampling is designed to examine a portion of a large eelgrass beds (within beds of approximately 1 km^2) over temporal scales of several years.

Methods

We sampled the percent cover of eelgrass at up to five designated sites in each area from 2010-2122. All sampling was conducted in early summer when eelgrass beds generally have reached their seasonal maximum in extent and density of plants. All beds sampled were in sheltered bays and were at beds in closest proximity to the randomly selected rocky intertidal sites (see intertidal invertebrates and algae section).

At each site, we sampled eelgrass within a prescribed area along a shoreline of approximately 200 m in length. The width of each bed examined depended on the depth contour at each site, but was generally on the order of 50 to 100 m. The areas sampled were bounded by an approximately 200 m segment of shoreline over which eelgrass was observed and extended offshore to a distance approximately 15 m beyond the last observed eelgrass. The percent cover of eelgrass within this area was estimated by determining the presence or absence of eelgrass at approximately evenly spaced intervals along a series of transects running perpendicular to shore that were spaced approximately 20 m apart. Presence or absence at each observation point was determined using an underwater video camera lowered from a small inflatable boat and/or a single-beam sonar.

These surveys will allow us to detect changes in average density of eelgrass over time. While we do not know the types of changes that might occur, these might include local reduction in cover due to increased boating activity and associated anchor scars, a lowering of the upper depth limitation due to a decline in water clarity, or larger scale die offs due to diseases or contaminants.

Results

The percent of observations with eelgrass present ranged from 25% to 82% in 2012 across all three regions (Tables 1, 2, 3). The highest percent covers observed in KATM were at Amalik Bay in 2010 and 2012. The highest percent covers observed in KEFJ were Harris Bay in 2010 and Nuka Pass in 2011 and 2012. The highest percent covers observed in WPWS were at Johnson Bay in 2010 and 2011 and in Iktua Bay in 2012.

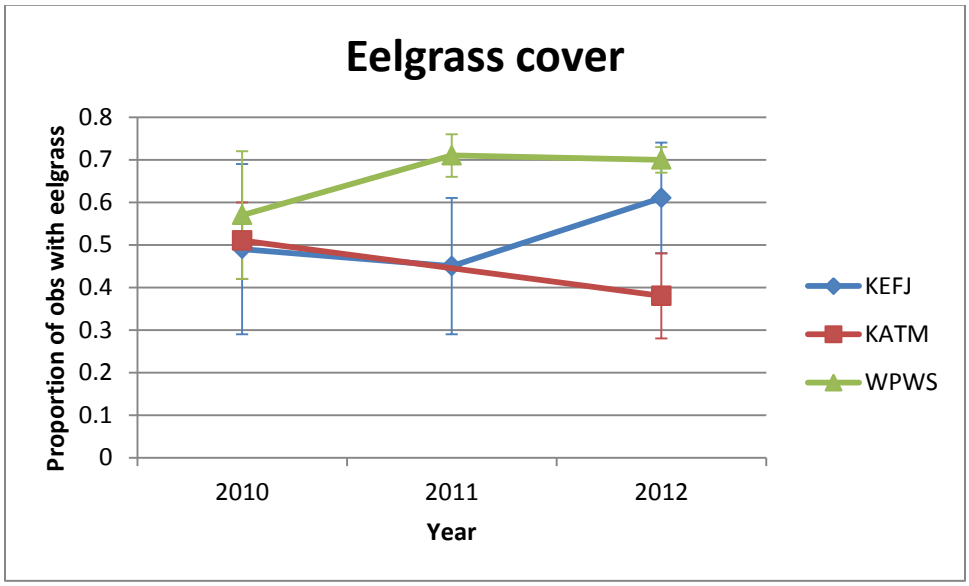


Figure 15. Proportion of observations with eelgrass present in KATM, KEFJ, and WPWS, 2008-2012. Error bars indicate 95% CI. KATM was not sampled in 2011.

Discussion

Using the methods briefly described above, we were able to estimate percent cover by eelgrass in designated sites. Data collected through 2012 should be sufficient to allow us to conduct power analyses to determine our ability to detect change in eelgrass cover over time; this will be considered as part of ongoing efforts.

Recommendations

Based on replicate sampling completed in 2008 (Coletti et al. 2009), our analysis indicated that the method produces relatively precise estimates of the relative density of eelgrass. We recommend the continuation of annual eelgrass bed sampling. Refinement of the SOP is on-going but we expect to finalize it in 2014.

Marine Bird Surveys

Introduction

Marine birds and mammals are important constituents of marine ecosystems and are sensitive to variation in marine conditions. Our focus on nearshore marine bird monitoring will be on species that are relatively abundant and trophically linked to the nearshore food web where the kelps and seagrasses contribute substantially to primary productivity and benthic invertebrates, such as clams, mussels and snails, transmit that energy to higher level trophic level fishes, birds and mammals. Species of focus in the nearshore food web include black oystercatchers (*Haematopus bachmani*), cormorants (*Phalacrocorax* spp.), glaucous-winged gulls (*Larus glaucescens*), black-legged kittiwakes (*Rissa tridactyla*), goldeneye ducks (*Bucephal*a spp.) (winter density and distribution), harlequin ducks (*Histrionicus histrionicus*), pigeon guillemots (*Cepphus columba*), mergansers (*Mergus* spp.) and scoters (*Melanitta* spp.). Because other birds and mammals will be encountered in the course of monitoring nearshore species, observations of all marine birds and mammals are recorded.

The sea ducks and black oystercatcher were selected for focus because of their reliance on habitats and prey associated with nearshore marine communities. These species play an important role as top level consumers of nearshore invertebrates, including mussels, clams, snails, and limpets, that are being monitored under the intertidal invertebrates and algae component (Draulans 1982, Marsh 1986a and b, Meire 1993, Lindberg et al. 1998, Hamilton and Nudds 2003, Lewis et al. 2007). Therefore, understanding changes in the abundance of these bird species over time is an important metric for nearshore monitoring. Abundance estimates will be enhanced by the monitoring of nearshore invertebrates, which focuses on their prey populations. Moreover, monitoring trends in abundance of the various guilds of other marine birds (e.g. pigeon guillemots, black-legged kittiwakes, and cormorants) that utilize other food sources may improve the ability to discriminate among potential causes of change in seabird populations and the nearshore ecosystem. For example, concurrent changes in sea ducks, which forage on nearshore invertebrates, and the pigeon guillemots that forage on small fish, may suggest a common cause of change, one that may be independent of food. Such an approach may provide insights related to competing hypotheses relative to cause of change within or among populations (Petersen et al. 2003). In addition many of these species, including the harlequin duck, Barrow's goldeneye, and black oystercatcher, were impacted by the *Exxon Valdez* oil spill, and exhibited protracted recovery periods as a consequence of lingering oil in nearshore habitats in western Prince William Sound (Andres 1999, Trust et al. 2000, Esler et al. 2000a and b, Esler et al. 2002). Long-term monitoring of these species at different locations will likely provide increased confidence in assessment of the status of these populations relative to restoration and recovery from the 1989 spill. Additionally, existing data collected using comparable methods are available from other nearshore habitats in the Gulf of Alaska for periods up to 20 years (Irons et al.1988, Irons et al. 2000).

Methods

Standardized surveys of marine birds were conducted in KATM (2006-2010 and 2012) and KEFJ (2007-2012) between late June and early July. Similar surveys are conducted by the USFWS in WPWS, but results for that area are not reported here. Surveys are conducted from small vessels (5-8 m length) traveling at speeds of 8-12 knots along selected sections of coastline that represent independent transects. The transect width is 200 m and the boat represents the midpoint. Transects are surveyed by a team of three. The boat operator generally surveys the 100 m offshore area of the transect, while a second observer surveys the 100 m nearshore area. The third team member enters the observations into a laptop running program dLOG, specifically designed for this type of surveying, and assists with observations. All marine birds and mammals within the 200 m transect width are identified and counted. All transects considered in this analysis are run 100 m offshore and parallel to the shoreline. Detailed descriptions of methods and procedures can be found in the Marine Bird and Mammal Survey SOP (Bodkin 2011a).

The survey design consists of a series of transects along shorelines such that a minimum of 20% of the shoreline is surveyed. Transects are systematically selected beginning at a random starting point from the pool of contiguous 2.5-5 km transects that are adjacent to the mainland or islands, plus the lengths of transects that were associated with islands or groups of islands with less than 5 km of shoreline.

Each species is identified as important to nearshore food webs and as an important indicator of change (Dean and Bodkin 2011a, Dean et al. 2014). Several species were grouped into higher order taxa (e.g., cormorants, mergansers and scoters) because identification to species within these groups was not always possible. Cormorant species included pelagic, red-faced, and double crested cormorants. Merganser species include common merganser and red-breasted mergansers. Scoters included surf, black, and white-winged scoters.

Results

Only focal species densities and standard errors observed on nearshore transects are reported here (Figures 15-22). In general, there have been no notable shifts in densities over time. However, a possible decline in black oystercatcher densities has occurred in KATM, but more rigorous analysis is needed.

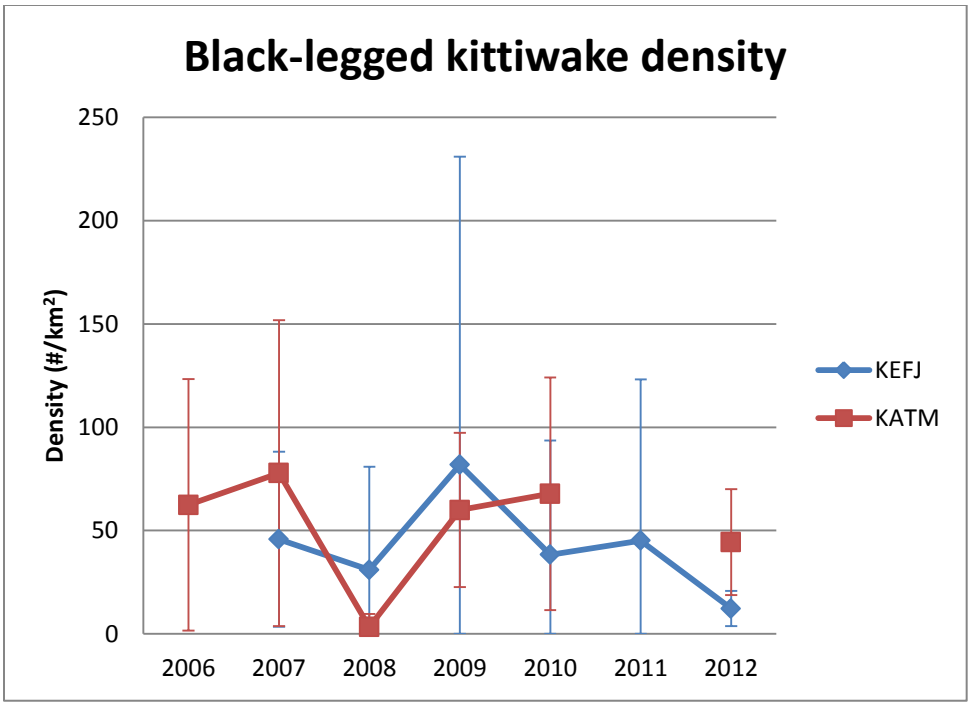


Figure 16. Density of black-legged kittiwake in KATM and KEFJ, 2006-2012. Error bars indicate 95% CI.

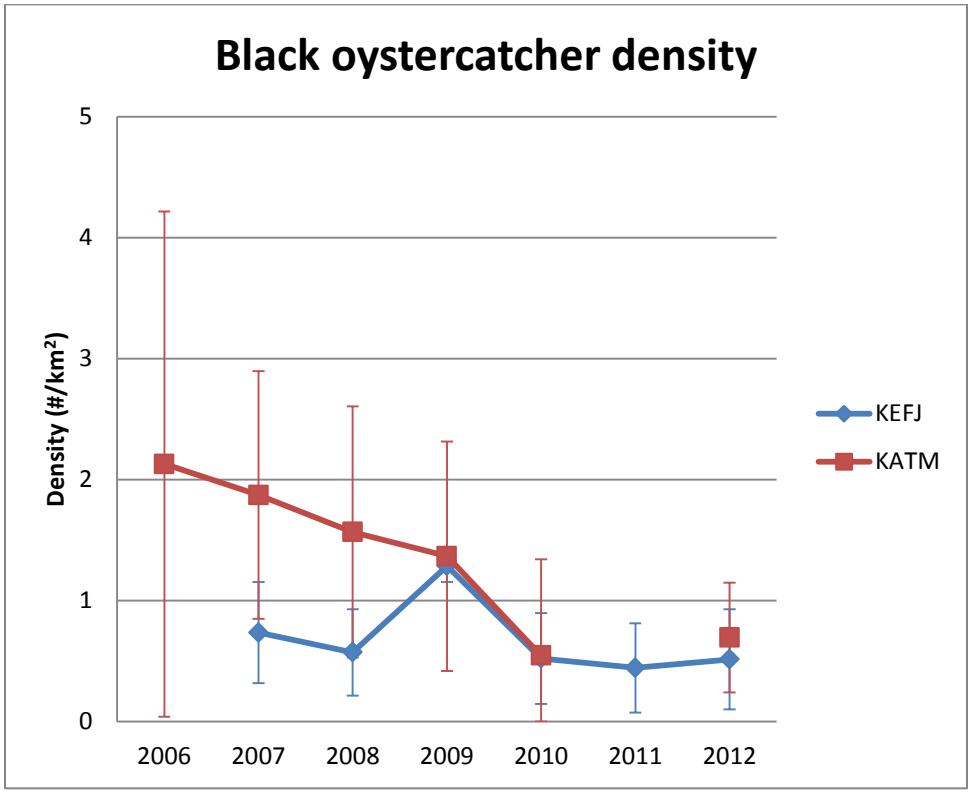


Figure 17. Density of black oystercatcher in KATM and KEFJ, 2006-2012. Error bars indicate 95% CI.

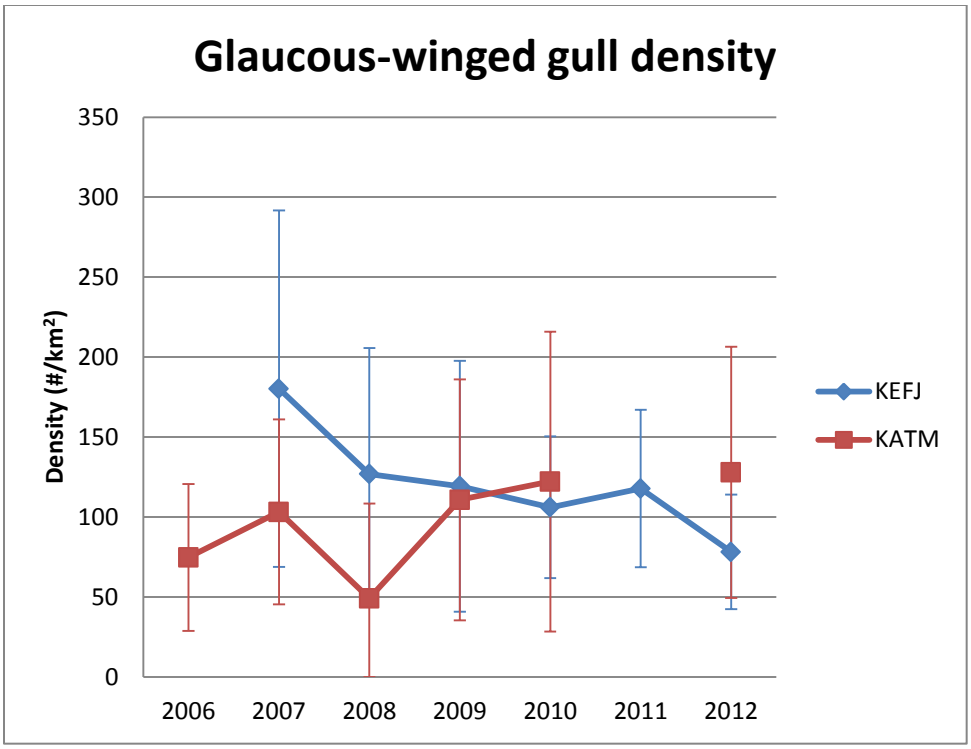


Figure 18. Density of glaucous-winged gull in KATM and KEFJ, 2006-2012. Error bars indicate 95% CI.

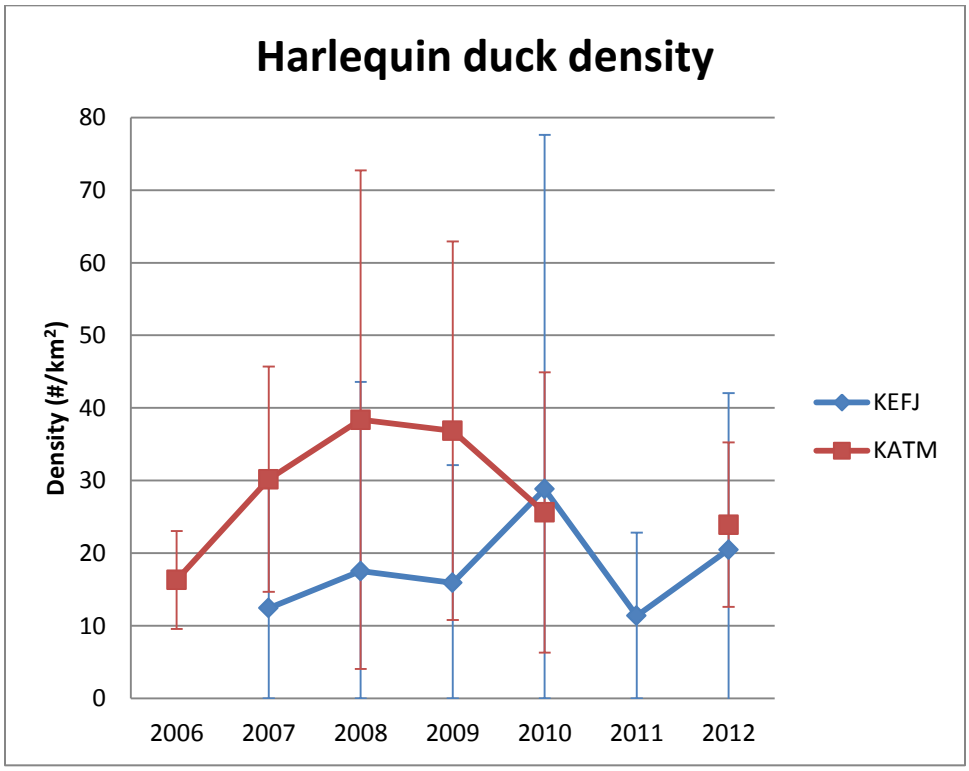


Figure 19. Density of Harlequin duck in KATM and KEFJ, 2006-2012. Error bars indicate 95% CI.

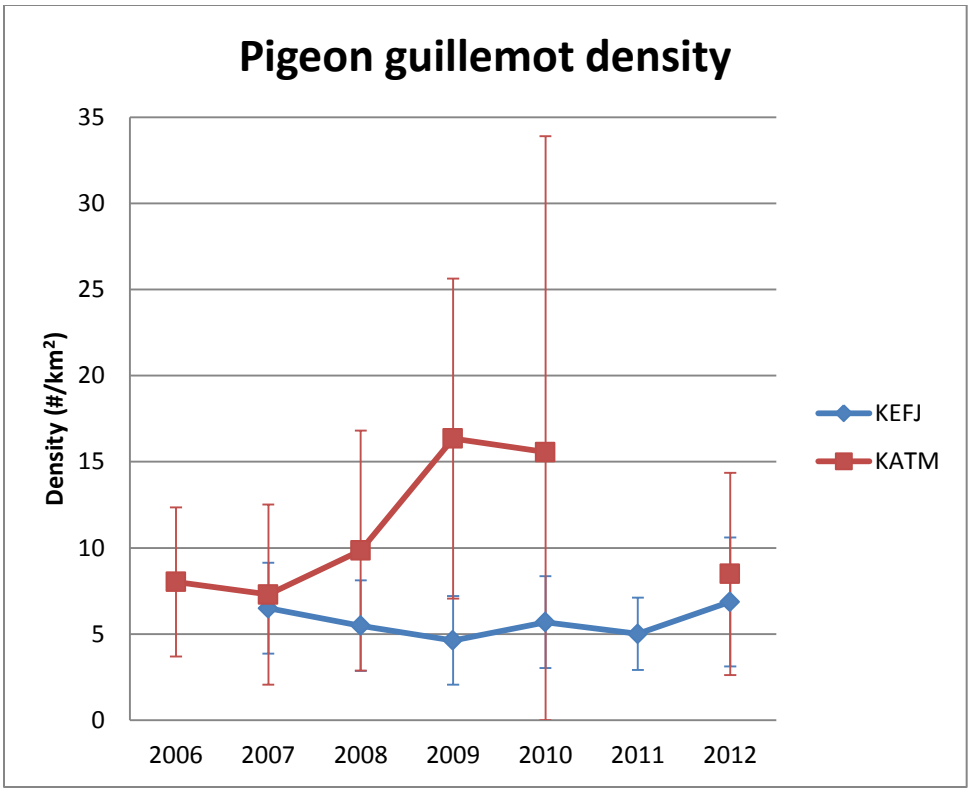


Figure 20. Density of pigeon guillemot in KATM and KEFJ, 2006-2012. Error bars indicate 95% CI.

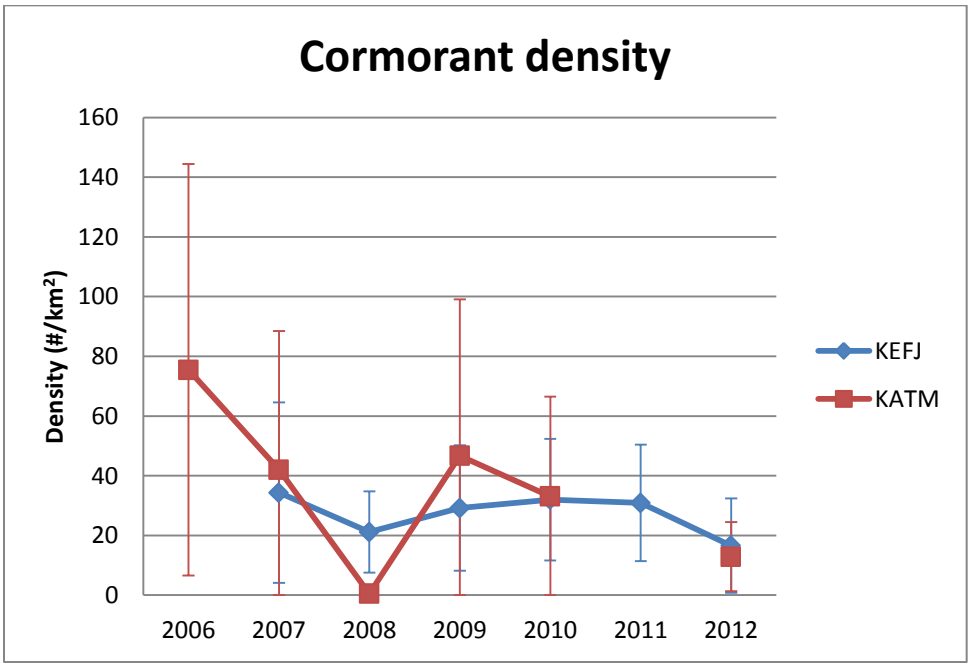


Figure 21. Density of cormorants in KATM and KEFJ, 2006-2012. Error bars indicate 95% CI.

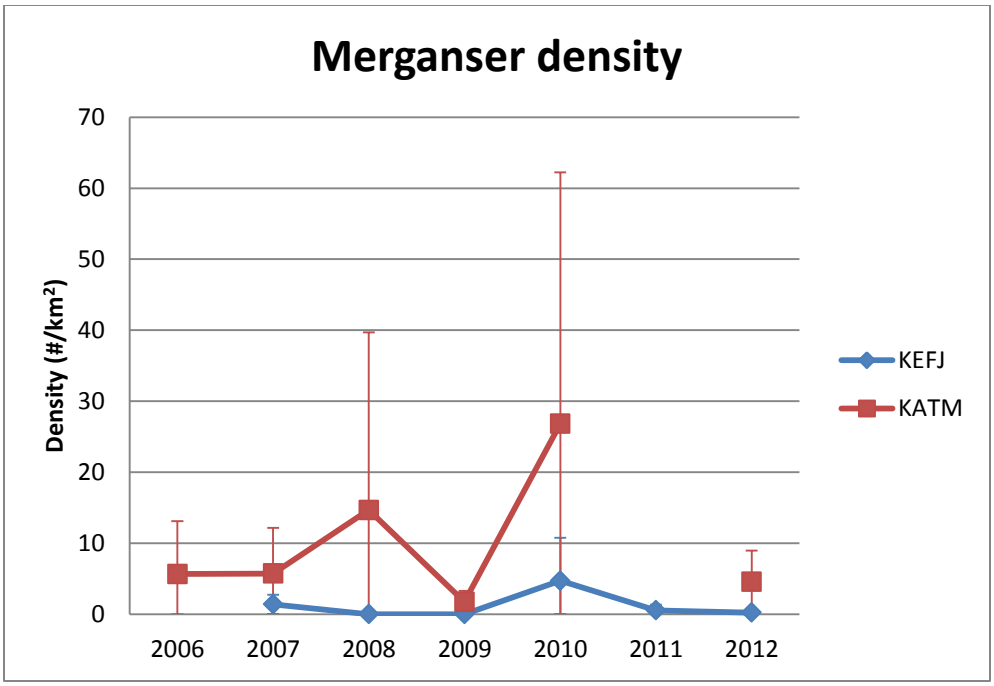


Figure 22. Density of mergansers in KATM and KEFJ, 2006-2012. Error bars indicate 95% CI.

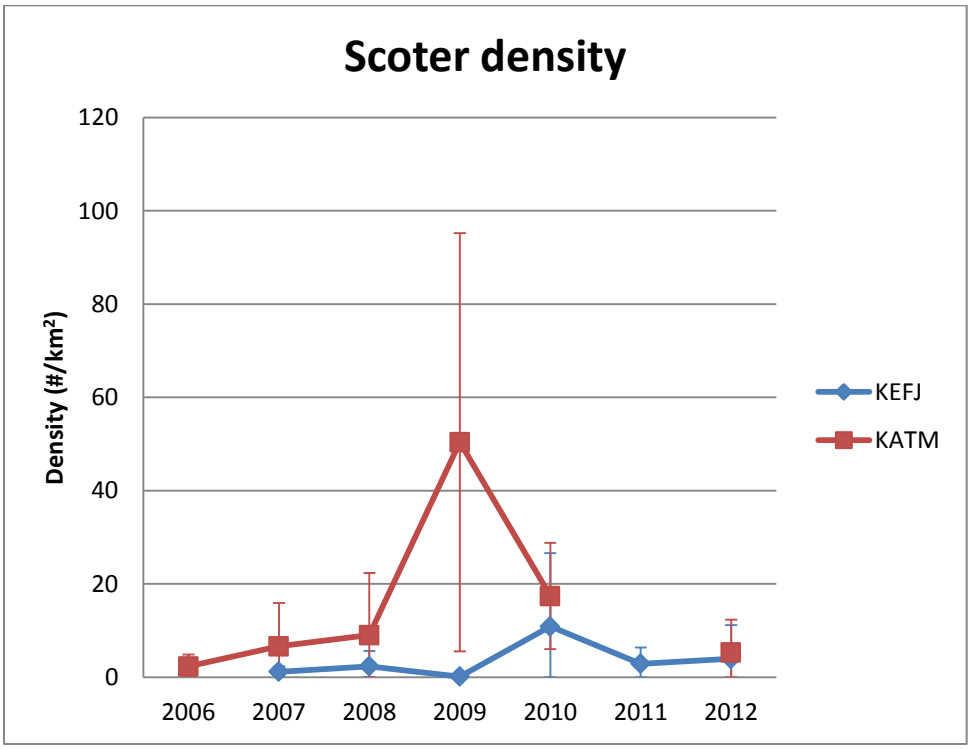


Figure 23. Density of scoters in KATM and KEFJ, 2006-2012. Error bars indicate 95% CI.

Discussion

KATM and KEFJ continue to be sampled annually during the summer. These shoreline skiff surveys provide baseline information on species composition, distribution and density for summer populations of marine bird and mammal fauna that occur in the nearshore waters of KATM and KEFJ. Because components of the marine bird and mammal fauna may change seasonally, inference of species composition, distribution, and densities to other seasons cannot be made. In particular, it is likely that some sea duck species that were rare or absent in the summer may be more common as over wintering residents (e.g. goldeneye, scoters, and long-tailed ducks). Sustainability of long-term monitoring programs requires the optimization of sampling intensity and efforts to minimize costs while concurrently having sufficient power to detect a trend. While there has been critical thought in the past regarding these questions, current available analytical methods now allow for the use of existing data to estimate number of samples and sample frequency required to detect a specified trend as well as examine effects contributing to variation, such as imperfect detection. An optimization exercise using existing data will occur in 2014.

Recommendations

We recommend that survey effort continue until further analysis can be completed. These datasets will be examined to determine levels of change that we can reasonably expect to detect based on this sampling method. We will also explore the possibility of re-allocating sampling efforts to specific habitat types or incorporate replicate sampling to enhance our ability to detect trends for species of interest.

Black Oystercatcher Sampling

Introduction

The black oystercatcher is a common and conspicuous member of the rocky and gravel intertidal marine communities of eastern Pacific shorelines and is completely dependent on nearshore marine habitats for all critical life history components including foraging, breeding, chick-rearing, and resting (Andres and Falxa 1995). During the late spring and summer breeding season pairs establish and defend both nest and forage areas, and these territories and nest sites can persist over many years (Groves 1984, Hazlitt and Butler 2001) with individual life expectancy exceeding 15 years (Andres and Falxa 1995). The diet consists primarily of mussels and limpets, which are ecologically and culturally important constituents of the intertidal community. The species is considered a Management Indicator Species by the Chugach National Forest and a species of concern nationally (Brown et al. 2001) and regionally (Alaska Shorebird Working Group 2000), and is widely recognized as a species representative of nearshore habitats. Because of their complete reliance on intertidal habitats, their reproductive biology, and foraging ecology, black oystercatchers are particularly amenable to long-term monitoring (Lentfer and Maier 1995, Andres 1998).

As a "keystone" species (Power et al. 1996), the black oystercatcher has a large influence on the structure of intertidal communities that is disproportionate to its abundance. The black oystercatcher receives its recognition as a keystone species through a three-trophic-level cascade initiated by the oystercatcher as a top level consumer in the nearshore (Marsh 1986a and b, Hahn and Denny 1989, Falxa 1992, Andres and Falxa 1995) whose diet consists largely of gastropod (limpets; *Lottia*, *Acmea*, and *Colisella* spp.) and bivalve mollusks (mussels; *Mytilus* spp.) that are ecologically important in the intertidal community. As a consequence of oystercatcher foraging, large numbers of herbivorous limpets can be removed (Frank 1982, Lindberg et al. 1987), resulting in shifts in limpet species composition and reduced size distribution (Marsh 1986a, Lindberg et al. 1987). As a consequence of reduced limpet densities and the diminished grazing intensity that results, algal populations respond through increased production and survival, resulting in enhanced algal populations (Marsh 1986a, Meese 1990, Wootton 1992, Lindberg et al. 1998). Additionally, like many other invertebrate, avian and mammalian predators in the nearshore, a large fraction of the oystercatcher's diet consists of mussels, an important filter feeding bivalve (Knox 2000, Menge and Branch 2001). Because the oystercatcher brings limpets, mussels and other prey back to its nest to provision chicks (Webster 1941, Frank 1982, Hartwick 1976, Lindberg et al. 1987), collections of those shell remains at nests provides an opportunity to obtain an independent sample of the species composition and size distribution of common and important nearshore invertebrate prey species that are directly estimated under intertidal algal and invertebrate vital signs (Intertidal Invertebrates and Algae section of this report). The collection of black oystercatcher diet and prey data offers a unique perspective into processes structuring nearshore communities (Marsh 1986a and b, Lindberg et al. 1987), including the potential consequences of anticipated increases in human presence and disturbance (Lindberg et al. 1998). Further, contrasting relative abundances and size-class composition of invertebrates collected under two independent protocols should increase our understanding of the processes responsible for change in nearshore ecosystems.

At a global scale, intertidal communities have been impacted by human activities (Liddle 1975, Kingsford et al. 1991, Povery and Keough 1991, Keough et al. 1993, Menge and Branch 2001) and one of the primary capabilities and intents of the nearshore monitoring program is to provide early detection of change in nearshore communities and to separate human from natural causes of change. Because of the critical nature of intertidal habitats for both breeding and foraging, black oystercatchers are particularly sensitive indicators to disturbances in the nearshore (Lindberg et al. 1998). Specifically, black oystercatchers nest exclusively in a narrow band just above the intertidal but below terrestrial vegetation, where eggs are laid in exposed nests consisting of depressions in pebbles, sand, gravel, and shell materials. During the 26-32 d incubation phase of reproduction, eggs are susceptible to predation by other birds (primarily C*orvids*; Lentfer and Meier 1995) and mammals (Vermeer et al. 1992), as well as human disturbance and trampling. Similar disturbance effects occur during the chick rearing stage, which lasts approximately 38 d (Andres and Falxa 1995). Thus, for several months during May-August, typically when humans are most present in nearshore habitats in Alaska, black oystercatchers are actively incubating or caring for young in a habitat with little protection from human induced disturbances. Chronic disturbance from human activities poses a significant threat to breeding black oystercatchers, either preventing nesting altogether, causing nest abandonment after eggs have been laid (Andres 1998), or through direct mortality of eggs or chicks. Monitoring of black oystercatcher density, breeding territory density and occupancy, and prey will provide a potentially powerful tool in identifying the magnitude and causes of inevitable change in Gulf of Alaska nearshore habitats and communities, particularly in response to the anticipated increased use and influence of those habitats by humans.

Methods

There are three components to the sampling related to black oystercatchers: estimation of breeding pair density and nest occupancy through oystercatcher-specific surveys; estimation of species composition and size distributions of prey returned to provision chicks; and density estimation of breeding and non-breeding black oystercatchers observed during the marine bird and mammal surveys. Results regarding the black oystercatcher density estimates are given in the marine bird survey section of this report. Detailed survey methods for estimation of nest occupancy and diet can be found in the black oystercatcher breeding territory occupancy and chick diet SOP (Bodkin 20011b). The detailed methods used to obtain marine bird densities can be found in the marine bird SOP (Bodkin 2011a) and in Bodkin et al. (2007b and 2008).

Black oystercatcher breeding territory density, nest occupancy, and prey data were collected along five 20 km transects, with each centered on the randomly (GRTS) selected rocky intertidal algal and invertebrate sites at KATM since 2006 (no sampling in 2011), KEFJ since 2007, and WPWS in 2007 and since 2010. Nest sites were located by surveying the shoreline in a small boat. All accessible nest sites were visited to determine the number of chicks and/or eggs present and all prey items (e.g. mussel or limpet shells) present at a nest site were collected. All prey were measured. Here, we present size data for most abundant prey species, Pacific blue mussels (*Mytilus trossulus*) and the limpets (*Lottia pelta*, *Lottia persona* and *Lottia scutum*).

Results

Density and Productivity

All five black oystercatcher GRTS transects were analyzed at the park / region level for nest density (nest/km) and productivity (chicks + eggs/nest) by year in KATM, KEFJ and WPWS. The mean density of active black oystercatcher nest sites at KATM ranged from 0.05 to 0.11 per km of shoreline from 2006-2012 (Figure 23). The mean density of active black oystercatcher nest sites at KEFJ ranged from 0.05 to 0.10 per km of shoreline from 2007-2012 (Figure 23) and from 0.06 to 0.14 per km of shoreline in WPWS between 2007 and 2012. The mean productivity (eggs + chicks / nest) ranged from 1.42 to 2.3 eggs + chicks / nest for KATM from 2006-2012 (Figure 24). The mean productivity (eggs + chicks / nest) ranged from 0.12 to 1.92 eggs + chicks / nest for KEFJ from 2007-2012 (Figure 24) and from 0.5 to 1.71 eggs + chicks / nest in PWS from 2007-2012. KEFJ and KATM showed a slight increase in the number of active nests in 2012. However, WPWS has showed a decline in the number of active nests since 2010 through 2012. KEFJ and WPWS have both shown a decline in the productivity of active nests, however, it appears that KATM has been stable from 2010-2012.

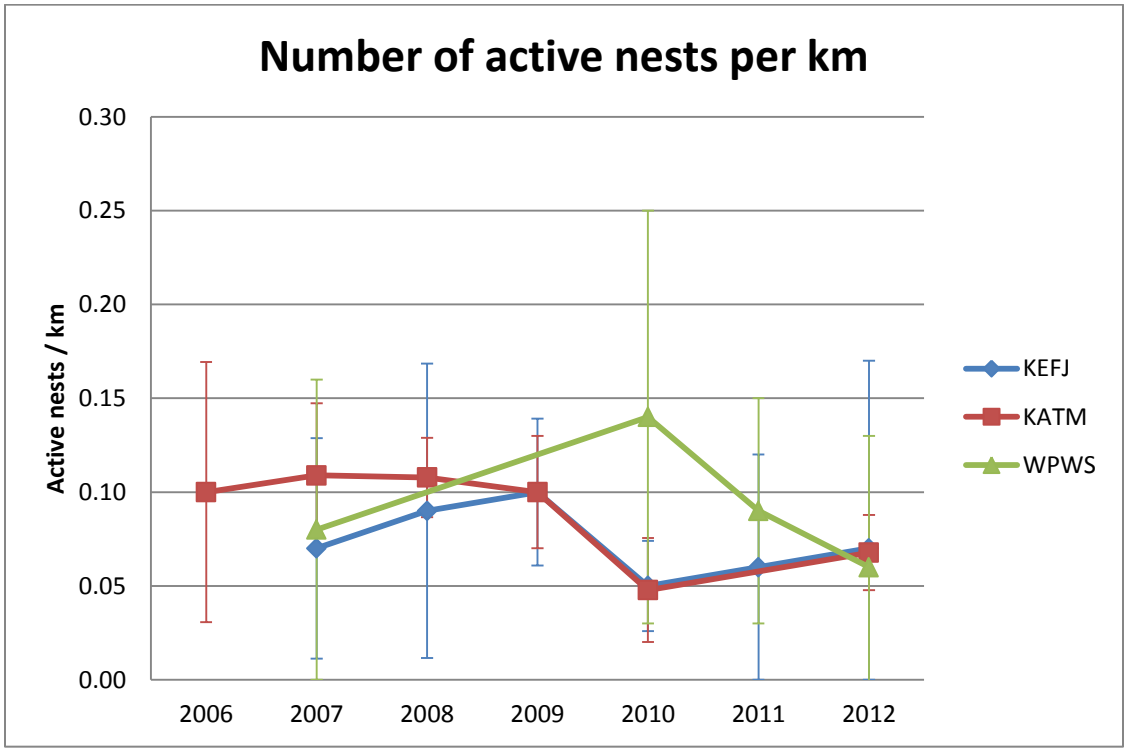


Figure 24. Number of active black oystercatcher nests / km in KATM, KEFJ, and WPWS, 2006-2012. Error bars indicate 95% CI.

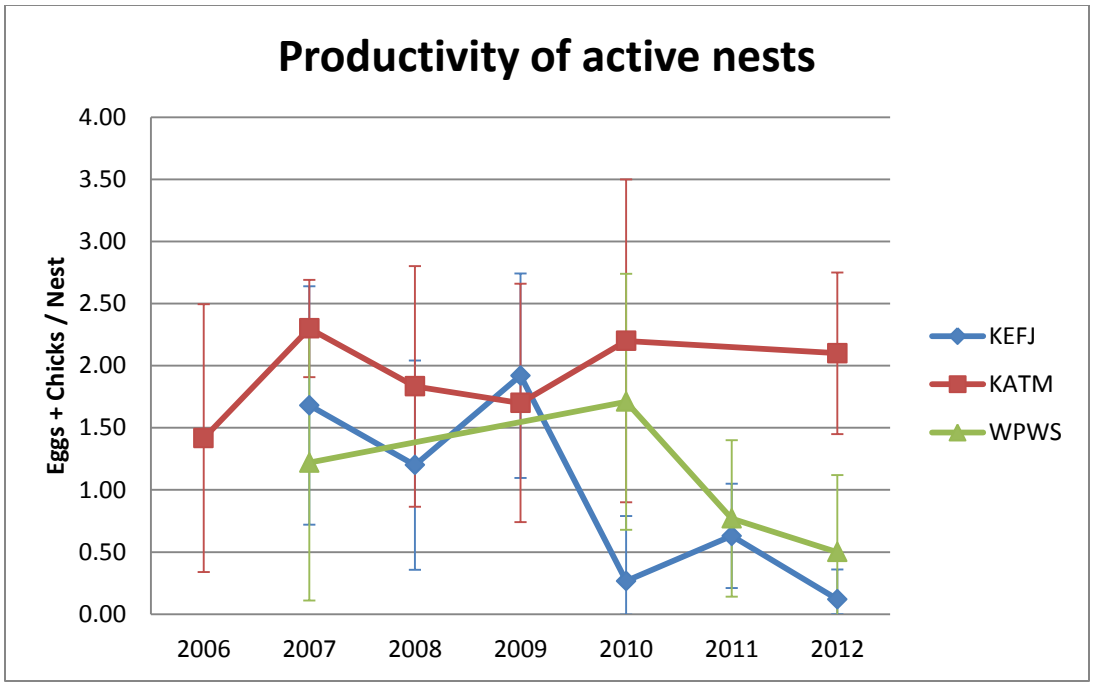


Figure 25. Productivity (eggs + chicks / nest) of active black oystercatcher nests / km in KATM, KEFJ, and WPWS, 2006-2011. Error bars indicate 95% CI.

Diet

Three species of limpets *(Lottia pelta, Lottia persona,* and to a lesser extent *Lottia scutum*) and the Pacific blue mussel (*Mytilus trossulus)* were the predominant prey items found at black oystercatcher nest sites in KATM, KEFJ and WPWS (Figures 25, 26 and 27). Together these species represented 94% of prey items found at KATM (2006-2012) nest sites and 96% in KEFJ and PWS (2007-2012) for all sampling years. No prey items were observed or collected in KEFJ in 2010 or 2012. Prey items were only available to be collected at two nests in KEFJ in 2011.

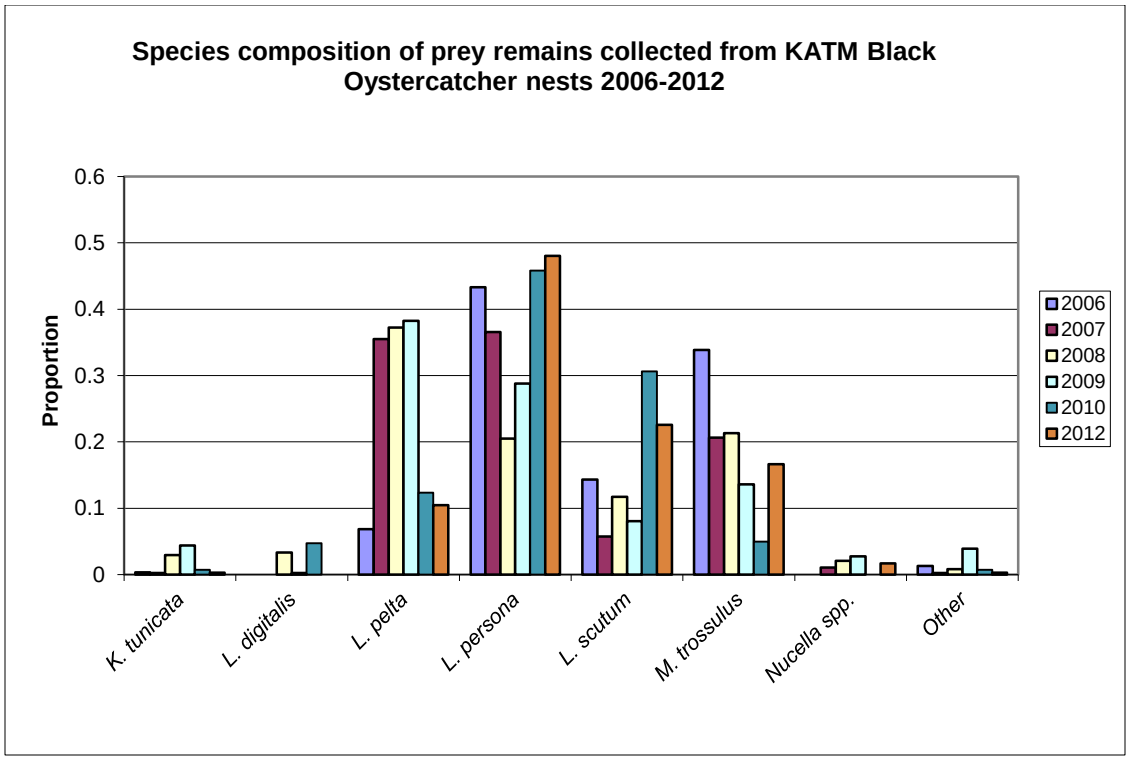


Figure 26. Species composition of prey items collected at active black oystercatcher in KATM, 2006-2012. KATM was not sampled in 2011.

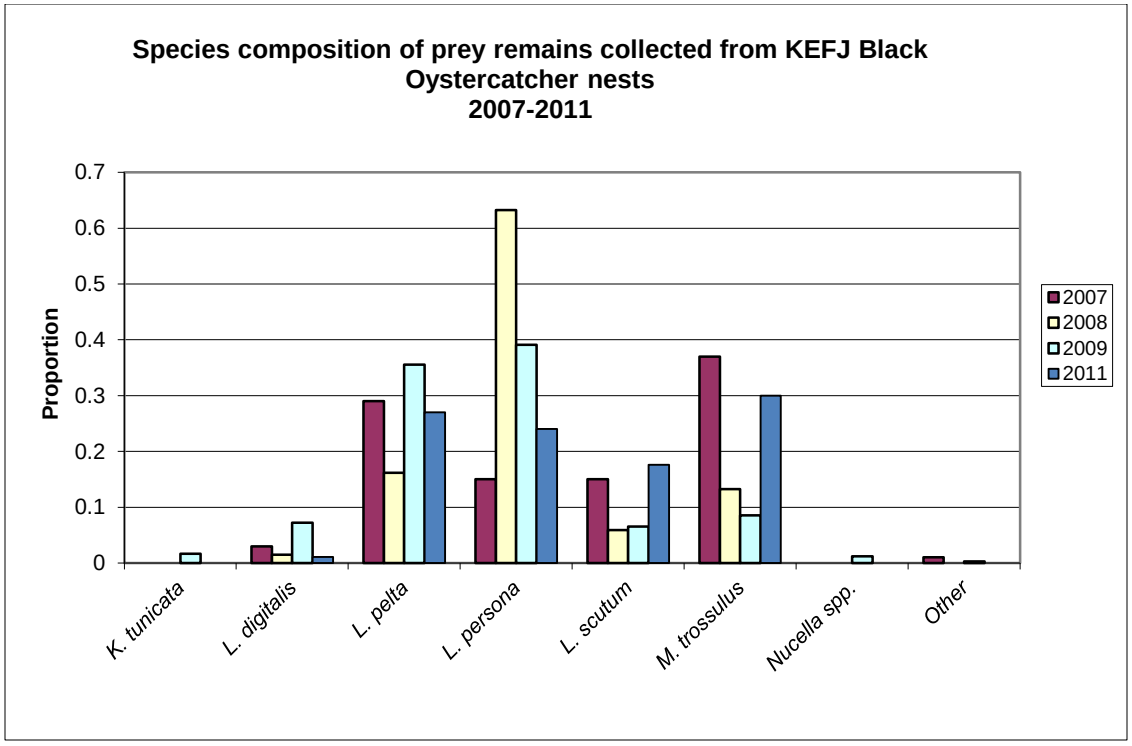


Figure 27. Species composition of prey items collected at active black oystercatcher in KEFJ, 2007-2012. No prey items were observed or collected in 2010 or in 2012.

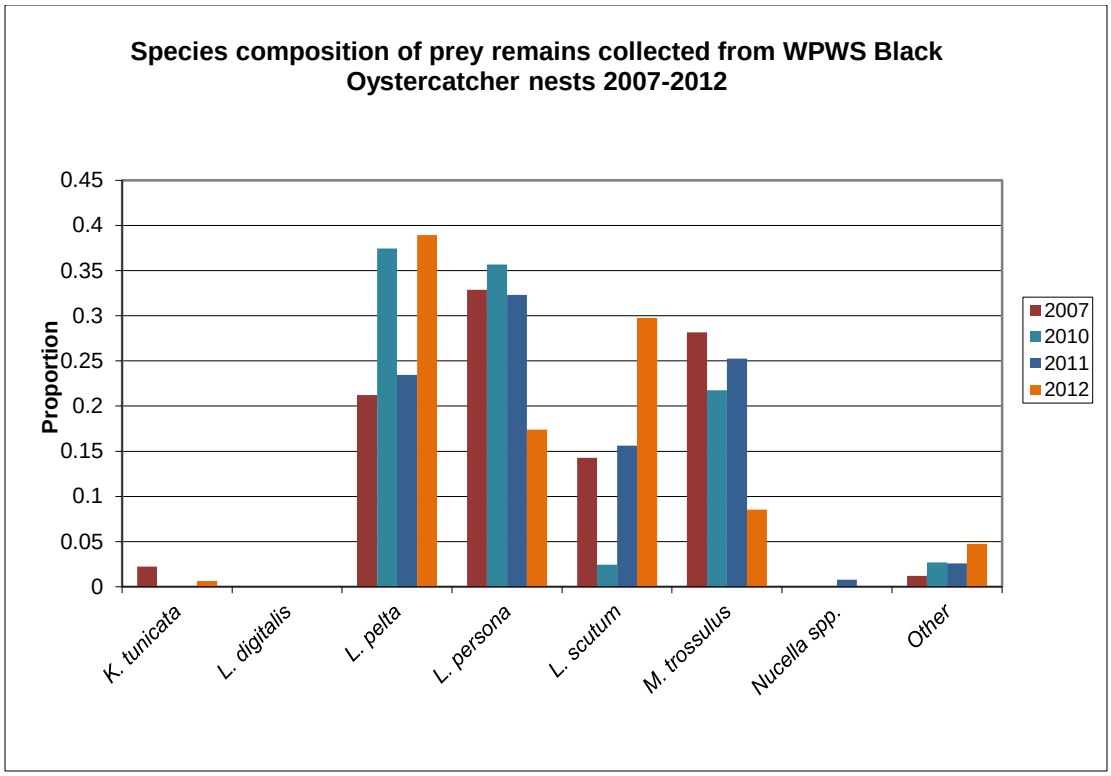


Figure 28. Species composition of prey items collected at active black oystercatcher in WPWS, 2007-2012. WPWS was not sampled in 2008 or 2009.

Prey size is measured for all species. However, we report only on the mean size of two of the most predominate species, the limpet *Lottia persona* and the mussel, *Mytilus trossolus*. Both of the species are also monitored for density and size within the sampling of Intertidal Invertebrates and Algae on Sheltered Rocky Shores SOP (Dean and Bodkin 2011b). Mean *L. persona* size ranged from 18.84 to 23.02 mm in KATM from 2006-2012, from 18.45 to 22.96 mm in KEFJ from 2007-2012 (no prey items observed in 2010 or 2012), and from 17.71 to 20.32 mm in WPWS from 2007-2012 (Figure 28). Mean *M. trossulus* size ranged from 27.44 to 45.05 mm in KATM from 2006-2012, from 20.07 to 29.92 mm in KEFJ from 2007-2012 (no prey items observed in 2010 or 2012), and from 30.57 to 35.27 mm in PWS from 2007-2012 (Figure 29).

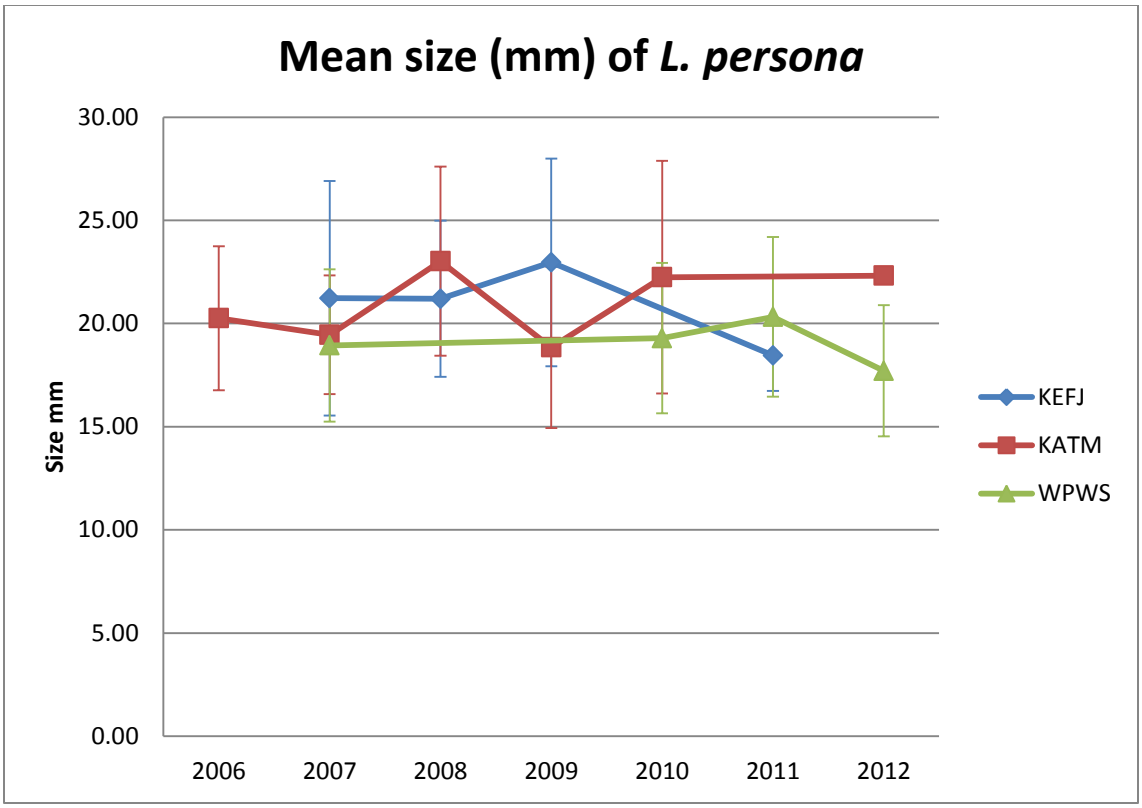


Figure 29. Mean size of *L. persona* from at active black oystercatcher nests in KATM (2006-2010, 2012), KEFJ (2007-2012) and WPWS (2007-2012). No prey items were observed in KEFJ in 2010 or 2012.

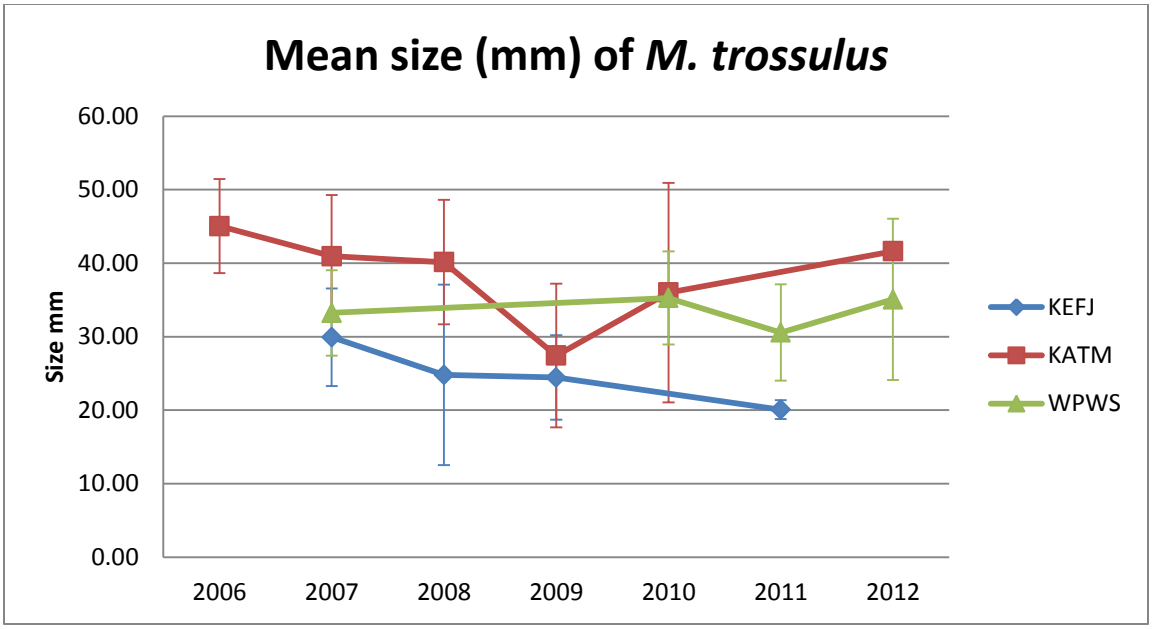


Figure 30. Mean size of *M. trossulus* from at active black oystercatcher nests in KATM (2006-2010, 2012), KEFJ (2007-2012) and WPWS (2007-2012). No prey items were observed in KEFJ in 2010 or 2012.

Discussion

Our data continues to show that black oystercatchers are targeting the larger size classes of mussels and limpets, based on our random sampling in the rocky intertidal and mussel bed sites. Variation in sizes of prey was generally relatively low. This is not surprising, but may be a key metric for monitoring purposes. Measurements of sea otter prey, pre- and post- arrival of sea otters in Glacier Bay, AK, have indicated a decline in prey sizes correlated with the increased occupation of Glacier Bay with sea otters (Bodkin et al. 2007a and c). A similar result possibly may occur as densities in nesting black oystercatchers changes. Lower densities of black oystercatchers may lead to increased densities of larger size classes of mussels and limpets sampled at the rocky intertidal sites and mussel beds or nest sites. The reverse may also be possible, with increased black oystercatcher densities associated with decreases in the densities of the larger size classes of prey.

Recommendations

Surveys of black oystercatcher abundance, nest density, and diet as reflected through prey remains brought to provision chicks have been successfully implemented in KATM, KEFJ and WPWS and have shown that at appropriate spatial scales of analysis, our data should continue to be collected with little revision. Sampling at the current intensity should allow us to detect trends in changes of nest density, productivity and diet (especially prey size) of the black oystercatcher. It appears as though breeding pairs may have multiple nests at a nest site and care should continue to be taken to recognize these as comprising the same nest site. It will be important to conduct future surveys as close as possible in time to these initial surveys and care must continue to be taken to minimize the disturbance to nests during sampling.

Sea Otter

Introduction

Sea otters (*Enhydra lutris*) are a common, conspicuous, and important component of the nearshore trophic food web throughout the North Pacific. They occupy all types of nearshore habitats from sheltered bays, estuaries, and fjords to exposed rocky coastlines (Kenyon 1969), but are constrained by their diving ability to habitats shallower than 100 m depth (Bodkin et al. 2004) and a near exclusive dietary reliance on benthic invertebrate prey (Riedman and Estes 1990). As a consequence of their nearshore distribution and relatively small home ranges, a rich literature exists on the biology, behavior, and ecology of the species. The sea otter provides one of the best documented examples of top-down forcing effects on the structure and function of nearshore marine ecosystems in the North Pacific Ocean (Kenyon 1969, VanBlaricom and Estes 1988, Riedman and Estes 1990, Estes and Duggins 1995) and are widely regarded as a "keystone" species in coastal marine ecosystems (Power et al. 1996). They cause well described top-down cascading effects on community structure by altering abundance of prey (e.g. sea urchins) which can in turn alter abundance of lower trophic levels (e.g. kelps). Sea otters generally have smaller home ranges than other marine mammals, eat large amounts of food, are susceptible to contaminants such as those related to oil spills, and have broad appeal to the public. From the mid-1980s through 2005 declines in sea otters have been observed in the Aleutian Islands (Doroff et al. 2003, Estes et al. 2005, Burn and Doroff 2005). As a result, the Western Alaska stock of sea otters, which occurs from Cook Inlet to the Western Aleutian Islands, which includes Katmai National Park and Preserve as well as Aniakchak National Monument and Preserve, was federally listed in September 2005 as threatened.

For the reasons outlined above, several metrics related to sea otters are incorporated under this vital sign. They include: observations of sea otter foraging, carcass collections to evaluate the age structure of the dying population, and aerial surveys to estimate population abundance. Because sea otters occur outside the boundaries of the skiff-based shoreline marine bird and mammal surveys, and because detection is not estimated during the skiff-based surveys, aerial surveys designed specifically to provide accurate and precise estimates of sea otter abundance (Bodkin and Udevitz 1999) are incorporated into the nearshore monitoring program.

Sea otter population abundance and trends are frequently influenced by the type and quantity of available prey (Kenyon 1969, Monson et al. 2000). Observations of foraging sea otters provide information on food habits, foraging success, (mean proportion of feeding dives that are successful) and efficiency (mean kcal/dive) based on prey numbers, types and sizes obtained by feeding animals. Because sea otter populations are often prey limited, data on foraging behavior will be useful in evaluating potential causes for differences in sea otter densities or trends among regions or years (Estes et al. 1982, 2003b, Gelatt et al. 2002, Dean et al. 2002, Bodkin et al. 2002, Tinker et al. 2008).

Due to high spatial variability in marine invertebrate populations (e.g. extreme patchiness) and difficulty in sampling underwater prey populations, foraging sea otters provide an alternative method to direct sampling of subtidal invertebrates. Following a successful foraging dive, sea otters return to the surface to consume their prey. This provides the opportunity to identify, enumerate, and estimate

the size of the benthic organisms they consume. Therefore sea otter foraging observations will provide data on species composition and sizes of subtidal invertebrate prey populations that are difficult to obtain directly. Observations collected over time may allow inference to changes in the species composition and sizes of the nearshore benthic invertebrate communities.

As a result of their nearshore distribution and relatively high density, moribund sea otters often haul out ashore, or their carcasses drift onto beaches. Annual collections of sea otter carcasses provide a record of the ages of dying individuals through analysis of cementum deposition in teeth (Bodkin et al. 1997). The age distributions of dying sea otters generated from annual carcass collections can provide a baseline against which future distributions can be compared and potentially provide inference regarding causes for change in population abundance, behavior, or diet (Monson et al. 2000, Estes et al. 2003a). Combined with data from a fresh carcass stranding program or annual population surveys, age-specific mortality data modeling can be used to inform managers regarding conservation decisions related to causes of mortality (Gerber et al. 2004, Tinker et al. 2006).

Brief summaries of the methods and 2012 results for sea otter foraging observations, carcass collections, and cementum tooth age analysis are presented in this report. The methods and results of the 2012 sea otter aerial survey in KATM are also reported here.

Methods

Aerial survey

The survey follows protocols described in detail in Bodkin and Udevitz (1999) which is summarized here. The survey is conducted from a small, single engine, float-equipped aircraft with both the pilot and observer able to observe out each side of the aircraft. The airplane is flown at a speed of 105 kph (65 mph) and at an elevation of 91 m (300 ft). The survey design consists of systematic sampling of 400 m wide transects spanning the survey area. Sampling intensity is proportional to expected sea otter abundance with most survey effort taking place where higher densities of sea otters are generally observed. The high density sea otter stratum extends from shore to 400 m seaward or to the 40 m depth contour, whichever is greater. Bays and inlets less than 6 km wide are also categorized as part of the high density stratum, regardless of depth. The remaining survey effort is over deeper, offshore waters where lower densities are generally observed (Figure 1). Specifically, the low density sea otter stratum extends from the high density stratum line to 2 km offshore or from the 40 m depth contour to the 100 m depth contour, whichever is greater. Intensive searches, initiated by the observer, are periodically conducted within the transect swaths to estimate the proportion of sea otters not initially detected during the strip counts. Strip counts are adjusted for the area not surveyed and by a detection correction factor to obtain an adjusted population size estimate. Additionally, groups larger than approximately 20 individuals are circled until a complete count is obtained and are treated as a separate stratum, uncorrected in the analysis. Surveys are conducted in alternate years in different areas; the 2012 survey was at KATM.

Survey transects used in KATM in 2012 were identical to those used in 2008 with spacing of transects in the shallow water strata or high density strata every 1.2 km and 2.4 km between transects in the deep water stratum or low density stratum. A total of 267 transects, representing approximately 975 linear km in the shallow water and deep water strata, were surveyed. The survey area ranged

from Cape Douglas to the southwest end of Cape Kubugakli at the park boundary. Transects located near river mouths were often dry at lower tides and thus not flown. In those circumstances, the transect was marked as such and removed from the area surveyed for analysis.

During the survey, we entered data using a custom survey application (Doug Burn, U.S. Fish and Wildlife Service, Anchorage, AK) in ArcPad (ESRI Inc., Redlands, CA). After the survey, data were post-processed in ArcMap (ESRI Inc.) and SAS 9.3 (SAS Institute, Cary, NC) to estimate population size.

Foraging

Prey composition, foraging success rate, and prey size were obtained from shore based observations of randomly selected foraging otters. Shore-based observations limited data collection to sea otters feeding within approximately 1 km of shore. High powered telescopes (Questar Corp., Hew Hope, PA) and 10X binoculars were used to record prey type, number, and size class during foraging bouts of focal animals. A bout consisted of observations of repeated dives for a focal animal while it remains in view and continues to forage (Calkins 1978). Assuming each foraging bout records the feeding activity of a unique individual, bouts were considered independent while dives within bouts were not. Thus the length of any one foraging bout was limited to 20 dives, or one hour, after which a new focal animal was chosen. Within each bout sampled the following data were recorded: date, start and end time, age class, sex, pup status and location coordinates. Foraging data collected include dive and surface interval times, success, prey species, number and size, and if prey were given or taken (typically given to a pup, or taken by a con-specific). The sampling design included the acquisition of foraging data within a 10 km radius of each of the five established rocky intertidal invertebrate and algal sites. The objective was to annually obtain data from 10 individuals within each of these 10 km buffers, a total of 50 bouts per year.

Sea otters in the study areas were generally not individually identifiable. In addition, some foraging areas may have been used more than others by individuals and by otters living in the area in general. Therefore individual sea otters may have been observed more than once leading to potential bias toward individuals sampled more than once. To minimize this potential, observers use characteristics such as sex, sizes, coloration, and pup presence to identify individuals. If more than one animal was observed foraging, selection was based on proximity, alternating between closest and furthest.

Carcass

Throughout the study areas in KATM, KEFJ, and WPWS we have identified segments of shoreline or offshore islands to search for sea otter carcasses. Annually, these areas have been consistently searched by two or more observers. Search patterns cover from the storm strand line to the water's edge and focus on areas where larger amounts of debris collect. When a carcass is found the skull and baculum, whiskers, and tissue if present, are collected. The following data are recorded: date, observers, condition of carcass, sex, parts collected, latitude/longitude, location on beach (e.g. strand line, above high tide, etc.), and cause of mortality (usually not known). A premolar tooth (or substitute if the premolar is not available) is sent to Matson's Laboratory in Montana for cementum layer age analysis.

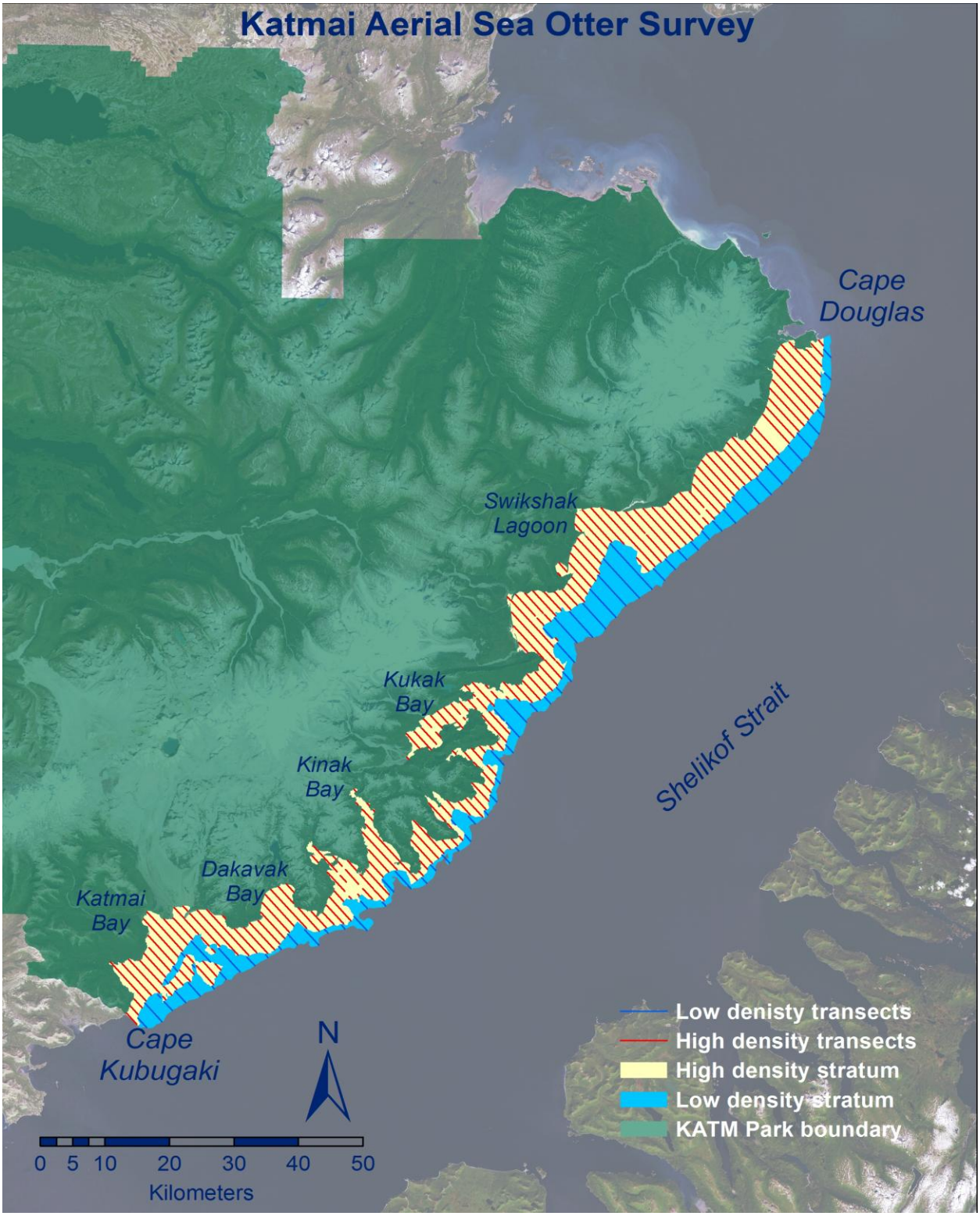


Figure 31. Sampling transect locations for the high density stratum (in yellow) and low density stratum (in blue) used in the aerial survey of sea otter abundance in KATM during August of 2012.

One of the objectives for this monitoring program is to detect levels of change deemed ecologically important (Dean and Bodkin 2011a, Dean et al. 2014). Ecologically relevant changes in sea otter population estimates have been set at 0.40 (40% increase or decrease). For the sea otter foraging data we have established a 0.35 change in the proportion of dominant prey categories, a 0.50 change in prey size and a 0.20 increase or 0.33 decrease in the number of hours needed to meet energetic requirements as ecologically relevant changes to detect. Programming capable of providing variance estimates of energy recovery rates is presently in revision, precluding power analysis for this metric. Power analysis for linear regression (Gerrodette 1993) was used to evaluate levels of change in focal species densities that could be detected over time. Forage data are analyzed at the spatial scale of a park. Future analyses may include finer spatial resolution analyses as sample sizes increase within each of the five buffers associated with the intertidal sites and should include caloric recovery rate power analyses. Grouping sea otter ages into juvenile, prime-age adult, and aged adult categories will be used to evaluate change over time. A 0.4 change in any age class has been determined to be ecologically significant.

Results

Aerial survey

Between 8 and 10 August, 2012, 267 transects in the high and low density strata were surveyed in KATM to estimate sea otter abundance (Table 1). The high density stratum consisted of approximately 985 km^2 and the low density of approximately 465 km^2, representing 975 linear km in the shallow water and deep water strata (Figure 31). One hundred and ninety seven transects comprising 793 km of high density transect length, and 70 transects comprising 182 km of low density transect were surveyed. Sea otters were observed on both high and low density transects (Table 1, Figure 32). Pups were primarily observed throughout the high density stratum and eleven large groups (≥20) were also observed on transect, primarily in the high density stratum (Figure 32). The estimated detection probability was 0.53 resulting in a correction factor of 1.88 and a total estimated population size of approximately 8,644 (SE=1,243) sea otters residing within the surveyed area of KATM. The overall density is 5.96/km^2 (Table 1). Six large groups (≥20) and one small group (n=1) of sea otters were observed off transect. Three of the large groups were in the vicinity of Dakavak Bay, and one each in Katmai Bay, Swikshak and off Cape Douglas. The one small group off transect was observed in Hallo Bay (Figure 33).

Table 1. Sea otter population abundance estimates for KATM from 2012. Uncorrected population size is the population size before the correction factor is applied to calculate adjusted population size.

Stratum	Uncorrected Population Size	Correction Factor	Adjusted Population Size	*SE*	Complete Counts	Corrected Density #/km2
High Density	3631	1.88	6808	1053	270	6.91
Low Density	256	1.88	479	197	81	1.03
Total			**8644**[1]	**1243**		**5.96**

[1] Total adjusted population size does not equal the sum of the high and low density strata because the adjusted population size also includes complete counts. Complete counts are treated as a separate stratum in the analysis.

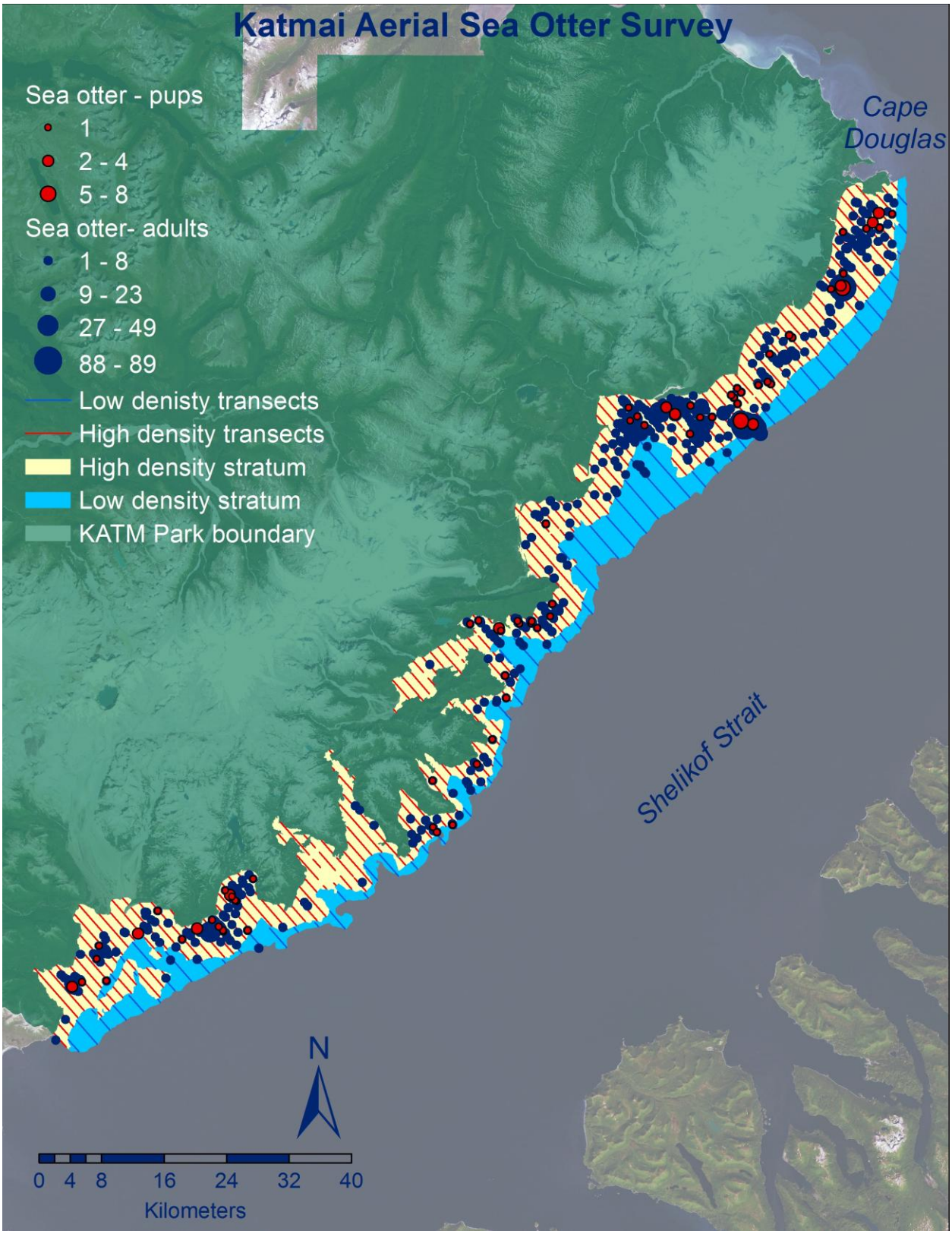


Figure 32. Distribution and relative abundance of adult and pup sea otters in KATM, August 2012.

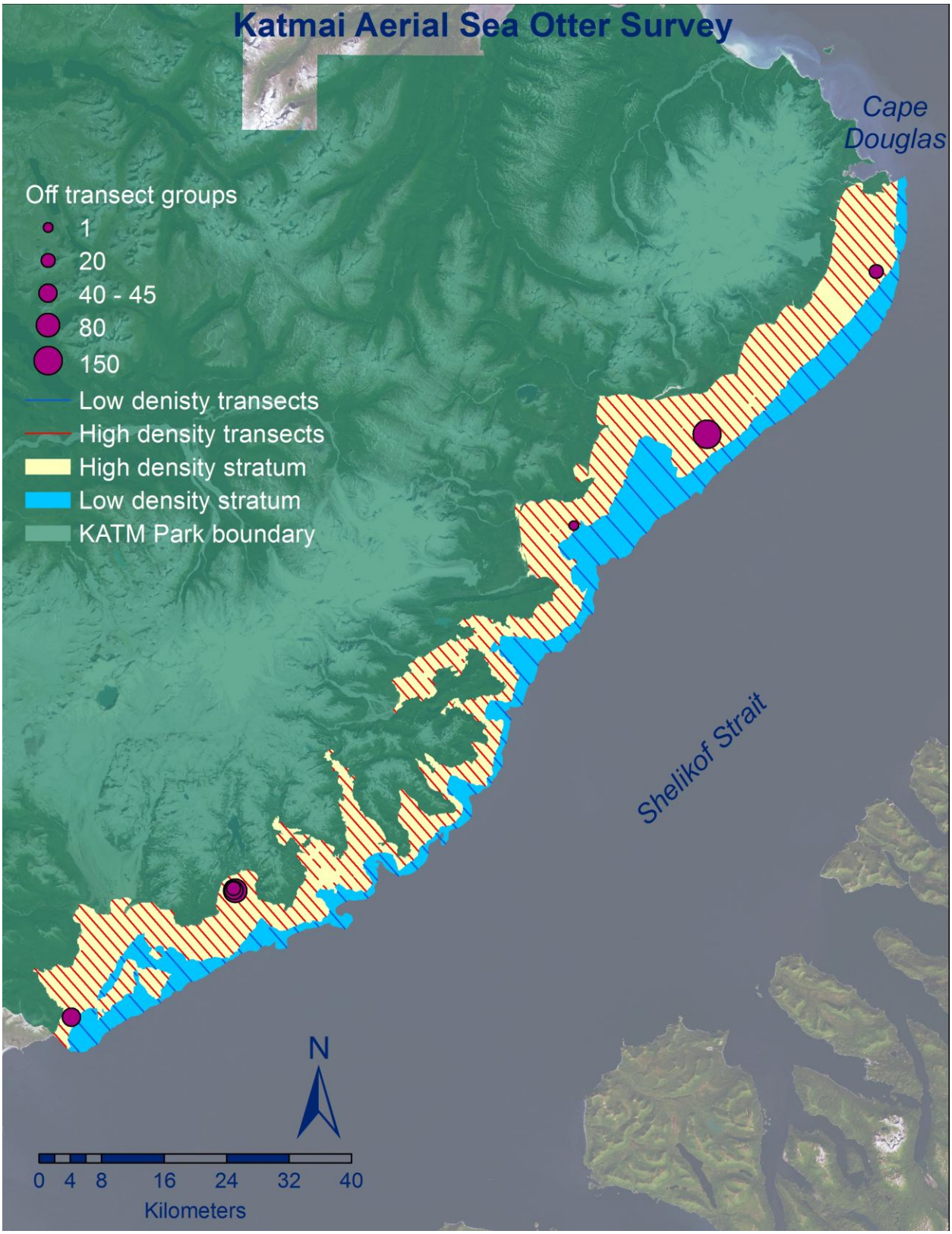


Figure 33. Groups of sea otters observed off transect, KATM, August 2012.

Foraging

During six field seasons (2006-2010, 2012) at KATM we obtained data from 289 independent sea otter foraging bouts, consisting of 2,726 dives (Table 5). The prey recovery success rate was 88% for dives with known outcomes (range 82% - 92%) (Figure 33). During six field seasons (2007-2012) at KEFJ we obtained data from 283 independent sea otter foraging bouts, consisting of 2,509 dives (Table 5). The prey recovery success rate was 88% for dives with known outcomes (range 68% - 96%) (Figure 33). During five field seasons (2007, 2008, 2010-2012) at WPWS we obtained data from 427 independent sea otter foraging bouts, consisting of 2,372 dives (Table 5). The prey recovery success rate was 89% for dives with known outcomes (range 88% - 92%) (Figure 33).

Since 2006, we have observed sea otters feeding on at least 40 different prey items including bivalves, decapod crustaceans, gastropods, echinoderms, and fish. At KATM, clams dominated sea otter diets across all years of data collection, comprising approximately 60% numerically, (range 36% - 71%) of the diet (Figure 34). Chitons, crabs, mussels, octopus, snails, sea stars, sea urchins, and other prey each comprised less than 10% of the of prey recovered during most years, although exceptions do exist. In 2006 octopus accounted for 13% of identified prey, in 2008 chitons were 17%, in 2009 snails and urchins accounted for 30% and 14%, respectively, in 2010 snails accounted for 11%, and in 2012 snails and urchins accounted for 11% each of the prey retrieved.

At KEFJ, mussels (*Mytilus trossulus*) dominated sea otter diets across all but the most recent year of data collection, comprising 58% (range 27% - 79%) of the diet (Figure 34). In all years but 2012, clams were the second most prominent prey item comprising 28% (range 13% - 61%) of the diet. Otherwise, chitons, crabs, octopus, snails, sea stars, sea urchins, and other prey each comprised less than 10% of the of prey recovered.

At WPWS, clams dominated sea otter diets across all years of data collection, comprising 56% (range 47% - 96%) of the diet (Figure 34). In 2007 and 2010 mussels accounted for 30% and 23% of identified prey, in 2012 crab accounted for 16% of identified prey, while in 2011 and 2012 ‘other prey’ accounted for 16% and 10%, respectively. The ‘other prey’ category for this location and this range of dates is comprised of non-clam/non-mussel bivalves, sea cucumbers, egg cases, and worms. This category should not be confused with ‘unknown’ prey which is not included in the prey composition calculations but will be shown in the mean size figures.

Sizes of prey captured by foraging sea otters vary by species (Figure 35). In KATM, the predominant prey, clams, averaged 54 mm over all sites and all years combined. Crabs (45mm), snails (32 mm), mussels (42 mm), urchins (39 mm), and unidentified (34 mm) prey items were smaller than the clams being retrieved while chitons (71 mm), and stars (99 mm) were larger than the clams.

In KEFJ, the predominant prey, mussels, averaged 24 mm over all sites and all years (Figure 35). Clams averaged 49 mm, crabs 60 mm, urchins 40 mm, and unidentified prey items were 27 mm. Sample sizes were low for the other prey categories.

In WPWS, the predominant prey, clams, averaged 48 mm over all sites and all years (Figure 35). Mussels averaged 23 mm, crabs 53 mm, urchins 34 mm, and unidentified prey items were 33 mm. Sample sizes were low for the other prey categories.

For clams and mussels, mean size per year has been reported in Figure 36. There is no observed difference in the size of clams between parks nor across years. Mussels, the primary prey item in KEFJ, have a similar mean size across years in KEFJ. Data are too scant to determine if the larger average size at KATM is meaningful. Unidentified prey size at both parks does not vary much across years. In KATM unidentified prey are consistently smaller than the mean size of the predominant prey while in KEFJ unidentified prey are similar in size to the predominant prey.

Table 2. Summary of sea otter foraging observations in KATM, KEFJ, and WPWS from nearshore monitoring data collection, 2006 - 2012. Foraging data were not collected in KEFJ and WPWS in 2006, WPWS in 2009, and KATM in 2011. A bout is the sampling unit for data analysis.

Year	Number of bouts observed			Number of dives observed			Mean number of dives per bout (SE)		
	KATM	KEFJ	WPWS	KATM	KEFJ	WPWS	KATM	KEFJ	WPWS
2006	65	.	.	451	.	.	6.7(0.2)	.	.
2007	54	45	81	498	471	365	7.7(0.2)	8.9(0.3)	7.6(0.3)
2008	38	57	5	427	392	28	8.6(0.3)	5.7(0.2)	6.3(1.0)
2009	36	37	.	392	269	.	8.4(0.3)	7.2(0.3)	.
2010	49	57	96	522	497	581	7.7(0.2)	7.0(0.3)	8.6(0.3)
2011	.	54	101	.	581	585	.	8.3(0.2)	7.9(0.3)
2012	47	33	144	436	299	813	7.5(0.3)	8.1(0.3)	8.1(0.2)
All Years	289	283	427	2,726	2,509	2,372	7.7(0.1)	7.6(0.1)	8.1(0.1)

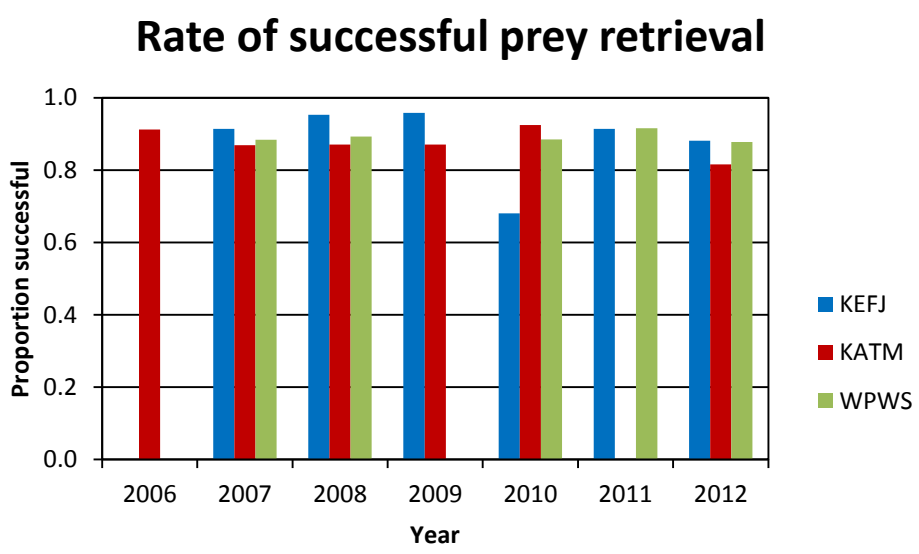
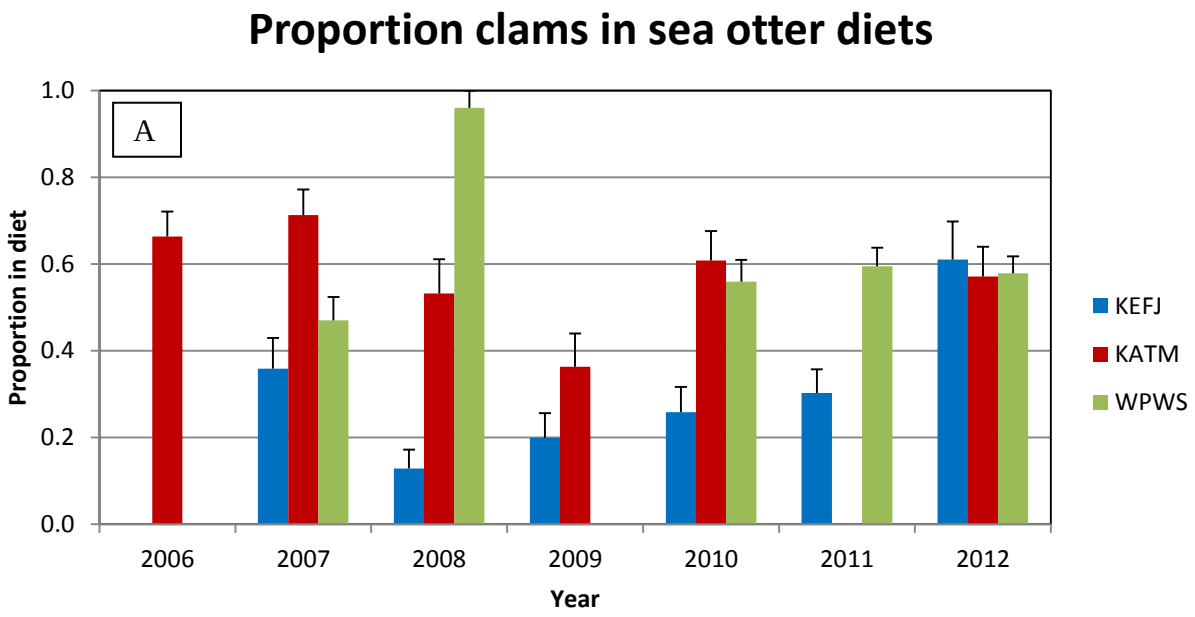
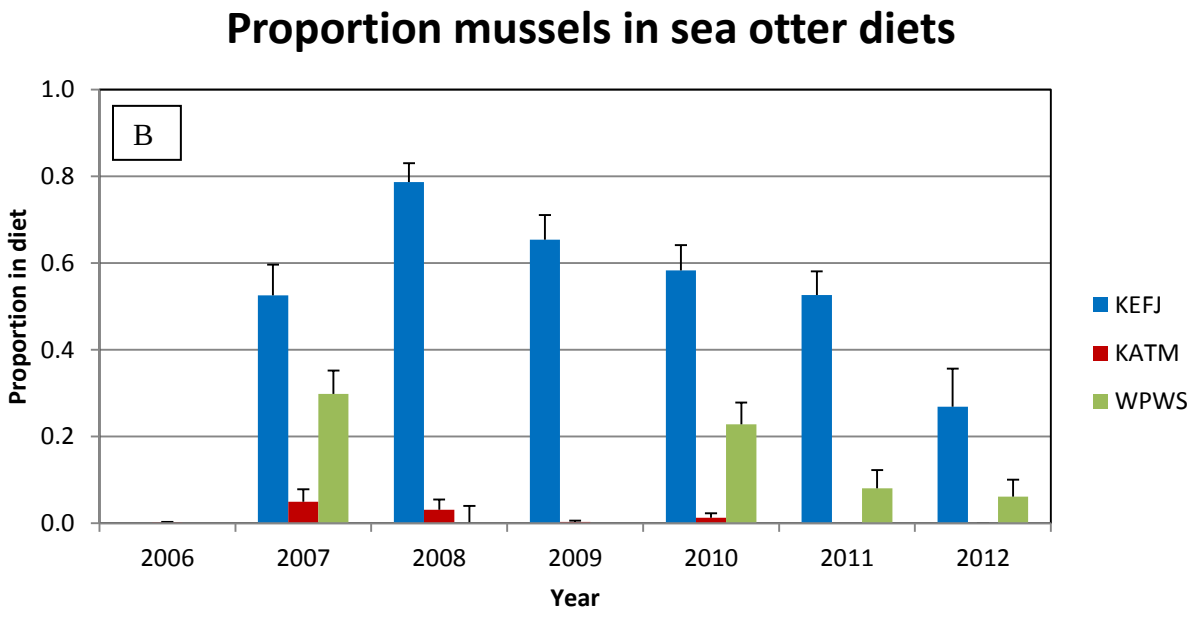
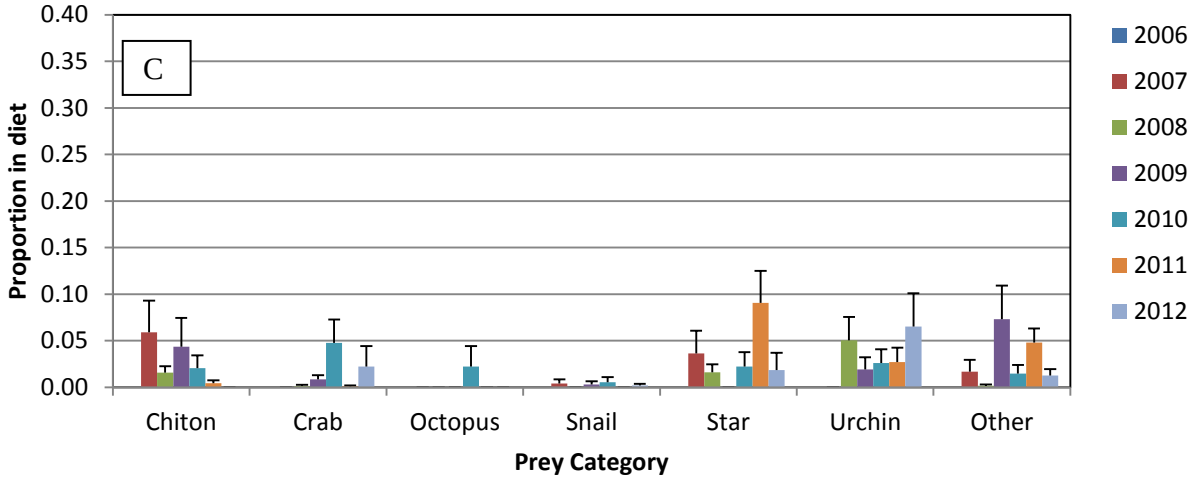


Figure 34. Success rate equals the proportion of known outcome dives where prey was successfully retrieved (Yes) by foraging sea otters in KATM 2006-2010, 2012, KEFJ, 2007-2012, and WPWS 2007-2008, 2010-2012. Dives in which otters were retrieving a previously collected prey item that had been dropped were not included. Additionally, a dive is only counted towards the success rate once, even if more than 1 item was retrieved.

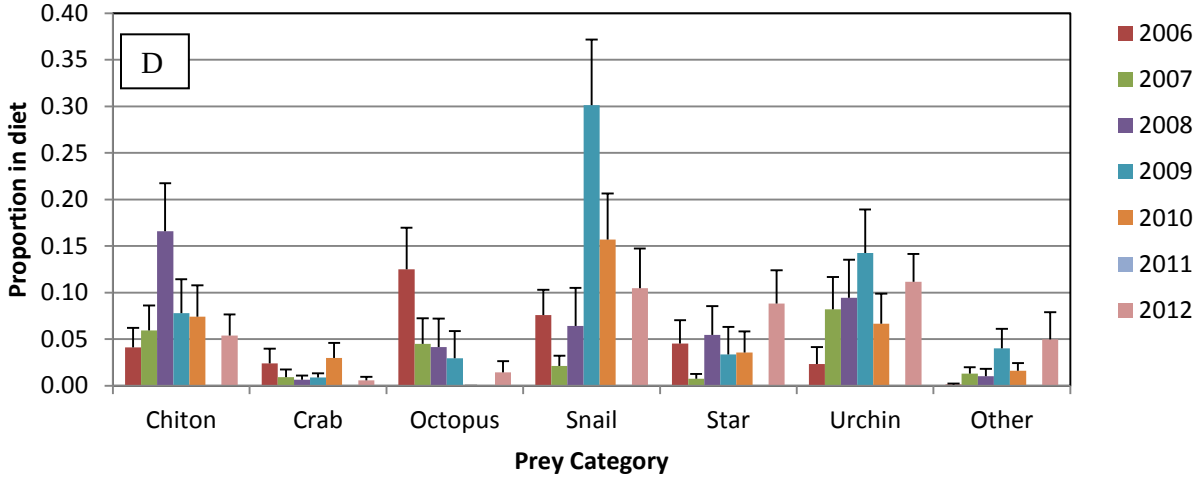




Prey composition of successful sea otter foraging dives in KEFJ, non-clam/mussel items



Prey composition of successful sea otter foraging dives in KATM, non-clam/mussel items



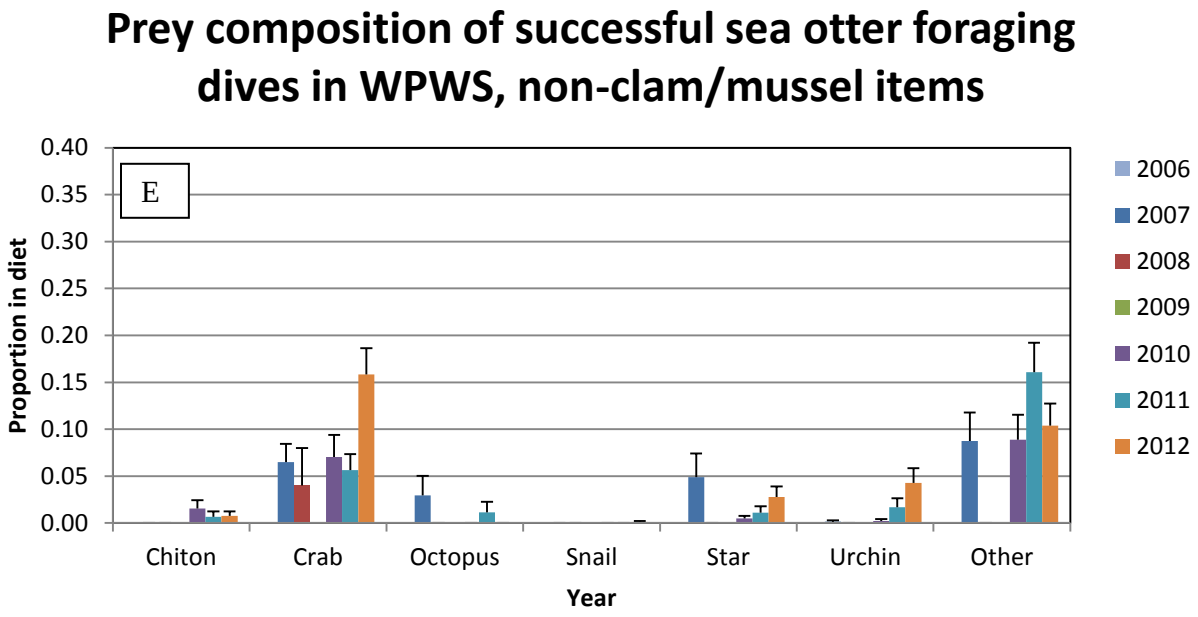


Figure 35. Proportion of identified prey retrieved by foraging sea otters in KEFJ, KATM, and WPWS from 2006 through 2012. Unidentified prey items are not included in these calculations. The "Other" category includes items such as worms, fish, egg cases and other infrequently consumed prey. Additionally, a prey item is only counted towards the proportion once, even if more than 1 of the same item was retrieved on the same dive. Error bars represent one standard error. A. Proportion of prey identified as clam; B. Proportion of prey identified as mussel, primarily *Mytilus trossulus*; C., D., E. Proportions of remaining prey categories for KEFJ, KATM, and WPWS, respectively.

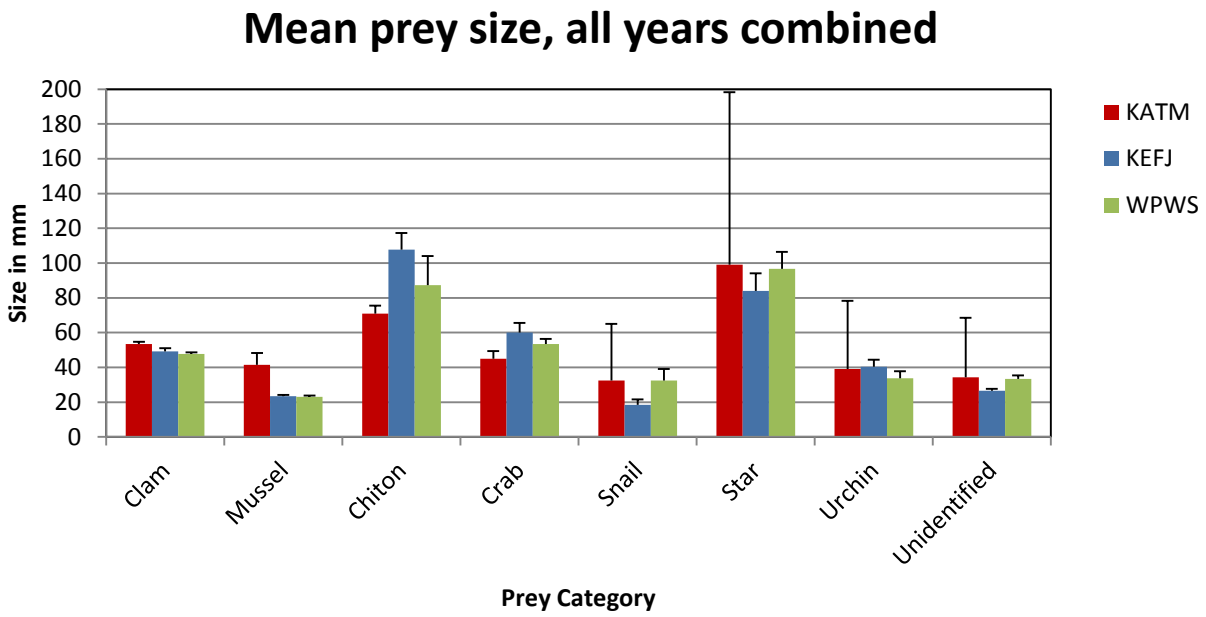
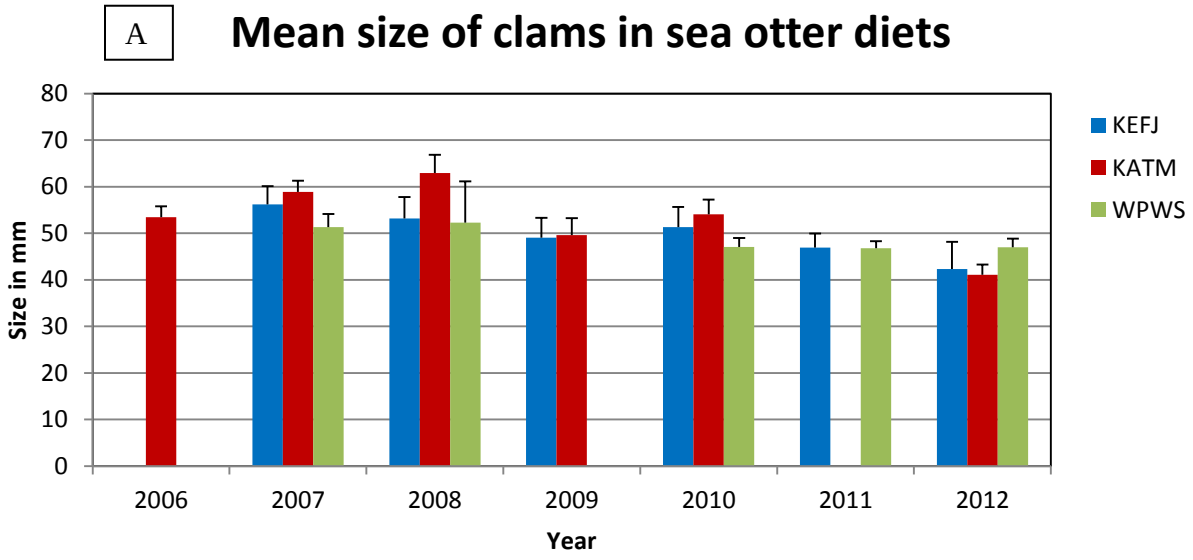


Figure 36. Mean size of prey items recovered by prey category by foraging sea otters in KATM, KEFJ, and WPWS (2006-2012) by region. Sizes from all prey items retrieved were used in the calculations. Error bars represent one standard error.



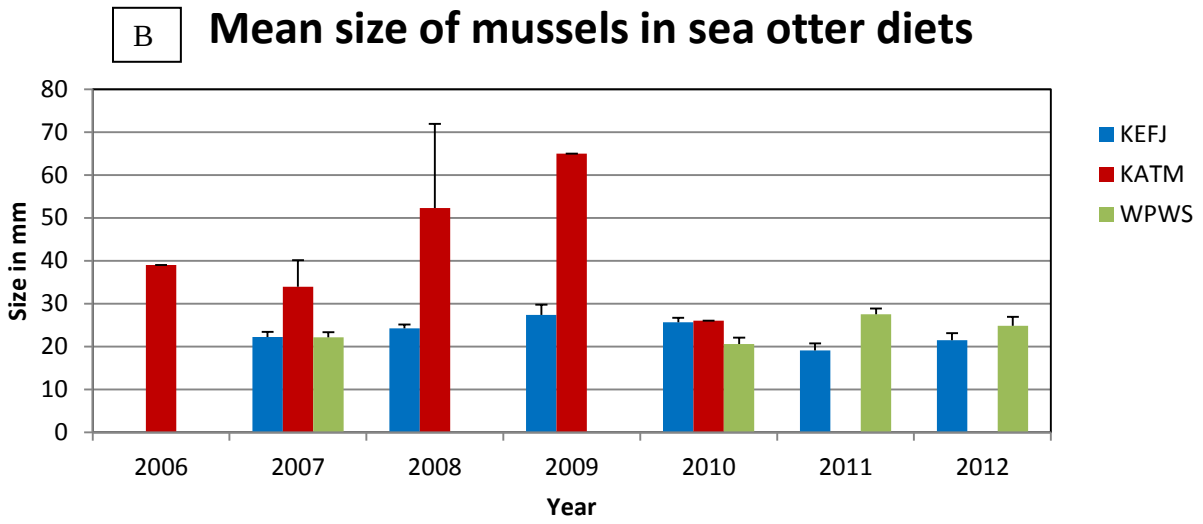


Figure 37. Mean size of A. clams and B. mussels recovered by foraging sea otters in KATM, KEFJ, and WPWS (2006-2012) by year. No mussels were observed being consumed in KATM in 2011 or 2012. Error bars represent one standard error.

Carcass

Since 2006, 179 sea otter carcasses have been successfully aged from KATM and 185 from WPWS (Table 6). The proportions of carcasses in each age all collection years combined are shown in Figure 37. We have also grouped counts into broader age categories to look for changes in proportions. One to two year olds are grouped, representing young, pre-reproductive otters. Three to eight year olds are considered the adult, prime reproductive age otters. Otters older than eight are grouped as aged adults, although still able to reproduce they are likely not as vigorous as prime age otters. The proportions of carcasses in each age category for each year of collection are shown in Figures 38 (KATM) and 39 (WPWS).

Table 3. Summary of sea otter carcasses found in KATM, KEFJ, and WPWS, 2006 - 2012. NS indicates that no surveys for carcasses were conducted.

Year	Number of carcasses		
	KATM	KEFJ	WPWS
2006	36	NS	17
2007	43	0	16
2008	30	0	35
2009	21	0	NS
2010	27	0	18
2011	NS	3	42
2012	22	1	57
All Years	179	4	185

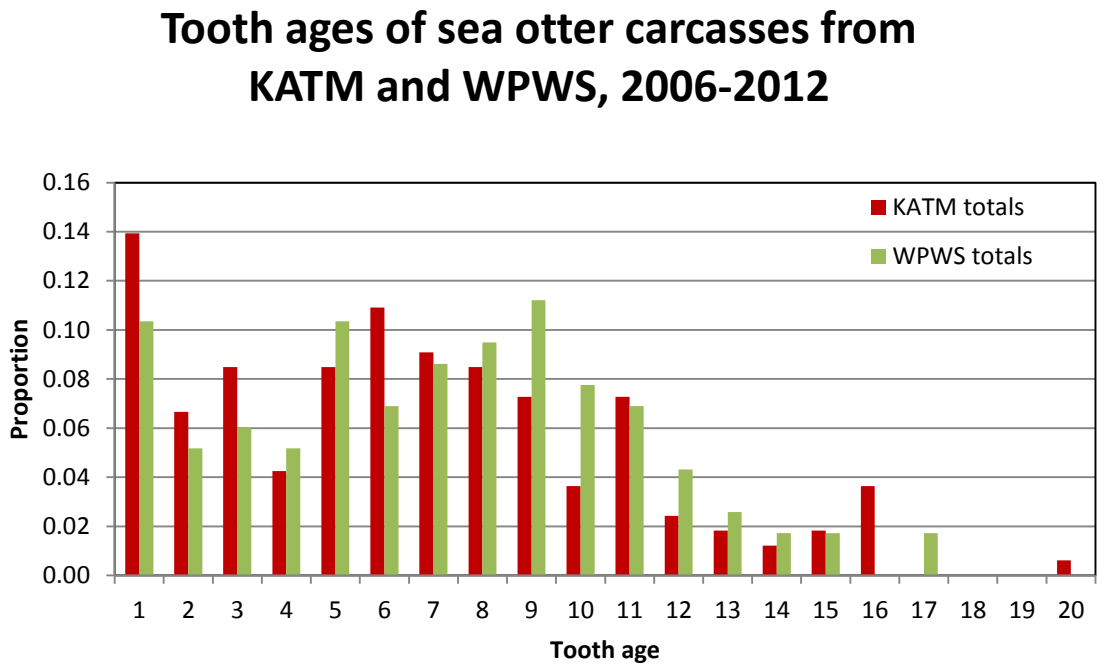


Figure 38. Proportion of sea otter carcasses in each age based on cementum layer analysis.

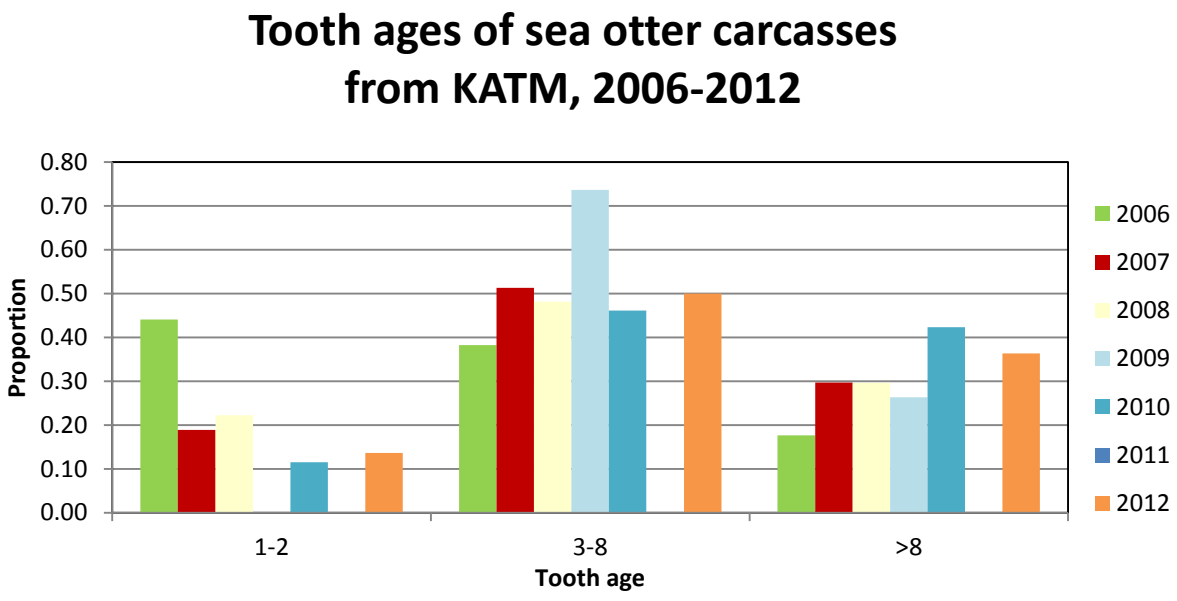


Figure 39. Proportion of sea otter carcasses collected from KATM in each age category based on cementum layer analysis. KATM was not sampled in 2011.

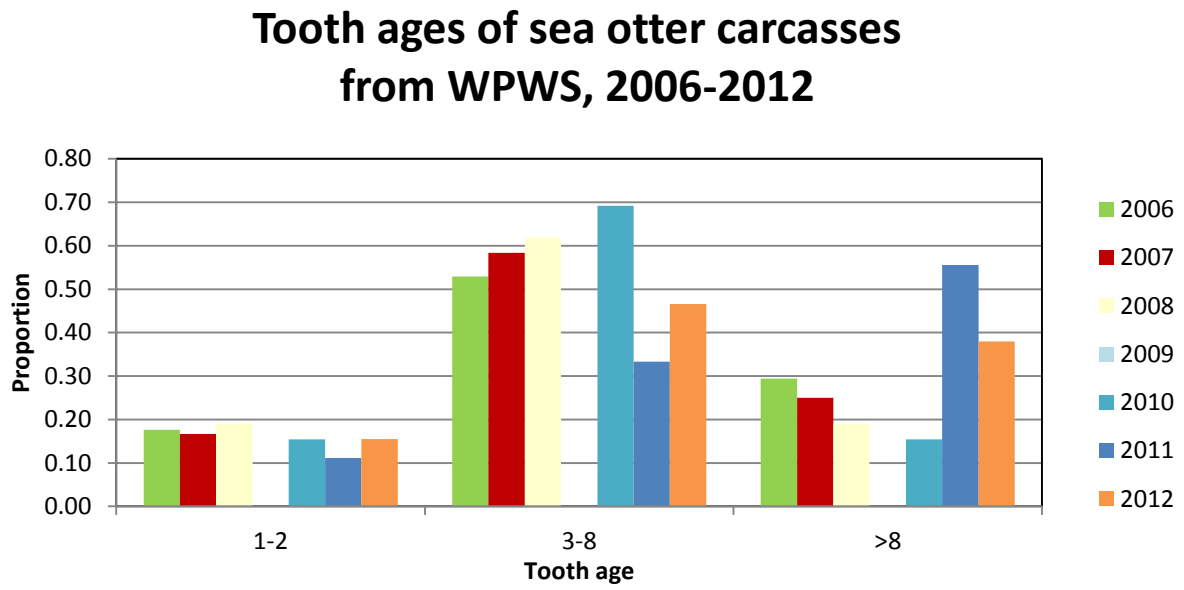


Figure 40. Proportion of sea otter carcasses collected from WPWS in each age category based on cementum layer analysis. WPWS was not sampled in 2009.

Discussion

Aerial survey

This is the second systematic survey of the KATM sea otter population designed to estimate population size. Within four years, the estimated sea otter population has increased by 22% to 8,644 (se=1,243) within the survey boundaries of KATM and an increase in density of > 1 sea otter / km^2 (5.96/ km^2) (Table 4). During the2008 survey, 98% of all sea otters were observed on high density transects and 821 sea otters in 13 large groups at KATM. The estimated detection probability along transects was 0.81 resulting in a correction factor of 1.24 and a total estimated population size of 7,095 sea otters (se = 922). The density of sea otters at KATM across all habitats sampled was 4.89 km^2 in 2008.

To complement that comparison, there are unpublished reports of counts of sea otters along the KATM coast that provide some historic perspective on the process of recovery of sea otters following their extirpation from most of their range during the commercial fur harvest period that ended in 1911 (Kenyon 1969). The first report of sea otters along the KATM coast is from an aerial survey in 1965 when 37 individuals were observed between Kinak Bay and Cape Douglas (Kenyon 1965). Subsequent reports include maximum counts of 443 in June of 1971 near Shakun Is. south of Douglas reef (Prasil 1971), and Goatcher (1994) reported 400-600 sea otters along the KATM coast in 1989. The origin of the initial recolonization of the KATM coast by sea otters is unknown, but most probably resulted from the Kodiak Archipelago, the nearest population known to have survived the commercial fur harvest period.

The current sea otter population that inhabits nearshore waters of KATM occurs at a high density of nearly 6 individuals per km^2. This is substantially higher than the approximate density of 1 individual per km^2 observed elsewhere in the Gulf of Alaska (Bodkin et al. 2008, Bodkin and Udevitz 1999) where populations are thought to be near equilibrium densities. The high density and number of large groups (≥20) encountered both on and off transect (17) with an average size of 48 and a maximum of 150 individuals is consistent with a population increasing in abundance and possibly above long-term equilibrium density.

The KATM sea otter population occurs within the geographic bounds of the Southwest Alaska stock of sea otters (Gorbics and Bodkin 2001) that extends from Cook Inlet to Attu Island in the Western Aleutians. In 2005 this stock was listed as Threatened under the Endangered Species Act (FWS 2005), largely as a result of declines observed in the Aleutian Archipelago and both north and south of the Alaska Peninsula (Doroff et al. 2003). The high density of sea otters we found at KATM strongly suggests that this region currently lies outside the area of decline and that the eastern extent of the decline lies west of KATM (Estes et al. 2010).

Table 4. Sea otter population abundance estimates for KATM, 2008 and 2012. Uncorrected population size is the population size before the correction factor is applied to calculate adjusted population size.

Year	Stratum	Uncorrected Population Size	Correction Factor	Adjusted Population Size	*SE*	Corrected Density #/km2
2012	High Density	3631	1.88	6808	1053	6.91
	Low Density	256	1.88	479	197	1.03
	Total			**8644**[1]	**1243**	**5.96**
2008	High Density	1120	1.24	4316	399	4.38
	Low Density	23	1.24	225	97	0.48
	Total			**7095**[1]	**922**	**4.89**

[1] Total adjusted population size does not equal the sum of the high and low density strata because the adjusted population size also includes complete counts. Complete counts are treated as a separate stratum in the analysis.

Foraging

Using the methods briefly described above, we were able to estimate sea otter foraging success, prey composition, and mean prey size. The predominant prey retrieved in KATM and WPWS was clams in 2012 and across prior years of data collection. In KEFJ mussels (*Mytilus trossulus*) were the predominant prey item from 2007-2011; however, in 2012 it was clams. These results are based on counts within the diet so we anticipate that further development of the model to analyze rates of energy recovery will allow us to detect ecologically meaningful levels of change based on biomass. Mean size of clams was similar in KEFJ and WPWS and slightly larger in KATM during some years. Mean size of mussels is also similar in KEFJ and WPWS and larger in KATM (2006-2009). However, it may simply indicate that otters in KATM were also feeding on a larger species of mussel, *Modiolus modiolus*. Unidentified prey items were similar in size in KATM and WPWS and smaller in KEFJ. For most other prey items there were too few observations to draw meaningful conclusions. Overall a wide range of prey items was observed across regions. Sea otters display individual preferences in prey selection that can be attributed to prey availability, maternally derived learning and likely several other factors. Since this monitoring protocol has no plans for marking and following individual sea otters' dietary preferences, our analyses will focus on population-level metrics that can be compared over time and to other populations. Unidentified prey is a large component of the diet in all regions. Our developing forage model addresses the unidentified prey component by resampling the known items weighting for other known metrics such as retrieval time, consumption time, and size.

Carcass

Searches for sea otter carcasses continue in KEFJ, KATM, and WPWS. To date, we have not recovered sufficient carcasses from KEFJ to employ age-specific mortality analyses. Discussions are underway to determine ways to improve our carcass recoveries in KEFJ such as adding areas of shoreline to search or searching more frequently to recover carcasses prior to removal by scavengers. Staff in KEFJ and KATM has been searching for carcasses although there are still too few recovered from KEFJ on an annual basis for descriptive analysis. Based on data where years are lumped, WPWS appears to have a higher proportion of older prime age and aged otters dying than KATM. KATM appears to have a higher proportion of prime age adults dying. When examining the annual summaries, lumped into young (age 1-2), adult (age 3-8), and aged (age >8) categories, there are possible trends that warrant more in-depth analyses. Age-0 animals were removed from this analysis under the assumption that age-0 animals are not independent of their mother. In WPWS the proportion of young otters dying appears to be steady over time. The adult category was increasing in proportion through 2008 then declining though 2012. The aged category proportion decreased through 2008 then increased through 2012. In KATM, there was a relatively high proportion of young otters dying in 2006, then that category was steady to declining slightly. The adult category was high in 2009, but stable all other years. The aged category was low in 2006, high in 2010 and 2011 and steady other years. It appears that the differences in proportions are fluctuating between the young and aged categories in KATM, while in WPWS there was a shift between adult and aged groups.

Recommendations

Based on these results, we recommend continued timely aerial surveys of sea otters in the three regions. We also recommend collection of sea otter foraging data with an emphasis on completing the analysis model. Additionally, 50 bouts should be set as the minimum target. Results should be viewed both longitudinally and within the larger framework of known otter foraging studies for context. Sea otter carcass collections should also be continued and the expansion of collection efforts should be seriously considered for KEFJ and KATM. It will be important to build an analysis model that facilitates the inclusion of additional data over time to recognize emerging trends.

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2013 Update on Sea Otter Studies to Assess Recovery from the 1989 *Exxon Valdez* Oil Spill, Prince William Sound, Alaska

Open-File Report 2014–1030

U.S. Department of the Interior
U.S. Geological Survey

Cover: Sea otter in kelp. Photograph by Benjamin Weitzman, U.S. Geological Survey.

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U.S. Department of the Interior
U.S. Geological Survey

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
	Volume	
liter (L)	0.2642	gallon (gal)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32.

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

2013 Update on Sea Otter Studies to Assess Recovery from the 1989 *Exxon Valdez* Oil Spill, Prince William Sound, Alaska

By B.E. Ballachey, D.H. Monson, G.G. Esslinger, K. Kloecker, J. Bodkin, L. Bowen, and A.K. Miles

Executive Summary

On March 24, 1989, the tanker vessel *Exxon Valdez* ran aground in Prince William Sound, Alaska, spilling an estimated 42 million liters of Prudhoe Bay crude oil. Oil spread in a southwesterly direction and was deposited on shores and waters in western Prince William Sound (WPWS). The sea otter (*Enhydra lutris*) was one of more than 20 nearshore species considered to have been injured by the spill. Since 1989, the U.S. Geological Survey has led a research program to evaluate effects of the spill on sea otters and assess progress toward recovery, as defined by demographic and biochemical indicators. Here, we provide an update on the status of sea otter populations in WPWS, presenting findings through 2013. To assess recovery based on demographic indicators, we used aerial surveys to estimate abundance and annual collections of sea otter carcasses to evaluate patterns in ages-at-death. To assess recovery based on biochemical indicators, we quantified transcription rates for a suite of genes selected as potential indicators of oil exposure in sea otters based on laboratory studies of a related species, the mink (*Mustela vison*). In our most recent assessment of sea otter recovery, which incorporated results from a subset of studies through 2009, we concluded that recovery of sea otters in WPWS was underway. This conclusion was based on increasing abundance throughout WPWS, including increasing numbers at northern Knight Island, an area that was heavily oiled in 1989 and where the local sea otter population had previously shown protracted injury and lack of recovery. However, we did not conclude that the WPWS sea otter population had fully recovered, due to indications of continuing reduced survival and exposure to lingering oil in sea otters at Knight Island, at least through 2009. Based on data available through 2013, we now conclude that the status of sea otters—at all spatial scales within WPWS—is consistent with the designation of recovery from the spill as defined by the *Exxon Valdez* Oil Spill Trustee Council. The support for this conclusion is based primarily on demographic data, including (1) a return to estimated pre-spill abundance of sea otters at northern Knight Island, and (2) a return to pre-spill mortality patterns. Gene transcription rates in 2012 were similar in sea otters from oiled, moderately oiled and unoiled areas, suggesting abatement of exposure effects in 2012. However, because 2012 gene transcription rates generally were low for sea otters from all areas relative to 2008, we cannot fully interpret these observations without data from a wider panel of genes. This slight uncertainty with respect to the data from the biochemical indicator is outweighed by the strength of the data for the demographic indicators. The return to pre-spill numbers and mortality patterns suggests a gradual dissipation of lingering oil over the past two decades, to the point where continuing exposure is no longer of biological significance to the WPWS sea otter population.

Introduction

On March 24, 1989, the tanker vessel *Exxon Valdez* ran aground on Bligh Reef in northeastern Prince William Sound (PWS), Alaska (fig. 1), spilling an estimated 42 million L of Prudhoe Bay crude oil (Spies and others, 1996). At that time, the *Exxon Valdez* oil spill (EVOS) was the largest recorded accidental release of oil into U.S. waters. Oil spread in a southwesterly direction, leaving a heavy layer on many beaches within western Prince William Sound (WPWS) before exiting Montague Strait and other passages at the southwestern corner of PWS (Galt and Payton, 1990). Islands in the central part of WPWS, particularly the Knight Island complex, were in the direct path of the moving oil and relatively close to the source, and thus were heavily contaminated. Oil eventually covered more than 26,000 km^2 of water in WPWS and the Gulf of Alaska and contaminated more than 1,900 km of coastline (Morris and Loughlin, 1994; Spies and others, 1996).

Much of the area affected by the spill was prime sea otter (*Enhydra lutris*) habitat. Sea otters were particularly vulnerable to acute effects of the spilled oil as they rely on their pelage rather than blubber for insulation, and oil drastically reduces the insulative value of the fur (Costa and Kooyman, 1982; Siniff and others, 1982). Within days of the spill, many live and dead oiled sea otters were captured or collected by spill response personnel, and nearly 1,000 sea otter deaths were documented over the months following the spill. However, not all carcasses were recovered and the total number of sea otters that succumbed to acute injuries has been estimated to be as high as several thousand (Ballachey and others, 1994).

Following initial injury assessment, research to evaluate the process and progress toward recovery of injured species and ecosystems identified unexpected delays for several species that occupy nearshore habitats (Peterson and others, 2003; Rice and others, 2007), including sea otters. Concerns about long-term lack of recovery of sea otters in WPWS led to implementation of an extensive and diverse series of post-spill studies that has spanned the 24 years since the spill. Recovery of sea otters has been defined by the *Exxon Valdez* Oil Spill Trustee Council as:

> "…when the population in oiled areas returns to conditions that would have existed had the spill not occurred and when biochemical indicators of hydrocarbon exposure in otters in the oiled areas are similar to those in otters in unoiled areas. An increasing population trend and normal reproduction and age structure in western Prince William Sound will indicate that recovery is underway" (*Exxon Valdez* Oil Spill Trustee Council, 2010; *www.evostc.state.ak.us/Recovery/status.cfm*).

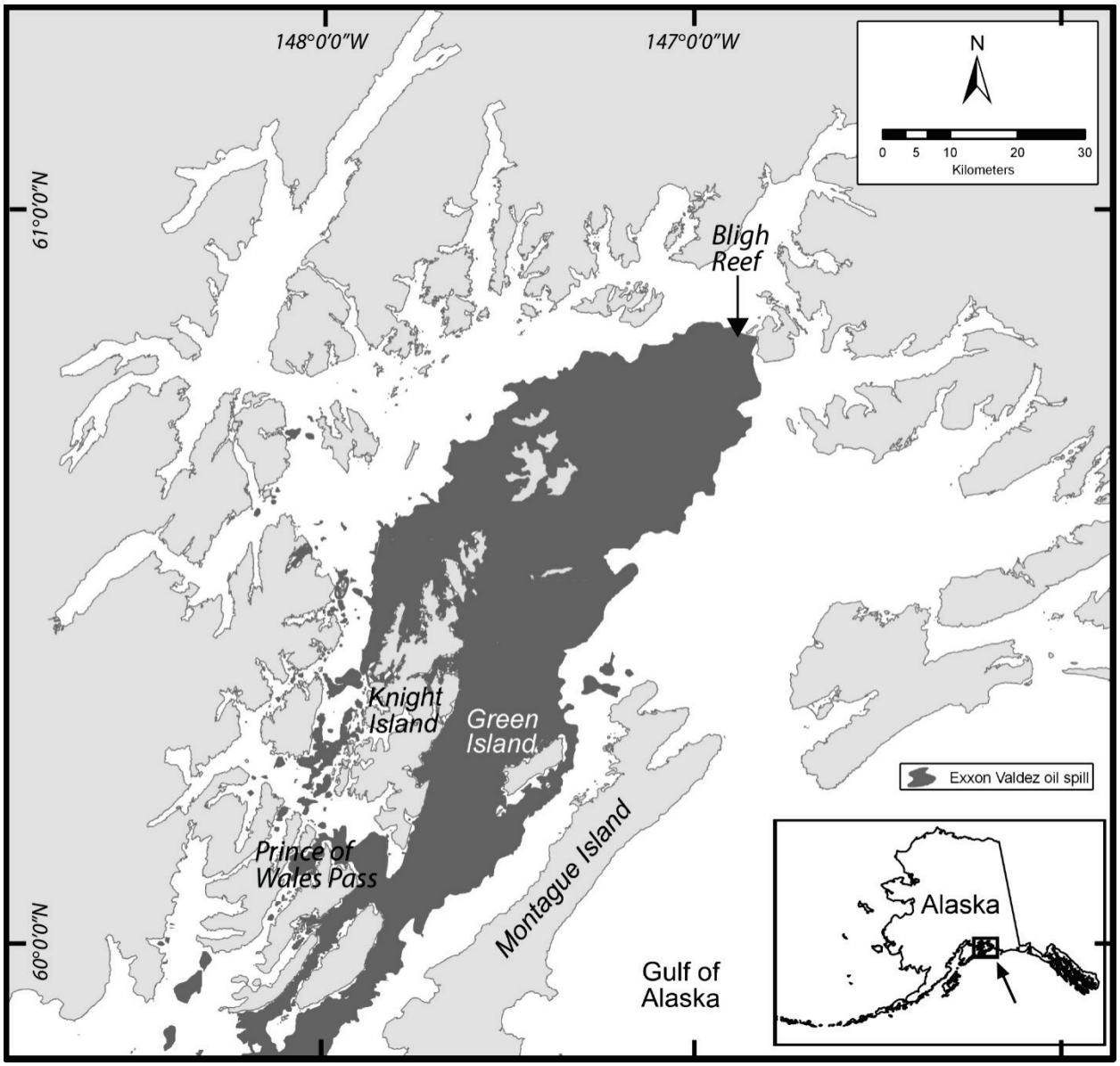

Figure 1. Map of Prince William Sound showing sea otter study areas. The dark gray area represents the extent of the spilled oil coverage in the Prince William Sound in 1989.

Findings of sea otter studies by the U.S. Geological Survey have been presented in multiple publications (appendix 1). Briefly, sea otter abundance in heavily oiled WPWS remained depressed, at about one-half the pre-spill estimate, with no evidence of recovery through 2005 (Bodkin and others, 2002, 2011). Reduced survival rates appeared to be the proximate factor for delayed sea otter recovery (Monson and others, 2000, 2011; Ballachey and others, 2003). Food limitation was discounted as contributing to that reduced survival, whereas chronic exposure to residual oil was implicated as a concern (Bodkin and others, 2002; Dean and others, 2002; Peterson and Holland-Bartels, 2002; Bodkin and others, 2012).

Several lines of evidence demonstrated that oil from the spill persisted in the environment longer than anticipated. In 2001, Short and others (2004, 2006) documented unexpected amounts (>55,000 kg) of *Exxon Valdez* oil remaining in intertidal habitats in WPWS, and estimated that subsurface oil might persist at some sites for several decades (Short and others, 2007). Studies of mussels and clams, both common prey items of sea otters foraging in intertidal habitats, indicated that lingering oil was bioavailable as late as 2002 (Fukuyama and others, 2000; Thomas and others, 2007). As recently as 2008, sea otters from WPWS showed elevated transcription in several genes consistent with potential recent and chronic exposure to organic contaminants (Miles and others, 2012). Evidence of exposure to lingering oil through metabolic pathways also has been documented in other nearshore species, including harlequin duck (*Histrionicus histrionicus*; Trust and others, 2000; Esler and others, 2010), Barrow's goldeneye (*Bucephala islandica*; Trust and others, 2000; Esler and others, 2011), pigeon guillemot (*Cepphus columba*; Golet and others, 2002) and two nearshore fishes—the masked greenling (*Hexagrammos octogrammus*) and the crescent gunnel (*Pholis laeta*) (Jewett and others, 2002).

Considering all data collected through 2009, we concluded that the body of evidence for sea otters suggested recovery in the spill area of PWS was underway but not yet complete (Bodkin and others, 2011, 2012; Monson and others, 2011; Miles and others, 2012). The finding of progress toward recovery was based on increased abundance of sea otters in the area of northern Knight Island in WPWS in 2009, following almost two decades of reduced numbers relative to estimated pre-spill numbers (Bodkin and others, 2011). Evidence for continuing exposure to lingering oil in the environment remained, based on potential for exposure to oil lingering in intertidal habitats (Bodkin and others, 2012), persistent depressed survival of sea otters in oiled areas (Monson and others, 2011), and molecular measures suggesting exposure to organic contaminants for sea otters in oiled areas (Miles and others, 2012).

In this report, we update findings on three aspects of long-term sea otter studies:

1. Aerial surveys of abundance in WPWS through 2013 (Chapter 1; update of Bodkin and others, 2011);
2. Ages-at-death, based on annual recovery of sea otter carcasses on shorelines of WPWS through 2013 (Chapter 2; update of data presented in Monson and others, 2011);
3. Gene transcription analyses of sea otters in oiled and unoiled areas of WPWS through 2012 (Chapter 3; update of Miles and others, 2012).

The report concludes with a synthesis and conclusions section in which we integrate findings from the three chapters.

Chapter 1. Sea Otter Abundance in Western Prince William Sound through 2013

By G.G. Esslinger, B.E. Ballachey, and J.L. Bodkin

Introduction

The 1989 *Exxon Valdez* oil spill (EVOS) caused significant sea otter mortality in western Prince William Sound (WPWS), both in the immediate weeks and months post-spill (Ballachey and others, 1994) and over longer time frames (years and decades; Monson and others, 2011). To assess recovery of sea otters, the *Exxon Valdez* Oil Spill Trustee Council established both demographic and biochemical criteria. As part of our effort to assess recovery based on demographic indicators, we used aerial surveys to estimate abundance in WPWS, including at the heavily oiled area of northern Knight Island and at Montague Island, an unoiled reference area (fig. 1.1).

At the time of the spill, survey data on the abundance of sea otters in WPWS were lacking. Aerial survey methods were developed after the spill (Bodkin and Udevitz, 1999), and annual surveys commenced in 1993. Our approach for assessing demographic recovery based on abundance was to consider overall trend (increasing, decreasing, or stable), and the time point at which the estimated number of new otters in the population was equal to or greater than the number of otters estimated to have died in the immediate aftermath of the spill. Acute spill-related mortality estimates for WPWS ranged from 750 (Garshelis, 1997) to 2,650 sea otters (Garrott and others, 1993). For northern Knight Island, Dean and others (2000) estimated pre-spill abundance to be 165 sea otters, based on the number of carcasses collected, an estimated number of unrecovered carcasses, and the number of sea otters removed for rehabilitation.

A comprehensive analysis of results of aerial surveys from 1993 to 2009 was presented by Bodkin and others (2011). They found that numbers of sea otters in WPWS increased through 2000 at an average annual rate of 4 percent. However, at northern Knight Island, where oiling was heaviest and sea otter mortality highest, no increase in abundance was evident by 2000. A continued significant increase in abundance was observed in WPWS between 2001 and 2009, with an average annual rate of increase from 1993 to 2009 of 2.6 percent. The 2009 estimate of numbers of sea otters in WPWS was 3,958 (standard error=653), nearly 2,000 more than the first post-spill estimate in 1993. Surveys between 2003 and 2009 also identified a significant increasing trend at heavily oiled northern Knight Island, averaging about 25 percent annually and resulting in a 2009 estimate of 116 sea otters (standard error=19). This 2009 abundance estimate was about 30 percent less than the pre-spill estimate of 165 sea otters, but was interpreted as evidence of progress toward recovery of sea otters in the most heavily oiled areas of WPWS.

Here, we update aerial survey results of Bodkin and others (2011) with data from 2011 to 2013, and evaluate trends in sea otter abundance in WPWS, including northern Knight Island.

Methods

Consistent with prior sea otter surveys in WPWS, we used an aerial survey method developed specifically for estimating sea otter abundance (Bodkin and Udevitz, 1999). As part of the survey design, a combination of water depth and distance from shore is used to divide sea otter habitat into high and low density strata (fig. 1.1). Transects are spaced systematically within strata according to expected sea otter densities and time available to conduct the survey. The 400-m wide strip transects are surveyed by a pilot and an observer in a fixed-wing aircraft at an altitude of 91 m and an airspeed of 65 mph. Because sea otters can be difficult to sight in areas with kelp and usually are not visible when they dive underwater to gather prey, intensive searches are conducted periodically throughout the survey area to estimate the proportion of sea otters being detected on the transects. The detection probability is used to adjust the estimate of abundance.

For the WPWS survey, the same set of transects was surveyed from 1995 to 2013, once for each survey year (fig. 1.1) except in 2001, 2006, and 2010. To increase precision in estimates for the intensive oiled (northern Knight Island) and unoiled (Montague Island) study areas, up to five replicate surveys were conducted each year (except in 1993, 1994, 2006, and 2010 for both areas, and in 2013 at Montague Island) using the same techniques described in Bodkin and Udevitz (1999). Each replicate survey was randomly selected from 18 possible combinations of 3 high density and 6 low density sets of spatially unique transects. During each survey, data were entered using a custom survey application (Doug Burn, U.S. Fish and Wildlife Service, Anchorage, Alaska) in ArcPad® (ESRI®, Inc., Redlands, Calif.) on a Toughbook® laptop computer (Panasonic©, Secaucus, N.J.). Survey data were post-processed in ArcMap™ (ESRI®, Inc.) and SAS® 9.2 (SAS Institute©, Cary, N.C.) to estimate abundance and associated variance at different spatial scales. To estimate population growth rate for WPWS, we used linear regression (PROC GLM, SAS Institute©, Cary, N.C.) to fit log-transformed population estimates weighted by standard errors.

Results

Results of aerial surveys conducted from 1993 to 2013 are summarized in table 1.1. Since aerial surveys designed specifically to estimate sea otter abundance began in 1993, numbers of sea otters in WPWS have increased at an average annual growth rate of 3 percent (fig. 1.2). Consistent with the upward trend in WPWS, numbers of sea otters at both the Knight Island (2011–2013; fig. 1.3) and Montague Island (2011–2012; fig. 1.4) study areas were elevated in recent years. The three most recent WPWS abundance estimates (2011–2013) represent an increase of about 850–2,200 sea otters since 1993 (table 1.1). Numbers of sea otters at northern Knight Island in 2011–2013 are similar to the pre-spill estimate of 165 (fig. 1.3).

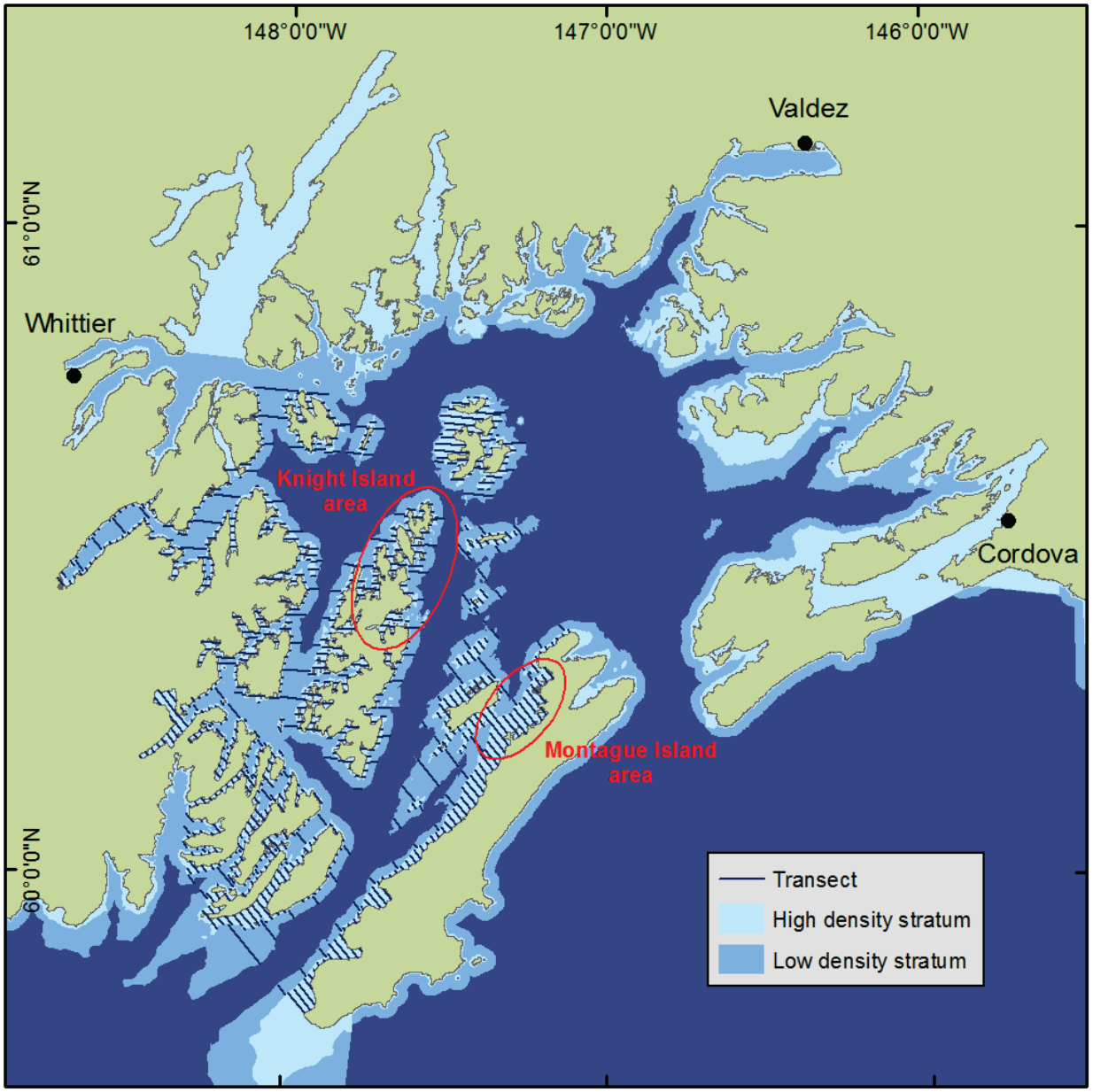

Figure 1.1. Prince William Sound (PWS), Alaska. Blue lines delineate the western PWS survey transects and collectively represent the survey area. Red ovals indicate general location of the intensive study areas at northern Knight Island (oiled area) and Montague Island (unoiled area) where up to five replicate surveys were conducted each survey year. The high density stratum is defined by water depths less than 40 m or 400 m from shore, whichever is greater. The low density stratum extends from the 40- to 100-m depth contour or 2 km from shore, whichever is greater. The high density stratum was sampled at a higher intensity (1,200 m between transects) than the low density stratum (4,800 m between transects).

Table 1.1. Estimates of sea otter numbers based on aerial surveys in western Prince William Sound, 1993–2013, including estimates for the heavily oiled Knight Island and unoiled Montague Island intensive study areas.

[–, no estimate]

	Western PWS		Knight Island		Montague Island	
Year	Abundance estimate	Standard error	Abundance estimate	Standard error	Abundance estimate	Standard error
1993	2,054	698	75	–	335	–
1994	2,228	356	78	–	303	–
1995	2,185	225	89	22	297	50
1996	2,180	218	65	13	382	39
1997	2,341	202	76	19	595	31
1998	3,119	494	76	16	623	92
1999	2,475	381	81	15	586	109
2000	2,658	294	79	6	544	95
2001	–	–	79	20	659	189
2002	1,840	334	38	11	369	48
2003	2,631	540	26	8	619	46
2004	2,704	315	54	17	561	86
2005	2,751	311	37	14	725	105
2006	–	–	–	–	–	–
2007	2,380	372	71	14	356	58
2008	3,609	635	98	24	589	162
2009	3,958	653	116	29	310	62
2010	–	–	–	–	–	–
2011	2,896	392	169	30	662	224
2012	3,459	448	152	28	995	136
2013	4,277	638	139	33	–	–

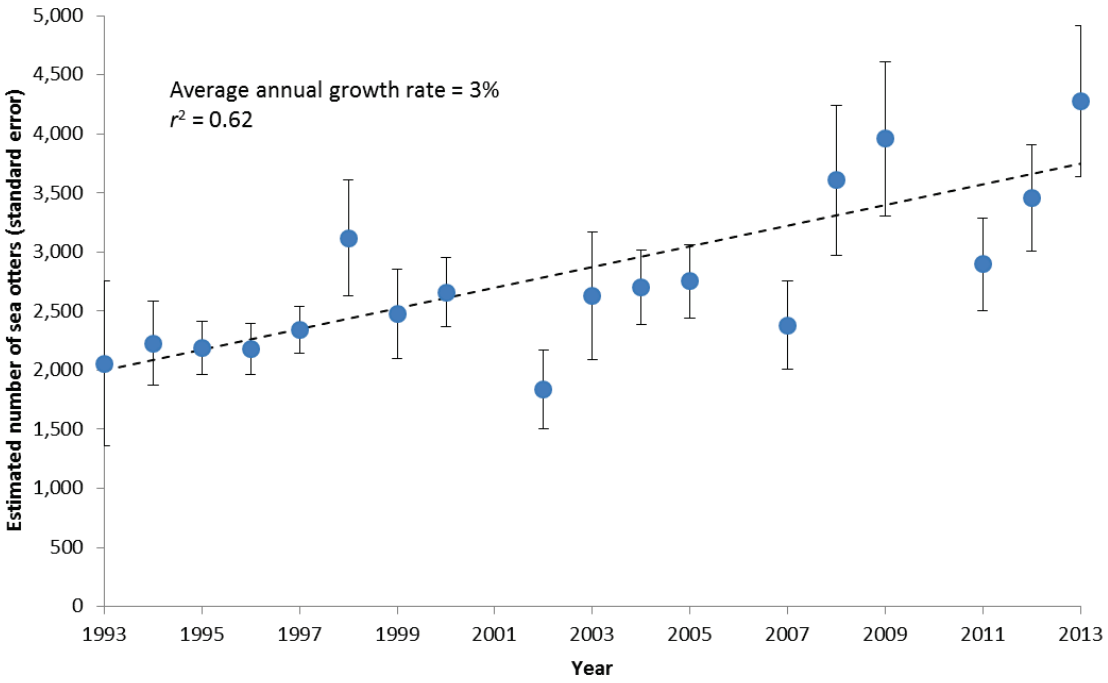

Figure 1.2. Trend in sea otter abundance (± standard error) in western Prince William Sound, Alaska, 1993–2013.

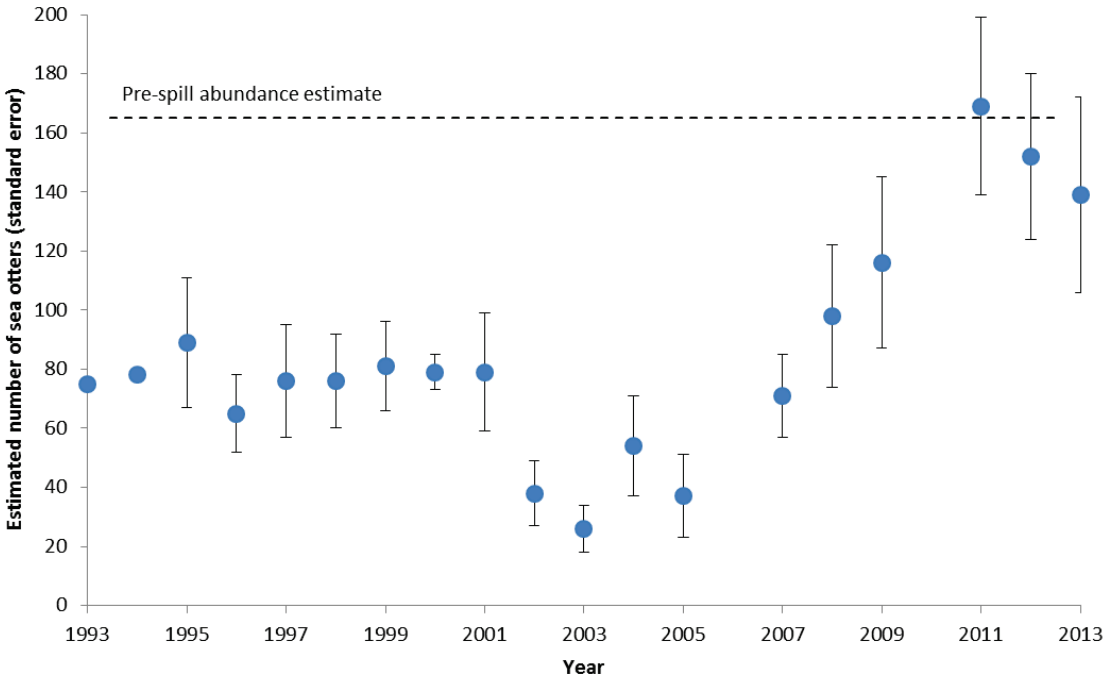

Figure 1.3. Estimated numbers of sea otters (± standard error) at heavily oiled northern Knight Island, Prince William Sound, Alaska, 1993–2013, compared to the pre-spill abundance estimate (Dean and others, 2000).

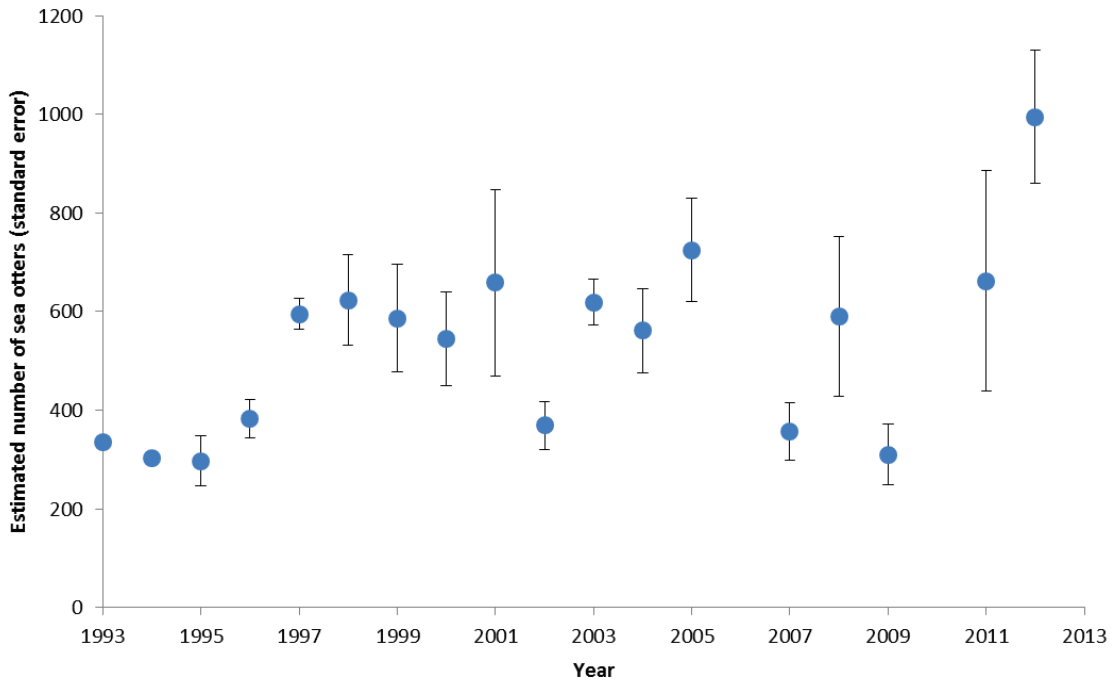

Figure 1.4. Estimated numbers of sea otters (± standard error) at the unoiled Montague Island study area, Prince William Sound, Alaska, 1993–2012.

Discussion

Following their recovery from the commercial fur harvests and reoccupation of WPWS prior to 1970, sea otters were thought to be at or near equilibrium density prior to the spill (Bodkin and others, 2000). However, no surveys were conducted in WPWS just prior to the spill, and accurate data on abundance of sea otters in the area were not available. Survey methods were developed in the first post-spill years (Bodkin and Udevitz, 1999) and implemented in 1993. To determine whether WPWS sea otter numbers had recovered from the spill, we used estimates of acute mortality from the spill, and considered when the number of otters that died immediately after the spill had been replaced. By this measure, the increased abundance of sea otters in WPWS was consistent with recovery by 2009, following almost a decade of population growth.

At the heavily oiled northern Knight Island study area, however, the point at which sea otter abundance recovered to the pre-spill abundance apparently was delayed relative to WPWS overall. The abundance estimates at northern Knight Island did not exceed the estimated pre-spill level until 2011, and the 2012 and 2013 survey results were consistent with the 2011 finding (no survey data are available for 2010). Thus by 2011, for both WPWS and northern Knight Island, the aerial survey data indicate that sea otter abundance is consistent with the definition of population recovery from the spill.

Chapter 2. Age Distributions of Sea Otters Found Dead in Western Prince William Sound, Alaska, through 2013

By D.H. Monson

Introduction

In spring 1989, the *Exxon Valdez* oil spill (EVOS) resulted in acute mortality of 1,000 to several thousand sea otters in western Prince William Sound (WPWS) and the central Gulf of Alaska (Ballachey and others, 1994). The spill also left crude oil in the intertidal zone in unconsolidated sediments of some WPWS beaches (Morris and Loughlin, 1994; Spies and others, 1996), some of which remained for more than two decades (Boufadel and others, 2010; Li and Boufadel, 2010; Xia and others, 2010). As sea otters forage, they excavate clams and other intertidal invertebrates, which can re-suspend buried oil and function as a pathway for chronic exposure of sea otters to toxic oil residues remaining in the environment (Bodkin and others, 2012). Surveys of sea otters indicated that numerical recovery in the most heavily oiled areas did not occur until approximately two decades post-spill (Chapter 1, this report). Extensive studies (appendix 1) suggested that delayed sea otter recovery was due to chronic exposure to oil, likely through effects on survival (Monson and others, 2000, 2011) rather than food limitation, reproductive constraints, or other alternative explanations.

To assess recovery of sea otters, the *Exxon Valdez* Oil Spill Trustee Council established both demographic and biochemical criteria. As part of our effort to assess recovery based on demographic indicators, we estimated abundance using aerial surveys (Chapter 1). We also continued collections of sea otter carcasses, a monitoring practice that began in WPWS in the 1970s. Age distributions of recovered carcasses can be used to describe trends and patterns in mortality of wild mammal populations (Caughley, 1966). Generally, mortality patterns of long-lived mammals include peaks in young and old age classes, with lower mortality in the prime-age class (Caughley, 1966; Emlen, 1970; Siler, 1979; Eberhardt, 1985). Sea otters are relatively long-lived, attaining ages of 15–20 years (Riedman and Estes, 1990), and follow this general pattern, with most natural mortality occurring in young and old age classes (Kenyon, 1969).

Based on age distributions of beach-cast sea otter carcasses collected each spring prior to the spill, the sea otter population in WPWS fit the previously described pattern with most natural mortality occurring in young and old age classes (Monson and others, 2000). Monson and others (2000) used the age distribution data to quantify the long-term effects of the oil spill on survival of sea otters. They found that from 1989 to 1998, survival of sea otters in WPWS was lower than pre-spill estimates, and that the magnitude of the difference was related to both age class of animals and time since the spill. Generally, survival of juveniles was low during the first few years following the spill while prime-age and old-age survival rates were less affected. Over time, juvenile survival increased, while survival of prime-age and old-age animals decreased (Monson and others, 2000). Decreases in survival were not limited to animals alive at the time of the spill (that is, individuals that potentially survived acute exposure), indicating that chronic exposure to residual contaminants in the environment continued to affect animals born in or

migrating into oiled habitats. Low survival of tagged juvenile sea otters following the spill (Monnett and Rotterman, 1995; Ballachey and others, 2003) and discovery of elevated activity of biomarkers associated with hydrocarbon exposure in other nearshore species (Esler and others, 2002, 2010, 2011; Golet and others, 2002; Jewett and others, 2002; Bowyer and others, 2003; Ricca and others, 2010) provided additional evidence that reduced survival may have been caused by lingering oil.

Only a portion of the WPWS sea otter population appeared to be experiencing decreased survival rates, creating a population sink that continued to limit the rate of recovery of the entire WPWS population through at least 2005 (Monson and others, 2011). Source-sink models fit to mortality data collected through 2008 found no indication that elevated mortality had ceased by 2008 (Monson and others, 2011). However, survey data indicated that significant increases in sea otter abundance occurred in the heavily oiled areas between 2005 and 2013 (Bodkin and others, 2011; Chapter 1, this report) suggesting that mortality effects may have modulated during the late 2000s (Monson and others, 2011). Here, we present age distributions of carcasses collected through 2013, and show that mortality patterns in WPWS have returned to "normal," defined as the pre-spill pattern of mortality.

Methods

Sea otter carcass collections from 1976 through 2008 have been described previously (Monson and others, 2000, 2011), and similar collections continued from 2010 through 2013. Green Island (fig. 1), which was oiled in 1989, was the site of pre-spill collections, and carcass collections were continued there through 2013. Beginning in 1996, in addition to Green Island collections, carcasses were collected from shorelines throughout WPWS that received heavy oiling in 1989, including areas where residual oil was found through at least 2008 (Short and others, 2004, 2006, 2007; U.S. Geological Survey, unpub. data, 2008). Because the sex of dead animals often could not be determined, sexes were combined when examining age-at-death distributions. Skulls were collected when present, and a tooth (preferentially a premolar) removed for age analysis, although pups (<1 year old) also were identified by open skull sutures and deciduous teeth (Schneider, 1973). Longitudinal sections of each tooth were decalcified for cementum annuli readings, generally providing age estimates ±1 year (Bodkin and others, 1997). Matson's Laboratory (Milltown, Mont.) sectioned and aged all teeth.

Kolmogorov-Smirnov (K-S) tests (Sokal and Rohlf, 1995) were used to compare the 2010–2013 age distribution to four other distributions including: (1) pre-spill (1974–1989), (2) spill-year (1989), (3) 1990–1993, and (4) 1994–2008. The two post-spill distributions (1990–1993 and 1994–2008) corresponded to two distinct periods of mortality pattern shifts identified by Monson and others (2011). Specifically, 1990–1993 was characterized by very low juvenile survival and only slightly reduced survival in the prime-age and old-age classes (Monson and others, 2011). In contrast, 1994–2008 was characterized by relatively normal juvenile survival but declining survival rates in the older age classes (Monson and others, 2011). For graphical presentation, age distributions were lumped into three age classes including—(1) juveniles (0-age pups and 1-yr-old juveniles), (2) prime-age (2–8-yr-olds), and (3) old-age (>8 yr), and variability was calculated as simultaneous confidence intervals for multinomial proportions (Quesenberry and Hurst, 1964). The age range for "prime-age" was defined based on pre-spill age-at-death data and prior to any post-spill carcass collections. Subsequent statistical models (Udevitz and Ballachey, 1998) supported our definition of "old-age" beginning at 9 years of age (that is, the first year adult survival began to decrease under normal conditions). For K-S tests,

ages were not lumped although 0-age animals were excluded because small pups are easily removed by scavengers and thus are known to be under-represented in carcass collections. As a result, yearly variability in proportions of 0-age animals may be influenced as much by variability in scavenging rates as actual mortality rates (Bodkin and Jameson, 1991).

Variability in the proportion of prime-age animals in the carcass collections was examined over time by plotting this proportion for each year with equal to or greater than five individuals in each age-class. For years with small sample sizes, defined as any age class having less than five individuals, that year's collection was combined with the following year, providing the combination did not cross any previously established "boundary" points (that is, 1989, 1993, and 2008, based on findings in Monson and others, 2011). If a small sample size distribution occurred at the boundary point, it was combined with the previous year's collection.

Results

From 2010 to 2013, 166 carcasses were recovered and had ages-at-death determined (fig. 2.1). In 2010, the proportion prime-age was high (0.56) and appeared similar to collections made in the previous 8–9 years (fig. 2.2). However, the 2010 sample was too small (n=18) for valid statistical comparisons and could not be combined a priori with the previous (1994–2008) grouping, and thus was included with the 2011–2013 data to form the most recent grouping. As a whole, the 2010–2013 distribution differed significantly from the spill-year distribution (K-S $d_{max} = 0.29$, $p<0.0001$) and the 1994–2008 post-spill distribution (K-S $d_{max} = 0.17$, $p=0.025$) but not from the 1990–1993 post-spill distribution (K-S $d_{max} = 0.17$, $p=0.14$; fig. 2.1). The 2010–2013 distribution also did not differ from the 1976–1989 pre-spill distribution (K-S $d_{max} = 0.12$, $p=0.33$; fig. 2.1), which is significant because it is the first post-spill grouping that did not differ from the pre-spill distribution. The 1989 spill year distribution was significantly different from all other age distributions (K-S $d_{max} > 0.16$, $p < 0.05$) while the 1990–1993 and 1994–2008 post-spill distributions both differed from the 1976–1989 pre-spill distribution (K-S $d_{max} > 0.23$, $p < 0.01$) and did not differ from each other (K-S $d_{max} = 0.11$, $p=0.4$) (fig. 2.1).

When the proportion of prime-age otters in the annual carcass collections is compared across years (fig. 2.2), lower proportions are noted for 2010–2013 relative to the proportions in collections from the previous decade. The 2010–2013 proportions are similar to those noted in the pre-spill collections.

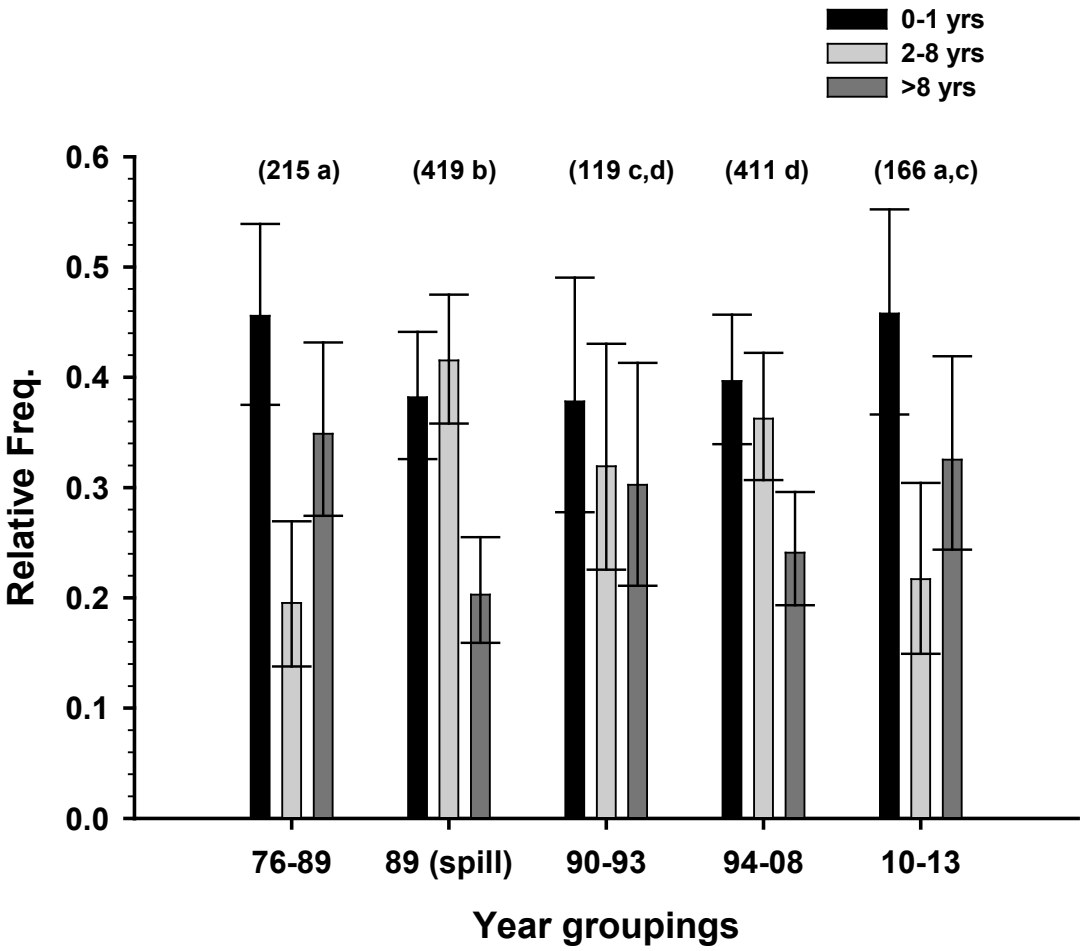

Figure 2.1. Relative age distributions of sea otter carcasses collected on western Prince William Sound beaches from 1976 to 2013. All non-pup ages were estimated by tooth cementum analysis (Matson's Laboratory, Milltown, Mont.). Total numbers of carcasses collected are in parentheses above each grouping and distributions with the same letter do not differ significantly from each other.

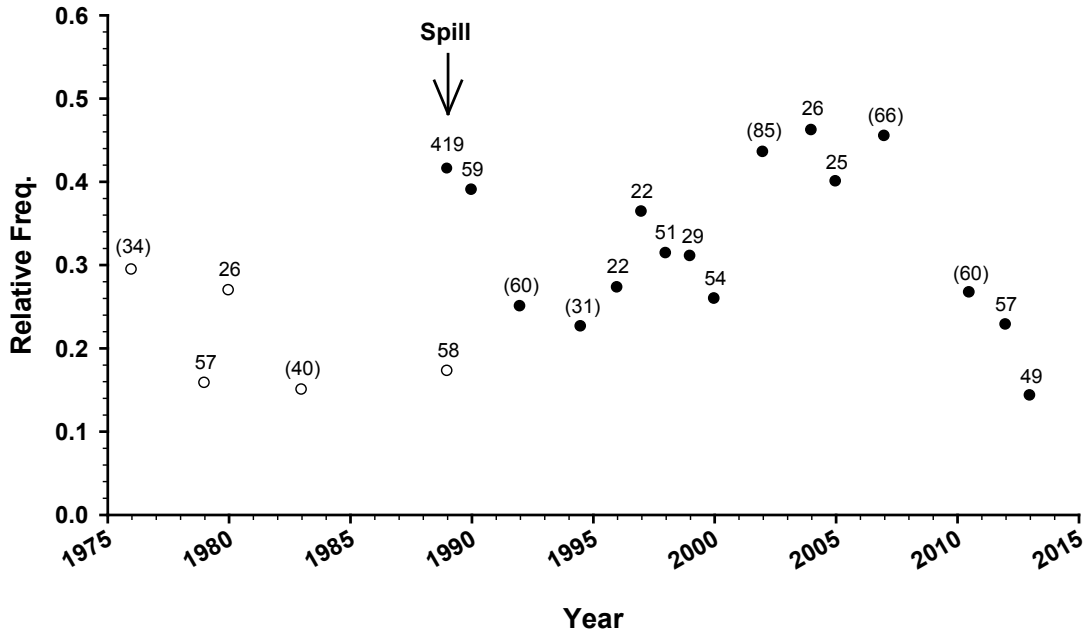

Figure 2.2. Relative proportion of prime-age animals (2–8 yr-olds) in age distributions of sea otter carcasses collected on western Prince William Sound beaches from 1976 to 2013. Open circles denote pre-spill collections and filled circles denote post-spill collections. Note: Carcasses recovered the year of the spill but deemed to be pre-spill deaths make up the 1989 pre-spill distribution, and carcasses recovered in 1989 after the spill and deemed to be spill-related deaths make up the 1989 post-spill distribution. Numbers above symbols indicate total N for each distribution, and numbers in parentheses signify multi-year collections combined to ensure equal to or greater than five individuals in each age-class.

Discussion

Survey data indicated increasing sea otter numbers in WPWS and at heavily oiled Knight Island, starting in about 2007 (Chapter 1, this report). However, survival models based on carcass collections did not predict improved survival rates through at least 2008 (Monson and others, 2011). In general, the proportion of prime-age animals in carcass collections had been increasing since the spill (fig. 2.2) while the proportion of older animals had been decreasing. In 2011, the proportion of prime-age animals decreased to pre-spill levels, and remained similar to pre-spill values in 2012 and 2013 (fig. 2.2). Thus, it appears that the elevated mortality described by Monson and others (2000, 2011) may have continued to affect at least some portion of the population until about 2010, with the combined 2010–2013 distribution representing a transition period in sea otter mortality to the pre-spill pattern.

The observed increase in sea otter abundance at heavily oiled northern Knight Island began between 2005 and 2007 (Chapter 1, this report), and preceded the return of the age-at-death distribution to the pre-spill pattern by four to six years. The lag between the increase in abundance and a return to a "normal" pre-spill age-at-death distribution may be explained by the time required for the standing population age-structure (that is, the distribution of ages of the living animals) to stabilize. Specifically, under normal conditions, the age-at-death distribution developed from a stable standing age-structure typical of a relatively long-lived species. However, during the period when survival rates were transitioning from post-spill rates to more normal rates, the standing age-structure of the population was shifting, and the age-at-death distributions reflected both the changing standing age-structure and the changing survival rates. As chronic exposure to lingering oil declined to a level where adverse effects on survival diminished, the living population began to increase in size. However, it took several years of relatively constant survival rates for the standing age-structure to re-stabilize, and allow the return of the age-at-death distribution to the normal pattern, dominated by juvenile and old-age classes.

Based on sea otter abundance data through 2013 (Chapter 1, this report) and return of the sea otter carcass age distributions to pre-spill proportions by 2013, exposure of pups and juveniles likely decreased to biologically insignificant levels by the early to mid-2000s, with the last of the affected cohorts dying out by the early 2010s. These findings are supported by the gene transcription data (Chapter 3, this report), which suggest that effects of exposure persisted through 2008 but declined by 2012. It appears that for all ages, survival consequences of exposure have abated over the past few years and the WPWS sea otter population no longer is limited to any demographically meaningful degree by oil exposure.

Chapter 3. Gene Transcript Profiles in Sea Otters from Prince William Sound, Alaska, 2008 and 2012, and Clinically Normal and Wild Reference Sea Otters

By L. Bowen, A.K. Miles, B.E. Ballachey, and J.L. Bodkin

Introduction

To assess recovery of sea otters from the 1989 *Exxon Valdez* oil spill, the *Exxon Valdez* Oil Spill Trustee Council established demographic and biochemical criteria. To examine the biochemical status of the sea otters in the oiled area of western Prince William Sound (WPWS), we used gene transcription studies. Exposure to petroleum hydrocarbons has the potential to cause not only catastrophic short-term effects, but also important but often underappreciated long-term damage to individuals, populations, and ecosystems. The question of extent and duration of long-term effects is difficult to answer, as the pathophysiological changes within an individual may be significant yet subtle, and consequently undetectable using classical diagnostic methods. The earliest observable signs of health impairment are altered levels of gene transcripts, evident prior to clinical manifestation (McLoughlin and others, 2006). As a result of this keystone function, analysis of mRNA can provide information about dynamic changes in the functional state of an organism. The utility of the methodology used in our study relies on the assumption that oil-induced pathology in sea otters is accompanied by predictable and specific changes in gene transcription.

In 2008, we sampled sea otters in oiled and unoiled areas of WPWS and compared them to captive and wild reference otters from the Alaska Peninsula. We concluded that sea otters in oiled areas had gene transcription patterns consistent with chronic, low-grade exposure to organic compounds (Miles and others, 2012). In 2012, we resampled sea otters in the same areas of WPWS to evaluate whether gene transcription patterns observed in 2008 persisted. Here, we provide results of gene transcription analyses on sea otters sampled in the summer of 2012, and compare these findings to those from 2008.

Methods

Free-Ranging Target Sea Otters

Forty-five sea otters from three different areas of WPWS were captured in summer 2008 and 60 sea otters were captured in 2012. Sea otters were captured at Knight Island (heavily oiled; n=16, 2008; n=24, 2012), Prince of Wales Passage (moderate level of oil contamination; n=15, 2008; n=18, 2012), and Montague Island (unoiled, reference area; n=14, 2008; n=18, 2012) (fig. 1, “Introduction”). Lingering oil from the EVOS was more prevalent at Knight Island than at Prince of Wales Passage at least through 2002 (Short and others, 2004). Sea otters were captured and blood drawn within 1–2 hours. All target as well as captive and free-ranging reference sea otters were anesthetized with fentanyl citrate and midazolam hydrochloride (Monson and others, 2001) prior to blood draw. Capture methods are presented in greater detail in Miles and others (2012) and Bodkin and others (2012).

Captive and Free-Ranging Reference Sea Otters

Blood samples from 17 captive reference sea otters were obtained from the Monterey Bay Aquarium (Monterey, Calif.), Shedd Aquarium (Chicago, Ill.), Oregon Coast Aquarium (Newport, Oreg.), and the Vancouver Aquarium (Vancouver, B.C.) in 2008, 2009, and 2010, and included both northern and southern subspecies (Bowen and others, 2011). These animals were identified as clinically normal by staff veterinarians at these aquaria at the time of blood collection.

Wild reference sea otters were captured along the southwestern Alaska Peninsula in summer 2009, and 25 of these sea otters used in our study were deemed clinically normal by the attending veterinarian. Alaska Peninsula sea otters were included as reference because they were from an area not affected by the EVOS, far removed from any known human perturbations, and were at or below equilibrium density. These sea otters were captured and processed the same as the WPWS sea otters.

Blood Collection and RNA Extraction

A 2.5 mL sample from each sea otter was drawn directly into a PAXgene™ blood RNA collection tube (PreAnalytiX©, Switzerland) from either the jugular or popliteal vein and then frozen at - 20°C until extraction of RNA (Bowen and others, 2011). The PAXgene™ tube contains RNA stabilizing reagents that protect RNA molecules from degradation by RNases and prevents further induction of gene transcription. Without stabilization, copy numbers of individual mRNA species in whole blood can change more than 1,000-fold during storage and transport. The RNA from blood in PAXgene™ tubes was isolated according to manufacturer's standard protocols (Bowen and others, 2007, 2011; Miles and others, 2012). All RNA was checked for quality by running on both an agarose gel and on a nanodrop 2000 and achieved A260/A280 ratios of approximately 2.0 and A260/A230 ratios of less than 1.0. A standard cDNA synthesis was performed on 2 µg of RNA template from each animal (Bowen and others, 2007, 2012; Miles and others, 2012). Real-time PCR systems for the individual, sea otter-specific reference or housekeeping gene (S9) and genes of interest were run in separate wells (Bowen and others, 2007, 2011; Miles and others, 2012; table 1). Amplifications were conducted on a 7300 Real-time Thermal Cycler (Applied Biosystems™, Foster City, Calif.) with reaction conditions identical to those in Bowen and others (2007, 2011) and Miles and others (2012).

Statistical Analysis

We used nonparametric statistical analyses because the cycle threshold (C_T) measure of gene transcription provided by qPCR may have a lognormal distribution (McLoughlin and others, 2006). We used ANOSIM (Primer v6 software, Plymouth, U.K.) nonparametric analysis of variance to test for differences in gene transcription among locations, that is, the WPWS subpopulations and reference sea otters (Alaska Peninsula and captive), and between years. We used conventional nonparametric mean comparison tests (Kruskal-Wallis with Dunns' Multiple Comparison; NCSS© Statistical Software, 2007, Kaysville, Utah) to evaluate transcript values of each gene by classification groups (that is, location [including reference] and year).

We conducted multivariate, multidimensional scaling analysis (MDS) in conjunction with cluster analysis of individual sea otters clustered by similarity in transcription and not by pre-defined groups such as location in order to facilitate comparison to Miles and others (2012). Statistical comparisons of clusters were made using SIMPROF (Primer v6). Statistical significance was based on *p* values <0.05, and in the case of the ANOSIM tests, relative to the R statistic value.

Results

Overall gene transcription (C_T) values differed between sea otters from WPWS in 2008 or 2012 and the Alaska Peninsula or captive sea otters (ANOSIM, $p< 0.001$, Global R=0.46, with 0 permuted statistics > Global R) (fig. 3.1). The Alaska Peninsula and captive sea otters did not differ (p=0.46) and hereafter "reference" refers to these two groups collectively. Individually, the three 2008 WPWS subpopulations differed significantly (p<0.001) from the reference sea otters, with indication of less chance of overlap in transcription profiles with Knight Island (R=0.40 [Alaska Peninsula], 0.53 [captives]) than with Montague Island (R=0.25, 0.28) or Prince of Wales Passage (R=0.28, 0.21) sea otters. Transcription profiles did not differ significantly within the three 2008 subpopulations (p>0.16).

The three 2012 WPWS subpopulations differed significantly (p<0.001) from the reference sea otters. There was less chance of overlap in transcription profiles with sea otters from moderately oiled Prince of Wales Passage (R=0.71, 0.85) than with those from oiled Knight Island (R=0.64, 0.75) or unoiled Montague Island (R=0.65, 0.83) (fig. 3.1). Transcription profiles did not differ significantly among the three 2012 WPWS subpopulations (p>0.42).All 2012 WPWS subpopulations differed significantly from all 2008 WPWS subpopulations (p<0.001), with an overall pattern of lower levels of gene transcription ("down-regulation" of genes) noted in 2012 (fig. 3.2).

Using Kruskal-Wallis, 11 of 13 genes were identified that had significant differences between at least two classification groups (fig. 3.2). Most evident, HDC, THRB, HSP70, IL10, MX1, and CaM differed between 2008 and 2012 otters regardless of location, with higher levels of gene transcription in 2008 than in 2012. Although not statistically significant, HDC (associated with tumor-formation) was more highly transcribed at Knight Island than at Montague Island or Prince of Wales Passage in 2008 (fig. 3.1), but this finding did not persist in 2012. There were minimal differences in transcription levels for COX2, AHR, IL18, DRB, and 5HTT between 2008 and 2012. Transcription of CYT and CCR3 did not differ among classification groups.

Patterns depicted by the MDS analyses were similar to that reported in Miles and others (2012), with differences attributable to the inclusion of the 2012 samples (fig. 3.2). More 2008 sea otters from Knight Island were found in Clusters 1, 1a, and 1b than those from Prince of Wales Passage or Montague Island, and these clusters included no sea otters from 2012. Cluster 2 included all captive and most (76 percent) Alaska Peninsula sea otters. Cluster 1 was characterized in particular by higher levels of transcription of HDC, CYT, and HSP70. Importantly, the 2008 and 2012 samples were distinctly separate; Cluster 3 contained mostly 2012 sea otters (regardless of location), attributed primarily to lower levels of gene transcription.

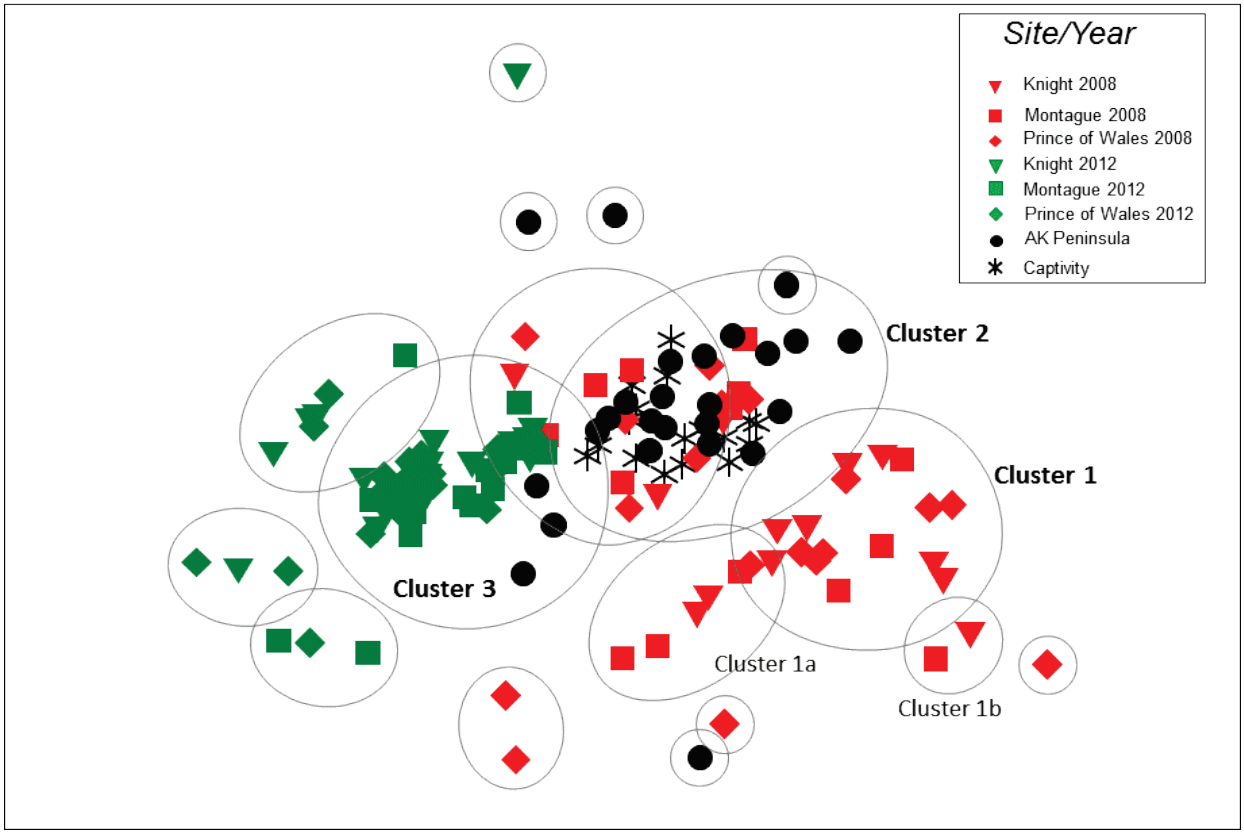

Figure 3.1. Multivariate, nonparametric, multidimensional scaling of gene transcription profiles (see table 3.1 for description of genes) of sea otters sampled at three locations in western Prince William Sound, Alaska, 2008 and 2012, the Alaska Peninsula, and in captivity at aquaria. Interpretive cluster analysis and SIMPROF (similarity profile permutation test; Primer, v6, Plymouth, U.K.) indicated significant (p< 0.001–0.05) separation among all clusters depicted by circles. The figure is two-dimensional (Stress=0.11), however, three-dimensional (Stress=0.08) representation depicted further separation among clusters in 3–D space.

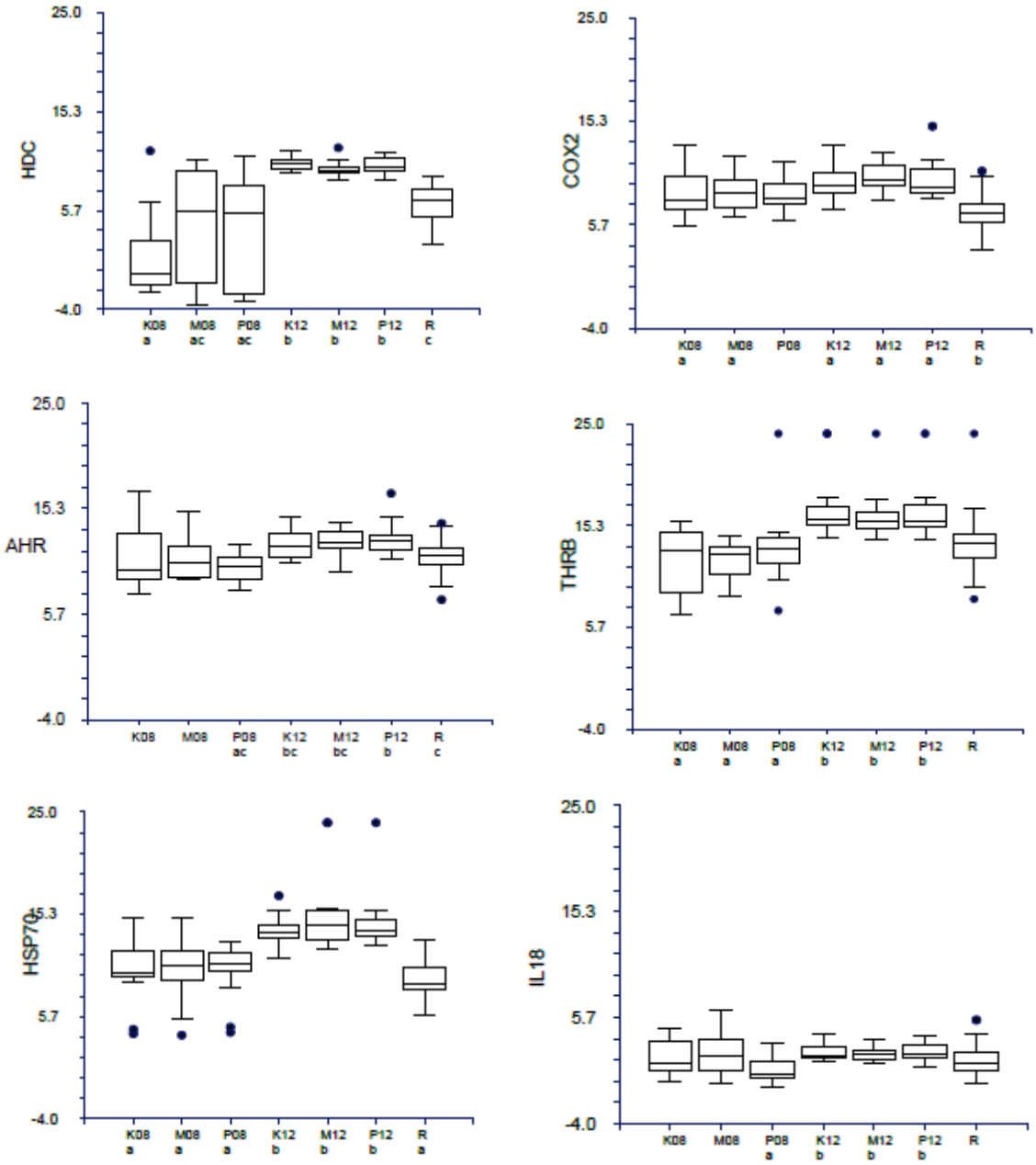

Figure 3.2. Distribution of average cycle threshold (CT) values across genes targeted by the panel of 13 primer sets. Bars range from the 10th to the 90th percentile of values for each gene, normalized to the S9 housekeeping gene for each sea otter. Circles represent 5th and 95th percentile outliers. Indicated are those genes that differed significantly among sea otters by classification groups (location and year), using Kruskal-Wallis and Dunns' Multiple Comparison Tests. K, Knight Island; M, Montague Island; P, Prince of Wales Passage; R, Reference; 08, 2008; 12, 2012. Classification groups with like letters (a, b, or c) do not differ significantly; no letter, does not differ from any comparisons.

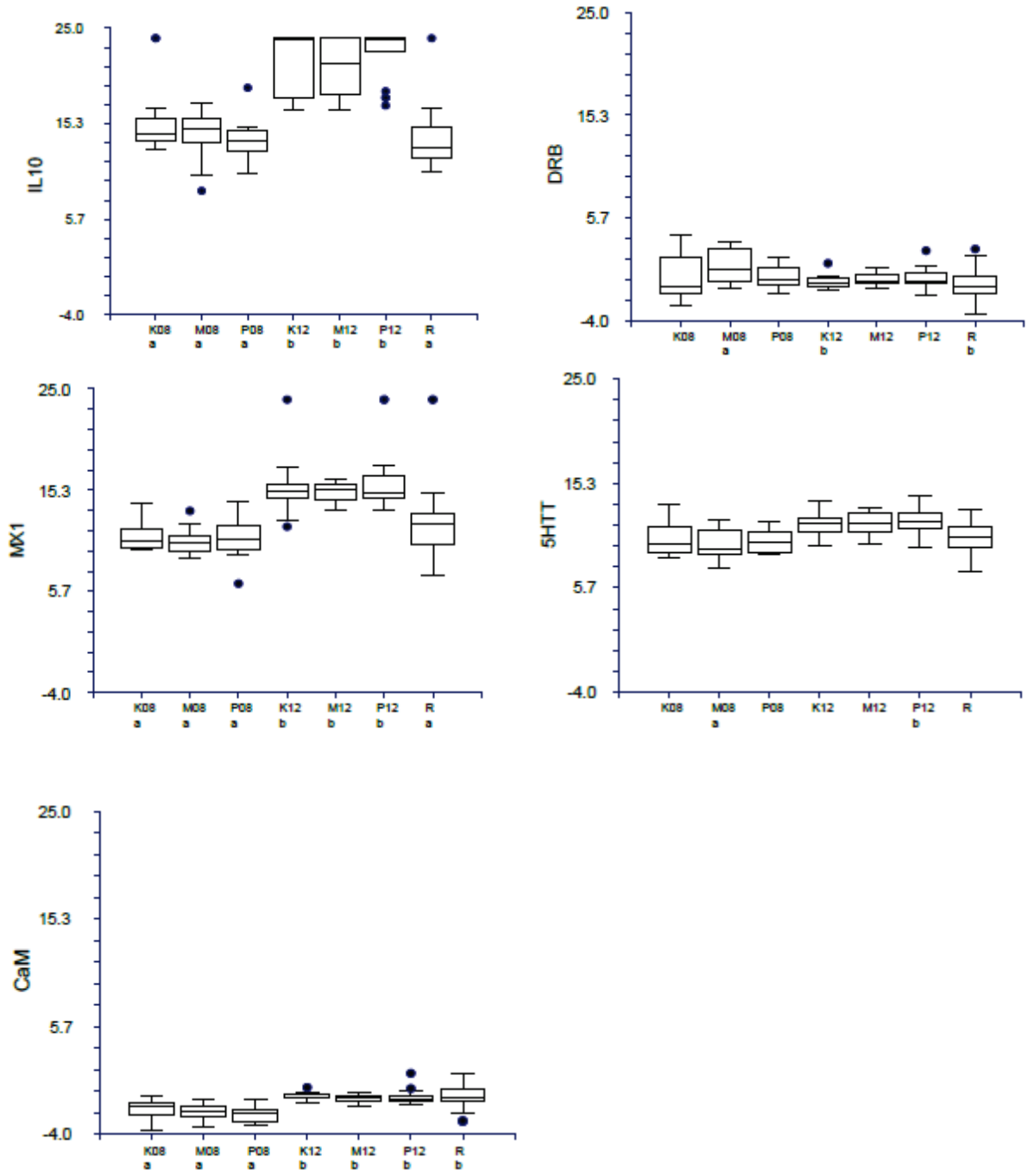

Figure 3.2.—Continued.

Discussion

Gene transcription patterns in the 2008 WPWS sea otters, particularly those from Knight Island, generally were suggestive of molecular reactions to organic exposure, tumor formation, inflammation, and viral infection that may be consistent with chronic, low-grade exposure to an organic substance (Miles and others, 2012). This is consistent with findings from Bodkin and others (2012), which document a potential pathway of exposure to lingering oil for sea otters foraging in the intertidal where lingering oil persisted. In particular, sea otters from the spill area demonstrated elevated transcription of several of the genes measured, including HDC and THR, and lower transcription, or down-regulation, of DRB. Dong and others (1997) reported down-regulation of DRB by a dioxin compound, and both polycyclic aromatic hydrocarbons (constituents of crude oil) and dioxin-like compounds have been implicated in similar biochemical detoxification responses.

In contrast, the 2012 WPWS sea otters had an overall pattern of down-regulation of gene transcription. In general, the regulation of gene transcription includes mechanisms to increase or decrease the production of mRNA, and the occurrence of low gene transcription has been observed in other marine mammal studies (Stott and McBain, 2012). However, the prevalence of down-regulation among 2012 WPWS sea otters was noteworthy and contributing factors are not fully understood. We confirmed that the observed low transcription values were not a result of a laboratory artifact. We analyzed all samples in duplicate, and if any duplicate samples were greater than 1 C_T difference, they were re-analyzed. All samples were run with an internal reference standard (the S9 housekeeping gene). If the internal reference was greater than 3 C_T values from the average internal reference value for control populations, the entire panel was re-run in duplicate; this always resulted from insufficient RNA and those samples were omitted from analysis (that is, <1 percent of the samples). Finally, samples were run with other samples from other Alaska and also California populations and re-run in different combinations to check for ‘plate’ or ‘batch’ effects; no such effects were encountered. Of significance, we conducted analyses of sea otters from California during the same time period as analyses of the 2012 WPWS sea otters. About 50 percent of the California otters analyzed aligned with the reference group, about 10 percent displayed high transcription, and about 40 percent had low transcription of 3–6 of 13 genes. Most of these low transcription animals were from a specific area of the California coastline. Causes of down-regulation of gene transcription in WPWS in 2012 are not certain, and should be a topic of continued research.

We found no evidence that gene transcription in sea otters captured in WPWS in 2012 differed by oiling history, including genes that indicated potential responses to organic compounds in 2008. We conclude that these findings indicate that conditions specific to effects of exposure to oil characterized by our suite of genes improved between 2008 and 2012. We caution that the implications of overall low transcription observed in 2012, in terms of interpretation of potential exposure to oil, are not certain. We note that the timing of convergence of patterns of transcription of potentially exposure-related genes in our suite across different oiling histories in 2012 relative to 2008 is consistent with improvements in survival (Chapter 2) and increasing population trajectories (Chapter 1) during that same period.

Table 3.1. Function of 13 genes identified in free-ranging sea otters sampled in western Prince William Sound, Alaska, in 2008 and 2012, and Alaska Peninsula in 2009, and in clinically normal captive sea otters sampled in 2008, 2009, or 2010.

Gene	Gene function
HDC	The HDCMB21P gene codes for a translationally controlled tumor protein (TCTP) implicated in cell growth, cell cycle progression, malignant transformation, tumor progression, and in the protection of cells against various stress conditions and apoptosis (Bommer and Thiele, 2004;Tuynder and others, 2004; Ma and others, 2010). Up-regulation of HDC is indicative of the development or existence of cancer. Environmental triggers may be responsible for population-based, up-regulation of HDC. HDC transcription is known to increase with exposure to carcinogenic compounds such as polycyclic aromatic hydrocarbons (Bowen and others, 2007; Raisuddin and others, 2007; Zheng and others, 2008).
COX2	Cyclooxygenase-2 catalyzes the production of prostaglandins that are responsible for promoting inflammation (Goldsby and others, 2003). Cox2 is responsible for the conversion of arachidonic acid to prostaglandin H2, a lipoprotein critical to the promotion of inflammation (Harris and others, 2002). Up-regulation of Cox2 is indicative of cellular or tissue damage and an associated inflammatory response.
CYT	The complement cytolysis inhibitor protects against cell death (Jenne and Tschopp, 1989). Up-regulation of CYT is indicative of cell or tissue death.
AHR	The arylhydrocarbon receptor responds to classes of environmental toxicants including polycyclic aromatic hydrocarbons, polyhalogenated hydrocarbons, dibenzofurans, and dioxin (Oesch-Bartlomowicz and others, 2005). Depending upon the ligand, AHR signaling can modulate T-regulatory (T_{REG}) (immune-suppressive) or T-helper type 17 (T_H17) (pro-inflammatory) immunologic activity (Quintana and others, 2008; Veldhoen and others, 2008).
THR	The thyroid hormone receptor beta can be used as a mechanistically based means of characterizing the thyroid-toxic potential of complex contaminant mixtures (Tabuchi and others, 2006). Thus, increases in THR transcription may indicate exposure to organic compounds including PCBs and associated potential health effects, such as developmental abnormalities and neurotoxicity (Tabuchi and others, 2006). Hormone-activated transcription factors bind DNA in the absence of hormone, usually leading to transcriptional repression (Tsai and O'Malley, 1994).
HSP 70	The heat shock protein 70 is produced in response to thermal or other stress (Iwama and others, 1999; Tsan and Gao, 2004). In addition to being expressed in response to a wide array of stressors (including hyperthermia, oxygen radicals, heavy metals, and ethanol), heat shock proteins act as molecular chaperones (De Maio, 1999). For example, heat shock proteins aid the transport of the AHR/toxin complex in the initiation of detoxification (Tanabe and others, 1994).
IL-18	Interleukin-18 is a pro-inflammatory cytokine (Goldsby and others, 2003) and plays an important role in inflammation and host defense against microbes (Krumm and others, 2008).

Table 3.1. Function of 13 genes identified in free-ranging sea otters sampled in western Prince William Sound, Alaska, in 2008 and 2012, and Alaska Peninsula in 2009, and in clinically normal captive sea otters sampled in 2008, 2009, or 2010.—Continued

Gene	Gene function
IL-10	Interleukin-10 is an anti-inflammatory cytokine (Goldsby and others, 2003). Levels of IL-10 have been correlated with relative health of free-ranging harbor porpoises, for example, increased amounts of IL-10 correlated with chronic disease whereas the cytokine was relatively reduced in apparently fit animals experiencing acute disease (Beineke and others, 2007). Association of IL-10 transcription with chronic disease also has been documented in humans (Rigopoulou and others, 2005).
DRB	A component of the major histocompatibility complex, the DRB class II gene, is responsible for the binding and presentation of processed antigen to T_H lymphocytes, thereby facilitating the initiation of an immune response (Goldsby and others, 2003; Bowen and others, 2006). Up-regulation of MHC genes has been positively correlated with parasite load (Wegner and others, 2006), whereas down-regulation of MHC has been associated with contaminant exposure (Dong and others, 1997).
Mx1	The Mx1 gene responds to viral infection (Tumpey and others, 2007). Vertebrates have an early strong innate immune response against viral infection, characterized by the induction and secretion of cytokines that mediate an antiviral state, leading to the up-regulation of the MX-1gene (Kibenge and others, 2005).
CCR3	The chemokine receptor 3 binds at least seven different chemokines and is expressed on eosinophils, mast cells (MC), and a subset of Th cells (Th2) that generate cytokines implicated in mucosal immune responses (Gurish and others, 2002; Kringel and others, 2006). Up-regulation of CCR3 occurs in the presence of parasites (Gurish and others, 2002; Kringel and others, 2006).
5HTT	The serotonin transport gene codes for an integral membrane protein that transports the neurotransmitter serotonin from synaptic spaces into presynaptic neurons. This transport of serotonin by the SERT protein terminates the action of serotonin and recycles it in a sodium-dependent manner (Jennings and others, 2006; Squire and others, 2008). Increased transcription of 5HTT confers a low anxiety phenotype (Jennings and others, 2006).
CaM	Calmodulin (CaM) is a small acidic Ca^{2+}-binding protein, with a structure and function that is highly conserved in all eukaryotes. CaM activates various Ca^{2+}-dependent enzyme reactions, thereby modulating a wide range of cellular events, including metabolism control, muscle contraction, exocytosis of hormones and neurotransmitters, and cell division and differentiation (Chen and others, 2012). CaM also has been reported to be a pivotal calcium metabolism regulator in shell formation (Li and others, 2004).

Synthesis and Conclusions

In this report, we present the latest findings from post-spill studies on sea otters that have been ongoing for more than two decades. The *Exxon Valdez* Oil Spill Trustee Council (EVOSTC) defined recovery for sea otters as the point in time when abundance of sea otters in oiled areas returns to level that would have existed had the spill not occurred, and there is no evidence of continuing exposure to lingering oil in the environment. In our summaries of data available through 2009 (Bodkin and others, 2011, 2012; Miles and others, 2012) for sea otters in areas of western Prince William Sound (WPWS) that received heavy shoreline oiling in 1989, these conditions had not been met, although there were indications that recovery was underway based on increasing numbers of sea otters at Knight Island. Further, demographic models based on ages-at-death and abundance data through 2008 (Monson and others, 2011) suggested that depressed survival of sea otters in heavily oiled areas continued to constrain recovery. Here, we integrate the results through 2013 and find our most recent data are consistent with the EVOSTC definition of recovery for sea otters.

Aerial surveys of abundance (Chapter 1) are a main component of our studies to evaluate status of recovery. By 2013, at the broader scale of WPWS, the estimated number of sea otters had more than doubled relative to the 1993 estimate (4,277 versus 2,054, respectively), and the increase over that time frame was greater than or similar to estimates of sea otters that died within the first year of the spill, indicating that the demographic metric of the recovery definition had been met. For the region of northern Knight Island, which received heavy oiling of shorelines in 1989 and consequently was anticipated to be an area where recovery would be slowest, abundance was depressed for almost two decades relative to the pre-spill estimate. By 2011, the number of sea otters at Knight Island was similar to estimated pre-spill numbers, and similar levels of abundance continued through 2012 and 2013. Thus, based solely on abundance estimates, the sea otter population in WPWS in 2013 had grown to a number consistent with the definition of recovery.

The most recent data on ages-at-death of sea otters in WPWS (Chapter 2) provide additional findings consistent with recovery of the population. Annual carcass collections were initiated in WPWS in the 1970s, so the ages-at-death data provide a solid empirical baseline for evaluating recovery from the spill. Pre-spill data indicate that mortality of sea otters typically was comprised largely of very young and older sea otters, with relatively few prime age (defined here as 2–8-year olds) otters dying each year. This pattern was altered after the spill when, for about two decades, annual carcass collections showed a relatively high proportion of prime-age otters dying each year. Starting in 2011, we observed a distinct change in the age-class proportions of dying sea otters, with a return to the pre-spill pattern of predominantly young and older sea otters recovered as carcasses. This pattern continued in 2012 and 2013, which we interpret as evidence that over the past few years, chronic exposure to lingering oil and/or chronic effects due to previous exposure have abated to the point where they are no longer factors constraining survival. A higher proportion of sea otters in oiled areas are again surviving to older ages, as documented in WPWS prior to the spill.

To assess continuing exposure to lingering oil, we have utilized gene transcription assays, monitoring an array of 13 genes selected based on studies of mink exposed to oil (Bowen and others, 2007). Results from sea otters sampled in WPWS in 2008 were consistent with ongoing exposure to organic compounds (Miles and others, 2012), and in concert with other data, we interpreted the gene transcription data to suggest continuing chronic exposure to oil from the 1989 spill. Sea otters were resampled in 2012 for gene transcription (Chapter 3), and gene transcription values from 2012 differed from 2008, as well as from the two reference groups (captive and Alaska Peninsula sea otters) used for comparison to the 2008 samples (Miles and others, 2012). In contrast to previous data, the 2012 samples indicated low levels of gene expression for all otters sampled in WPWS (that is, in both oiled and unoiled areas). This result was not expected, and is difficult to interpret without data from a wider panel of genes. However, the low transcription levels for genes that previously showed elevated levels, and lack of difference in transcription rates between otters from heavily, moderately, and unoiled areas of WPWS suggest that sea otters were not exposed to oil in 2012.

Overall, we conclude that current population level data for sea otters in WPWS are consistent with the EVOSTC definition of recovery for sea otters from the long-term injury incurred in the wake of the 1989 oil spill. The support for this is based primarily on demographic data, including (1) a return to estimated pre-spill abundance of sea otters at northern Knight Island, a heavily oiled area within WPWS, and (2) a return to pre-spill mortality patterns based on ages-at-death. Gene transcription rates in 2012 were similar in sea otters from oiled, moderately oiled and unoiled areas, suggesting abatement of exposure effects in 2012. However, because 2012 gene transcription rates generally were low for sea otters from all areas relative to 2008, we cannot fully interpret these observations without data from a wider panel of genes. This slight uncertainty with respect to the data from the biochemical indicator is outweighed by the strength of the data for the demographic indicators. The return to pre-spill numbers and mortality patterns suggests a gradual dissipation of lingering oil over the past two decades, to the point where continuing exposure is no longer of biological significance to the WPWS sea otter population.

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