Exxon Valdez Oil Spill
Long-Term Monitoring Program (Gulf Watch Alaska) Final Report

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

Exxon Valdez Oil Spill Trustee Council Project 16120114
Final Report

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Study History: The Gulf Watch Alaska program was initiated in 2012 in response to an invitation for proposals from the *Exxon Valdez* Oil Spill Trustee Council for a long-term monitoring program that would track the recovery of resources since the spill, and assess how factors other than oil may inhibit full recovery. Gulf Watch Alaska included 15 scientific monitoring projects assessing environmental drivers, the pelagic ecosystem, the nearshore ecosystem, and lingering oil. Additionally, five administrative and data management projects were established to support the Gulf Watch Alaska program, including; 1) program integration and science synthesis, 2) historic data retrieval and synthesis, 3) data management, 4) administration, and 5) outreach. Many of the long-term monitoring projects incorporated into Gulf Watch Alaska were previously funded by the EVOSTC, with some originating prior to the spill in 1989 and representing > 40-year time series. Based on the success of the first five-year period, the Gulf Watch Alaska program was approved for funding by the *Exxon Valdez* Oil Spill Trustee Council to continue long-term monitoring for fiscal years 2017-2021.

Abstract: The Gulf Watch Alaska long-term monitoring program was developed around three core ecosystem components: 1) Environmental Drivers – physical and biological oceanography to assess the effect of “bottom-up” changes in ocean productivity; 2) Pelagic – studies of forage fishes, seabirds, humpback whales, and killer whales to assess effects on higher trophic levels and the role of “top-down” predation; and 3) Nearshore – studies of subtidal and intertidal habitats and dependent species such as sea otters and marine birds. Sustaining and building on existing long-term datasets in *Exxon Valdez* oil spill-affected regions was also a central focus for the Gulf Watch Alaska long-term monitoring program. Fortuitously, Gulf Watch Alaska field sampling began at a critical time to capture a multi-year warm water anomaly known as the Pacific marine heatwave. All scientific projects associated with the Gulf Watch Alaska long-term monitoring program detected significant environmental or species changes during the anomaly. Gulf Watch Alaska investigators identified lingering oil remaining in Prince William Sound, however, its chronic impacts on wildlife has declined. More than 50 peer reviewed journal articles and book chapters have been published using Gulf Watch Alaska originated or historical data and 189 datasets from Gulf Watch Alaska were published online for public access in DataONE. Gulf Watch Alaska investigators also gave more than 200 oral and poster presentations at science conferences and public venues. Community outreach included online virtual field trips, hands-on discovery labs and interviews with diverse audiences from rural Alaskan villages to larger spill-affected communities. Gulf Watch Alaska has led to an improved understanding of how ecosystem change affects resources and services injured by the *Exxon Valdez* oil spill, and is well positioned to continue assessing impacts on *Exxon Valdez* Oil Spill Trustee Council injured resources and inform ecosystem-based fisheries management in the Gulf of Alaska.

Key words: ecosystem, *Exxon Valdez* oil spill, Gulf of Alaska, intertidal, long-term monitoring, nearshore, oceanography, pelagic, Prince William Sound, program management, science coordination, science synthesis

Project Data: Data collected for Gulf Watch Alaska program projects that contributed to this report are available through the Alaska Ocean Observing System (AOOS) Gulf of Alaska data portal: http://portal.aoos.org/gulf-of-alaska.php#module-search?lg=5040a46e-25db-11e1-94b9-0019b9dae22b&page=1&tagId=Tag%3AEVOS+Gulf+Watch+Projects&q=&tags=Tag%3AEVOS+Gulf+Watch+Projects

The data may also be found through the DataONE earth and environmental data archive at https://search.dataone.org/#data and by selecting the Gulf of Alaska Data Portal under the Member Node filter.

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EXECUTIVE SUMMARY

The Gulf Watch Alaska (GWA) long-term ecosystem monitoring (LTM) program was initiated by the *Exxon Valdez* Oil Spill Trustee Council (EVOSTC) to better understand how continued changes in the Gulf of Alaska (GOA) marine ecosystem may hinder a return to pre-spill conditions for some injured resources. GWA began in 2012 with an anticipated lifespan of 20 years. While the EVOSTC had previously funded several shorter-term (≤ 6 years) studies focused on individual ecosystem components, GWA was the first to include all major ecosystem components and span much of the oil spill affected area. Major review and funding approval for the GWA program occurs annually within the five-year program. This report summarizes accomplishments and findings during the first five years of GWA, 2012-2016, and highlights directions for the next five years, 2017-2021.

GWA was developed around three core ecosystem components and together with program administration were composed of 20 cohesive projects. The three core ecosystem components included: (1) Environmental Drivers – five projects focused on physical and biological oceanography to assess the effect of "bottom-up" changes in ocean productivity on EVOS injured and recovered species; (2) Pelagic - six projects focused on forage fishes, seabirds, humpback whales, and killer whales to assess effects on higher trophic levels and the role of "top-down" predation and forage fish abundance in the recovery of injured species; and (3) Nearshore - two projects evaluating subtidal and intertidal habitats and dependent species such as sea otters and marine birds that were affected by the *Exxon Valdez* oil spill (EVOS). Program administration was comprised of four projects focused on overall program management, science integration and synthesis, data management, and outreach. Three additional projects were added to GWA once underway, two projects focused on the effects of lingering oil and one focused on recovering historic data related to injured resources and synthesizing long-term datasets.

Sustaining and building on existing long-term datasets in the EVOS-affected regions of the GOA was the heart of the GWA LTM monitoring program. Most field sampling projects in the GWA LTM program began before EVOS or in response to the need to better understand long-term ecosystem effects on injured species following EVOS. Four projects include long-term datasets beginning before or the year of EVOS (longest are > 40-year time series) and 10 projects have time series of greater than a decade. Several additional projects in the GWA LTM program were developed in response to information gaps in understanding ecosystem changes in the spill-affected region and the lack of recovery of some injured species to better inform recovery decisions.

Program management focused on maintaining coordination within GWA, but also ensured external coordination with other research and monitoring programs in Prince William Sound (PWS) and the GOA. For example, GWA and the EVOSTC-funded Herring Research and Monitoring (HRM) program co-convened annual principal investigators meetings, coordinated field sampling activities, shared data, and published collaborative research papers. GWA investigators also participated in the North Pacific Research Board-initiated

Gulf of Alaska Project, a 5-year, large-scale (50 investigators) ecosystem study and subsequent science synthesis efforts. Synthesis efforts included working with National Oceanic and Atmospheric Administration (NOAA) scientists to develop a few (e.g., Gulf of Alaska 1 mooring, continuous plankton recorder, and humpback whale predation on herring projects provided index information) GWA long-term datasets as ecosystem indicators for the North Pacific Fisheries Management Council (an effort we intend to expand upon in the next five years). GWA investigators leveraged partnerships with their own agencies and institutions to provide a nearly ¾ match of EVOSTC funds supporting GWA. Agency and external grant matching funds supplemented salaries, vessel time, field logistics, data collection, data analysis, and publication. These leveraged assets greatly enhanced the overall scope and effectiveness of the GWA LTM program.

GWA investigators collectively published 48 peer-reviewed science articles, with 17 additional manuscripts completed or in progress from the data recovery and long-term synthesis project. Furthermore, the GWA and HRM programs are nearing completion of a special issue of the journal *Deep-Sea Research Part II* with the theme "Spatial and Temporal Ecological Variability in the Northern Gulf of Alaska: What Have We Learned since the *Exxon Valdez* Oil Spill?" A total of 189 datasets from GWA were published online for public access in DataONE; 53 datasets were from GWA sampling and 126 datasets were recovered from historical EVOSTC-funded projects. Each of these datasets were published with detailed metadata and given a unique digital object identifier (DOI) for future use and citation by the broader scientific community. GWA investigators also gave more than 200 oral and poster presentations at science conferences and public venues. Community involvement and public outreach ranged from website development and online virtual field trips to hands-on discovery labs, K-12 school presentations, and articles and interviews in popular news outlets (print, radio, television). Within Alaska, GWA reached out to diverse audiences from rural Alaskan villages to larger spill-affected communities.

GWA field sampling began at a critical time to capture a multi-year warm water anomaly referred to as the "Blob" that was enhanced by El Niño conditions creating a multi-year Pacific marine heatwave. The marine heatwave began at the end of 2013, one year after GWA began, and continued for the remainder of the first five years of the GWA program. This warm water anomaly affected weather patterns and ecosystems across marine and terrestrial regions of Alaska and beyond. All scientific projects associated with the GWA LTM program detected environmental or species changes during the anomaly. Our environmental drivers components documented increased temperatures throughout the water column (the extent of warming was unique to this event), fresher (less saline) water at depth, with a higher abundance of warm water copepod species (generally lower energy value than more typical cold water species) and lower abundance of euphausiids such as krill which are an important food for many species, including whales. Nearshore and pelagic components documented the emergence of sea star wasting disease, increased paralytic shellfish poisoning, anomalous mortality events of seabirds and sea otters, and widespread reproductive failures of breeding seabirds. The next five years of GWA sampling will provide important insight into the recovery or potentially longer-term biological impacts of this marine heatwave.

Our results show that lingering *Exxon Valdez* oil (EVO) remains in PWS at levels unchanged since 2001. Although this oil maintains its potential toxicity, most of the oil is sequestered in subsurface sediments and therefore not biologically available to marine organisms. Data collected from passive samplers and oil exposure metrics for nearshore foraging sea otters and harlequin ducks support this conclusion in showing little evidence for continued exposure in the oil-affected area of PWS. Furthermore, long-term marine bird surveys in PWS indicate that recovery is underway at the population level for many species, including bald eagles, cormorants, and harlequin ducks. Some species, however, continue to decline, including mergansers, murrelets, pigeon guillemots, and terns. The AT1 pod of killer whales also continues to decline post EVOS, with extinction likely because no new calves have been produced since 1984.

Science synthesis products included publications noted above, the year 3 synthesis workshop and report, data visualization tools on the Gulf of Alaska Data Portal, and a conceptual ecological model of the northern GOA ecosystem. The conceptual ecological model included four submodels: (1) key trophic linkages in nearshore northern GOA ecosystem (sea otter and Barrow's goldeneye), (2) ecological linchpin hypothesis that upper trophic level dynamics are driven by the dynamics of mid-trophic forage stocks, (3) top-down forage fish control with humpback whale predation, and (4) bottom-up control with environmental forcing on plankton.

The GWA LTM program met or exceeded each of its objectives for the 2012-2016 funding period. Each project in the GWA LTM program provided significant contributions to the program as a whole. The outcomes of the first five years of the GWA LTM program drove planning for the second five years. The program's objectives will remain similar: sustain and build upon existing time series; provide scientific data, data products, and outreach; develop science synthesis products; continue to build on collaborations between the GWA and HRM programs; and leverage partnerships with outside agencies and groups. The program's management team has been modified, based on knowledge gained in the first five years; we separated the roles of science coordination and science synthesis and combined the roles of program and science leads into one. The scientific monitoring components will largely remain the same, except that the two nearshore ecosystem projects will be combined into one, three projects in PWS (fall/winter seabird abundance and distribution; humpback whale predation on herring; and forage fish distribution, abundance, and body condition) will now occur simultaneously using a shared vessel - with the forage fish project modifying its sampling procedures accordingly.

During the first five years, the GWA LTM program has led to an improved understanding of how changes in the GOA ecosystem affect resources and services injured by EVOS and conditions limiting a return to pre-spill conditions. The continuation and augmentation of GWA legacy datasets are critical to our understanding of long-term ecosystem change in the GOA. GWA is well positioned over the next five years to document biological impacts of continued ecosystem change, assess impacts on EVOSTC injured resources, and inform ecosystem-based fisheries management in the GOA.

INTRODUCTION

The 1994 EVOS Restoration Plan recognized that recovery from the spill would likely take decades (EVOSTC 1994). Two decades later, however, it was clear that reaching recovery goals was complicated by natural ecosystem variability. The EVOSTC's fiscal year 2012 invitation for proposals was therefore adapted and recognized that "in the twenty-one years since the *Exxon Valdez* oil spill, it has become apparent that the ocean ecosystem can undergo profound changes and such changes may hinder a return to pre-spill conditions" (EVOSTC 2010). In that year, EVOSTC's invitation sought proposals for a multi-year, multi-component program for long-term monitoring of marine conditions and injured resources. While EVOSTC had funded ecosystem studies in the past such as the Nearshore Vertebrate Predator project, Alaska Predator Ecosystem Experiment, and Sound Ecosystem Assessment, the scale and complexity of the 2012 invitation for proposals was unique. The invitation called for the program to: (1) be self-directed by a team leader rather than being overseen by EVOSTC staff; (2) include a science panel to provide guidance and oversight on the direction of the program; (3) be multi-disciplinary with components for environmental drivers, pelagic monitoring, and benthic monitoring; (4) commit to making data, documents, and reports available to the public; and (5) provide mechanisms for outreach to the public on program activities. Further, EVOSTC intended for the program to continue for 20 years (at five year grant increments with annual funding reviews).

The GWA LTM program was selected for funding during EVOSTC's fiscal year 2012 invitation for proposals. Agencies and organizations with a history of working in the spill-affected area and studying the recovery of injured resources following the spill came together to develop a program structure that responded to the requirements of the invitation. The agencies and organizations comprising the GWA program included: Alaska Ocean Observing System (AOOS), Prince William Sound Science Center (PWSSC), National Oceanographic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), National Park Service (NPS), U.S. Fish and Wildlife Service (USFWS), University of Alaska Fairbanks (UAF), University of Alaska Southeast (UAS), Kachemak Bay National Estuarine Research Reserve (KBRR), North Gulf Oceanic Society (NGOS), Sir Alister Hardy Foundation for Ocean Science (SAHFOS), Axiom Data Science (Axiom), Alaska SeaLife Center (ASLC), and Coastal Resources Associates, Inc.

GWA developed around three ecosystem components and administrative requirements called for in the invitation and initially included 17 projects. Ecosystem components included:

- Environmental Drivers projects studying physical and biological oceanographic conditions, including plankton abundance throughout the spill affected area from PWS through the northern GOA shelf, and into lower Cook Inlet and Kachemak Bay to assess the effect of bottom-up influences on injured species recovery
- Pelagic projects to continue monitoring recovery of forage fish, seabirds, humpback whales, and killer whales, and evaluate the role of top-down predation and bottom-up food availability in recovery of injured species,

- Nearshore projects studying subtidal and intertidal habitats that were affected by the EVOS and the associated species, including EVOSTC-designated injured sea otter ("recovered" in 2013) and several bird species (8 species originally listed, 2 currently designated "not recovering") that depend on these habitats

In addition to field sampling projects, the program team established administrative projects to meet the requirements, and overall goals and objectives of the LTM program. These projects included:

- Administration, Logistics, and Outreach, which administered funds under the NOAA grant for non-Trustee agencies, coordinated logistics and travel for annual meetings and the science review team, and performed public outreach activities for the program
- Data Management Support, which established a platform and structure for science projects to store, share, and visualize data, and make data and reports publicly available
- Science Coordination and Synthesis, which coordinated the projects within the program and supported synthesis of information across projects and components
- Conceptual Ecological Modeling, which worked with projects within and among components to develop conceptual models of the northern GOA ecosystem

Following the establishment and initial funding of the GWA LTM program, EVOSTC requested the program incorporate three additional projects, two studying the effects of lingering oil on the ecosystem and injured resources and one to recover historic data related to injured resource recovery and to synthesize existing long-term datasets.

The overall goals of the GWA LTM program are to:

- Provide sound scientific information on biological resources and environmental conditions to management agencies, the scientific research community and the general public
- Identify and help understand the impacts of multiple factors on recovery of resources injured by EVOS
- Leverage partnerships with state and federal agencies, universities, non-profits and private entities to integrate and provide access to data from broader monitoring efforts in the region

After five years of monitoring and collaboration among the scientists associated with the GWA LTM program, the timing of the establishment of a long-term monitoring program was fortuitous. The warm water anomaly known as the "Blob" that was enhanced by El Niño conditions created a multi-year Pacific marine heatwave. The heat wave began at the end of 2013 (just over a year after GWA's initiation) and extended for the remainder of the first five years of the GWA program, affecting weather patterns across marine and terrestrial regions of Alaska and beyond. All scientific projects associated with the GWA LTM program detected environmental or species changes associated with the anomaly.

OBJECTIVES

The objectives of the first five years of GWA program included:

1. Implement the guidance of EVOSTC planning efforts.
2. Sustain and build upon existing time series.
3. Enhance collaborations between principal investigator (PI) projects in the GWA LTM program and the Herring Research and Monitoring (HRM) program.
4. Leverage partnerships with outside agencies and groups to integrate data from broader monitoring efforts than that funded by the EVOSTC.
5. Provide data and scientifically-based data products to a wide variety of users.
6. Develop science synthesis products to assist management actions, inform the public, and guide the evolution of monitoring priorities for the next 20 years.

Herein, we provide brief summaries of methods and results for individual projects. Specific information about each project can be found in their respective final reports.

METHODS

The 2012 invitation for proposals (EVOSTC 2010) included mandatory and preferred requirements for the LTM program. These requirements included:

- Focus within the oil spill-affected area
- Responsive to the herring focal area in PWS
- Compliant with EVOSTC's founding documents reporting policies, and procedures
- Administrative structure to manage funds and projects
- Communication with EVOSTC through a team leader to work with and be responsive to EVOSTC's objectives and requirements, and facilitate cost-effective and scientifically-supportive funding across the program
- Program science panel to review projects and provide guidance and oversight on the direction of the program
- Commitment to make all data, documents, and annual and final reports available electronically to the public
- Mechanism for public outreach and opportunities for public comment on program activities
- Continual reassessment of the program's progress and relevancy
- Demonstrated understanding and synthesis of scientific literature and recognition of available research infrastructure
- Demonstrated effective and balanced use of funds
- Detailed plans for local and native community involvement and public outreach
- Realistic and detailed timelines and milestones for individual projects and the overall program
- Credible, feasible, and detailed administrative structure and scientific implementation

The methods used to meet the GWA LTM program's objectives are presented in detail in each of the project reports and summarized briefly here.

The scope of the GWA LTM program is inclusive of all components—environmental drivers, pelagic, nearshore, and lingering oil—and administrative projects associated with the program. The study region included the EVOS-affected area, specifically the northern GOA, PWS, Kenai Fjords, lower Cook Inlet, and the Katmai Coast in Shelikof Strait (Fig. 1).

The GWA LTM program team developed an organizational structure (Fig. 2) to meet EVOSTC requirements for the LTM program and to meet the GWA objectives. As a self-managed program, a robust and dedicated team was needed to maintain high quality science, make data publicly available, synthesize data collected by the program, and communicate the relevance of the data to resource managers and the public.

The program management team originally consisted of a program coordinator, administrative lead, and science team lead. The program coordinator provided oversight for all of GWA. The administrative lead provided oversight for the NOAA grant to non-Trustee agencies, travel logistics for the science review team, and outreach team. Both the program coordinator and administrative lead worked under the administrative, logistics, and outreach project (Table 1). The science team lead oversaw the scientific aspects of GWA with support of a science coordinator and facilitated overall science coordination and synthesis. A science coordinator was proposed to EVOSTC and added to the program during the first five years of the program based on the need to have one person provide full-time scientific and program support to the GWA team.

The program management team oversaw the outreach and community involvement steering committee. Outreach of GWA LTM program observations and findings to resource managers, stakeholders, and the public was an important aspect of the first five years of monitoring. To ensure that outreach efforts were most effective, the outreach coordinator developed a steering committee that consisted of experienced environmental educators and community involvement specialists (Hoffman and McCammon 2018).

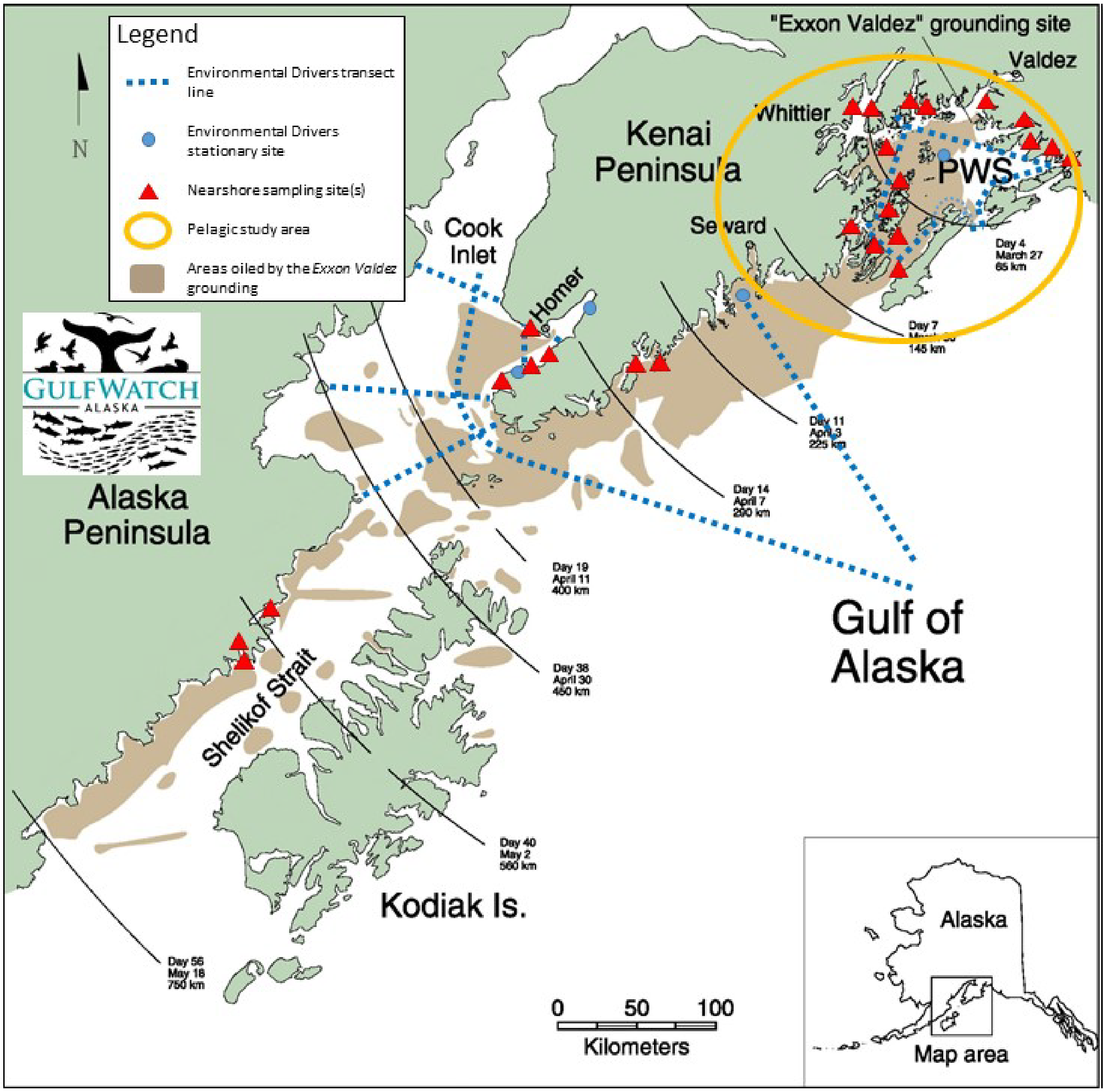


Figure 1. Gulf Watch Alaska long-term monitoring program study area within the *Exxon Valdez* oil spill affected area showing the approximate locations of projects in environmental drivers, nearshore, and pelagic components.

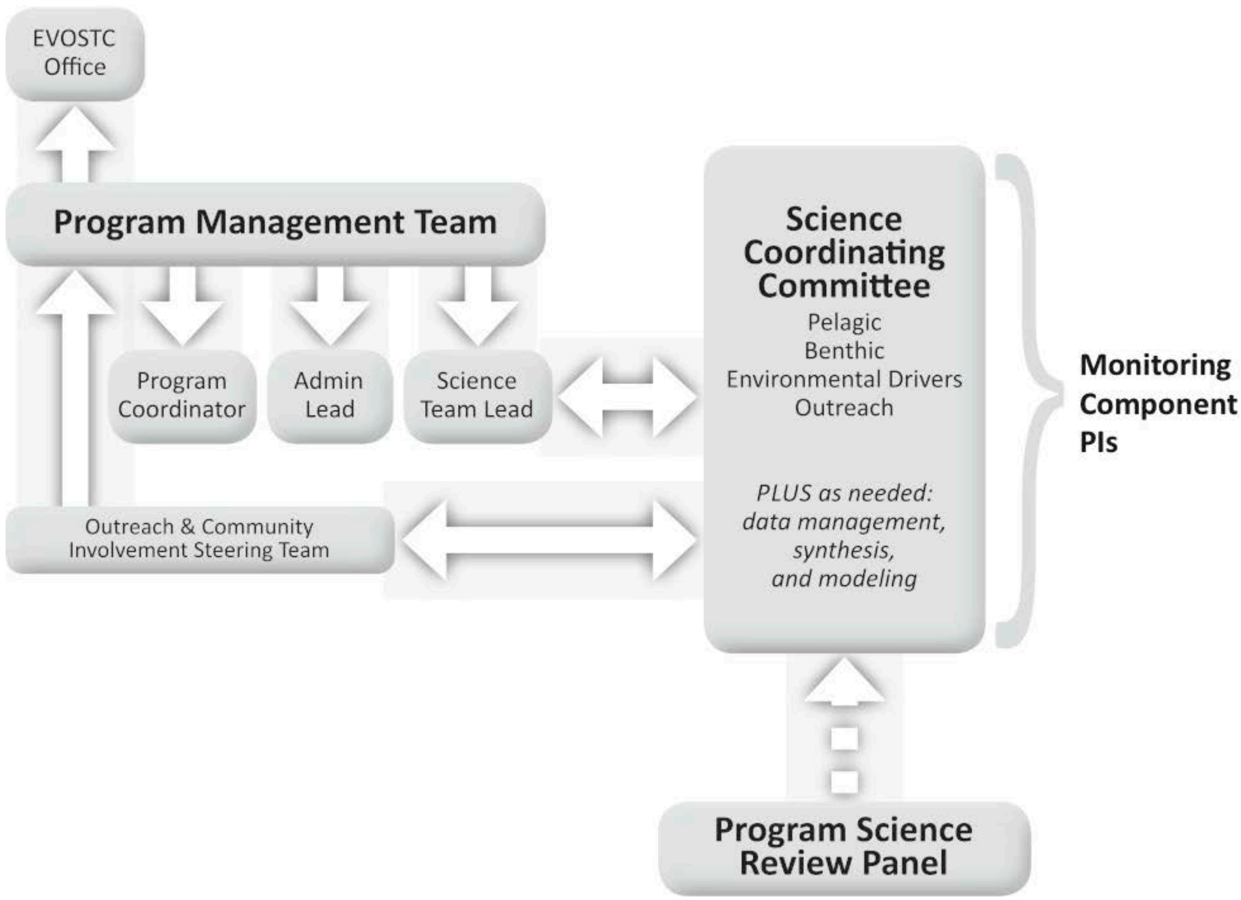


Figure 2. Organizational structure proposed in 2011 for the Gulf Watch Alaska long-term monitoring program funded by the *Exxon Valdez* Oil Spill Trustee Council.

The program management team worked with the component projects with the aid of a science coordinating committee (Fig. 2). The science coordinating committee was internal to the GWA LTM program and consisted of lead PIs (and alternates) from each of the study components: environmental drivers, pelagic, and nearshore/lingering oil. The science coordinating committee's roles included supporting communication between the program management team and the GWA LTM program PIs; providing internal oversight, coordination, and review of program deliverables; supporting data management; and aiding the program management team in program-level decision-making. Science coordinating committee members also took lead roles in the synthesis workshop and subsequent report initiated in year 3 of the program, and in the science journal special issue initiated in year 5 of the program.

The GWA program management team also established an external science review team. The external science review team consisted of eminent scientists with expertise and interest related to northeast Pacific oceanography, pelagic species, and nearshore ecosystems. The all-volunteer science review team provided peer review of program deliverables (e.g., work plans, reports, and proposals) and high-level scientific guidance to the program as a whole.

In all, the GWA LTM program included 20 projects, representing administration, monitoring, and synthesis (Table 1). PIs included in the GWA LTM program were experts in their field of study with knowledge of the northern GOA, the spill, and EVOSTC requirements. The lingering oil component was a separate part of the EVOSTC's fiscal year 2012 invitation for proposals and was added to the GWA LTM program after projects were awarded.

Table 1. Projects included in the Gulf Watch Alaska long-term monitoring program.

Project Title (Number)	**Brief Project Description (Lead Organization)[1]**
Administrative, Data Management, and Synthesis Projects	
Administration, logistics, and outreach (16120114-B)	Administered funds and reporting under the NOAA grant for non-trustee agencies, coordinated logistics and travel for annual meetings and the science review team, and performed public outreach activities for the program (AOOS and PWSSC)
Data management support (16120114-D and 16150114-T)	Established a platform and structure for science projects to store and share data, visualize data, and make data and reports publicly available (Axiom)
Science coordination and synthesis (16120114-H)	Coordinated projects within the program and supported synthesis of information across projects and components (NOAA)
Conceptual ecological modeling (16120114-I)	Worked with projects within and among components to develop conceptual models of the northern Gulf of Alaska ecosystem (ASLC)
Collaborative data management and holistic synthesis project (16120120)	Compiled and published data from projects historically funded by EVOSTC and hosted working groups to evaluate and synthesize historic EVOSTC data (NCEAS)
Environmental Drivers Component Projects	
Continuous plankton recorders (16120114-A)	A device collecting plankton data along the shipping route through the northern Gulf of

Project Title (Number)	Brief Project Description (Lead Organization)[1]
	Alaska into Cook Inlet, 2002-2016 (SAHFOS)
Long-term monitoring of oceanographic conditions in Prince William Sound (16120114-E)	Monitoring oceanography with a stationary mooring and cruise sampling in Prince William Sound, 2009-2016 (PWSSC)
Long-term monitoring of oceanographic conditions in Cook Inlet and Kachemak Bay (16120114-G)	Monitoring oceanography in lower Cook Inlet and Kachemak Bay which is downstream of GAK1 and Seward Line, 2001-2016 (KBRR and NOAA)
Seward Line (16120114-J)	An oceanographic transect extending from GAK1 to beyond the edge of the Gulf of Alaska continental shelf, 1998-2016 (UAF)
GAK1 (16120114-P)	GAK1 mooring located on the Gulf of Alaska shelf outside Resurrection Bay, a site with more than 40 years of oceanographic data, 1970-2016 (UAF)
Pelagic Ecosystem Component Projects	
Prince William Sound late fall/winter seabird abundance (16120114-B)	Evaluates the importance of Prince William Sound to overwintering marine birds and estimates population trends, 2007-2016 (PWSSC)
Ability to detect trends in nearshore marine bird surveys (16120114-F)	Synthesis study to evaluate trends in long-term data on marine birds observed in nearshore habitats from previously collected data (NPS)
Prince William Sound marine bird population trends (16120114-K)	Continuation of summer surveys in Prince William Sound to estimate marine bird populations and trends over time following the injury of marine birds from the spill, 1972-2016 (USFWS)
Killer whale monitoring (16120114-M)	Continuation of injured killer whale pod and population monitoring in Prince William Sound and Resurrection Bay, 1984-2016 (NGOS),

Project Title (Number)	Brief Project Description (Lead Organization)[1]
Humpback whale predation on herring (16120114-N)	Evaluates the potential role of humpback whales in the lack of recovery of herring populations in Prince William Sound, 2006-2016 (NOAA and UAS)
Forage fish distribution, abundance, and body condition (16120114-O)	Testing a variety of methods to evaluate forage fish in Prince William Sound, 2012-2016 (USGS)
Nearshore Ecosystem Component Projects	
Ecological communities in Kachemak Bay (16120114-L)	Sampling nearshore ecosystems in Kachemak Bay, 2008-2016 (UAF)
Nearshore benthic systems in the Gulf of Alaska (16120114-R)	Sampling nearshore ecosystems in Prince William Sound, Kenai Fjords, and Katmai, 1993-2016 (NPS and USGS)
Lingering Oil Component Projects	
Chronic exposure of harlequin ducks and sea otters to lingering oil (16120114-Q)	Continued investigations into the recovery of nearshore-dependent species injured by the spill, 1998-2013 (USGS)
Tracking oil levels and weathering in Prince William Sound (16120114-S)	Continued monitoring of subsurface oil at select beaches in Prince William Sound, 2001, 2003, 2005, 2015 (NOAA)

1 Organizations leading Gulf Watch Alaska program projects included the following, in alphabetical order: Alaska Ocean Observing System (AOOS), Alaska SeaLife Center (ASLC), Axiom Data Science (Axiom), Kachemak Bay National Estuarine Research Reserve (KBRR), National Center for Ecological Analysis and Synthesis (NCEAS), National Oceanic and Atmospheric Administration (NOAA), National Park Service (NPS), North Gulf Oceanic Society (NGOS), Prince William Sound Science Center (PWSSC), Sir Alister Hardy Foundation for Ocean Science (SAHFOS), University of Alaska Fairbanks (UAF), University of Alaska Southeast (UAS), U.S. Fish and Wildlife Service (USFWS), and U.S. Geological Survey (USGS).

The methods associated with each of these projects are summarized below by program objective. Detailed methods for each project may be found within individual project final reports.

Objective 1. Implement the Guidance of *Exxon Valdez* Oil Spill Trustee Council Planning Efforts

The projects that contributed to this objective included administration, logistics, and outreach; data management support; and science coordination and synthesis (Table 1).

Administration, Logistics, and Outreach
Project 16120114-B

GWA was the first self-managed LTM program funded by the EVOSTC, therefore, internal administration provided umbrella support and oversight to ensure the program as a whole operated smoothly and met objectives and project deliverable deadlines. Groups participating in GWA included EVOS Trustee and non-Trustee agencies/organizations. PWSSC implemented the administration, logistics, and outreach project and served as the agent responsible for awarding and managing all non-Trustee Agency contracts for the GWA LTM program (Hoffman and McCammon 2018).

Data Management Support
Projects 16120114-D and 16150114-T

The data management support project developed and implemented a central data management system for the EVOSTC's GWA and HRM programs that supported the entire data lifecycle for collecting and sharing data (Bochenek et al. 2018). The system was composed of several tools, including:

- The Ocean Workspace, a scientific collaboration and data management tool used to secure, centralize, and publish data files on public portals and catalogs
- The Gulf of Alaska data portal, which provided public access to data and allowed users to visualize and integrate data from different sources, including the GWA and HRM programs
- Participation as a member node in the Data Observation Network for Earth (DataONE) archive, to which GWA project data and metadata were deposited through the Workspace via an automated submission pathway

These services allowed for the query, discovery, and use of data and metadata through web-based search, catalog, and visualization interfaces for data produced by the GWA and HRM. This also ensured long-term preservation of data for public discovery and reuse.

Science Coordination and Synthesis
Project 16120114-H

A science coordinator implemented the science integration and synthesis project, in conjunction with the administration, logistics, outreach, and data management projects (Holderied and Aderhold 2018). The science coordinator facilitated communication among the GWA LTM program PIs, supported data sharing, and coordinated with the HRM program and other scientific groups working in the GOA. The GWA LTM program integrated science monitoring results through annual reporting by all projects; coordinated with data management, conceptual ecological modeling, and historic data synthesis; coordinated the science synthesis workshop and report in year 3 of the program; facilitated data integration, and worked with the data management team to archive and make datasets publically available.

Numerous means and tools were employed to communicate GWA objectives and results to resource managers and the public. These included the GWA website; incorporation of program data into resource management reports, presentations and posters at scientific and resource management meetings; scientific publications; data publication; and public outreach.

Objective 2. Sustain and Build Upon Existing Time Series

Sustaining and building on existing time series in the EVOS-affected regions of the GOA was the heart of the GWA LTM program. Numerous projects in the GWA LTM program began before or in response to EVOS and are critical for understanding ecosystem impacts on EVOS injured resources. A full description of project methods can be found in the project final reports.

Continuous Plankton Recorder
Project 16120114-A

Continuous Plankton Recorder (CPR) surveys have taken place in the northern GOA since 2000 (Batten and Brown 2018). Transects extended across the GOA into Cook Inlet monthly from April to September via ships of opportunity (Fig. 1). CPRs collected phytoplankton and zooplankton species that were identified in laboratory analysis following each transect. Temperature was recorded by self-powered, self-logging temperature recorders attached to the tail section of the CPR. A full description of the CPR instrument and sampling is given in Batten et al. (2003), and Richardson et al. (2006) describe data analysis methods.

Prince William Sound Oceanography
Project 16120114-E

Oceanographic monitoring in PWS included an autonomous moored profiler and 12 stations sampled during vessel surveys (Campbell 2018). The autonomous moored profiler was deployed at a site 9 km southeast of Naked Island, in 200m water depth (Fig. 1, blue dot in PWS); the same location of a biophysical buoy deployed by UAF in the 1990s as part of the EVOSTC-funded Sound Ecosystem Assessment program (see Eslinger et al. 2001). The profiler collected conductivity and temperature at depth (CTD), nitrate, fluorescence, turbidity, and plankton (via a camera) data.

The 12 stations in PWS were located, in part, to support HRM project studies (Fig. 1, blue dashed lines in PWS) and were sampled year-round at regular intervals 6 times per year. Data collected at each station included CTD, plankton, nutrients, and chlorophyll-a.

Cook Inlet/Kachemak Bay Oceanography
Project 16120114-G

Scientists conducted oceanographic surveys in lower Cook Inlet and Kachemak Bay along with shore-based oceanographic data collection (Fig. 1, blue dashed lines in lower Cook Inlet and Kachemak Bay; Doroff and Holderied 2018). Outer Kachemak Bay and lower Cook Inlet transects were surveyed quarterly with a chartered vessel, and the mid-Kachemak Bay transect was surveyed monthly from NOAA Kasitsna Bay Laboratory small boats. Data collection was prioritized along the northern and southern Cook Inlet transects, with sampling also conducted on the middle line when conditions allowed. Oceanographic data were collected at vertical stations with CTD profilers. Plankton sampling was conducted at three of the stations along each transect. To provide more temporal resolution, continuous oceanographic measurements were made year-round at the KBRR's system-wide monitoring program water quality stations located at the Seldovia and Homer harbors as well as in ice-free months from a buoy in Bear Cove near the head of Kachemak Bay.

Seward Line
Project 16120114-J

The Seward Line Program consisted of 13 primary and 9 secondary stations along the Seward Line, and 12 stations in PWS (eastern PWS stations were added in 2012) sampled in May and early September from the USFWS vessel *Tiglax* (Fig. 1, dotted blue line starting south of Seward; Hopcroft et al. 2018). Beginning in 2014, two stations were added to the offshore end of the line to ensure coverage of the oceanic end of the coastal ecosystem.

Oceanographic sampling methodology has remained stable since sampling began in the fall of 1997 (i.e. Weingartner et al. 2002), although the logistics of vessel availability pushed summer sampling from mid-August to early/mid-September. All hydrographic and bottle-based sampling was conducted during the day, as well as collection of the smaller zooplankton species that do not migrate vertically, and do not avoid nets. Seabird and mammal observations were made during station transits. At night, sampling was conducted for the larger and more mobile zooplankton, many of which could only be sampled efficiently during their daily migration toward the surface under the cover of darkness.

Gulf of Alaska 1 Mooring
Project 16120114-P

Hydrographic measurements at the Gulf of Alaska 1 (GAK1) mooring, located near the mouth of Resurrection Bay (Fig. 1, blue dot south of Seward at start of Seward Line), began in 1970 (Weingartner and Danielson 2018). Initially the sampling was opportunistic, became more regular in the 1980s and 1990s, and then systematic beginning in 1997 with EVOSTC support. Since then the sampling protocol has included both quasi-monthly CTD casts and hourly temperature and salinity measurements obtained by moored instruments at six depths distributed over the water column. GAK1 is the only station in the GOA that measures both salinity and temperature over the 250 m deep water column. Nutrient, chlorophyll and zooplankton sampling at GAK1 has occurred since 1997 with support from the Seward Line sampling.

Prince William Sound Fall/Winter Seabird Abundance
Project 16120114-C

Monitoring the winter numbers and distribution of marine birds in bays, passages, and open waters of PWS began in 2007 (Bishop 2018). Early years of the survey were used to refine methods. Since 2012, marine bird surveys took place in PWS during the nonbreeding season (September through March) onboard regularly-scheduled research cruises sponsored by EVOSTC, the Alaska Department of Fish and Game, and the Ocean Tracking Network maintenance cruise. Established U.S. Fish and Wildlife Service (USFWS) protocols (USFWS 2002, 2007) were used to record the number and species of birds occurring within a strip transect width of 300 m (150 m both sides and ahead of the boat).

Ability to Detect Trends in Nearshore Marine Bird Surveys
Project 12120114-F

This project originated from the need to have sufficient power to detect trends within a long-term monitoring program (Coletti and Wilson 2015). Sustainability of long-term monitoring programs requires 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 issues, we attempted to use currently available analytical methods to allow for use of existing data in simulations to estimate number of samples and sample frequency required to detect a specified trend as well as to examine factors contributing to variation, such as imperfect detection.

Prince William Sound Marine Bird Trends
Project 16120114-K

The USFWS has conducted summer marine bird abundance surveys in PWS since 1972. Four surveys were completed before the spill and 13 surveys after through 2016. Data from the 1989-1991 surveys were used to assess natural resource damage from the EVOS. These data indicated that populations of sea otters and several marine bird species had declined in the oil spill area in the years immediately following the spill.

For GWA, the study was designed to monitor marine bird populations of PWS to assess recovery of species affected by the EVOS (Kaler et al. 2018). To do so, biologists estimated abundance of marine bird taxa in PWS in summer 2012, 2014, and 2016 (Fig. 1, large circle). The main criteria used to evaluate post-spill recovery of marine bird populations was to compare whether trends in abundance of injured species differed between oiled areas and unoiled areas. A species was considered recovering if either an absolute or relative increase in abundance occurred in oiled areas. A species was considered not recovering if there was either an absolute or relative decrease in abundance in the oiled area. Recovery was considered uncertain if there was no statistically significant trend in abundance in oiled areas.

Killer Whale Monitoring
Project 16120114-M

Population monitoring of killer whales (*Orcinus orca*) in PWS, Resurrection Bay, and adjacent waters has occurred annually since 1984 (Fig. 1, large circle; Matkin et al. 2018). This project uses photo-identification methods to monitor changes in resident killer whale pods. Researchers maximized the number of encounters with as many killer whale pods or groups as possible and based field timing and search tracks on current and historical sighting information. Killer whales were found visually, or by listening for calls with a hydrophone, or by responding to VHF radio calls from other vessel operators. Diet studies of killer whales were conducted using extendable, fine mesh, dip nets to retrieve fish scales or pieces of flesh from prey at the site of a kill and collecting whale feces during the last year of the study.

Humpback Whale Predation on Herring
Project 16120114-N

Studies of humpback whale (*Megaptera novaeangliae*) predation on Pacific herring (*Clupea pallasii*) in PWS began in 2007 after scientific investigators collaborated to integrate information and identify factors contributing to the lack of recovery of Pacific herring following EVOS. Top down control by predation and disease were identified as key factors to investigate. Two winter predation studies conducted in 2007-2008 and 2008-2009 estimated that humpback whales consume between 21% and 77% of pre-spawning adult herring biomass in PWS. Humpback whale abundance and foraging patterns were monitored within PWS (Fig 1. large circle; Moran and Straley 2018). Individual whales were identified based on photographs of tail fluke patterns. When daylight (winter) and weather conditions were limiting, an adaptive survey approach was used to focus on areas with higher concentrations of whales. Aerial surveys and traditional local knowledge were employed to ensure aggregations of whales were not overlooked during boat-based surveys. When whales were located, a combination of techniques was used to identify prey, including direct observations of prey being consumed, collection of prey remains after feeding, collection of feces, and visual interpretation of the prey fields observed on a dual frequency echosounder. Confidence in identification of the target prey was recorded as certain, probable or undetermined. Only cases were the identification was certain or probable were used in analyses.

Forage Fish Distribution, Abundance, and Body Condition
Project 16120114-O

Data were collected on forage fish abundance, distribution and body condition in PWS during summers of 2012 through 2016 (Arimitsu et al. 2018). As a new project not relying on an existing time series, the primary objective was to determine robust methods to monitor forage fish in the spill-affected region. Investigators tested a variety of methods to monitor forage fish in PWS (Fig. 1, large circle). The original approach included a random systematic sampling design but was discontinued because the effort was concentrated in poor forage fish habitat and frequency of occurrence of target species on surveys was too low to adequately describe distribution or abundance at the sound-wide scale. Beginning in 2014, scientists tested an approach that combined aerial surveys and hydroacoustic-trawl surveys, using existing aerial shoreline data on school distribution and persistence to identify density strata within the study region. This method was found to be more useful than the systematic design because it targeted more suitable habitat for the most common species of forage fishes. Investigators also sampled forage fish habitat, biological and oceanographic conditions during surveys in each year.

Nearshore: Benthic Gulf of Alaska and Kachemak Bay
Projects 16120114-Q and 16120114-L

The two nearshore projects shared similar methods and are described together here. The nearshore monitoring work performed under the GWA LTM program builds on a long history of nearshore ecosystem monitoring and research, some of which dates back prior to EVOS (Coletti et al. 2018, Konar et al. 2018). Fieldwork was conducted in four regions within the spill-affected area of the northern GOA: western Prince William Sound (WPWS), Kenai Fjords National Park, Katmai National Park and Preserve, and Kachemak Bay (Fig 1., red triangles). The nearshore monitoring protocol focused on sampling of multiple components of nearshore ecosystems in the GOA that are both numerically and functionally important to the system's health. These are termed "vital signs" by the NPS inventory and monitoring program (Bennett et al. 2006) and include kelps (and other marine algae), seagrasses, marine intertidal invertebrates, marine birds, black oystercatchers, sea otters, and marine water quality. The rationale for focusing on these vital signs is detailed by Dean et al. (2014) and Coletti et al. (2016), and includes components of the nearshore that both detect change and infer cause. Nearshore monitoring was carefully designed, with coordinated sampling of all metrics, to provide insights into drivers of variation observed at different spatial and temporal scales.

Chronic Exposure to Lingering Oil
Project 14120114-Q

Harlequin ducks (*Histrionicus histrionicus*) and sea otters (*Enhydra lutris*) were two species injured by EVOS and dependent on nearshore and intertidal habitats that were slow to recover. The GWA LTM program proposed this project because of the importance of tracking the recovery of these species (Bowen et al. 2015).

Harlequin Ducks: Studies of harlequin ducks related to injury and recovery have included population monitoring by the USFWS and the Alaska Department of Fish and Game, as well as a series of directed research projects designed to elucidate the process of, and constraints to, population recovery. These studies demonstrated that harlequin ducks were exposed to lingering oil over a much longer time frame (i.e., through at least 2011, 22 years following the spill) than expected at the time of the spill, based on elevated levels of cytochrome P4501A (indicating exposure to polycyclic aromatic hydrocarbons) in birds from oiled areas. GWA sampling occurred during March 2013, when 25 harlequin ducks each were captured in oiled and unoiled areas of PWS. Small liver biopsies were surgically removed from each individual, frozen immediately in liquid nitrogen, and subsequently shipped to the University of California Davis for analysis of cytochrome P4501A.

Sea Otters: Studies of sea otters related to injury and recovery included surveys of abundance and studies of demographics, foraging behavior, and habitat use. GWA investigators used molecular gene transcription studies to examine the physiological status of the sea otters from the oiled area of western PWS. Gene transcription is the process by which information from the DNA template of a particular gene is transcribed into messenger RNA (mRNA) and eventually translated into a functional protein. The amount of mRNA transcribed from a particular gene is physiologically dictated by a number of intrinsic and extrinsic factors, including stimuli such as infectious agents, toxin exposure, trauma, or neoplasia. Altered levels of gene transcripts provide the earliest observable signs of health impairment, discernable prior to clinical manifestation. In 2012, sea otters from western PWS were sampled to evaluate whether gene transcription patterns still persisted since 2008 when this study was last conducted at the same locations. Analysis by GWA investigators in 2012 also included archived gene transcription data on sea otters from the Alaska Peninsula (2009), Katmai (2009), Clam Lagoon (Adak Island; 2012), Kodiak (2005), and captive aquaria populations (2008-2010), and additional captures in western PWS (2006, 2007, 2010) with the western PWS data from 2008 and 2012.

Tracking Oil Levels and Weathering
Project 16120114-S

Following the EVOS, initial shoreline cleanup assessment teams in PWS estimated that 40% of the spilled oil made landfall on beaches in PWS (Galt et al. 1991). However, during the first decade after the EVOS, some site-specific observations of oiled shoreline in PWS cast doubt on the expected loss rate and EVO was observed persisting in a fairly unweathered state. During the 2000s a new series of comprehensive surveys to update estimates of lingering oil in PWS were initiated by the EVOSTC.

The GWA program proposed this project because of the importance of tracking the long-term fate of lingering oil in the environment (Lindeberg et al. 2018). Nine previously surveyed beach segments in PWS were prioritized and sampled for lingering oil in 2015 following established lingering oil survey methods and analysis of oil composition. Bioavailability was assessed in ambient water with low-density polyethylene membrane sampling devices.

Objective 3. Enhance Collaborations between Gulf Watch Alaska and Herring Research and Monitoring

GWA and HRM programs coordinated on PI meetings, field activities, process studies, conceptual ecological modeling, and working groups. Integrated work between the two programs included data sharing by the environmental drivers component projects and collaborative field efforts between the humpback whale, marine birds, and forage fish GWA LTM projects and HRM projects.

The GWA LTM and HRM programs held a joint science workshop in February 2015 during which PIs presented the findings of synthesis reports prepared by each of the programs. The two programs collaborated on the publication of a special issue on spatial and temporal ecological variability in the northern GOA.

Objective 4. Leverage Partnerships

GWA LTM scientists and projects leveraged partnerships with agencies and individual grants to provide a nearly 0.75:1 match of EVOSTC funds supporting GWA. PI agencies contributed additional funds to GWA LTM projects to supplement data collection, data analysis, or scientist salaries. PIs sought grants from other agencies and organizations to supplement EVOSTC-provided funds. Program participants built off existing projects and platforms to reduce overall program costs. The GWA LTM program coordinated with research and monitoring projects and programs funded through other sources to minimize overlap in data collection and share information.

Objective 5. Provide Data, Data Products, and Outreach

The data management support project had primary responsibility for publishing data. The collaborative data management and holistic synthesis project retrieved historic EVOSTC datasets and published them online with unique digital object identifiers (DOIs) for long-term archival and use. Data products were developed through collaborations between the data management, conceptual ecological modeling, and collaborative data management and holistic synthesis projects and the monitoring projects. The administration, logistics, and outreach project led outreach efforts in conjunction with scientists from all other projects. Methods for data and outreach are briefly described below.

Data Management Support
Project 16120114-D

The data management support project (Bochenek et al. 2018) provided the platform for publishing data and managed the process for annual data publication and final publication on DataONE.

Collaborative Data Management
Project 16120120

The collaborative data management and holistic synthesis project was contracted by EVOSTC under a separate solicitation and added to the GWA LTM program. In this project, the National Center for Ecological Analysis and Synthesis (NCEAS) working group built data management systems that allowed the rescue and preservation of 126 historical data sets spanning the 25-year period following EVOS (Jones et al. 2018). From 2012 to 2014, a team recovered and archived data funded by the EVOSTC, specifically targeting projects funded between 1989 and 2010. Project information was obtained from the projects page on the EVOSTC website. Data archiving efforts spanned an initial intensive two-year period with follow-ups in the subsequent three years of the project. Recovered data were documented using Morpho metadata to produce structured metadata in Ecological

Metadata Language format (EML), and archived on a Gulf of Alaska Historical Data Portal (https://goa.nceas.ucsb.edu) as well as at replica sites in the DataONE network (https://search.dataone.org) and at the AOOS Gulf of Alaska Data Portal (http://portal.aoos.org/gulf-of-alaska.php).

Conceptual Ecological Modeling
Project 16120114-I

Development of conceptual ecological models to support synthesis and planning of the long-term monitoring program was a multi-phase process (Hollmen et al. 2018). In all conceptual ecological models a basic set of steps was followed: (1) identify the goals and objectives of the model, (2) conduct a literature review and assess the available data for the model components and linkages, (3) assemble a core modeling team, (4) create a preliminary model for review by the PIs, (5) perform iterative updates until a final model is approved, and (6) visualize results and communicate outcomes. A conceptual model for the northern GOA ecosystem and four submodels were developed. The four submodels included: (1) key trophic linkages in nearshore northern GOA ecosystem, (2) ecological linchpin hypothesis with forage fish abundance, (3) top-down forage fish control with humpback whale predation, and (4) bottom-up control with environmental forcing by plankton populations.

Outreach
Project 16120114-B

Under the administration, logistics, and outreach project (Hoffman and McCammon 2018), an outreach steering committee was established, made up of specialists from numerous organizations with expertise in environmental education and outreach. The committee decided on and implemented outreach and community involvement activities throughout the five-year period. Approaches used for outreach and community involvement included developing and maintaining a website for the program, holding discovery labs for children and adults, conducting scientist lectures, conducting in-school presentations, publishing articles in PWSSC's Delta Sound Connections and other news outlets, interviewing GWA LTM PIs for radio and video, producing virtual field trips, and youth film-making workshops and film nights.

Objective 6. Develop Science Synthesis Products

Science synthesis products were a collaborative effort among all projects within the GWA LTM program. The science coordination and synthesis project coordinated the synthesis efforts, while the data management project developed tools to compile multiple datasets over time and space to assess relationships. The conceptual ecological modeling project worked with other GWA LTM projects to synthesize information. The collaborative data management and holistic synthesis project also worked to synthesize historic data.

Science Coordination and Synthesis
Project 16120114-H

The science coordination and synthesis project team worked among PIs within GWA and among GWA and other groups/organizations working in the GOA (Holderied and Aderhold 2018). Methods used to coordinate and synthesize data within GWA included: facilitating quarterly team meetings during which PIs shared and discussed recent findings; planning and facilitating an integrated synthesis workshop between the GWA LTM and HRM programs; leading preparation of the science synthesis report in year 3; coordinating with PIs to improve integration of multi-disciplinary monitoring activities within and between geographic regions of the study area; and supporting and facilitating cooperation among projects for data management, modeling, and data exploration and visualization.

Data Management
Project 16120114-D

The Gulf of Alaska Data Portal was initiated in September 2013 (Bochenek et al. 2018). The portal was designed to give access to hundreds of datasets from the GOA region that could be visualized, integrated with other data, and parsed both spatially and temporally. These data included significant amounts of atmospheric, terrestrial, oceanographic, and coastal data. This also provided GWA PIs with access to a large, diverse set of valuable information for retrospective analysis, synthesis, and model development.

Data visualizations were completed for several EVOSTC long-term monitoring datasets. The goal of visualizations was to provide a clear and efficient visual communication of data by making complex or long-term information more accessible, understandable, and usable. Additionally, visualizations helped researchers to make comparisons to related environmental datasets.

Conceptual Ecological Modeling
Project 16120114-I

The general northern GOA conceptual ecosystem model synthesized knowledge from each of the GWA LTM program's components and PIs (Hollmen et al. 2018). Initially, information about previous conceptual modeling efforts within the study area was compiled and reviewed. Then, an evaluation was conducted to determine the best-suited modeling tools for GWA purposes. A one-day modeling session was held at the annual GWA LTM program PI meeting in November 2012. PIs provided expert input into the development of general model. PI responses were analyzed to produce the first version of the northern GOA conceptual model. The final step of the process involved reconstructing a visual representation of the conceptual model. The results were used to create two visualizations: (1) a comprehensive model incorporating the full set of components and linkages indicated by PIs, and (2) a parsimonious model with minimally sufficient detail to adequately describe the northern GOA ecosystem which contained only those linkages and model elements which ≥ 3 PIs included. The northern GOA ecosystem model was then re-evaluated in 2016 with GWA PI input based on knowledge gained over the five-year period.

Holistic Synthesis
Project 16120120

As part of the collaborative data management and holistic synthesis project, NCEAS formed two ecological community-driven synthesis working groups, one focusing on GOA dynamics, and the other on portfolio effects (i.e., the relationship between biodiversity and stability of ecological populations and communities; the principle being that, similar to diverse stock holdings leading to greater financial stability, greater biodiversity minimizes the risk of instability of biological systems) in the GOA (Jones et al. 2018). Each working group used historical and contemporary data to drive cross-disciplinary analyses of spill-impacted regions of the GOA. Two working groups were selected to conduct synthetic analyses of the GOA ecosystems based on the 25 years of data collected since the EVOS. Two postdoctoral researchers were recruited to participate in the working groups and conduct further analyses of the GOA systems. Both groups held organizational meetings in late 2014 and work began in early in 2015. The GOA dynamics working group and the portfolio effects working group each held two working group meetings in 2015 and two in 2016 at NCEAS in Santa Barbara, California. The two postdocs associated with these groups worked concurrently with the synthesis working groups. Both groups used standardized methods to collate, clean, integrate, and analyze historical data associated with the spill-affected region and to generate novel insights into the impacts and recovery of the oil spill and its relationship to other ecological and environmental factors.

Publications

PIs worked collaboratively with other scientists within and outside of the GWA LTM program to publish results based on data collected as part of GWA. Some of the results published include data collected before and after the creation of the LTM program. Journals targeted for publications varied widely, representing focus on general science, marine science, oceanography, ecology, arctic science, toxicology, coastal and estuarine science, fisheries, mammalogy, ornithology, plankton, and acoustics. PIs also contributed chapters to books focused on particular species, oil spill response and impacts, statistical methods, and other topics. Graduate students were incorporated into several projects within the program and they published theses from universities.

RESULTS

GWA LTM program results are presented in detail in each of the project reports and summarized briefly here. Where appropriate references to project final reports are provided.

Objective 1. Implement the Guidance of *Exxon Valdez* Oil Spill Trustee Council Planning Efforts

The administration, logistics, and outreach; data management support; and science coordination and synthesis projects implemented EVOSTC guidance based on the invitation for proposals (EVOSTC 2010), restoration plan (EVOSTC 1994), annual work plans, reporting procedures (EVOSTC 2016), and correspondence and meetings with EVOSTC and EVOSTC staff.

Administration. Logistics, and Outreach
Project 16120114-B

PWSSC issued and managed subaward contracts for all non-Trustee Agency projects in all five years of the GWA LTM program (Hoffman and McCammon 2018). Activities included remunerating subawardees based on demonstrated expenses, tracking spending, and completing annual audits. PWSSC provided outreach funding as directed by AOOS and the outreach steering committee. Semi-annual program reports to NOAA and annual EVOSTC reports and work plans were submitted on time. Fiscal reports such as SF425s were submitted to NOAA by all required deadlines. The program management team was very proactive and conducted conference calls approximately twice monthly, and occasionally weekly or greater frequency, as needed.

Four PI meetings were held per year. Two quarterly meetings were held by phone; the other two were held in person at the Alaska Marine Science Symposium and at the annual PI meeting each fall. PWSSC coordinated logistics and processed expenses for all in-person meetings and managed travel and logistics for the science review team in each of the years they were involved in the program. Fall PI meetings were typically scheduled in collaboration with the HRM program to enable cross-component and cross-program collaboration. All financial reports were submitted to NOAA and the EVOSTC as required and on time. Additionally, GWA program management team members attended EVOSTC Public Advisory Committee and Trustee Council meetings each year and either presented updates on the program or answered questions.

In year 3, the program management team participated in the synthesis workshop with EVOSTC Science Panel members and PIs from both GWA and HRM. The program management team worked closely with EVOSTC staff to streamline reporting and communications processes and ensure that the program was responsive to requests and input.

Data Management Support
Projects 16120114-D and 16120114-T

In year 1, data management staff worked with GWA PIs to assess the types of data that were to be collected during the program. The intent was to identify the data management needs and the types of tools needed by researchers to increase their abilities to manage and share their data in an automated, standard fashion. The details of the assessment were then used to assist and guide overall data management for the program (Bochenek et al. 2018).

Using the results of the assessment, a shared program platform was developed to facilitate data transfer, metadata generation and archiving for the entire GWA program data management lifecycle. The data management group developed a web-based platform, the

Ocean Workspace (Workspace), for PIs to manage project-level datasets and author metadata. The Workspace was released in 2012 for the GWA program as a web-based data management application built specifically for storing and sharing data among members of scientific communities. GWA PIs and their teams used the Workspace as an internal staging area prior to public release of data. The Workspace provided users with an intuitive, web-based interface. The Workspace was developed with capabilities that included secure group, user, and project profiles and advanced and secure file management.

Beginning in 2012, the metadata elements available to researchers in the Workspace were consistent with the Federal Geographic Data Committee (FGDC) standards. Axiom also developed an integrated FGDC biological profile extension editor that allowed users to search the ~625,000 taxonomic entities of the Integrated Taxonomic Information System (ITIS) and rapidly generate taxonomic metadata.

In 2016, the metadata editor was updated to meet International Organization for Standardization (ISO) 19115-2 compliant metadata. Features of the new editor included increased metadata fields to allow for more robust descriptions of datasets and their connections to other resources - notably the historic EVOSTC and time series datasets that were salvaged under the collaborative data management and holistic synthesis project. Further, the new editor helped ease the metadata generation process through short, modular, and easily understood entry forms (Figs. 3 and 4).

Axiom data management workflow included technical support and oversight on metadata format and content throughout the project lifecycle. A data inventory for the program was developed and used as the foundation to track actual data and metadata submission to the Workspace by PIs. The data management team then focused on quality control of the data and metadata, including data file formatting and documentation to ensure authoring met best practices and accurately reflected data captured within individual data files.

Data from the GWA projects have been made available through multiple pathways. During the data collection and analysis phases, provisional datasets from GWA projects were securely available for internal use through the Workspace (described above). As datasets were quality-reviewed and finalized, the data were made available for exploration and discovery through the AOOS Gulf of Alaska Data Portal (http://portal.aoos.org/gulf-of-alaska.php) (Fig. 4). Simultaneously, finalized datasets from the 2012-2016 GWA project efforts were archived through DataONE, where they will receive DOIs and will be preserved over the long-term. National repositories, such as DataONE, have the advantage of reaching wider audiences, thus expanding the access, discoverability, and active management of data collections generated through the GWA program.

The Gulf of Alaska Data Portal was initiated in September 2013. The portal was designed to give access to hundreds of datasets from the GOA region that could be visualized, integrated with other data, and parsed both spatially and temporally. It included both catalog and interactive mapping interfaces. Additionally, to simplify the publication of data and metadata for PIs, the Workspace was designed as a gateway to publish GWA project data and associated metadata into the Gulf of Alaska Data Portal.

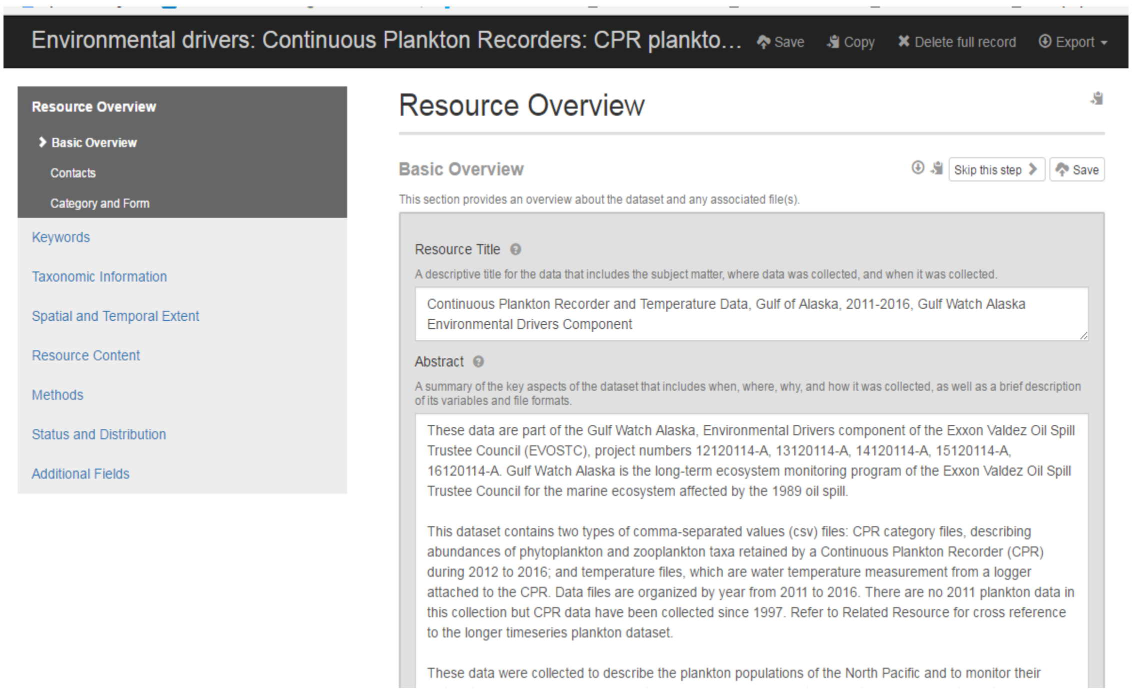


Figure 3. The metadata editor interface within the Ocean Workspace. The editor assisted users in authoring robust International Organization for Standardization-compliant metadata records alongside data objects. Individual fields were accompanied with help text and examples to guide users in creating metadata following best practice.

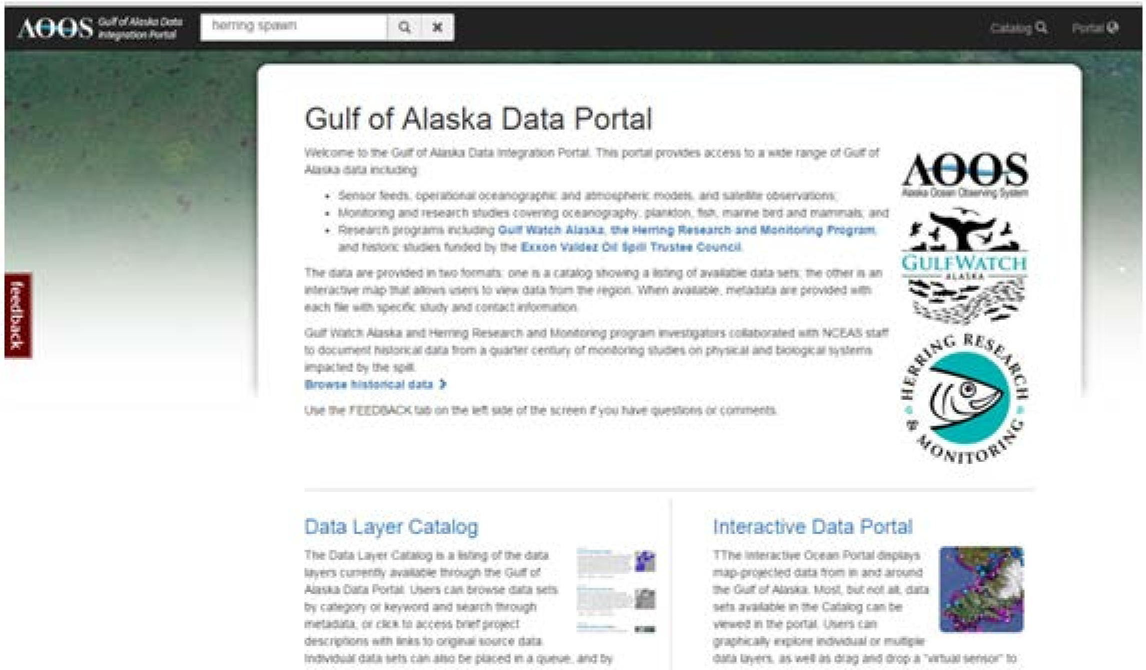


Figure 4. The overview page to the Gulf of Alaska Data Portal which highlights the availability of information from the EVOSTC-funded GWA and HRM programs as well as historical data available through the Gulf of Alaska Historical Data Portal. From here, users can access the catalog or the interactive mapping interface.

To facilitate the long-term storage and public-use of GWA data, final data and metadata were submitted to DataONE, a nationally recognized long-term archive for scientific data. DataONE links together existing cyberinfrastructure to provide a distributed framework that enables long-term preservation of diverse multi-discipline observational data. The distributed framework is composed of geographically-distributed Member Nodes that provide resources for their own data and replicated data and focus on serving their specific constituencies and diverse implementations. Axiom is a Member Node of the DataONE federation.

Science Coordination and Synthesis
Project 16120114-H

The science coordination and synthesis team (Holderied and Aderhold 2018) worked closely with the administration, logistics, and outreach team to hire a science coordinator, and establish the science coordination committee and science review team (Fig. 2). The science coordinating committee was internal to the GWA LTM program and consisted of lead PIs (and alternates) from each of the study components. The science coordinating committee's roles included supporting communication between the program management team and the GWA LTM program PIs; providing internal oversight, coordination, and review of program deliverables; supporting data management; and aiding the program management team in program-level decision-making. Science coordination and synthesis team members also took lead roles in the synthesis workshop and subsequent report initiated in year 3 of the program, and in the special issue initiated in year 5 of the program.

Science review team members included Terrie Klinger (University of Washington); Stanley "Jeep" Rice (NOAA, retired); Eric Volk (ADF&G) who retired and was replaced by Rich Brenner (ADF&G); Leslie Holland-Bartels (USGS, retired); and Hal Batchelder (North Pacific Marine Science Organization [PICES]). The science review team, working as volunteers for the program, exceeded expectations in their dedicated engagement and participation in GWA LTM program meetings and reviews for program synthesis, annual report, and program proposal review for the fiscal years 2017-2021 proposal.

The science coordinator ensured that project deadlines and deliverables were met, that deliverables were prepared according to EVOTC guidance (EVOSTC 2016), coordinated and hosted quarterly meetings, facilitated the science synthesis workshop and subsequent report, and acted as guest editor for a special issue in the journal *Deep-Sea Research Part II* that culminated the first 5 years of the GWA and HRM programs.

Objective 2. Sustain and Build Upon Existing Time Series

Continuous Plankton Recorder
Project 16120114-A

Six CPR transects were sampled each year (Batten and Brown 2018). Spacing between sampling was typically monthly as planned, though occasionally shorter than this (for example, when the ship went into dry dock in early September 2015 and the last two transects had to be towed closer together). Sometimes 6 weeks occurred between samplings to accommodate the technicians' schedule or to lengthen the field season (e.g., July to August 2016).

Four summary plankton variables are shown in Fig. 5, for the shelf region of the transect: total diatom abundance (an index of the large diatoms captured by the CPR), total mesozooplankton abundance (an index of the number of zooplankton organisms in the size range ~200 µm to ~1 cm), total mesozooplankton biomass (total dry weight, estimated from taxon-specific values and the abundance of each taxon), and average copepod community size (a community composition index, based on the adult female length of each copepod taxon recorded). The monthly mean data from 2012-2016 are superimposed on the mean time series values for all data collected from 2004-2015 (2016 data are provisional at this time). These indices are contributed each year to the NOAA Ecosystem Considerations report and the Fisheries and Oceans Canada State of the Pacific Ocean report (Chandler et al. 2016, Zador and Yasumiishi 2016).

Long-term averages show that there are typically two peaks in diatoms each year, in spring and autumn, with spring abundances higher than autumn. Mesozooplankton abundance and biomass have similar seasonal patterns being highest in spring and declining through summer and autumn; however, the decline in biomass is steeper than the decline in abundance. As the copepod community size index shows, spring is dominated by large copepods, which have a high individual biomass. Summer and autumn see smaller species dominating (many of the large species enter a dormant overwintering phase at depth by summer and disappear from surface waters); thus, while there are still numerous organisms present in summer (sometimes more than in spring), overall biomass is much less than in spring.

Most copepods in CPR samples are identified to species and so changes in the abundance of specific taxa can be indicative of changing oceanographic conditions. Given that anomalous warmth was a strong feature of the last part of the sampling period, the PIs further examined copepod taxa that tend to have a more southerly distribution, i.e., occur in warmer water, including the large copepod *Calanus pacificus*, associated with warm water, and a suite of four rarer taxa that tend to occur on the Alaskan shelf only in warm conditions (*Mesocalanus tenuicornis, Corycaeus* spp., *Clausocalanus* spp., and *Acartia danae*). Abundances of both indicators were higher in 2014-2016, second only to 2005, which was also a warm year.

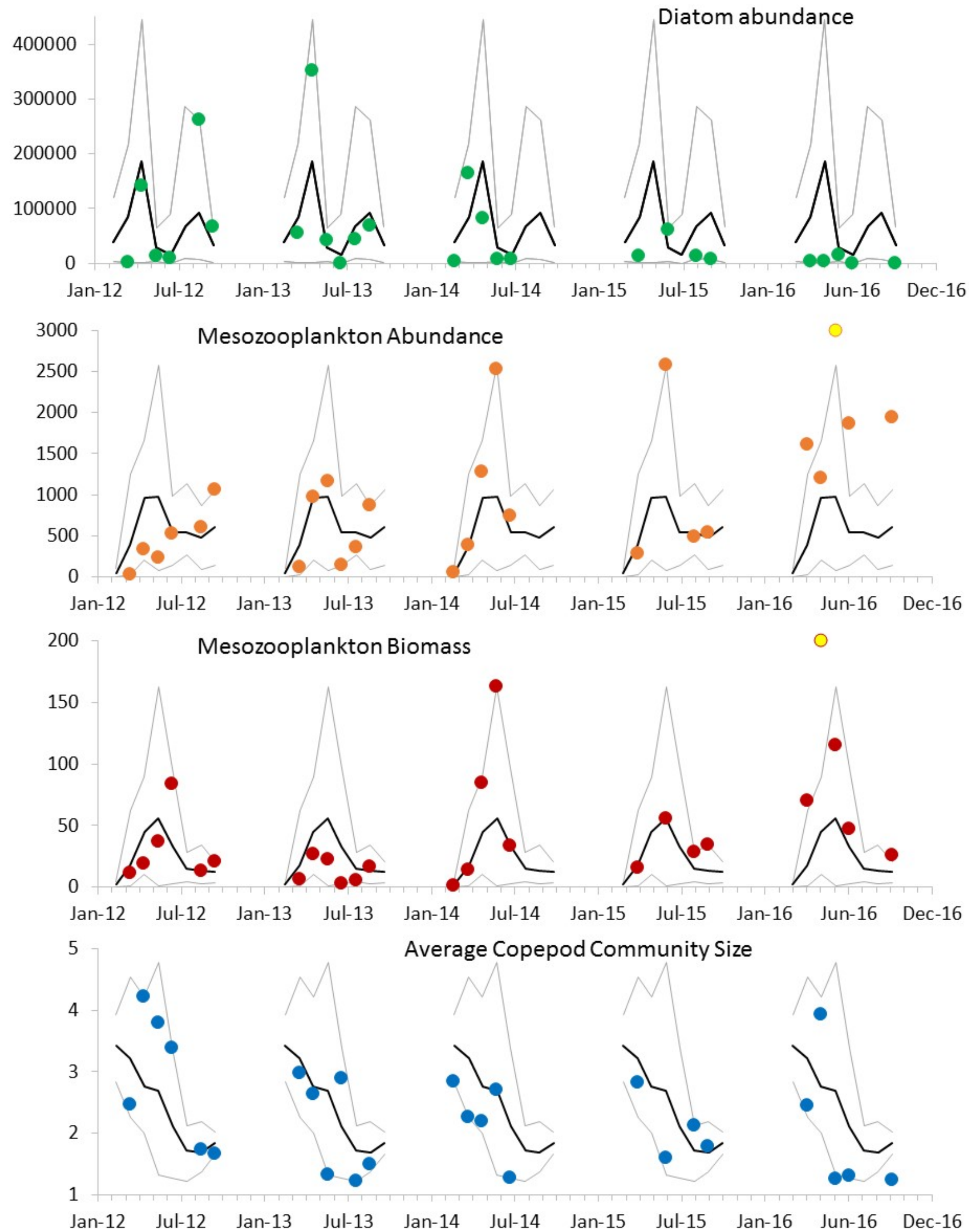


Figure 5. Monthly mean values (dots) per sample (monthly transect) for all shelf samples, 2012-2016 for four plankton indices: Abundance = number organisms per sample for diatoms and mesozooplankton, Biomass = mg dry weight per sample, Size = mm. Black line is the monthly mean, 2004-2015 and thin grey lines are the monthly minimum and maximum 2004-2015, in each case. 2016 data are provisional and the yellow points indicate values that are currently larger than the y-axis maximum.

The 2013 autonomous moored profiler deployment was done very late in the year, and was done primarily as a trial deployment to operationally test the profiler (Campbell 2018). Thirty-three daily profiles were completed during the deployment and showed the deepening of the seasonal thermocline in temperature and salinity (Fig. 6). There was no indication of an autumn bloom in the fluorescence record, and there was a pronounced nitricline. In 2014, the profiler was deployed on April 21. Although there was little indication that the spring thermocline had formed (Fig. 6), the spring bloom was already in progress, with a subsurface chlorophyll maximum, and significant draw-down of nitrate in the top 20 m of the water column. The 2014 deployment ended in late June following a hardware failure caused by a corrosion issue.

The 2015 deployment was started earlier in the year (March 22) and captured the development of the spring bloom, which began near-surface in late April and shifted towards a subsurface maximum into May (Fig. 6); the highest chlorophyll fluorescence at that time was located near the nitricline. The seasonal thermocline developed in late April and into May and was disrupted by large wind events in May and June that disrupted the thermocline (Fig. 6) and mixed nitrate towards the surface. Near surface salinity began to decline in late June and was also disrupted by a wind event in late July. Through July and August there was a chlorophyll maximum present at the nitricline, and there was not any indication of an autumn bloom during September and October when the seasonal pycnocline began to break down. However, there was about a 2-week gap where profiles were not done (the profiler was recovered after a software bug left it stuck at the surface, and weather prevented its redeployment for several days).

The start of the 2016 deployment was delayed by delays in the upgrades to the profiler at the factory, the need to test the new camera system, and an unexpected hardware failure when the electronics were initially returned. The profiler was deployed on April 4, and the spring bloom was already underway, with high chlorophyll fluorescence near-surface and nitrate depleted from the top 5 m of the water column. The seasonal thermocline began to form in late April / early May and broke down late September into October (Fig. 6). Near-surface salinity increased at approximately the same time (Fig. 6). There was again a chlorophyll maximum at the nitricline for much of the summer months, and a pronounced autumn bloom in late September and October, with high fluorescence occurring near the surface into November.

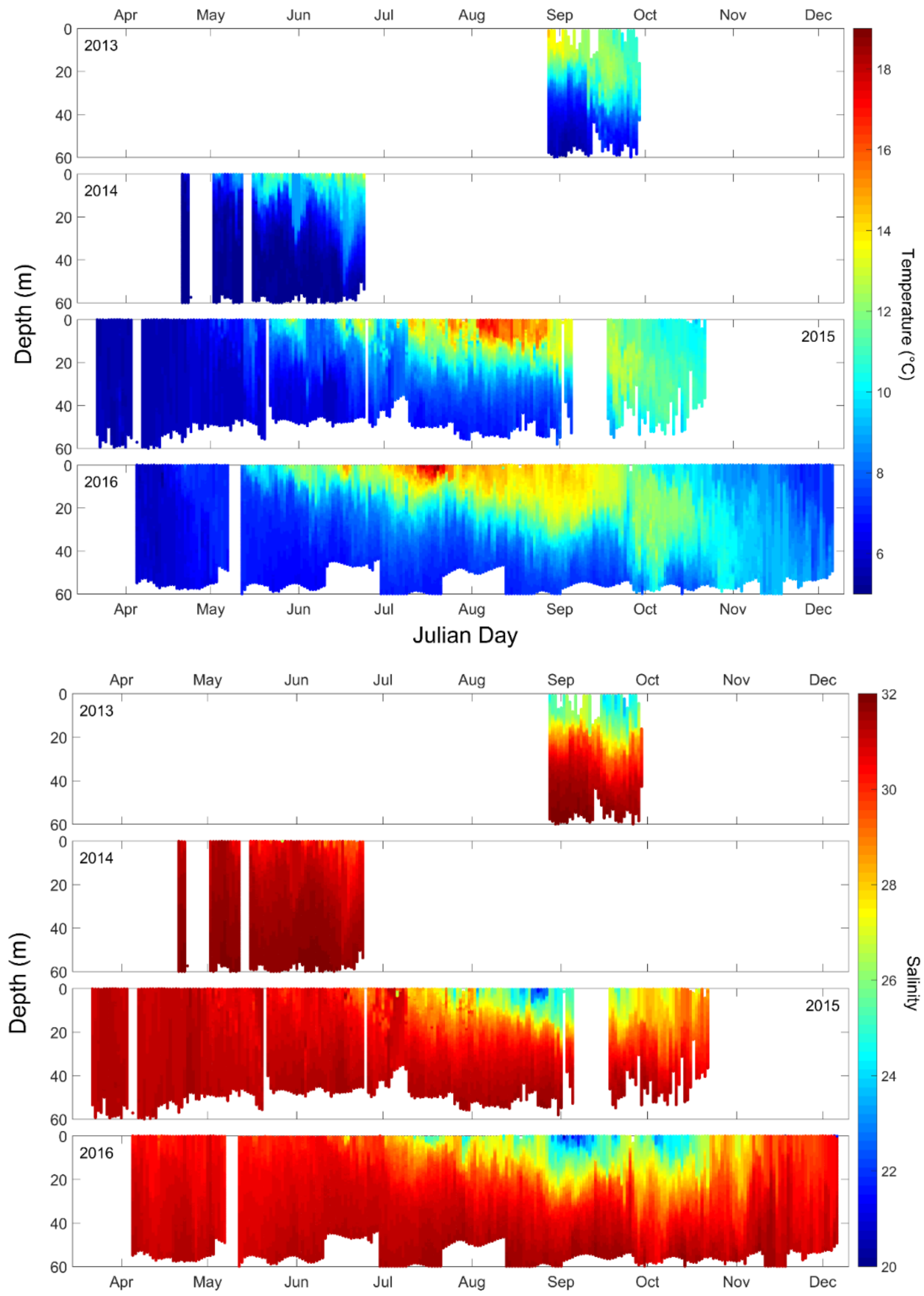


Figure 6. Temperature (top) and salinity (bottom) time series measured by the autonomous profiler during each year of deployment in Prince William Sound, Alaska.

Cook Inlet/Kachemak Bay Oceanography
Project 16120114-G

The 5-year time series of shipboard oceanographic data collected as part of this project, in conjunction with the 16-year record of continuous observations from nearshore water quality stations, enabled an initial detailed assessment of seasonal and interannual variability in lower Cook Inlet (Doroff and Holderied 2018). During the 2012-2016 study period, the GOA and the Cook Inlet/Kachemak Bay region experienced a transition from anomalously cold water temperatures in 2012 to persistent warm temperature anomalies (up to 3° C) during 2014-2016, particularly during winter months. Warm temperature anomalies were observed throughout the water column and deeper waters in Kachemak Bay were observed to become slightly fresher (less saline) in 2015 and 2016 (Fig. 7). An initial regional comparison of water temperature time series from Kachemak Bay, PWS, and the GAK1 mooring found that temporal patterns were quasi-synchronous at time scales longer than a couple months, but asynchronous at shorter time scales (Neher et al. 2014). Highest densities of seabirds and sea otters were found in outer Kachemak Bay and on the east side of the Cook Inlet entrance region (Fig. 8), which are also areas where oceanographic convergences frequently occur. Biological responses in Cook Inlet and Kachemak Bay associated with the Pacific warm anomaly event included changes in relative abundance of zooplankton species, emergence of sea star wasting disease in the Kachemak Bay nearshore ecosystem, seabird and sea otter mortality events, increased paralytic shellfish poisoning events, and changes in whale distributions. Year-round oceanographic observations with high spatial resolution from the Cook Inlet project are being used in ongoing studies to assess the biological response of coastal nearshore and pelagic ecosystem responses to climate variability in the GOA.

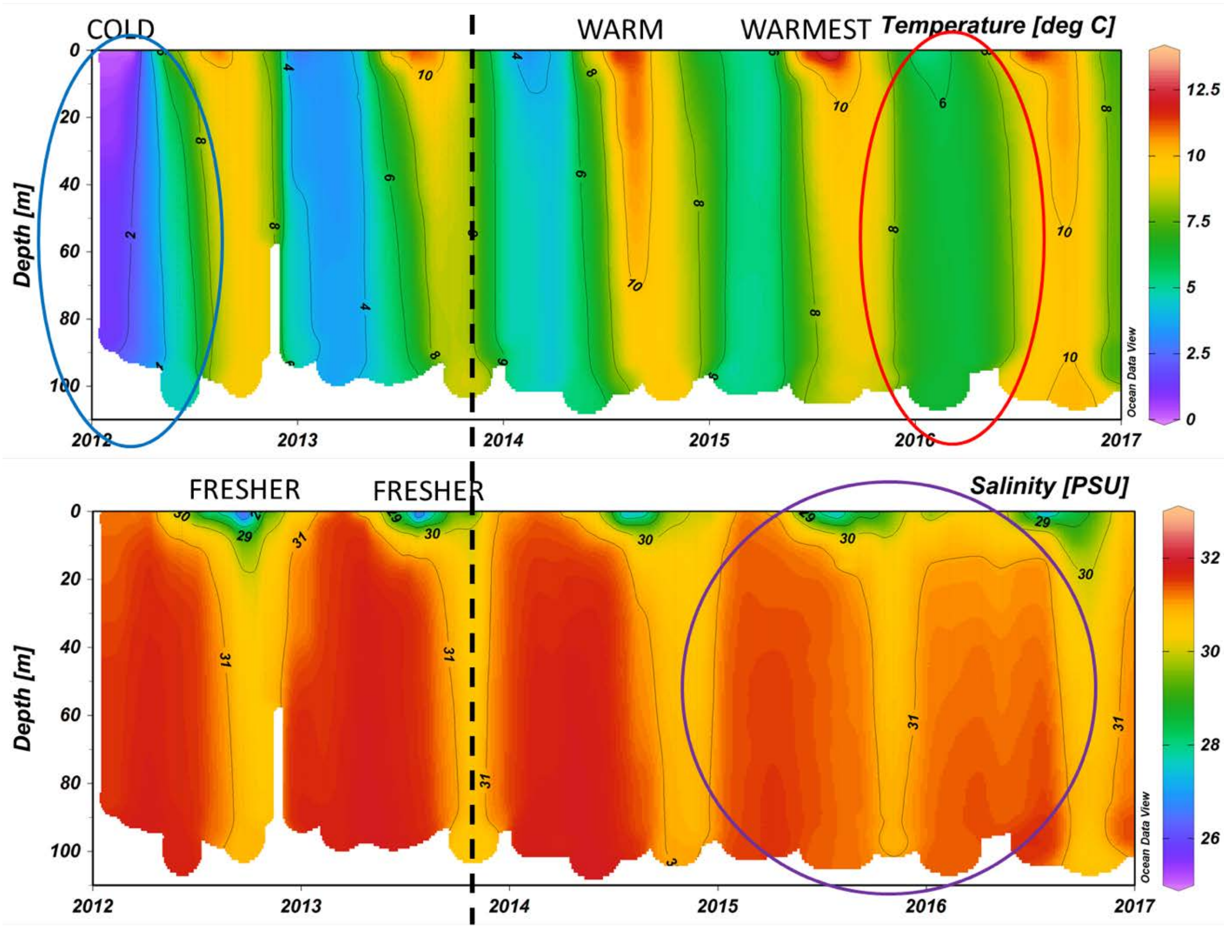


Figure 7. Time series of vertical profiles of water column temperature (top) and salinity (bottom) from 2012-2016 collected from monthly conductivity-temperature-vs-depth (CTD) casts at mid-Kachemak Bay station. The dashed black line marks the transition to warmer temperatures in late 2013, with warmer surface waters observed in the summers of 2014-2016. The cold winter water temperatures in 2012 (blue circle) were not seen in subsequent winters and 2015-2016 winter temperatures were much warmer than normal throughout the water column (red circle). Surface salinities were lowest in late summer and early fall, with freshest conditions in 2012 and 2013, but deeper waters freshened in 2015-2016 (purple circle).

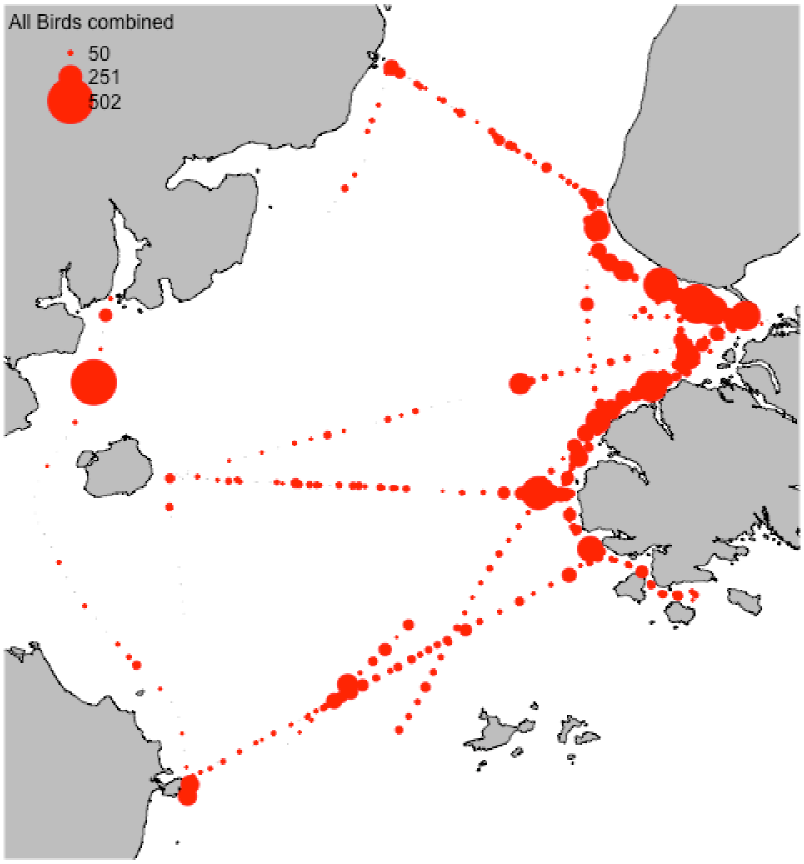


Figure 8. Total marine bird distributions [birds/km^2] for all lower Cook Inlet and Kachemak Bay shipboard surveys combined, 2012-2016.

Seward Line
Project 16120114-J

Using the average temperature within the upper 100 m of the ocean as a heat index, it is clear that May temperatures along the Seward Line were well above average during 2015 and 2016 (Fig. 9; Hopcroft et al. 2018). This anomaly was due to the sequential occurrence of a feature referred to as "the Blob" that began in early 2014 followed by an El Niño during 2015/16. It is notable that the other two warm Mays in the time series, 1998 and 2003, were also El Niño-related. Fall temperatures and their anomalies appear less clearly influenced by El Niño events; however, 2014-2016 appears consistently warm. A unique aspect of the 2014-2016 warm period was the large depth range over which this extra heat was distributed, with anomalously warm temperatures occurring down to 300 m.

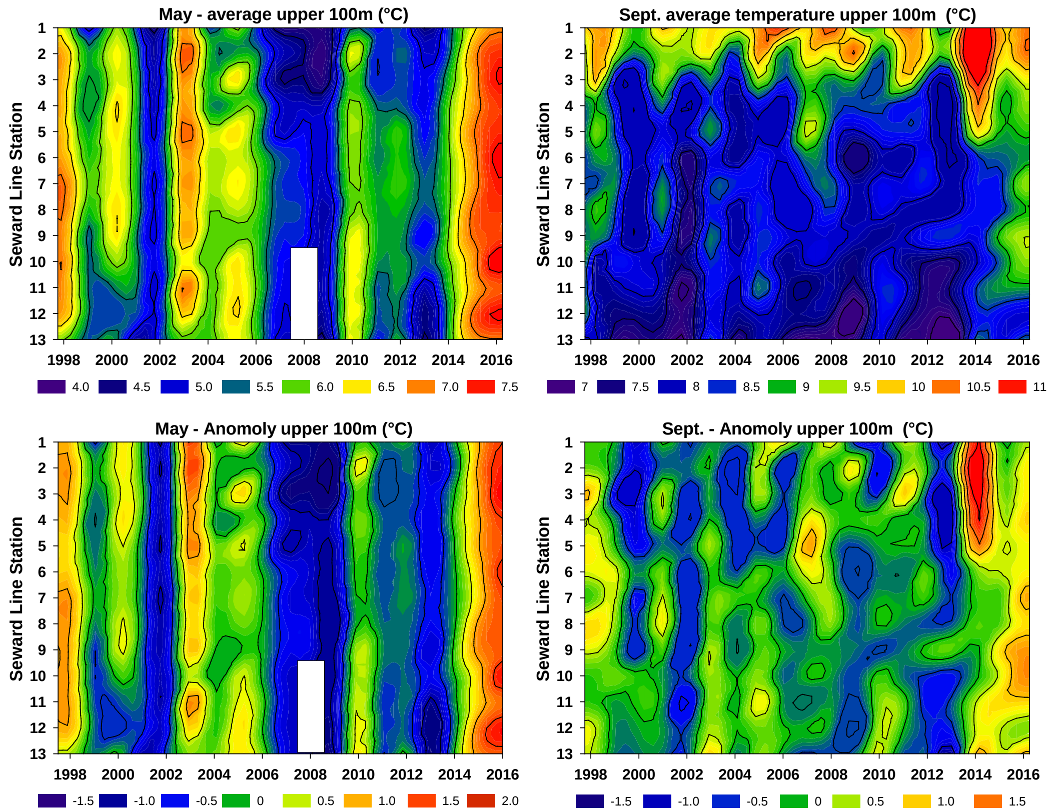


Figure 9. Average water temperatures in the upper 100 m along the Seward Line during May and September (upper), and the station-specific temperature anomalies (lower).

The metazoan zooplankton community on the GOA shelf consists of over 200 recognized holoplanktonic species, of which about 3 dozen contribute the majority of the abundance and biomass. The major suspension feeding groups captured by the 500-µm nets are the calanoid copepods and euphausiids, while the cnidarians (jellyfish and kin) and chaetognaths (arrow worms) are the major planktonic predators. Over the last 5 years, large calanoid abundance and biomass during May increased steadily from below to above the long-term mean, while euphausiid abundance and biomass was variable, with particularly low biomass during 2015-2016. Chaetognath abundance and biomass over this period were at or below the long-term mean, except for 2016 when both exceeded the long-term mean. Cnidarian abundance increased significantly during 2015-2016, but without consistent correspondence to biomass.

Gulf of Alaska 1 Mooring
Project 16120114-P

The GAK1 is one of the longest time series in GWA, extending over 45 years (Weingartner and Danielson 2018). Fig. 10A shows the distribution in time and depth of the monthly temperature, salinity, and density CTD data from GAK1 since 1970. Fig. 10B shows the corresponding monthly anomalies. The anomalies shown in Fig. 10B are based on the 2000

– 2016 period of the moorings. The corresponding time series of density profiles closely correspond to the salinity distribution because salinity is the primary driver of density variations in the GOA.

Note that over the 1970 – 2016 period, the coldest waters (Fig. 10B) occurred through the first pentad of the 1970s. Thereafter temperatures warmed in association with the mid-1970s regime shift (Hare and Mantua 2000). The only other noteworthy cooling events occurred in 1991, 2007-13. The extended period of cool years late in the record was replaced by the very warm waters of 2014-2016, which in addition to a very strong 2015 El Niño included the recent North Pacific "blob" or "marine heat wave" (Bond et al. 2015).

The results indicate that the GOA shelf has warmed by ~1 °C in the upper 100m and by ~0.6 °C between 100m and 200m the last 46 years. Salinity has decreased by ~0.6 °C at the surface and by ~0.2 °C over the upper 100m. These temperature trends are slightly lower than previously reported (Royer and Grosch 2006) and can be attributed to the anomalous cooling over 2007-2013. In contrast, the salinity between 100m and 200m depth has increased by ~0.1 °C. These contrasting changes in salinity between the upper and lower layers of the shelf imply that the vertical stratification of the water column has increased substantially since the early 1970s.

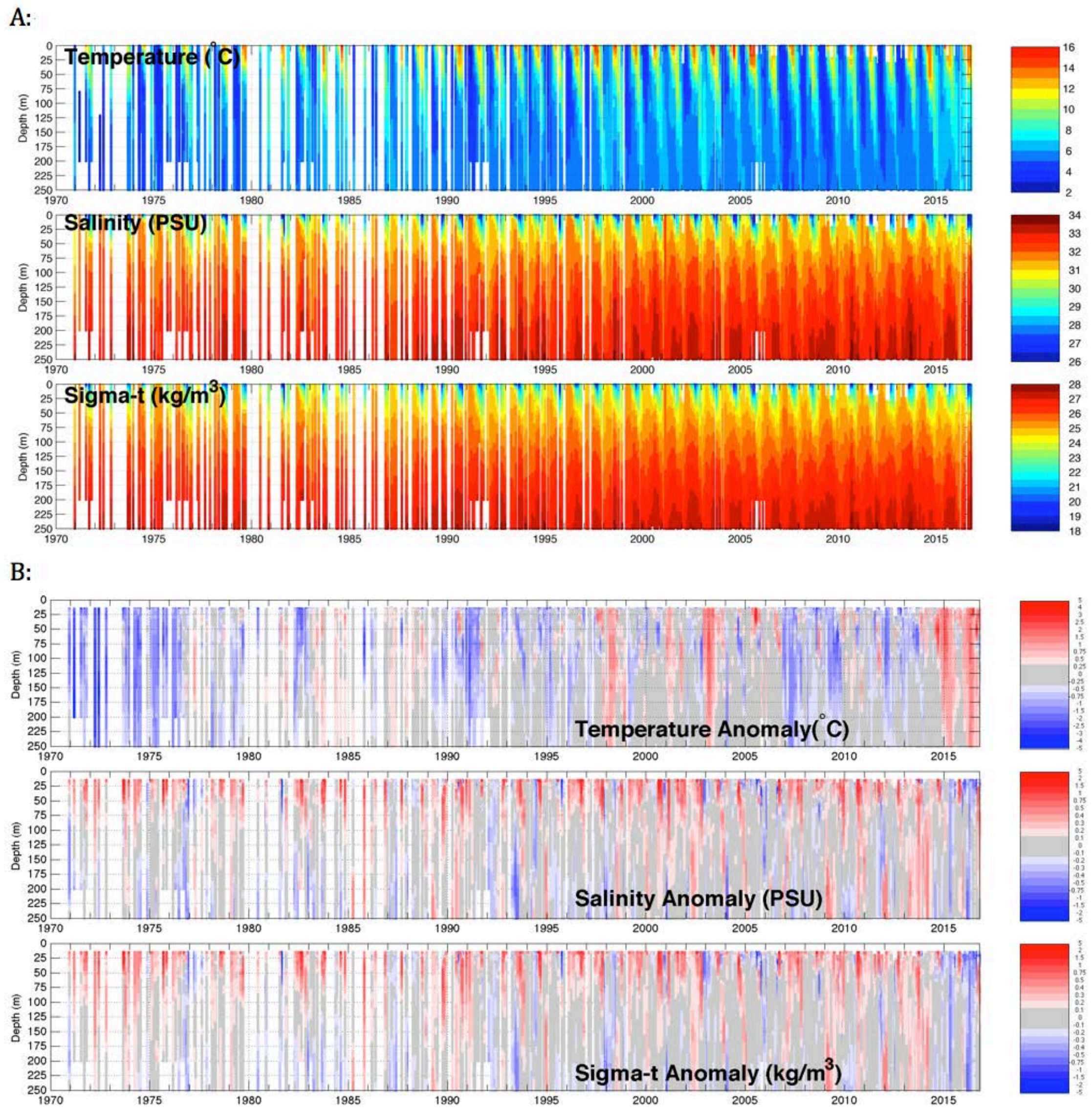


Figure 10. (A) Time series of monthly temperature, salinity and density (Sigma-t) obtained from GAK1 CTD casts over 1970-2016. (B) Corresponding time series of monthly anomalies.

Prince William Sound Fall/Winter Seabird Abundance
Project 16120114-C

Temporal patterns in density and distribution were observed for several seabird species (Bishop 2018). Common murre (*Uria aalge*) and marbled murrelet (*Brachyramphus marmoratus)* both increased in density from early to midwinter, with murrelets decreasing as winter progressed. Black-legged kittiwake (*Rissa tridactyla*) decreased to extremely low numbers during January surveys, increasing again in March. Habitat association models revealed that common murre favored relatively protected waters while marbled murrelet favored inside bays and passages (which make up 45% of semi-protected waters) and areas of higher sea surface temperatures. These results suggest that winter storms influenced seabird distribution, particularly in midwinter when temperatures were lowest and storms more frequent. This influence was greater than variables providing proxies for foraging opportunities, which were absent from selected models.

Results from nine species groups across nine nonbreeding seasons demonstrated that the nonbreeding season cannot be characterized as a single time period when describing marine bird distribution (Stocking et al. in review). The top models identified depth and distance to shore to be consistently associated with groups. Spatial predictions for several species groups aligned with known concentrations or migration pathways for prey fish. For multiple species groups, areas northwest of Montague Island, Montague Strait, and around the Southwest Passages appear to be consistently used, suggesting multiple prey types and/or complementary feeding activity. These same areas support concentrations of humpback whales and killer whales. This suggests environmental drivers such as currents and nutrients create persistent, favorable foraging conditions for marine birds and marine mammals.

Weak associations between marine bird densities and the prey index were found. Overall, season seemed to provide the best explanation of variation in seabird abundance and was included in the most supported models for kittiwakes, large *Larus* gulls, small *Larus* gulls, loons, murres, and murrelets. Given the large amount of unexplained variation present in the models, there are likely other factors influencing seabird distribution in PWS during winter.

Marine birds are responsible for a substantial and interannually variable source of herring mortality (Bishop et al. 2015). During ten winters over an 18-year period (1990-2007) the PI estimated that marine birds as a group consumed on average 2409 $\pm$ 950 t of herring. In all winters, birds consumed more juvenile ($\bar{x}$ = 1596 ± 820 t) than adult ($\bar{x}$ = 812 ± 479 t) herring. Common murres consumed far more herring than other bird species in eight of the ten winters modeled. The model showed that in winters with relatively high numbers of marine birds or with relatively low adult herring biomass, as much as 10% of the adult herring biomass can be removed by avian predators (Fig. 11). The results highlight the importance of herring to marine birds in PWS during winter, and the PI proposes that future management of herring stocks seek to reduce negative impacts to marine birds that prey on herring.

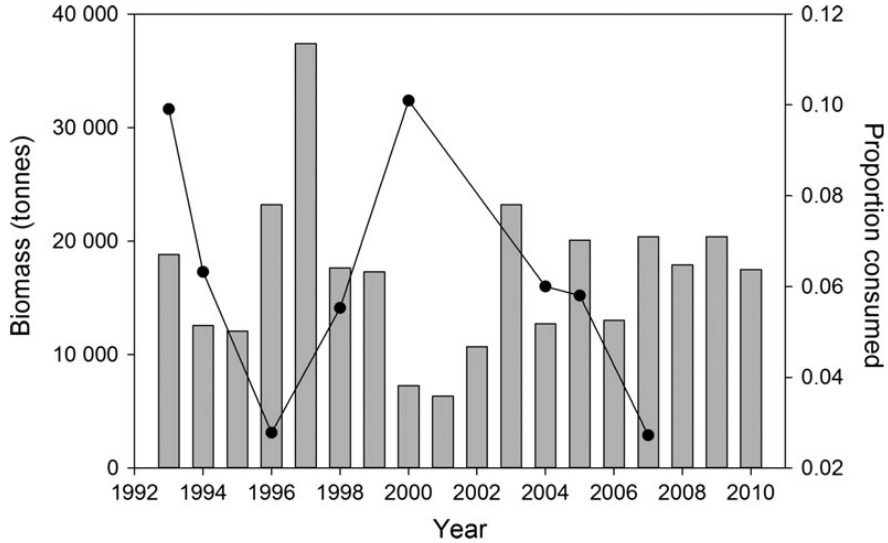


Figure 11. Estimated proportion of adult Pacific herring biomass consumed by marine birds (dots) for eight survey years compared to available adult herring biomass (bars), Bishop et al. (2015).

Ability to Detect Trends in Nearshore Marine Bird Surveys
Project 12120114-F

Transect length was the most important predictor of both marine bird detection and occupancy (Coletti and Wilson 2015). Both marine bird detection and occupancy increased with increasing transect length. There was weak evidence of diversity in species occupancy in sites with different habitat types. Although there was much variation, protected and semi-protected sites had a slightly lower probability of being occupied by marine birds than exposed sites. A slight latitudinal gradient was observed, where the probability of occupancy increased with increasing latitude. The model-averaged proportion of sites occupied was 0.87 (90% CI = 0.77 - 0.97).

Because a unit of occupancy is spatially defined, biologists also assumed they would be able to quantify metrics such as prey availability, habitat type, exposure, shoreline complexity, water quality parameters, etc. to that same spatial unit(s). Changes or shifts in site occupancy could theoretically be correlated to other physical or biological drivers of the system. This becomes particularly important in the face of climate change as potential stressors to a system increase. Understanding how a species or community is responding to those stressors through changes in distribution will be informative for resource managers to implement appropriate management actions.

During summer, the abundance of three taxa (bald eagles [*Haliaeetus leucocephalus*], cormorants [*Phalacrocorax* spp.], and harlequin ducks) increased in the oiled area, while the abundance of four taxa (mergansers [*Mergus* spp.], murrelets, pigeon guillemots [*Cepphus columba*], and terns [*Sterna* spp.]) decreased (Table 2). The abundance of the other thirteen of the twenty evaluated taxa (black-legged kittiwakes, black oystercatcher [*Haematopus bachmani*], bufflehead [*Bucephala albeola*], goldeneyes [*Bucephala* spp.], grebes [*Podiceps* spp.], glaucous-winged gulls [*Larus glaucescens*], Kittlitz's murrelets [*B. brevirostris*], loons [*Gavia* spp.], marbled murrelets, mew gulls [*L. canus*], murres, and scoters [*Melanitta* spp.]) showed no trend in the oiled area during the twenty seven year study period (Table 2).

Table 2. Taxa and trends of oiled areas in Prince William Sound, Alaska, 1989-2016. Bold text indicates p > 0.05; "ns" indicates no significant change in trend; "NA" indicates not assessed.

Taxon	f	prob	intercept	slope	trend
Bald eagle	6.11	**0.03**	6.03	0.03	**increase**
Black-legged kittiwake	0.55	0.47	9.81	0.01	ns
Black oystercatcher	0.15	0.70	5.12	0.00	ns
Bufflehead	1.13	0.33	-1.07	0.05	ns
Cormorants	14.62	**0.00**	5.88	0.06	**increase**
Goldeneyes	0.04	0.84	3.53	-0.01	ns
Grebes	3.75	0.08	6.51	-0.03	ns
Glaucous-winged gull	0.71	0.42	-0.79	0.02	ns
Harlequin duck	13.90	**0.00**	8.73	0.03	**increase**
Kittlitz's murrelet	1.94	0.24	6.88	0.02	ns
Loons	1.00	0.34	4.91	-0.06	ns
Marbled murrelet	0.48	0.50	4.41	-0.02	ns
Mew gull	0.02	0.89	9.64	0.00	ns
Mergansers	5.13	**0.04**	6.70	-0.03	**decrease**
Murrelets	10.90	**0.01**	10.59	-0.04	**decrease**
Murres	0.00	0.98	7.01	0.00	ns
Northwestern crow	NA	NA	6.40	-0.59	NA
Pigeon guillemot	29.23	**0.00**	7.23	-0.03	**decrease**
Scoters	1.15	0.31	7.43	-0.09	na
Terns	22.78	**0.02**	6.50	-0.35	**decrease**

PWS-wide summer population trends from 1989-2016 for PWS showed the abundance of Glaucous-winged Gulls increased, while murrelets and pigeon guillemots declined (Table 3).

Table 3. Taxa and trends of marine birds in Prince William Sound, Alaska, 1989-2016. Bold text indicates p > 0.05; "ns" indicates no significant change in trend; "NA" indicates not assessed.

Taxon	f	prob	intercept	slope	trend
Bald eagle	1.04	0.33	7.33	0.01	ns
Black-legged kittiwake	1.41	0.26	10.26	0.01	ns
Black oystercatcher	4.10	0.07	6.25	0.01	ns
Bufflehead	3.11	0.13	3.18	-0.08	ns
Cormorants	2.01	0.18	5.71	0.03	ns
Goldeneyes	0.02	0.90	5.69	0.00	ns
Grebes	3.93	0.07	4.47	-0.05	ns
Glaucous-winged gull	6.32	**0.03**	9.80	**0.02**	**increase**
Harlequin duck	0.41	0.56	8.62	0.01	ns
Kittlitz's murrelet	0.48	0.50	7.58	-0.02	ns
Loons	0.13	0.72	6.45	-0.01	ns
Marbled murrelet	1.04	0.33	10.03	0.01	ns
Mew gull	0.18	0.68	7.99	0.00	ns
Mergansers	0.03	0.86	8.51	0.00	ns
Murrelets	7.94	**0.02**	11.02	**-0.03**	**decrease**
Murres	0.05	0.84	7.98	-0.01	ns
Northwestern crow	.	.	7.36	-0.30	ns
Pigeon guillemot	5.84	**0.03**	7.88	**-0.03**	**decrease**
Scoters	0.82	0.38	7.79	0.02	ns
Terns	0.74	0.45	6.18	-0.11	ns

Killer Whale Monitoring
Project 16120114-M

During 249 days of survey from 2013-2016, there were 138 encounters with killer whales (Matkin et al. 2018). The oil spill-damaged AB pod contained 21 whales in 2015 and has not recovered to the pre-spill number of 27 individuals (Fig. 12). The threatened AT1 transient population numbered 7 whales in 2015 and totaled 22 prior to the spill (Fig. 12). Extinction of the AT1 pod is likely with no new calves produced since 1984. Individual tracking data from 33 resident killer whales indicated distinct shifts in core use areas that were highly specific to season and pod. Genetic analysis supported the area south of Kodiak

Island as the southwestern limit of the Southern Alaska resident population as well as a boundary for the GOA transient population. Sampling of fish scales from southern Alaska resident predation sites indicates a pattern of Chinook salmon (*Oncorhynchus tshawytscha*) predation in the spring followed by increasing predation on chum salmon (*O. keta*) and Coho salmon (*O. kisutch*) the summer and fall. There has also been a decline in the average annual carbon and nitrogen stable isotope levels in resident killer whales over the past 12 years. This suggests a change in food habits possibly a decline in Chinook salmon (generally show higher isotope values) and an increase in chum salmon (generally show lower isotope values) in the diet.

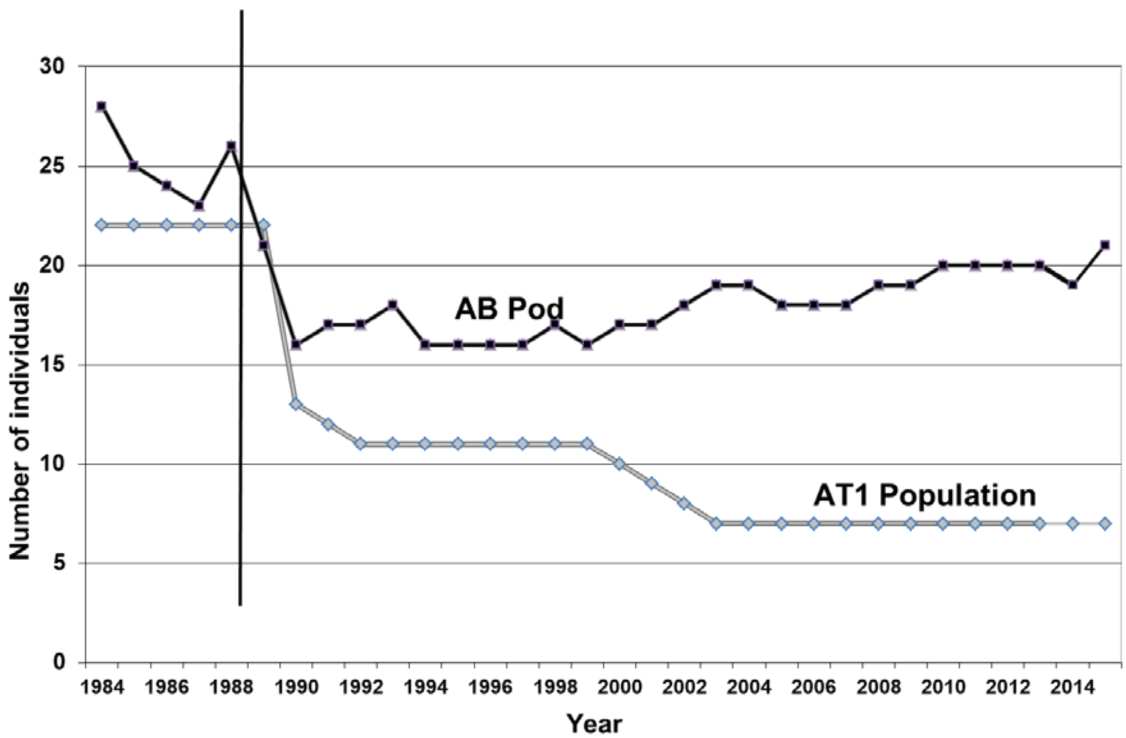


Figure 12. Number of killer whales in AB pod and AT1 population from 1984 to 2015.

Humpback Whale Predation on Herring
Project 16120114-N

Seasonal trend in humpback whale numbers are influenced by the annual migration to low latitude breeding ground and the movement of herring in PWS (Moran and Straley 2018). Encounter rates with whales in PWS varied seasonally, peaking in the fall and early winter months, then declining in January coincident with migration and peak numbers of whales in Hawaiian waters.

Humpback whales in PWS were generally associated with large shoals of adult Pacific herring (Fig. 13). Herring were accompanied by whales as they moved into PWS during early fall through Montague Strait on their way to overwintering grounds. In the spring whales returned to PWS to feed on spawning herring. After spawning, both herring and whales dispersed, resulting in lower whale numbers during the summer months.

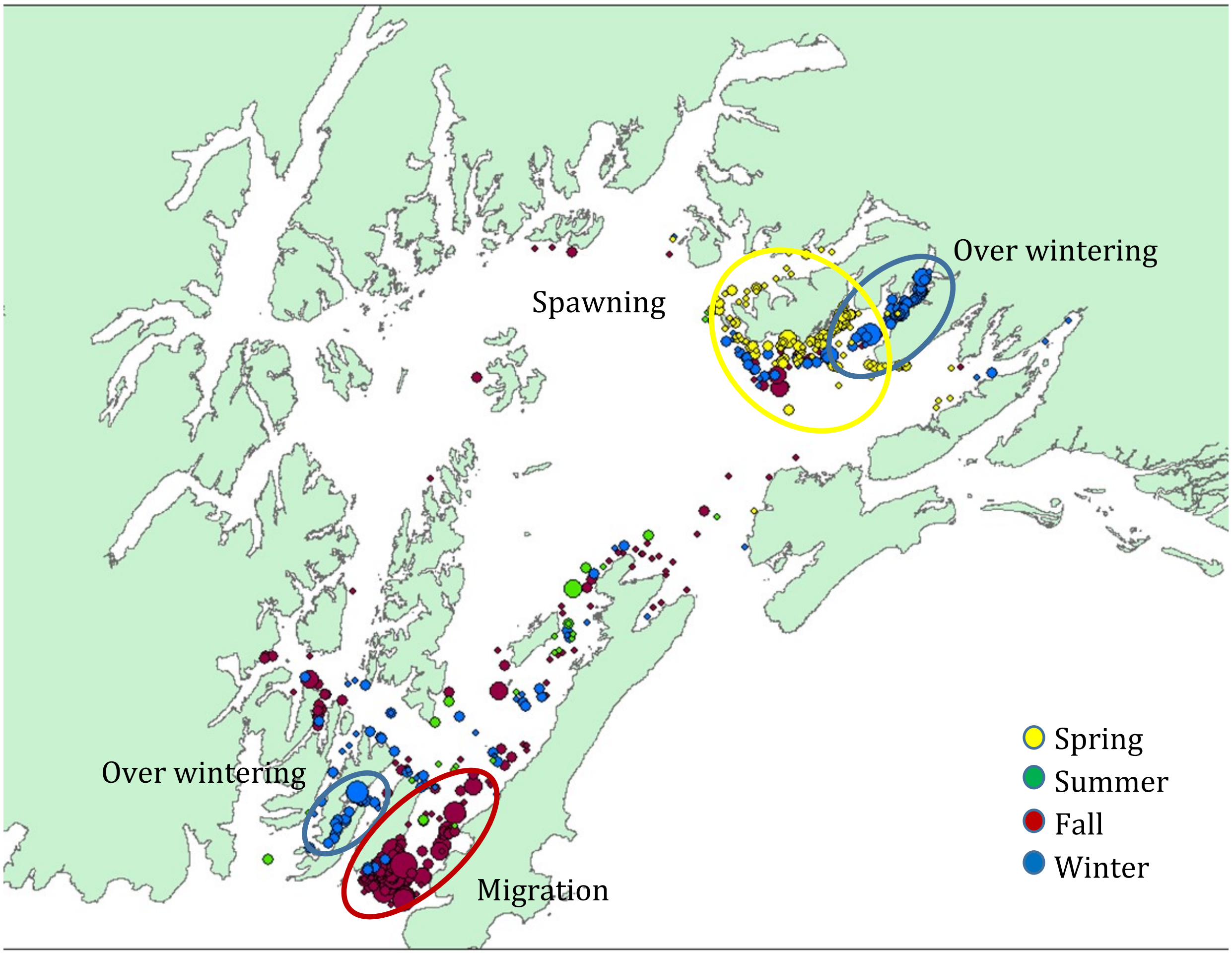


Figure 13. The distribution of humpback whales (solid circles) and important areas for adult Pacific herring (open ovals) in Prince William Sound, Alaska (2006-2015).

Over the course of this study whales fed primarily on herring in PWS (Table 4). This translates into average of 2,695 (Std. Dev. = 876) to 4,454 (Std. Dev. = 500) tonnes of herring /year if we assume a starting point of 50 whales. This amount consumed by whales is approximately 20% of the pre-spawning biomass of herring in PWS, a similar percentage to that removed during the last commercial harvest of herring from PWS (ADF&G 2010). When 200 whales are used as a starting point, they have the potential of consuming an average of 10,779 (Std. Dev. = 3504) to 17,817(Std. Dev. = 2001) tonnes of herring /year, essentially all of the adult herring in PWS.

Table 4. Observed prey by season for 1045 humpback whales in Prince William Sound, Alaska from Sept. 2007- April 2015.

	Season				
	Spring	Summer	Fall	Winter	Late Winter
Pacific herring	81.9%	0.0%	69.8%	83.5%	97.3%
Fish (may include herring)	18.0%	0.0%	19.8%	11.2%	1.8%
Euphausiids	10.6%	100.0%	7.1%	5.0%	0.0%
Zooplankton (may include euphausiids)	7.4%	0.0%	1.4%	0.3%	0.9%
Juvenile coho salmon	0.0%	0.0%	0.5%	0.3%	0.0%
Walleye pollock	0.0%	0.0%	1.4%	0.0%	0.0%
Number of observations	94	6	368	358	219

Humpback whales foraged on herring in large numbers over much of the spring, fall, and winter in PWS. Although many factors play into predation intensity (e.g., number of whales, diet, and attendance patterns) maintaining a high herring biomass provides a buffer to whale predation when predation intensity is variable.

Forage Fish Distribution, Abundance, and Body Condition
Project 16120114-O

Forage fish crews caught 198,133 fish with 167 deployments of seven types of fishing gear (Table 5) during summers in 2012 – 2016 (Fig. 14; Arimitsu et al. 2018). Several large purse seine catches targeting sand lance schools caught 66% of the fish, and modified herring trawls caught 32 % of the total catch. Jigs were primarily used to validate size and species when a strong hydroacoustic signal was encountered and were particularly effective at quickly identifying size and species of Pacific herring and walleye Pollock schools. On the other hand, trawls were more effective for catching young of the year walleye pollock and capelin. Beach seines were least effective at catching target species (Table 5), although they have been very effective for sampling Pacific sand lance in other studies (Robards et al. 2002, Piatt 2002, Arimitsu et al. 2007).

Table 5. Effort (number of hauls), catch (number of fish), catch by species, and percent of catch that was bycatch (i.e., non-target species) by fishing method during July forage fish surveys 2012 - 2016 in Prince William Sound, Alaska.

Fishing Method	Effort	Catch	Capelin	Herring	Sand lance	Eulachon	Walleye pollock	% Bycatch
Beach seine	28	2,324	0	399	66	0	226	70.3
Cast net	10	1,216	990	134	61	0	25	0.5
Dip net	8	1,759	98	1,443	218	0	0	0
Gill net	2	47	0	3	36	0	0	17
Jig	47	154	0	101	13	0	21	12.3
Modified herring trawl	65	62,585	203	1,336	0	36	56,809	6.7
Purse seine	7	130,048	0	38	127,976	0	1,909	0.1
Total	167	198,133	1,291	3,454	128,370	36	58,990	3

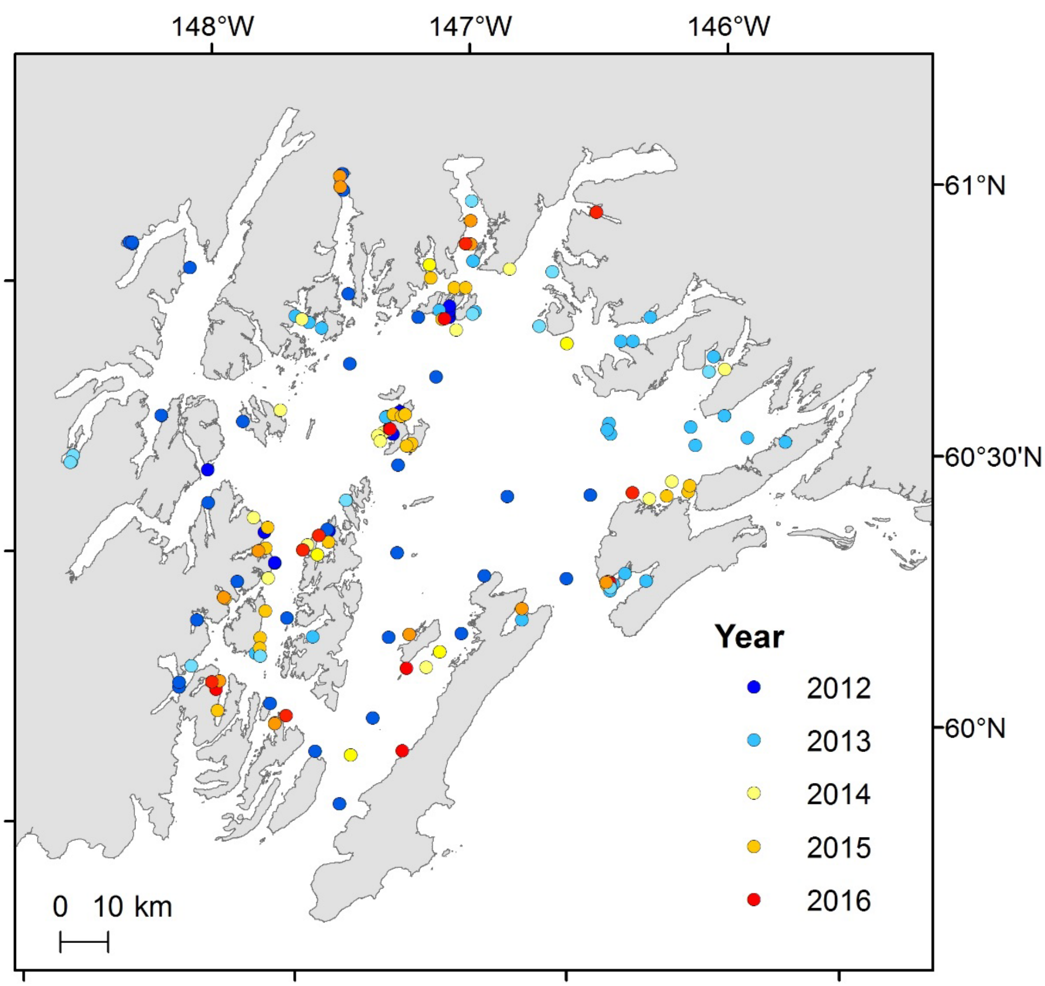


Figure 14. Distribution of forage fish sampling effort by year.

The vast majority of hydroacoustic backscatter due to fish occurred in the upper 120 m of the water column where the bottom depth was shallower than 200 m. Copepod and phytoplankton (i.e., chlorophyll a) indices were lowest in 2015, and this may have been a primary influence in the lower body condition of capelin and sand lance we observed in that year. In contrast to 2014 and 2016, when higher than average chlorophyll concentrations corresponded with lower than average nitrate (suggesting nutrient drawdown), in 2015 below average chlorophyll a concentrations occurred with higher than average nitrate concentrations (suggesting low nutrient demand). Stratification in the upper 10 m of the water column was above average in 2015, which also coincided with above average temperatures in the water column above 125m (i.e., the maximum depth we could sample fish with the trawl). Warm water anomalies occurred throughout the GOA during 2014 – 2016 (Di Lorenzo and Mantua 2016) and in the inshore waters of PWS, the 2015 water column conditions were the warmest of those three years.

Nearshore: Benthic Gulf of Alaska and Kachemak Bay
Projects 16120114-Q and 16120114-L

The first five years of GWA sampling, coupled with the extensive data streams preceding GWA for some metrics, have resulted in observations of many interesting patterns, which differ widely among vital signs (Coletti et al. 2018, Konar et al. 2018). For example, some metrics (e.g., large Pacific blue mussel [*Mytilus trossulus*] density) show somewhat synchronous temporal patterns across the northern GOA. Others (e.g., sea otter density) vary independently within the different regions. Finally, other metrics (e.g., eelgrass [*Zostera* spp.] percent cover) appear to vary on a site-by-site basis. The spatial and temporal scales over which metrics vary are beginning to provide insights on the potential drivers of those observed patterns. This understanding will continue to improve as the timeline of the data streams lengthens with continued annual sampling.

One important result has been the recognition of differing population trajectories and equilibrium densities of sea otters at our different sampling regions. When coupled with sea otter foraging data that indicate proximity to a food-dictated carrying capacity, this information provides important insights into the factors that influence sea otter populations at each region (Fig. 15). These results are reported in detail by Coletti et al. (2016).

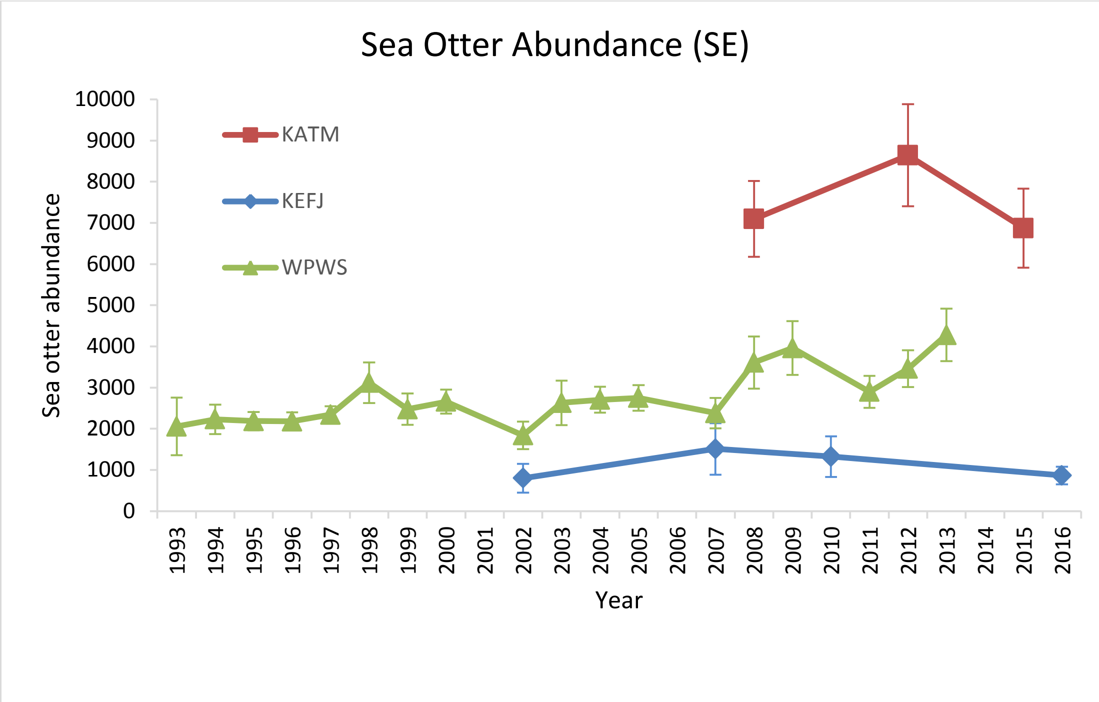


Figure 15. Sea otter abundance in Katmai National Park (KATM), Kenai Fjords National Park (KEFJ), and western Prince William Sound (WPWS).

Scientists evaluated the role of selected static physical factors in dictating rocky intertidal community structure across our study regions (Konar et al. 2016). Surprisingly, these static drivers were not strongly related to intertidal community structure across regions. This may have resulted from our selection of similar, sheltered rocky sites; however, the observed similarity in static physical drivers strengthens our ability to understand the role of dynamic sources of variation across the region.

Mussel metrics varied considerably on a site-by-site basis (Fig. 16), which highlights the importance of local conditions for mussel recruitment and abundance (Bodkin et al. in press). However, after accounting for site differences, scientists also found patterns in several measures of abundance that indicated synchronous decline and subsequent recovery of mussels across the entire northern GOA, suggesting an influence of broad-scale drivers.

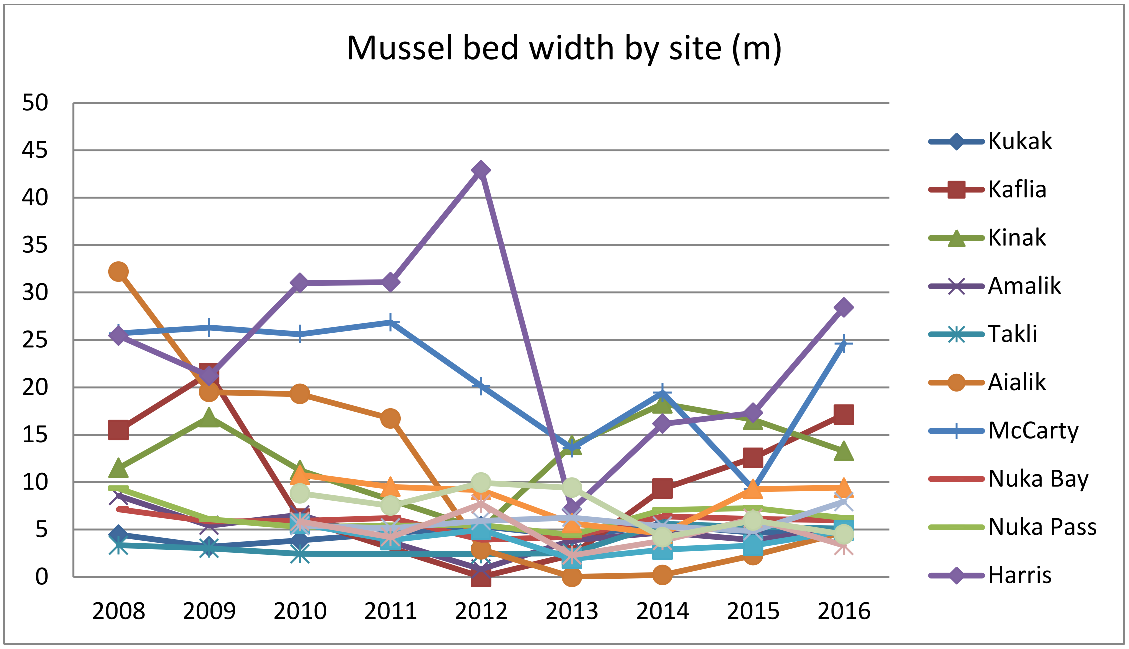


Figure 16. Pacific blue mussel bed width by site across years illustrating variation.

A number of interesting patterns were observed in other metrics. For example, water temperature data confirm that the warm water anomalies that are well established in offshore measurements also are expressed in intertidal regions across the northern GOA. Nearshore biological effects of abnormally warm water remain under investigation. As another example, in response to the well-publicized common murre die-offs during winter 2015-2016, examination of nearshore marine bird survey data determined that biologists observed anomalous distributions and numbers of murres preceding the winter die-off. As a final example, the nearshore projects discovered that sea star abundance and species dominance varied markedly among regions, suggesting local drivers of these patterns.

Chronic Exposure to Lingering Oil
Project 14120114-Q

Harlequin Ducks: CYP1A induction was not related to area, with average (pmol/min/mg ± SE) 7-ethoxyresorufin-O-deethylase (EROD) enzyme activity of 17.8 (± 3.0) in oiled areas and 27.7 (± 5.9) in unoiled areas (Bowen et al. 2015). 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. 17). This critical result follows the observation during 2011 that, although CYP1A induction was higher in oiled areas, the magnitude of the difference was reduced relative to previous years (1998 to 2009). Scientists 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, 4% of individuals captured in oiled areas had elevated EROD, compared to 12% in unoiled areas. As in previous years, scientists found that attributes of individuals (age, sex, and mass) were not related to variation in EROD.

Scientists interpret these results to indicate that harlequin ducks were no longer exposed to residual EVO as of March 2013, 24 years after the spill.

This work adds to the body of literature evaluating cytochrome P4501A induction in several nearshore vertebrates in PWS and defines the timeline over which exposure to lingering oil was evident for a species particularly vulnerable to long-term exposure.

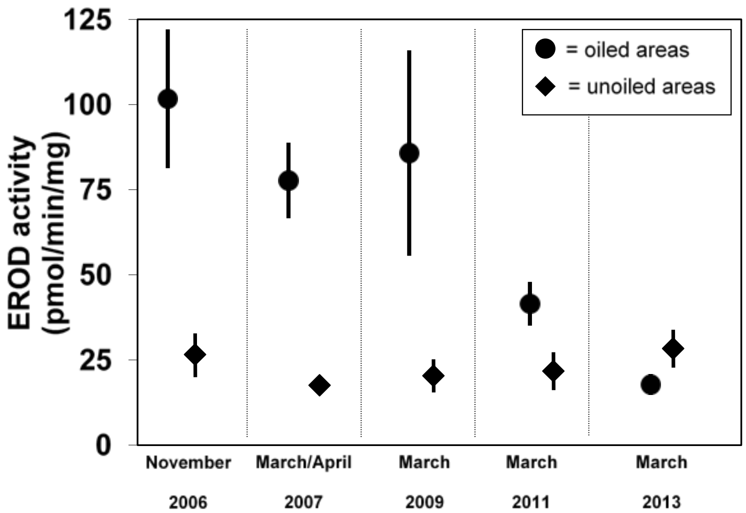


Figure 17. Average (± SE) hepatic7-ethoxyresorufin-O-deethylase (EROD) activity (pmol/min/mg protein) of harlequin ducks (n = 50) captured in Prince William Sound, Alaska in March 2013, contrasted with results from previous years.

<u>Sea Otters:</u> Preliminary analyses using nonparametric, multi-dimensional scaling analysis in conjunction with cluster analysis, SIMPROF, and ANOSIM (R Core Team 2012), indicated gene expression profiles of otters sampled in 2006, 2007, and 2008 in WPWS differed from those collected in 2010 and 2012; thus, they are split into two groups: PWS1 (2006-2008) and PWS2 (2010 and 2012). Cluster analysis of gene transcription patterns used in two statistical multivariate approaches, non-metric multidimensional scaling and heatmap analysis, revealed similar results. The majority of sea otters sampled separated into 3 distinctive clusters: Cluster 1, Kodiak and PWS1; Cluster 2, Clam Lagoon and PWS2; and Cluster 3, Katmai, Alaska Peninsula, and captive sea otters. Heatmap analysis showed lower relative transcription in Cluster 2 sea otters, higher relative transcription in Cluster 1 otters, and mixed transcriptional responses in Cluster 3 sea otters.

We suggest that the PWS2 sea otters exhibit transcript patterns consistent with a nutritional deficit or alternate resource allocation regime. Implications of this type of molecular profile can include an inability to mount effective responses to pathogens, contaminants, or stress. In effect, overall suppression of the transcription response precludes our evaluation of whether or not individual sea otters show continued signs of exposure to lingering oil. However, related studies on sea otter demographics indicate that by 2012, numbers and mortality patterns had returned to pre-spill conditions (Ballachey et al. 2014); this result is supported by harlequin duck findings in 2013 and 2014 that indicated cessation of oil exposure for that species (Esler and Ballachey 2014). Overall, the gene transcription studies indicate that in 2008 sea otters in WPWS were still subject to lingering oil exposure, while for the 2012 samples, interpretation of the gene expression data is complicated by general decreased transcription but associated sea otter studies indicate no continuing oil exposure.

Tracking Oil Levels and Weathering
Project 16120114-S

Biomarker patterns were typically consistent with Alaska North Slope Crude Oil (ANSCO) over the entire observation period at contaminated sites (up to 25 years) (Lindeberg et al. 2018). The combined result of all classes (triterpanes, hopanes, steranes) matched ANSCO in 77% of these samples (n = 62). Other potential biomarker sources were not plausible alternatives to ANSCO. Samples from the 2015 survey showed that relative concentrations of biomarkers in subsurface oil was highly correlated with the relative concentrations found in EVO.

Oil was readily found in subsurface sediments sampled in eight of the nine beaches re-surveyed in 2015. Most of the contaminated sediments were lightly to moderately oiled. Of the 400 pits dug, 20 had lightly oiled residues compared with 19 moderately oiled and 8 heavily oiled residues. The probability of encountering oil on these beach segments, expressed as the number of oiled pits divided by the total number dug, generally agreed with model prediction estimates (Michel et al. 2010) used to select beach segments. Eleanor Island segment EL056C had the largest estimated oiled area at 1,218 m^2 (±112 m^2) as well as the largest total weight of oil estimated at 1,124kg (±470kg). In contrast, no subsurface oil was encountered in the 50 pits dug on Evans Island segment EV039A.

Comparisons of the estimated oiled areas and weights for six beach segments that were sampled in 2005 and 2015 revealed little change in subsurface oil estimates. Based on 95% confidence intervals, there was little evidence for a decline in subsurface oiled area or oil weight at the survey sites, nor was there evidence of a change in tidal elevation of the subsurface oil. There was little if any evidence that oil has been lost from the beaches surveyed in 2001, 2005, and 2015, based on the probability of encountering oil. Based on a semi-parametric bootstrap analysis (Lindeberg et al. 2018), estimates of retention for the periods 2001 to 2005, 2001 to 2015, and 2005 to 2015 did not differ from each other ($p=0.612$) (Fig. 18). The only significant loss in oil was detected at Eleanor Island on segment EL056C during 2001-2015 (95% CI: 0.89-0.998) which had been used as a test site for remediation experiments within this time period.

Oil was not present in passive samplers, based on polyaromatic hydrocarbons (PAH) source modeling and concentration. Based on a phase-only analysis of variance (PANOVA), total PAH concentrations were statistically indistinguishable from concentrations in blanks (PANOVA = 0.739) and composition also was indistinguishable (PANOVA = 0.517). Observed concentrations were ≤ 77 ng/g device. These concentrations are within typical background levels for passive samplers.

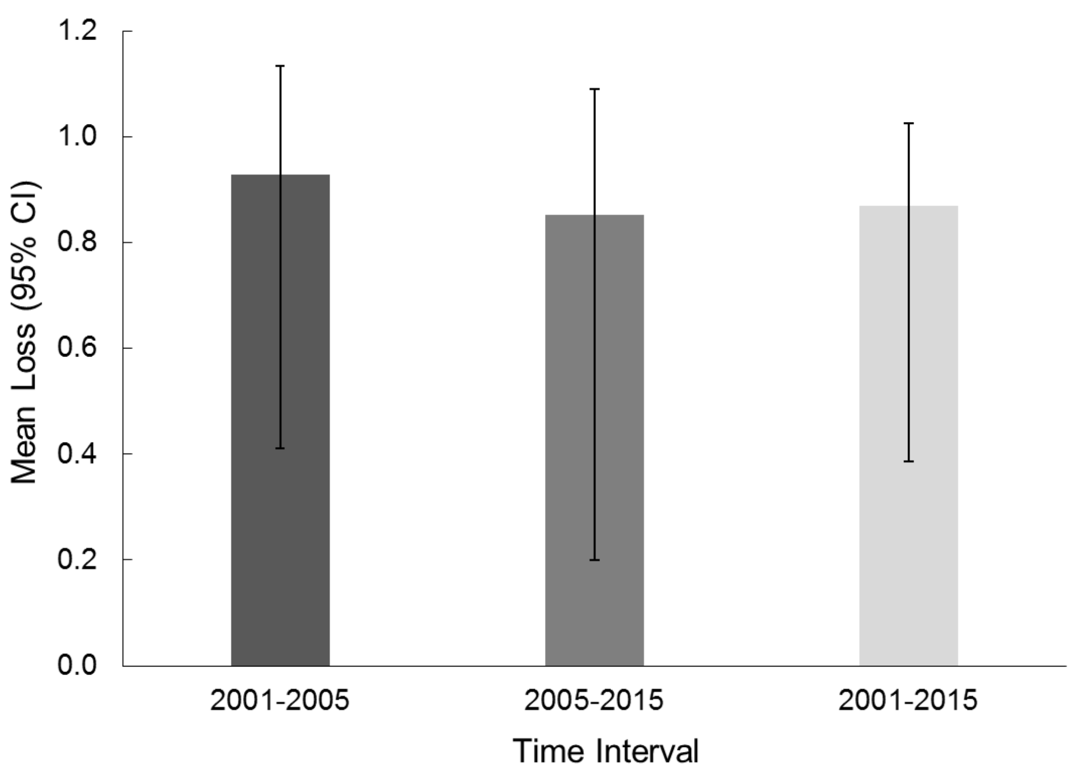


Figure 18. Annualized oil retention rates with bootstrap 95% confidence intervals indicated by error bars. Comparison are limited to the 2001 survey grid because only sampled tidal elevations MVD 1 – MVD 3 were surveyed in 2001.

Objective 3. Enhance Collaborations between Gulf Watch Alaska and Herring Research and Monitoring

The GWA and HRM programs held five annual meetings during which PIs from both programs had opportunity to share findings and discuss collaboration. This time allowed scientists to become more familiar with each program's goals and objectives.

The PWS oceanographic project provided data regularly to HRM program PIs for their use. The forage fish project coordinated and collaborated with HRM program scientists on aerial fish surveys and because herring is a forage fish. The humpback whale project collaborated with HRM program scientists because the primary goal of the project was to evaluate how humpback whale predation may affect herring population recovery in PWS.

The February 2015 joint science workshop provided an opportunity for scientists from both programs to discuss the important role of forage fish, including herring, in the GOA ecosystem and bottom-up and top-down ecological pressures on the ecosystem.

The culminating scientific work of the first five years of both programs is a special issue to be published in 2018 in the journal *Deep-Sea Research Part II*. The theme of the special issue is "Spatial and Temporal Ecological Variability in the Northern Gulf of Alaska: What have we Learned since the *Exxon Valdez* Oil Spill?" The special issue will include approximately 20 papers, depending on the number accepted, up to 15 from the GWA LTM program and up to 5 from the HRM program. Topics include persistent spill effects, environmental drivers, nearshore, herring and forage fish, and pelagic species. The GWA program science coordinator acted as corresponding guest editor and other guest editors included representatives of both GWA and HRM programs.

Objective 4. Leverage Partnerships

The GWA LTM program would not have been possible or successful without leveraged partnerships (Table 6) and additional funding sources that that ultimately provided a nearly ¾ match of EVOSTC funds supporting GWA.

Most Trustee Agencies covered all or a portion of PI salary to work on the GWA LTM program. Projects leveraged funds from other sources to add or extend sampling surveys and increase data collection, and the GWA LTM program benefited because the additional data were published on the Gulf of Alaska Data Portal and used in GWA LTM program analyses. Projects also leveraged GWA LTM funds to purchase new equipment from separate sources that were used to perform program monitoring. Data management activities were highly leveraged with partner agencies and organizations.

GWA LTM scientists coordinated with scientists from programs funded through other sources, notably the North Pacific Research Board's Gulf of Alaska Integrated Ecological Research Program, to share information and minimize overlap in data collection.

The University of Alaska negotiated a reduced overhead rate for university scientists working on the GWA LTM program. PWSSC waived its indirect rate and instead charged a flat fee that included costs typically included in the indirect rate.

Table 6. Agencies and organizations that participated in fund and resource leveraging for the Gulf Watch Alaska long-term monitoring program from 2012 to 2016.

Alaska Department of Fish and Game	National Park Service
Alaska Ocean Observing System	National Science Foundation
Bureau of Ocean Energy Management	Norcross Foundation
Canadian Department of Fisheries and Oceans	North Pacific Marine Science Organization
Cook Inlet Regional Citizens Advisory Council	North Pacific Research Board
Kachemak Bay National Estuarine Research Reserve	U.S. Fish and Wildlife Service
Kenai Fish Habitat Partnership	U.S. Geological Survey
National Oceanic and Atmospheric Administration	

Objective 5. Provide Data, Data Products, and Outreach

Data Management
Projects 16120114-D and 16120114-T

During the initial phase of this project, the Workspace was established with 20 projects, 16 of these representing individually-funded GWA LTM field projects and 4 dedicated to aspects of program coordination and outreach. The Workspace was utilized consistently through the program duration as the internal location for data storage and program file sharing among the PIs. From 2012 to 2013, there was relatively limited use of the Workspace as the program was becoming established and PIs were familiarizing themselves with the system. By the 2015 field season, however, files stored internally reached 10,000 and the volume of stored data rose exponentially to 350 gigabytes. Data storage to the Workspace maintained a similar growth rate throughout 2016 and concluded with over 20,000 files and 450 gigabytes of available GWA data. As such, the Workspace was successfully relied upon as a key location used by GWA program managers, PIs, and project team members to facilitate the logistical, curatorial, and preservation-oriented aspects of data collection and management.

In December 2016, the new metadata editor was released into the Workspace. The new editor was designed to be more flexible and to completely describe various dataset and project types. The editor also generated metadata in format that is necessary for preservation and publication in DataONE. In March 2017, Axiom became a Member Node in the DataONE federation. The goals for becoming a DataONE Member Node were to ease the requirement of providing EVOSTC-funded datasets to a data archive center by simplifying the upload of content, generation of metadata, and archive submission processes for the PI while simultaneously providing transparency of program data management and archiving to the data managers, program leads, and funders. Enhancements planned to be developed and implemented during the upcoming 5-year GWA funding cycle include automated data and metadata quality assurance steps and completeness checks for metadata content, customized metadata entry forms based on data types and programmatic requirements, and tools for reading in xml-formatted metadata from other standards.

The primary results for this project include the acquisition and documentation of historical and GWA PI-produced datasets and the aggregation of ancillary environmental datasets for integration into the public-facing Gulf of Alaska Data Portal. The individual GWA project descriptions, sampling activities, datasets, and other products are showcased within the portal while being coupled with historical data and other GOA models, sensor feeds, and GIS datasets for use by managers and scientists within Trustee Agencies.

Collaborative Data Management
Project 16120120

Data sets that were recovered spanned a huge variety of disciplines, including lingering oil, oceanography, habitat, invertebrates, fish, mammals, birds, plankton, and socio-ecological interactions between people and the environment. NCEAS worked to identify critical data sets and attempted to locate people and sources of information about data set disposition. These efforts results in a cumulative total to 126 recovered data sets recovered (30% of the 419 projects).

After completing this process, reasons why data were not recovered were classified (Fig. 19), which clearly showed that communication breakdowns were the primary obstacle to obtaining data, either because NCEAS never was able to obtain effective contact information, or, when contact was established initially, researchers stopped communicating before their data were fully recovered. In a much smaller number of cases, the data were confirmed to be lost, or too laborious to digitize. The final two categories, unwilling to share and requested funding, represent cases where investigators refused to share their data, which was effectively the case for all of the communication lost cases as well.

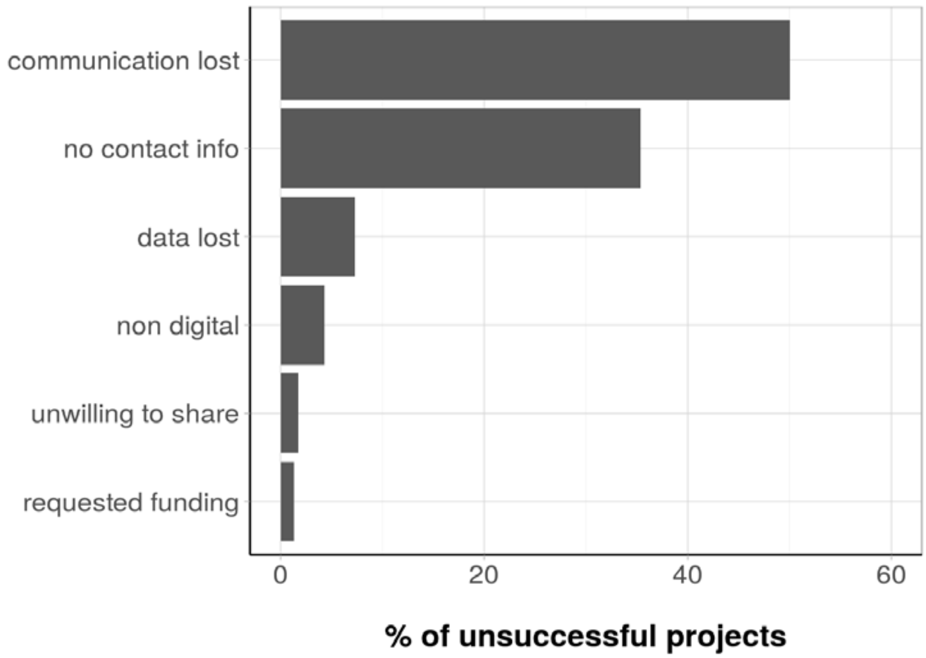


Figure 19. Categorized reasons for unrecovered data from projects. While specific data loss was rare, the de facto lack of communication also represents an unwillingness to share data.

All data recovered during this effort were published with documentation in the Gulf of Alaska Historical Data Portal (https://goa.nceas.ucsb.edu), which is a data repository that was established for the purposes of this project using the Metacat data repository system (Fig. 20).

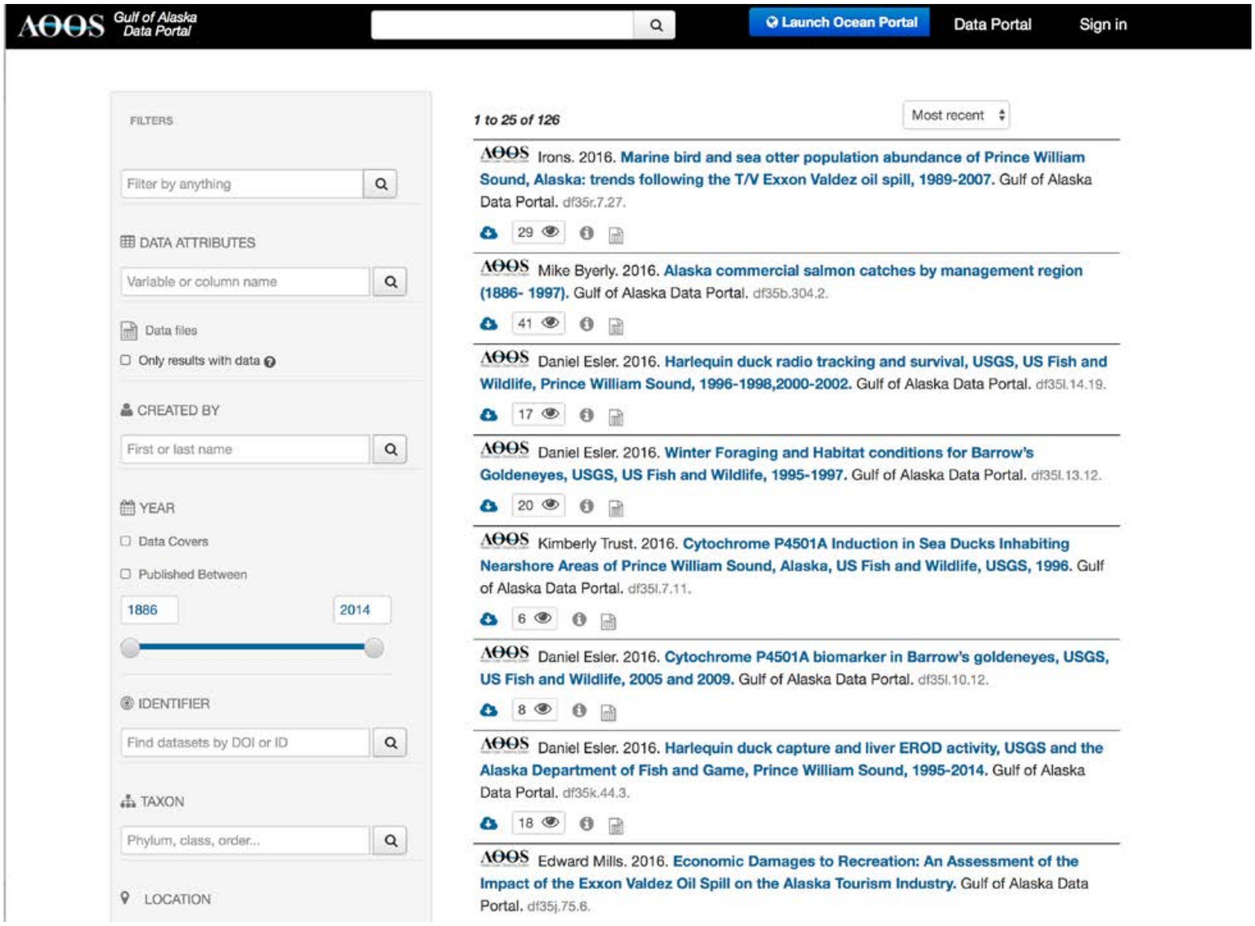


Figure 20. Gulf of Alaska Historical Data Portal screen capture showing the data listing and search filters that were designed and deployed during the project (https://goa.nceas.ucsb.edu).

This repository allowed replication of the data sets to the DataONE federation of repositories to ensure their long-term preservation, in addition to the copy deposited with AOOS. The Metacat-housed copy of the data were accessible through a machine accessible programming interface, which allowed these data to be automatically ingested into analyses using R statistical language during analysis for synthesis activities.

Conceptual Ecological Modeling
Project 16120114-I

Four submodels were developed.

Submodel 1: Key Trophic Linkages in Nearshore Northern Gulf of Alaska Ecosystem (sea otter and Barrow's goldeneye): Reproductive rate and adult survival of sea otters were relatively stable and high regardless of the prey scenario modeled, which accurately reflects empirical observations of sea otter life history. Reproductive success (pup survival through weaning) demonstrated more variability than other demographic responses, with changes in means and distributions between scenarios and in relation to length of occupancy. For the generalized, non-site-specific models, recently occupied scenarios had higher reproductive success than long-occupied and reduced prey scenarios. For the site-specific models, Katmai National Park showed the largest changes in reproductive success; pup survival was lowered more by reduced clam availability than by reduced mussels. However, at Kenai Fjords, where mussels were more dominant in the diet, demographic responses were robust to reductions in clams. Reducing all prey items at Katmai National Park led to the widest distribution and lowest reproductive success in sea otters, representing a worst-case and unsustainable scenario. Reproductive success in WPWS was consistent across all scenarios, due to the relatively small adjustments between prey availability in the WPWS baseline model and the reduced prey simulations.

Adult survival of Barrow's goldeneye was high and relatively stable across different prey scenarios, with a small drop (2 to 3%) and increased variability in adult survival corresponding to the lowest mussel availability scenario. Juvenile survival, while lower than adult survival, showed similar responses of declining survival and increasing variability with declining mussel availability. When confronted with low mussel availability, juvenile survival declined by approximately 4%, with substantially increased variability in survival outcomes.

Submodel 2: Ecological Linchpin Hypothesis with Forage Fish Abundance: The ecological linchpin hypothesis in the marine environment explores the degree to which upper trophic level dynamics are driven by the dynamics of mid-trophic forage stocks. Two visualizations for the forage fish framework associated with the ecological linchpin hypothesis were constructed, which were consistent with expert opinion within pelagic ecosystem component scientists (Fig. 21). These visual conceptual ecological models were presented in a poster at Alaska Marine Science Symposium 2015 and at the PI meeting and public outreach open house in Cordova, Alaska, in 2016.

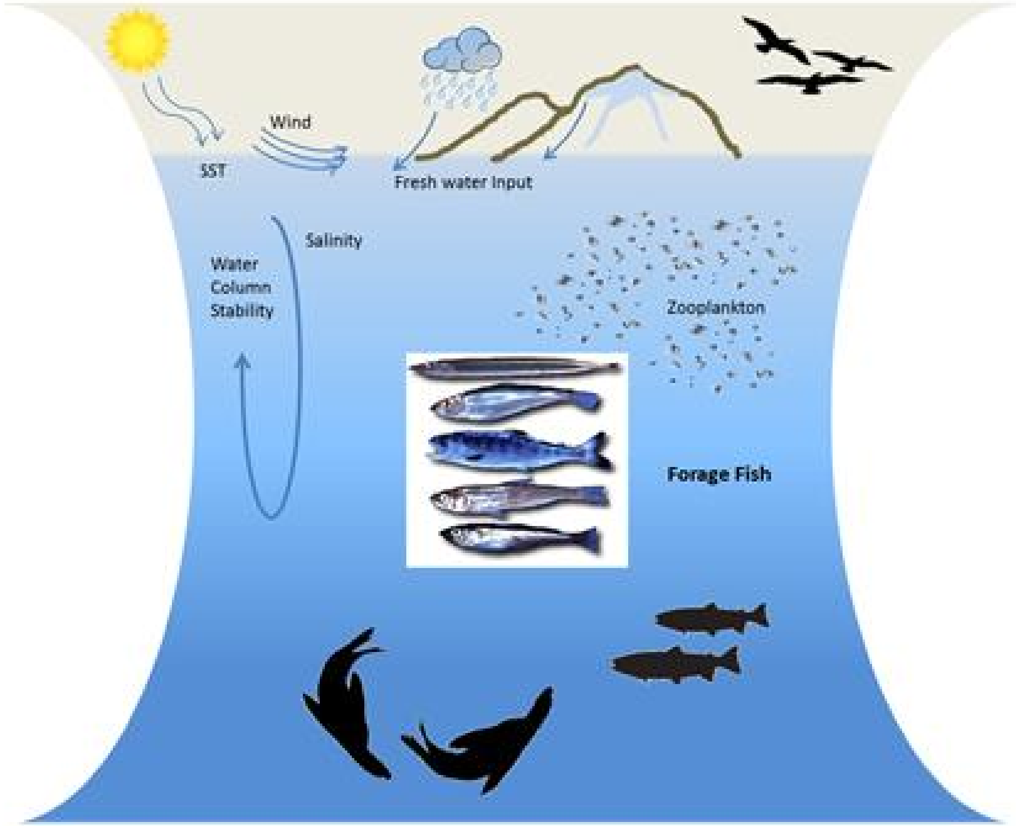


Figure 21. One of the two visualizations constructed for the forage fish framework associated with the ecological linchpin hypothesis.

Submodel 3: Top-down Forage Fish Control with Humpback Whale Predation: The GWA pelagic component team explored movements and distribution of humpback whales in PWS, represented in a conceptual model. Current understanding about the processes affecting herring-whale dynamics in the northern GOA was explored in a submodel exercise rating properties of linkages in a zooplankton-herring-whale submodel system, including assessment of the state of knowledge, the strength of ecological impact, and the state of management or research attention devoted to a given component. Nineteen responses from GWA PIs were received on the submodel linkage rating survey. The strongest linkages were the positive effect of zooplankton on herring, followed by the positive effect of upwelling on zooplankton and the positive effect of herring on whales. The weakest linkage was the effect of whales on zooplankton. The ratio of the consensus strength of interaction over the state of knowledge rating for linkages suggested research evaluating the effects of ocean acidification is high priority, followed by the effect of zooplankton on herring. This model framework has been published in Sethi and Hollmen (2015).

Submodel 4: Bottom-up Control with Environmental Forcing on Plankton Populations: GWA PIs expect temperature changes to result in cascading effects ultimately altering plankton abundance and community composition and microbial biomass. Modelers used published and GWA data as well as expert opinion to define linkages between nodes. The current model indicates stratification plays a central role in the ecosystem, which is reflected in the upper layer of the water column and the lower layer. Recognizing that the depth of this stratification will change with different ocean conditions, modelers seek to develop this model into a Bayesian Belief Network to test scenarios of climate change and publish the results if future funding opportunities arise.

Outreach
Project 16120114-B

Outreach and community involvement events, products, and publications reached both targeted and diverse audiences everywhere from rural Alaskan villages to larger spill-affected communities, to in and out of state visitors, to any interested viewer on the internet.

A GWA LTM program website (see Other References section at the end of this report) provided links to the Gulf of Alaska Data Portal where data are publicly available; displayed program, component, and project overview pages; provided PI contact information; listed project publications, reports, and presentations; and provided links to outreach materials. The website was updated regularly as new findings became available.

Two-page profiles were written for each science project in the GWA LTM program (Fig. 22). Hard copies were printed for distribution and electronic copies were posted to the website project pages. Project profiles mirrored project information provided on the website and included contact information for the project PI(s) and answered to four questions: Why are we sampling? Where are we sampling? How are we sampling? What are we finding?

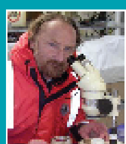
GWA LTM program PIs provided public lectures and talks in a variety of venues and locations throughout the five years of the program, including PWSSC community and pub talk lecture series; festivals such as Ocean Fests in Valdez and Cordova, the shorebird festivals in Cordova and Homer, Sitka WhaleFest; Prince William Sound Regional Citizens' Advisory Council science night in Anchorage; KBRR sponsored lecture series in Homer; and various other venues and locations. Presentations by PIs are listed at the end of this report under the Other References section.

The GWA LTM program has its own YouTube channel. Through the course of the first five years of the program, scientists and professional videographers collected video footage of science in action. The video footage was developed into several-minute vignettes describing the program as a whole as well as individual projects. In addition, PWSSC interviewed scientists about their work and combined the interviews with video and photographs from field work. Videos were presented during discovery labs and at public lectures and are available from the website or YouTube channel. Links to videos and the YouTube channel are listed at the end of this report under the Other References section.

PROJECT PROFILE

The Seward Line: Marine Ecosystem Monitoring in the Northern Gulf of Alaska

WHO WE ARE
Principal Investigators



Russ Hopcroft
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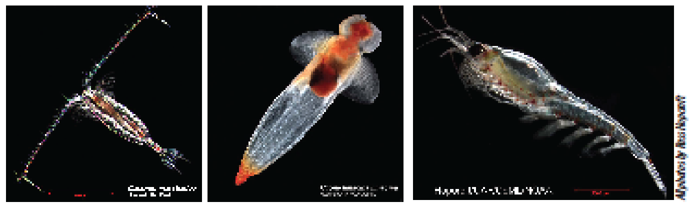

*Left: A copepod, Calanus marshallae, captured during sampling of the Seward line. **Middle:** Pteropods are a pelagic snail. Their name means "winged foot," a reference to the modification of their fleshy molluscan foot that allows them to swim in the ocean. These animals, such as Clione limacine pictured here, are generally present in low numbers year round but can be the preferred prey of some species of fish. **Right:** Euphasids, such as this Thysanoessa inermis pictured here, generally rank second or third in abundance in most ocean waters below copepods. These animals are important prey items for fish, birds, and mammals.*

WHY ARE WE SAMPLING?

The Gulf of Alaska supports a diverse ecosystem that includes several commercially important fishes, as well as culturally and economically important mammals and plants. Historic observations suggest a connection between the Gulf of Alaska ecosystems and climate variations that range from interannual to interdecadal. The specific mechanisms by which climate variation causes ecosystem changes, however, are poorly understood. Sampling along the Seward line is producing a multi-year data set that will lead to a better understanding of the seasonal cycle and the variability that occurs from year to year in environmental conditions and biological productivity in the Gulf of Alaska.

WHERE ARE WE SAMPLING?

The Seward line is a transect of oceanographic survey stations that begins at the GAK1 mooring at the mouth of Resurrection Bay in the Gulf of Alaska (59°50.7'N, 149°28.0'W) and continues south across the Gulf of Alaska to past the outer edge of the continental Shelf, or "shelf break" (58°5.9'N, 147° W).

Location of the Seward line oceanographic survey transect in the Gulf of Alaska and Prince William Sound (red).

www.gulfwatchalaska.org
info@gulfwatchalaska.org

Figure 22. The first page of the Seward Line's project profile provides an example of the two-page project profiles written and distributed for each Gulf Watch Alaska monitoring project.

KBRR's education program conducted summer discovery labs in Homer from 2013 to 2016 (Fig. 23). The labs were open to all ages and attracted both residents and visitors. Each year the lab presented materials, experiments, and activities related to the GOA ecosystem and GWA projects and findings.

Figure 23. Kim Kloecker, a scientist with the nearshore ecosystem component, examines a sea otter skull with a curious discovery lab participant.

Delta Sound Connections is a newspaper produced annually by the PWSSC and distributed widely throughout Prince William Sound and the Copper River Delta regions. The newspaper includes articles on the natural history and science news from the PWS and Copper River Delta bioregion. The GWA LTM program contributed several brief articles per year and financially supported production of the newspaper (Fig. 24). *Delta Sound Connections* articles are listed at the end of this report under the Other References section.


GULF WATCH ALASKA

Introducing Gulf Watch Alaska

Monitoring Pelagic Food Webs for Change

Fish, Birds, Whales—They're All Connected

Tidewater Trends in Nearshore Ecosystems

Recent Climate Change in PWS Oceanography

Figure 24. Example of Gulf Watch Alaska articles and page layout in *Delta Sound Connections*, Prince William Sound Science Center's annual newspaper.

A community-based monitoring (CBM) workshop was held in April 2014 and organized by AOOS and Alaska Sea Grant. Immediately afterwards, a half-day work session was held with participants to discuss opportunities for CBM in the northern GOA region. Participants included representatives of most of the currently active CBM projects, as well as village representatives. More than 30 people attended, and largely agreed that existing programs could be supported and enhanced before starting up any new programs.

An informational webinar was hosted in September 2014 about GWA, targeting Trustee Agency staff as part of an effort to engage more deeply with management agencies.

GWA LTM program PIs participated in community workshops and symposia intended to present science information to lay audiences. These include the Sitka WhaleFest in Sitka and the Kachemak Bay Science Symposium in Homer. GWA LTM program scientists also participated in a series of workshops on coastal resiliency to climate change in Homer. Presentations are listed at the end of this report under the Other References section.

A five-panel interactive exhibit about the GWA LTM program was produced and is on public display at the ASLC in Seward (Fig. 25). The exhibit is suitable for travel and could be transported to other venues. The panels provide an overview of the program and details about each of the program's components: lingering oil, environmental drivers, pelagic ecosystems, and nearshore ecosystems. Videos produced for the program display on a screen.

Figure 25. Gulf Watch Alaska program panels on display near the entrance of the Alaska SeaLife Center in Seward, Alaska.

A professional videographer was contracted to lead filmmaking workshops with youth in spill-affected communities. The workshops took place in schools in Nanwalek, Tatitlek, Cordova, Valdez, Whittier, and Chenega Bay. Students created short films about GWA-related subjects such as how EVOS affected their community; how valued ecosystem components have changed over time; and how community members have observed both change and recovery evolving over time. Students learned skills in shooting video, interviewing, editing, and production of short films. Some students interviewed elders about their experience during and following EVOS. The resulting videos where screened in the villages on movie nights, allowing the students to display their new-found talents and community members to connect between generations as they recalled the ecological, physical, and emotional impacts of the spill. Links to films produced during the workshops are listed at the end of this report under the Other References section.

ASLC produced two virtual field trips, designed to complement middle-school science curricula, related to the GWA LTM program, and made them available from their website and on compact disc (Fig. 26). Both virtual field trips are interactive, with written material, videos, and interviews with GWA LTM program PIs, and include lesson plans for teachers. The first, called Gulf Watch Alaska Long-term Monitoring, includes background information on EVOS and the GOA ecosystem and introduced the GWA LTM program with videos featuring four program components and the work and careers of GWA scientists. The second, called The Mystery of the Blob, compared seasonal patterns of ocean conditions in the GOA and implications for food webs under anomalously warm conditions. Yosty Storms, a former intern with GWA through the Alaska Native Science and Engineering Program in Anchorage, narrates the second virtual field trip as she learns about the Mystery of the Blob talking with GWA Scientists. The link to the ASLC virtual field trip website is listed at the end of this report under the Other References section.

In addition to the outreach methods presented above, several PIs wrote articles for newspapers, books, and short stories regarding the findings of GWA LTM program projects. Much of this work was completed on PIs' personal time. Journalists with newspapers and magazines sought out GWA LTM program PIs and wrote articles based on interviews. These are listed at the end of this report under the Other References section.

Figure 26. Example of one of the Alaska SeaLife Center's virtual field trips. This screen shot snows the opening page of The Mystery of the Blob, which introduces students to the Pacific warm anomaly, A.K.A the Blob, and how the warm ocean waters affected the marine ecosystem of the northern Gulf of Alaska.

Objective 6. Develop Science Synthesis Products

Science Coordination and Synthesis
Project 16120114-H

The primary science synthesis products developed under the science coordination and synthesis project included the synthesis report prepared following the symposium in year 3 (Neher et al. 2014) and the special issue of *Deep-Sea Research Part II*. Additional synthesis products included presentations and posters at the Alaska Marine Science Symposium and other conferences (see Other References section at the end of this report) and support in developing visualizations and outreach products.

The science synthesis workshop held with EVOSTC in year 3 of the program, along with subsequent report preparation, represented the first steps toward interdisciplinary synthesis of EVOSTC-funded data, including previously gathered historic data and the two to three years of data collected under the GWA and HRM programs, supplemented by other studies. As part of the workshop, program scientists developed the following cross-disciplinary questions:

1. Are changes in oceanographic conditions in the outer GOA shelf mirrored in the nearshore marine environment and population trends of injured, recovering, and recovered resources?
2. Are population trends of nearshore and pelagic injured, recovering, and recovered species responding similarly to changes in ocean conditions?
3. Is herring and forage fish overwintering success tied to spring and summer productivity and season or year-to-year differences in the zooplankton community?
4. Is herring and forage fish overwinter success associated with winter conditions on the shelf or in PWS?
5. Are variations in seabird abundance and distribution associated with zooplankton stocks and/or oceanographic conditions?
6. What are predation rates of humpback whales and seabirds on PWS herring and other forage fish populations?
7. How do oceanographic patterns compare (and co-vary) between different locations in PWS, the GOA shelf, and lower Cook Inlet?
8. What are the spatial patterns and timing of ocean stratification that lead to spring and autumn phytoplankton blooms?
9. How are the timing, intensity, and duration of stratification changing, and what are the consequences?
10. How do zooplankton community assemblages and abundances vary spatially, from year to year, with the timing of the spring phytoplankton bloom, and with water properties (temperature, salinity, and nutrients)?
11. What are the population trends of key pelagic species groups (killer whales, seabirds, humpback whales, and forage fish) in PWS?
12. How can forage fish population trends in PWS be effectively monitored?
13. Are there significant inter-annual changes in the nearshore communities and are they synchronous across the GOA?

14. Have injured resources in the nearshore environment recovered from EVOS? If not, can we identify or rule out other, non-spill related, factors that are constraining their recovery?

The GWA and HRM programs co-presented the workshop and prepared separate reports (Herring Research and Monitoring Team 2014, Neher et al. 2014). Workshop participants included EVOSTC members, staff, and science review panel members; HRM PIs and science review team members; and GWA PIs and science review team members. Select PIs presented brief scientific overviews. All workshop participants discussed the presentations and findings, hypotheses related to GOA ecosystem functioning, and the synthesis of information. The GWA synthesis report included chapters providing historical context and overview, environmental drivers, variability within the pelagic ecosystem, variability within the nearshore ecosystem, lingering oil monitoring, conceptual models, and program summary and recommendations (Neher et al. 2014).

Based on the key findings from the science synthesis report, GOA demonstrates paths of energy transport through two distinct, but connected food webs: a pelagic, offshore environment with most primary production from phytoplankton, and a nearshore environment with primary production from macroalgae, phytoplankton and benthic microalgae. Both food webs are driven by environmental conditions, including temperature, salinity, nutrient supply, and solar radiation, that control primary production and biological processes at higher trophic levels.

The first five years of the GWA LTM program culminated in a special issue jointly developed with the HRM program. The special issue in the journal *Deep-Sea Research Part II* is entitled "Spatial and Temporal Ecological Variability in the Northern Gulf of Alaska: What Have We Learned Since the *Exxon Valdez* Oil Spill?" Leaders from both GWA LTM and HRM programs served as guest editors for the special issue. PIs submitted manuscripts for the special issue during summer and fall 2016. Manuscript peer reviews began in late fall 2016. The special issue includes 19 peer-reviewed and two editorial papers, out of 27 submissions, associated with persistent spill effects, environmental drivers, the nearshore ecosystem, herring and other forage fish, and upper trophic levels. The journal issue (volume 147) was published in January 2018. Publications are listed below under Other References (Publications Incorporating Gulf Watch Alaska and Historical Data) and titles and authors are summarized in Table 7.

Table 7. Peer-reviewed and editorial papers published in volume 147 of the peer-reviewed journal *Deep-Sea Research Part II*, a special issue jointly developed by the Gulf Watch Alaska (GWA) and Herring Research and Monitoring (HRM) programs, in order of their appearance in the journal.

Title	**Co-authors**	**Program/ Component**
Foreword: The evolution from species specific damage assessment to ecosystem centric studies over the multi-decade period following the *Exxon Valdez* oil spill	Rice and Peterson	EVOSTC Science Panel and GWA Science Review Team
Spatial and temporal ecological variability in the northern Gulf of Alaska: What have we learned since the *Exxon Valdez* oil spill?	Aderhold, Lindeberg, Holderied, and Pegau	GWA and HRM program management
Conditions of persistent oil on beaches in Prince William Sound 26 years after the *Exxon Valdez* oil spill	Lindeberg, Maselko, Heintz, Fugate, and Holland	GWA lingering oil
A review of distribution and quantity of lingering subsurface oil from the *Exxon Valdez* oil spill	Nixon and Michel	GWA lingering oil
Gene transcription patterns in response to low level petroleum contaminants in *Mytilus trossulus* from field sites and harbors in southcentral Alaska	Bowen, Miles, Ballachey, Waters, Bodkin, Lindeberg, and Esler	GWA lingering oil
Timelines and mechanisms of wildlife population recovery following the *Exxon Valdez* oil spill	Esler, Ballachey, Matkin, Cushing, Kaler, Bodkin, Monson, Esslinger, and Kloecker	GWA Nearshore and Pelagic
Hydrographic trends in Prince William Sound, Alaska, 1960-2016	Campbell	GWA Environmental Drivers
Interannual variability in lower trophic levels on the Alaskan shelf	Batten, Raitsos, Danielson, Hopcroft, Coyle, and McQuatters-Gollop	GWA Environmental Drivers
Seasonal variation of zooplankton abundance and community structure in Prince William Sound, Alaska, 2009-2016	McKinstry and Campbell	GWA Environmental Drivers
The use of unmanned aerial vehicle	Konar and Iken	GWA Nearshore

Title	Co-authors	Program/ Component
imagery in intertidal monitoring		
Variation in abundance of the Pacific blue mussel (*Mytilus trossulus*) in the northern Gulf of Alaska, 2006-2015	Bodkin, Coletti, Ballachey, Monson, Esler, and Dean	GWA Nearshore
Distribution of juvenile Pacific herring relative to environmental and geospatial factors in Prince William Sound, Alaska	Lewandowski and Bishop	HRM
Migration patterns of post-spawning Pacific herring in a subarctic sound	Bishop and Eiler	HRM
Spatial and temporal variation in winter condition of juvenile Pacific herring (*Clupea pallasii*) in Prince William Sound, Alaska: Oceanographic exchange with the Gulf of Alaska	Gorman, Kline, Roberts, Sewall, Heintz, and Pegau	HRM
Empirically based models of oceanographic and biological influences on Pacific herring recruitment in Prince William Sound	Sewall, Norcross, Mueter, and Heintz	HRM
Spatio-temporal distributions of piscivorous birds in a subarctic sound during the nonbreeding season	Stocking, Bishop, and Arab	GWA Pelagic
Patterns of distribution, abundance, and change over time in a subarctic marine bird community	Cushing, Roby, and Irons	GWA Pelagic
Seasonal distribution of Dall's porpoise in Prince William Sound, Alaska	Moran, O'Dell, Arimitsu, Straley, and Dickson	GWA Pelagic
Seasonal presence and potential influence of humpback whales on wintering Pacific herring populations in the Gulf of Alaska	Straley, Moran, Boswell, Vollenweider, Heintz, Quinn, Witteveen, and Rice	GWA Pelagic
Regional variation in the intensity of humpback whale predation on Pacific herring in the Gulf of Alaska	Moran, Heintz, Straley, and Vollenweider	GWA Pelagic
Seasonal and pod-specific differences in core use areas by resident killer whales in the northern Gulf of Alaska	Olsen, Matkin, Andrews, and Atkinson	GWA Pelagic

Data Management
Projects 16120114-D and 16120114-T

Data visualizations were completed for several GWA datasets. The goal of visualizations was to provide a clear and efficient visual communication of data by making complex or long-term information more accessible, understandable, and usable. Additionally, visualizations helped researchers make comparisons to other related or environmental datasets.

Hundreds of additional datasets are available in the Gulf of Alaska Data Portal, allowing for simplified, visual integration. As additional data are added from the GWA and HRM programs, the Gulf of Alaska Data Portal will continue to provide researchers with a streamlined visual environment for data selection, filtering, and exploration from multiple sources (including environmental, atmospheric, and numeric models). This tool allows rapid discovery of interesting findings to support (or refute) initial study hypotheses, inform further experimentation and experimental design, and generate additional hypotheses or “hot spots” related to drivers of environmental change in the northern GOA.

Capabilities have also been developed to visualize 4-dimensional oceanographic data enabled by the netCDF data format. NetCDF is a well-documented, open, and self-describing format that was designed with the needs of long-term preservation in mind. Axiom analysts worked with GWA PIs to convert CTD data from 1997 through 2013 for the Seward Line and GAK1 projects into netCDF files that were used to create rich, 4D visualizations. With these data format conversions complete, the datasets were more robustly visualized along standardized parameters while being ready for archiving in a long-term preservation environment. Specifically, in this 4D visualization interface, the physical oceanographic datasets can be spatially and temporally parsed to view data from a particular location or time period on the transect (Fig. 27). For each location the vertical profile information has been mapped for each of the data parameters (e.g., water temperature, salinity, conductivity, and fluorescence). Further, various linear interpolation analyses (including inverse distance weighting, linear, Krig, and nearest neighbor) can be applied across depth increments to provide parameter measurements across the entire water column. The measurements are displayed in both a graph and 4D image that can be interacted with to observe changes in the water column both across spatial areas and time.

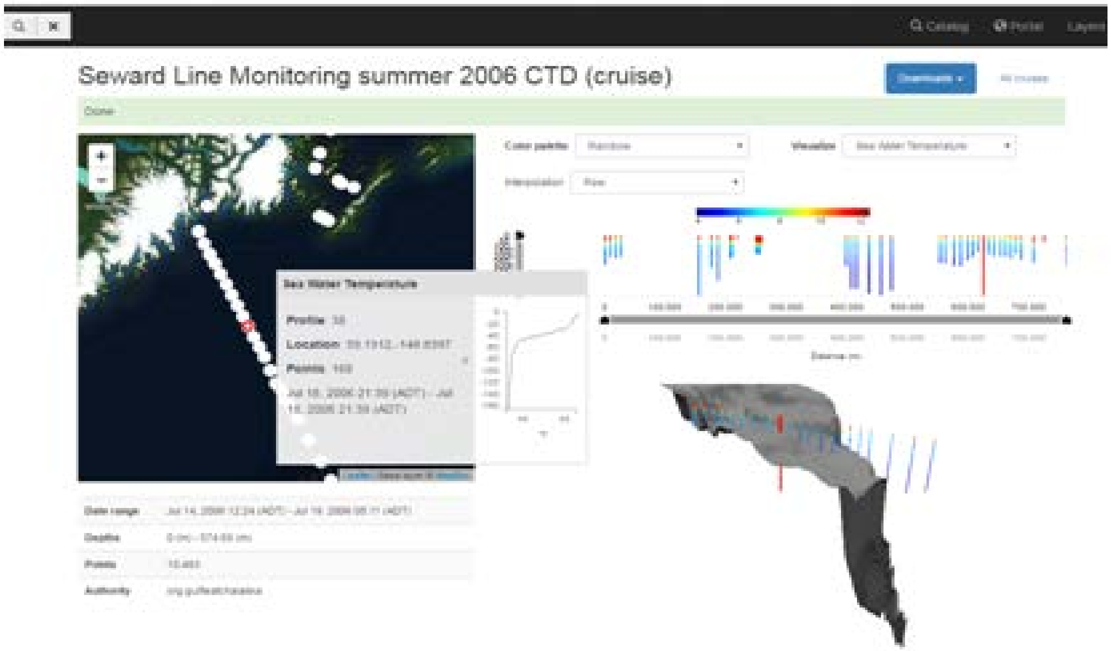

Figure 27. Visualizations of conductivity and temperature vs. depth (CTD) data in the Gulf of Alaska Data Portal, including spatial and temporal data parsing, vertical profiles, and linear interpolation for various oceanographic parameters.

Conceptual Ecological Modeling
Project 16120114-I

Modelers received 19 responses from GWA PIs, including lists of model components and visual representations of a general North GOA conceptual model. Two conceptual model visualizations were created: one general model which included all elements and linkages listed in the responses, and a parsimonious consensus model which included elements and linkages with three or more responses.

This visual representation of a general North GOA conceptual ecological model was re-evaluated by 18 GWA PIs in 2016. The resulting model and visualization (Fig. 28) added the following ecosystem components: dust-storms, glacial input, jellyfish, and temperature. Marine debris was replaced by microplastics. Recreational traffic, sea ice, and sea level rise were removed from the model as three or more participants indicated the elements did not play a central role in the functioning of the system. Flow, contaminants, larval transport, microbial processes, pelagic macroinvertebrates, noise, ship strike, and stratification were also mentioned as important components in the ecosystem by one or two participants but were not included in the consensus model.

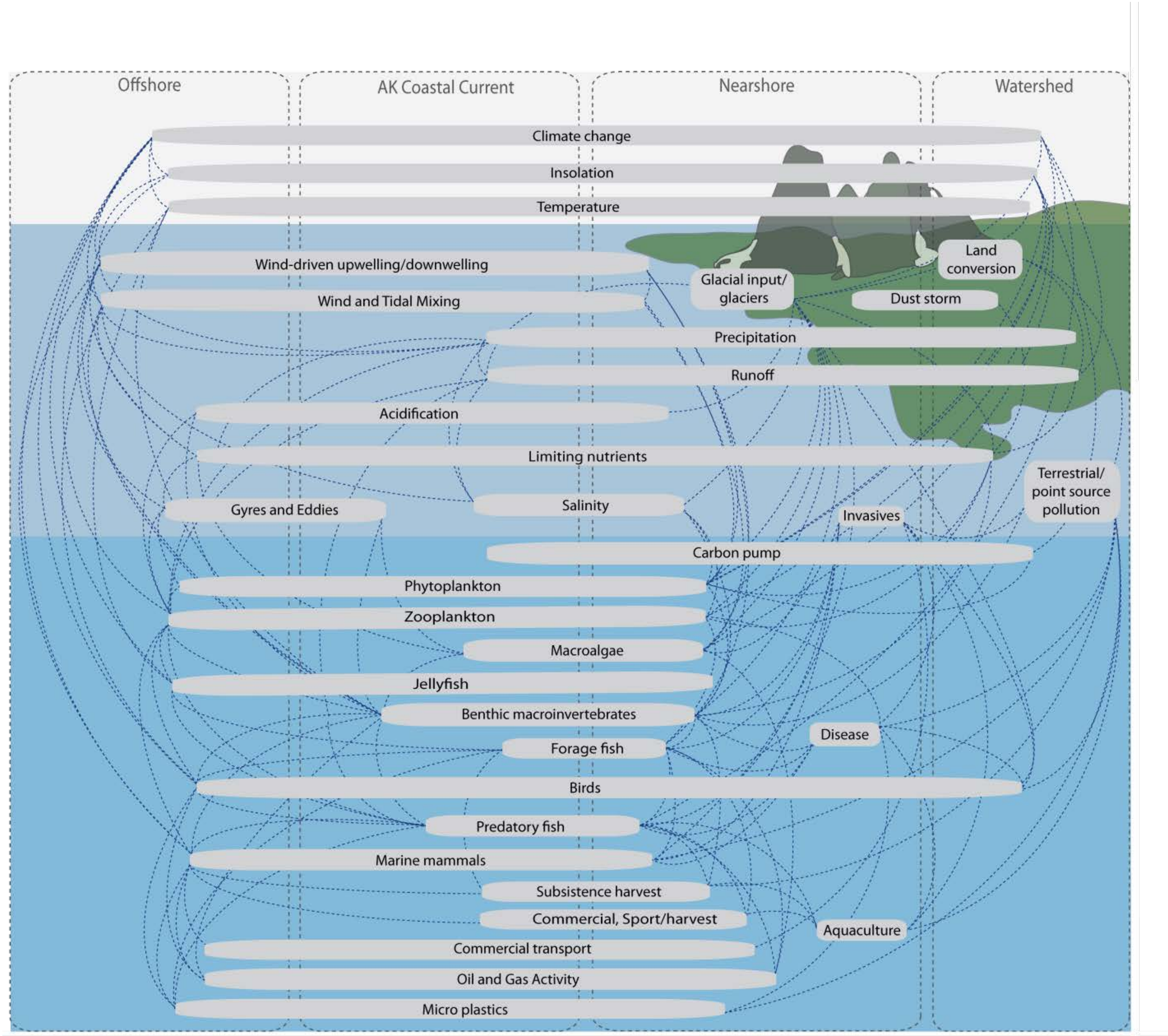

Figure 28. Visual representation of a general census conceptual ecological model for North Gulf of Alaska as re-evaluated in 2016.

Holistic Synthesis
Project 16120120

Synthesis groups convened in 2016 and met four times in person at NCEAS in Santa Barbara, California, to collate and analyze data, collaborate on research, and write manuscripts.

Synthesis Working Group: Gulf of Alaska Dynamics working group: This working group examined the effects of stressors on the resilience of social-ecological systems of the GOA, with focus on food webs, fisheries, pollutants, and nearshore habitats. This working group has actively been working on the following synthesis publications (Table 8).

Table 8. Gulf of Alaska Dynamics working group manuscripts.

Manuscript Title, status, and journal	Co-authors
Linking ecosystem processes to communities of practice through commercially fished species in the Gulf of Alaska; 2017; ICES Journal of Marine Science	Zador, Gaichas, Kasperski, Ward, Blake, Ban, Himes-Cornell, and Koehn
Factors affecting disaster preparedness, response and recovery in the context of the Community Capitals Framework; In press; Annals of the Association of American Geographers	Himes-Cornell, Ormond, Hoelting, Ban, Koehn, Allison, Larson, Monson, Huntington, and Okey
Comparing the roles of Pacific halibut and arrowtooth flounder within the Gulf of Alaska ecosystem and fishing economy; in prep; Fisheries Oceanography	Ruzicka, Zador, Himes-Cornell, and Kasperski
Large-scale environmental variability and changes in coastal Gulf of Alaska food web structure; in prep; Journal of Marine Science	Ruzicka, Siedelecki, Okey, Himes-Cornell, Klinger, Dean, Wootton, and Kasperski
Associations between Mussel Abundance and Environmental Drivers in the Gulf of Alaska; in prep; PLoS One	Blake, Dean, Klinger, Monson, Siedlecki, and Wootton
Can oil spills shift marine ecosystems to alternate stable states?: Preliminary simulations with an Ecopath model of Prince William Sound, Alaska; in prep; PLoS One	Okey
Simulating effects of the *Exxon Valdez* Oil Spill on the Prince William Sound ecosystem in the context of changing fisheries and climate; in prep; Marine Pollution Bulletin	Okey, Ainsworth, Kasperski, Seidlecki, Ruzicka, Dean, Bodkin, and possibly Klinger, Himes-Cornell, and Pauly
Associations between mussel abundance and environmental drivers in the Gulf of Alaska; in prep; PLoS One	Blake, Dean, Klinger, Monson, Siedlecki, and Wootton

Synthesis Working Group: Applying Portfolio Effects to the Gulf of Alaska working group: Similar to the economic principle that diversification of financial portfolios across assets can stabilize returns, portfolio effects in ecology states that the dynamics of many biological systems are often less variable than the individual components they are composed of (Schindler et al. 2015). This working group sought to assess the relationship between biodiversity and stability of ecological populations and communities, as well as harvest of marine species, in the GOA. This group has 13 research papers underway (Table 11).

Table 9. Applying Portfolio Effects to the Gulf of Alaska working group manuscripts.

Manuscript Title, status, and journal	Co-authors
Spatial and temporal patterns in demersal fish communities following *Exxon Valdez*; 2017; ICES Journal of Marine Science	Shelton, Hunsicker, Ward, Feist, Ward, Williams, Anderson, Hollowed, and Haynie
Evaluating signals of climate, oil spill impacts, and interspecific interactions in Pacific salmon and Pacific herring populations in Prince William Sound and Copper River, Alaska; 2017; PLoS One	Ward, Adkison, Couture, Dressel, Litzow, S. Moffitt, Hoem Neher, Trochta, and Brenner
Environmental heterogeneity and conserved community architecture drive spatial patterns of diversity across the Gulf of Alaska large marine ecosystem; in review, Marine Ecology Progress Series	Blake, Ward, Hunsicker, Shelton, and Hollowed
From local to regional: spatial scaling of long-term diversity and stability in the Gulf of Alaska groundfish community; in prep; Proceedings of the Royal Society of London B: Biological Sciences	Ward, Blake, Hunsicker, Shelton, Hollowed, and Petchey
Long term trends in ichthyoplankton assemblage structure, biodiversity, and community synchrony in the Gulf of Alaska and their relationships to climate; in revision; Progress in Oceanography	Marshall and Duffy-Anderson
Benefits and risks of diversification for individual fishers; in press; Proceedings of the National Academy of Sciences of the United States of America	Anderson, Ward, Shelton, Adkison, Beaudreau, Brenner, Haynie, Shriver, Watson, and Williams
Effects of increased specialization on revenue of Alaska salmon fishers over four decades; 2017; Journal of Applied Ecology	Ward, Anderson, Shelton, Brenner, Adkison, Beaudreau, Watson, Shriver, Haynie, and Williams
Examination of trends and variability in sex ratios in herring in PWS; in review; Fisheries Research	Ward, Delgado-Nordmann, Brenner, Beaudreau, Shelton, Moffitt
Diversity-stability in the Gulf of Alaska ecosystem; in prep; Ecology or Proceedings of the Royal Society B	Ward, C.
Groundfish-salmon relationships; in prep; ICES or similar	Ward, Hunsicker, Shelton, et al.
Historical patterns and drivers of diversification in Gulf of Alaska fisheries; in prep; Fish and Fisheries	Beaudreau, et al.
Twenty-five years after the *Exxon Valdez* oil spill: A	Marshall and all working group

Manuscript Title, status, and journal	Co-authors
synthesis of climatic, anthropogenic, and ecological drivers of Gulf of Alaska communities; in prep; Frontiers in Ecology and the Environment	members

Working group members presented summaries of the work at numerous conferences (see Other References).

Publications

GWA program PIs published 71 peer-reviewed articles, editorials, book chapters, and theses in 30 journals, four presses, and two universities. Many of the publications included co-authors and incorporated data from outside the GWA program. The publications are listed under Other References at the end of this report, in the science coordination and synthesis final report (Holderied and Aderhold 2018), and in the individual project final reports.

DISCUSSION

The GWA LTM program met or exceeded each of its objectives for the 2012-2016 funding period. Each project in the GWA LTM program provided significant contributions to the program as a whole.

Through the administration, logistics, and outreach; data management support; and science coordination and synthesis projects, the GWA program successfully implemented EVOSTC guidance. PWSSC successfully managed the NOAA grant and non-Trustee Agency funds. Annual reports and work plans were submitted on schedule following EVOSTC procedures. GWA program data were reviewed for quality assurance and quality control and published with federally compliant metadata.

Monitoring projects associated with the GWA LTM program contributed to scientific understanding of the northern GOA ecosystem, and, because the projects were combined under a single program, scientists were better able to discuss and evaluate linkages between geographic areas and aspects of the ecosystem (e.g., effect of physical oceanography on trophic systems and effect of top predators on lower trophic levels). The Pacific warm anomaly, including what was referred to as "The Blob," occurred during the 2012-2016 funding period and all field projects associated with the GWA LTM program documented effects associated with it. GWA-collected data contributed to the overall scientific understanding of the warm anomaly and the publically available data from the GWA LTM program will contribute to the evaluation of the anomaly by management agencies and others far into the future.

The environmental drivers projects, CPR, PWS oceanographic, Cook Inlet/Kachemak Bay oceanographic, Seward Line, and GAK1, provided important baseline information for all

GWA projects and provided northern GOA context for the Pacific warm anomaly and its effects on marine species from plankton to whales.

Each of the pelagic ecosystem projects observed species changes related to the Pacific warm anomaly. The forage fish distribution, abundance, and body condition project detected changes in species distribution which translated to changes in humpback whale and marine bird distribution and a wide-spread common murre die-off detected by both marine bird projects and the nearshore projects. In contrast, the killer whale project found resident killer whales feeding on salmon to be fat relative to earlier years.

The nearshore ecosystem projects confirmed that the warm water temperatures measured by the environmental drivers projects were expressed in intertidal regions across the northern GOA, although the biological effects are still under investigation.

Continuing the lingering oil projects led to the finding that two injured species dependent on nearshore habitats, harlequin ducks and sea otters, are no longer exposed to lingering oil. These findings are corroborated by the project tracking oil levels and weathering in PWS, which found that, while oil remains buried in some locations, the oil is sequestered in place.

Collaboration between the GWA and HRM programs strengthened throughout the first five years of EVOSTC funding and will continue as the programs move forward. While the greatest collaboration with the HRM program involved direct field collaboration and data sharing from the PWS oceanographic, humpback whale, and forage fish projects, presentations and discussions at meetings, the 3-year synthesis workshop, and coordination on the *Deep-Sea Research Part II* special issue provided opportunities for scientists from both programs to develop a deeper understanding of the northern GOA ecosystem as a whole.

Financial and collaborative partnerships with Trustee Agencies and other funding organizations and consortiums studying other aspects of the northern GOA ecosystem further strengthened the outcomes of the GWA LTM program during its first five years. The GWA LTM program received similar partnership commitments from funding organizations in the next five years, and relationships with other researchers will strengthen based on relationships developed in the first five years.

The GWA program was highly successful at attaining the objective to provide scientific data, data products, and outreach to management agencies and a wide variety of users. Not only were data from the first five years of the GWA LTM program published, but also data collected historically with EVOSTC funding was located and published with DOIs for public accessibility and citation. Conceptual ecological modeling allowed scientists in the GWA LTM program to evaluate the relationships among datasets within and between projects in new ways; however, the EVOSTC decision to not fund this project in year 5, limited the completion of the modeling effort. Outreach efforts reached broad audiences, including other scientists, lay audiences in Alaska and beyond, students and teachers, and spill-affected community members.

Including the GWA scientific monitoring projects under the umbrella of a single program, and funding a science coordination and synthesis project to bring the monitoring projects together, allowed greater collaboration among scientists studying different aspects of the northern GOA ecosystem and the provided scientists the ability to make connections sooner than if the projects were funded individually. The collaborative nature of the program contributed to synthetic products and outreach to data users.

The synthesis workshop held jointly with the HRM program in year 3 solidified the relationships between the projects and programs, resulting in deeper evaluation of questions about ecosystem function and the relationships associated with bottom up and top down drivers. Throughout the years, presentations and posters at scientific meetings included greater synthesis of datasets. Axiom developed tools for scientists to overlay and assess data from multiple projects, allowing spatial and temporal patterns to emerge. Working groups from the collaborative data management and holistic synthesis project examined historical EVOSTC-funded data and approached synthesis of data in novel ways. The general consensus conceptual ecological model initiated in year 1 was reevaluated and enhanced in year 5, and the results demonstrated the GWA program's evolved understanding of the northern GOA ecosystem as a whole. Science synthesis in the first five years culminated with publication of a special issue of the journal *Deep-Sea Research Part II* with a publication date of January 2018.

With more than 50 publications and more than 200 oral and poster presentations during the first five years of the program, outreach about the scientific findings of the GWA LTM program to the scientific community and the public is off to a good start. More peer-reviewed articles from the first five years of GWA were published in early 2018 and will continue to be published in the years to come. As the time-series builds and top-down and bottom up relationships between the environment, predators, and injured species are developed, the GWA program will contribute to a greater extent to the scientific literature regarding marine ecology in general and Gulf of Alaska ecology specifically.

The outcomes of the first five years of the GWA LTM program drove the direction of the program for the second five years. The program's objectives will remain similar: sustain and build upon existing time series; provide scientific data, data products, and outreach; develop science synthesis products; continue to build on collaborations between the GWA and HRM programs; and leverage partnerships with outside agencies and groups. The program's management team has been modified, based on knowledge gained in the first five years, to separate the roles of program and science coordination and to combine the roles of program and science leads into one. The scientific monitoring program will largely remain the same, with minor exceptions as follows: the two nearshore ecosystem projects will be combined into one; based on knowledge gained about species distribution in the first five years, three projects (PWS fall/winter seabird abundance and distribution, humpback whale predation on herring, and forage fish distribution, abundance, and body condition) will conduct at-sea surveys on a shared vessel; and the forage fish project has modified its sampling procedures based on the results of preliminary studies in the first five years.

The end result of the GWA LTM program will be to improve understanding of how ocean ecosystem changes may affect resources and services injured by EVOS and a return to pre-spill conditions.

CONCLUSIONS

The GWA LTM program met its objectives for the first five years and has proposed to continue for another five years with some modifications at the program and project levels. Administrative, oversight, and support projects ensured financial obligations were met and all EVOSTC plans, policies, and guidance were followed. Without leveraged partnerships the GWA LTM program would not have been successful. The program was fortuitously formed and in place in time for all monitoring projects to document the effects of the Pacific warm anomaly on the northern GOA ecosystem. Data, reports, publications, and findings from the GWA LTM program are available for the scientific community and the public.

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Olsen, D. W., C. O. Matkin, R. D. Andrews, and S. Atkinson. 2018. Seasonal and pod-specific differences in core use areas by resident killer whales in the Northern Gulf of Alaska. Deep-Sea Research Part II 147:196-202. DOI:10.1016/j.dsr2.2017.10.009

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Shelton, A. O., M. E. Hunsicker, E. J. Ward, B. Feist, C. L. Ward, B. Williams, J. T. Anderson, A. B. Hollowed, and A. C. Haynie. 2017. Spatial and temporal patterns in demersal fish communities following *Exxon Valdez*. ICES Journal of Marine Science. doi:10.1093/icesjms/fsx079

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Presentations and Posters by Gulf Watch Alaska Project Team Members

Aderhold, D. 2016. Gulf Watch Alaska program overview. Science after the spill: How are our ecosystems changing? Homer. Presentation.

Aderhold, D. 2016. Wreck. Science night, Cordova. Reading.

Arimitsu, M. 2014. Geographic structure of ocean food webs along 4000 km of Alaska coast: Implications for marine predators. Alaska Marine Science Symposium, Anchorage. Presentation.

Arimitsu, M. L., S. Pegau, J. Piatt, B. Heflin, and S. Schoen. 2017. Spatial and temporal variability of forage fish in coastal waters of Prince William Sound, Alaska. Alaska Marine Science Symposium, Anchorage. Poster.

Arimitsu, M., and J. Piatt. 2015. Forage fish in marine ecosystems: Combining strategies to sample patchy populations. University of Alaska Fairbanks Fisheries Seminar, Juneau. Presentation.

Arimitsu, M. L., J. Piatt, B. Heflin, and S. Schoen. 2017. Jellyfish blooms in warm water may signal trouble for forage fish in a warming climate. ICES/PICES Symposium on Drivers of Dynamics of Small Pelagic Fish Resources, Victoria, B.C. Canada. Poster.

Arimitsu, M. L., J. F. Piatt, V. von Biela, E. Madison, S. Schoen, B. Heflin. 2013. Detecting long-term changes in forage fish populations in Prince William Sound, Alaska. Alaska Marine Science Symposium, Anchorage. Poster.

Atkinson, S., J. Straley, A. Pack, C. Gabriele, J. Moran, D. Gendron, and K. Mashburn. 2016. Detection of pregnancy and stress biomarkers in large whales. Alaska Marine Science Symposium, Anchorage. Poster.

Ballachey, B., L. Bowen, A. K. Miles, G. Esslinger, M. Lindeberg, K. Kloecker, and H. Coletti. 2014. Gene transcription profiles in mussels (*Mytilus trossulus*) from Prince William Sound, Alaska, 2012 & 2013, as indicators of nearshore ecosystem health. Alaska Marine Science Symposium, Anchorage. Poster.

Batten, S. 2013. A tale of little and large: How big ships help us understand the ocean's smallest critters. Prince William Sound Science Center weekly lecture series, Cordova. Presentation.

Batten, S. 2014. Zooplankton community structure around the Gulf of Alaska. Alaska Marine Science Symposium, Anchorage. Poster.

Batten, S. 2015. Interannual variability in lower trophic levels on the Alaskan shelf. Alaska Marine Science Symposium, Anchorage. Presentation.

Batten, S. 2015. The effects of the anomalous warming on lower trophic levels in the NE Pacific. North Pacific Marine Science Organization (PICES) Meeting, Anchorage. Presentation.

Batten, S. 2016. The effects of the anomalous warming on lower trophic levels. Alaska Marine Science Symposium, Anchorage. Presentation.

Batten, S. D., D. Raitsos, R. R. Hopcroft, and K. O. Coyle. 2015. Interannual variability in lower trophic levels on the Alaskan Shelf. Alaska Marine Science Symposium. Anchorage. Presentation.

Beaudreau, A., E. Ward, R. Brenner, J. Watson, A. O. Shelton, J. Shriver, B. Williams, and A. Haynie. 2017. Historical patterns and drivers of diversification in Gulf of Alaska fisheries. Society for Applied Anthropology Meeting, Santa Fe, NM. Presentation.

Bishop, M. A., K. Kuletz, J. Stocking, and A. Schaefer. 2016. Spatial and temporal patterns of winter marine bird distribution in Prince William Sound, Alaska. Alaska Marine Science Symposium, Anchorage. Poster.

Bishop, M. A., K. Kuletz, J. Stocking, and A. Schaefer. 2016. Winter marine bird distribution in Prince William Sound: Spatial and temporal patterns. Alaska Bird Conference, Cordova. Presentation.

Blake, R. E., C. L. Ward, M. Hunsicker, A. O. Shelton, and A. B. Hollowed. 2016. Patterns of diversity: Gulf of Alaska groundfish. Western Society of Naturalists Annual Meeting, Monterey, CA. Presentation.

Blake, R. E., C. L. Ward, M. Hunsicker, A. Shelton , A. B. Hollowed, and A. Haynie. 2017. Environmental heterogeneity and conserved community architecture drive spatial patterns of diversity across the Gulf of Alaska large marine ecosystem. Alaska Marine Science Symposium, Anchorage, AK. Poster.

Bodkin, J. 2015. Gulf Watch Alaska and the nearshore food web. Prince William Sound Science Center weekly lecture series, Cordova. Presentation.

Boswell, K., M. Barton, A. Brownstein, J. Straley, and J. Moran. 2016. Stable isotope analysis of humpback whales (*Megaptera moveangliae*) to confirm diet during winter foraging. Alaska Marine Science Symposium. Poster.

Buckelew, S. 2016. Gulf Watch Alaska: Data management. Science after the spill: How are our ecosystems changing? Homer. Presentation.

Campbell, R. 2012. State of the Sound: Recent oceanographic conditions in Prince William Sound. Prince William Sound Science Center weekly lecture series, Cordova. Presentation.

Campbell, R. 2014. Recent trends in surface oceanography and lower trophic levels of Prince William Sound. Alaska Marine Science Symposium, Anchorage. Poster.

Campbell, R. 2015. Recent trends in the oceanography of Prince William Sound. Alaska Marine Science Symposium, Anchorage. Poster.

Campbell, R. W. 2015. State of the Sound: Oceanography, surface layer dynamics, and plankton blooms in PWS. Prince William Sound Science Center Lecture series, Cordova. Presentation.

Campbell, R. W. 2015. State of the Sound: Oceanography, surface layer dynamics, and plankton blooms in PWS. Prince William Sound Science Center Pub Talk, Cordova. Presentation.

Campbell, R. W. 2015. Oceanography, surface layer dynamics, and plankton blooms in PWS. Prince William Sound Regional Citizens' Advisory Council, Anchorage. Presentation.

Campbell, R. W. 2016. Effects of the 2013-2015 warm anomaly in Prince William Sound, Alaska. Pacific Anomalies Workshop 2, Seattle. Poster.

Campbell, R. W. 2016. Surface layer and bloom dynamics in Prince William Sound. Alaska Marine Science Symposium, Anchorage. Presentation.

Carls, M. 2014. *Exxon Valdez* oil spill 25 years later. Prince William Sound Science Center weekly lecture series, Cordova. Presentation.

Carney, B., D. Tessler, H. Coletti, and D. Causey. 2013. Long-term diets of black oystercactchers (*Haematopus bachmani*), evidence from stable isotopes - preliminary results. Alaska Marine Science Symposium, Anchorage. Poster.

Cates, K., S. Atkinson, J. Moran, A. Pack, and Jan Straley. 2015. Do testosterone levels of humpback whales suggest breeding activity in summer feeding grounds? Society for Marine Mammals Biennial Conference, San Francisco. Poster.

Coletti, H.A., D. Esler, B. E. Ballachey, J. L. Bodkin, T. A. Dean, G. Esslinger, K. Iken, K. A. Kloecker, B. Konar, M. Lindeberg, D. H. Monson, and B. Weitzman. 2013. Monitoring nearshore marine ecosystems in the Gulf of Alaska: Detecting change and understanding cause. Alaska Marine Science Symposium, Anchorage. Poster.

Coletti, H., D. Esler, B. Ballachey, J. Bodkin, T. Dean, G. Esslinger, K. Iken, K. Kloecker, B. Konar, M. Lindeberg, D. Monson, and B. Weitzman. 2016. Updates of key metrics from long-term monitoring of nearshore marine ecosystems in the Gulf of Alaska: Detecting change and understanding cause. Alaska Marine Science Symposium, Anchorage. Poster.

Coletti, H., G. Hilderbrand, J. Pfeiffenberger, C. Turner, B. Ballachey, L. Bowen, K. Counihan, J. Erlenbach, D. Esler, T. Hollmen, D. Gustine, B. Mangipane, B. Pister, C. Robbins, and T. Wilson. 2016. Changing tides – The convergence of intertidal invertebrates, bears and people. Alaska Marine Science Symposium, Anchorage. Poster.

Counihan-Edgar, K. L., T. Hollmen, and H. Coletti. 2013. Physiological assessment of *Mytilus* spp. in Kenai Fjords National Park. Alaska Marine Science Symposium, Anchorage. Poster.

Cushing, D. A. 2014. Patterns of distribution, abundance, and change over time in the marine bird community of Prince William Sound, Alaska, 1989-2012. Oregon State University, Department of Fisheries and Wildlife, Corvallis. Master of Science Thesis Defense Seminar.

Cushing, D., K. Kuletz, R. Hopcroft, S. Danielson, and E. Labunski. 2017. Shifts in cross-shelf distribution of seabirds in the northern Gulf of Alaska under different temperature regimes, 2007-2016. Annual meeting of the Pacific Seabird Group, Tacoma. Poster.

Cushing, D., D. Roby, and D. Irons. 2015. Boats, binoculars, and birds: What a long-term marine bird survey program can tell us about a changing ecosystem. Willamette Valley Bird Symposium, Oregon State University, Corvallis. Presentation.

Cushing, D., D. Roby, and D. Irons. 2014. Patterns of long-term change in the marine bird community of Prince William Sound, Alaska. Oregon State University 'Bird Nerds' Student Club, Corvallis. Invited seminar,

Cushing, D., D. Roby, and D. Irons. 2015. Two decades of change in the marine bird community of Prince William Sound, Alaska. Annual Meeting of the Pacific Seabird Group, San Jose. Presentation.

Cushing, D., D. Roby, K. Kuletz, and D. Irons. 2013. Decadal declines in mid-summer abundance ff *Brachyramphus* murrelets in Prince William Sound, Alaska. Pacific Seabird Group, Portland, OR. Presentation.

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. Alaska Marine Science Symposium, Anchorage. Presentation.

Cushing, D., D. D. Roby, K. J. Kuletz, and D. B. Irons. 2014. Decadal change in the marine bird community of Prince William Sound, Alaska linked to differences in habitat association. Alaska Marine Science Symposium, Anchorage. Presentation.

Danielson, S., S. Batten, R. Campbell, A. Doroff, K. Holderied, R. Hopcroft, R. Thoman, and T. Weingartner. 2016. Gulf of Alaska 2015 anomalous conditions workshop: Oceanography. Large Whale Unusual Mortality Event Workshop, Anchorage. Presentation.

Danielson, S. L., T. J. Weingartner, and R. R. Hopcroft. 2015. Temperature and salinity anomalies on the Northern Gulf of Alaska Shelf. Pacific Anomalies Workshop. Presentation.

Danielson, S., T. Weingartner, and R. Hopcroft. 2016. 1970 to 2015 thermal and haline anomalies on the northern Gulf of Alaska continental shelf. Pacific Anomalies Workshop 2, Seattle. Poster and slides.

Doroff, A. M., R. Campbell, and C. McKinstry. 2016. Zooplankton assemblages in lower Cook Inlet and Kachemak Bay 2012-2014. Alaska Marine Science Symposium, Anchorage. Poster.

Doubleday, A. J., and R. R. Hopcroft. 2012. Decadal estimates of productivity by pteropods and larvaceans in the Coastal Gulf of Alaska. Alaska Marine Science Symposium. Anchorage. Poster.

Doubleday, A. J., and R. R. Hopcroft. 2012. Estimates of the composition, abundance, and biomass of pteropods and larvaceans in the coastal Gulf of Alaska. Ocean Sciences Meeting. Salt Lake City, Utah. Presentation.

Doubleday, A. J., and R. R. Hopcroft. 2013. Estimates of the composition, abundance, and biomass of pteropods and larvaceans in the coastal Gulf of Alaska. Alaska Marine Science Symposium. Anchorage Presentation.

Doubleday, A. J., and R. R. Hopcroft. 2013. Estimates of the composition, abundance, and biomass of pteropods and larvaceans in the coastal Gulf of Alaska. ASLO meeting. New Orleans, LA. Presentation.

Ershova, E., R. R. Hopcroft, and K. N. Kosobokova. 2014, February. The effect of temperature on the reproductive success of 3 species of Pseudocalanus in the Pacific Arctic. Ocean Sciences Meeting. Honolulu, HI. Poster.

Esler, D. 2017. Sea ducks as indicators of nearshore marine conditions. 6th International Sea Duck Conference, San Francisco. Presentation.

Esler, D. 2017. Sea Duck Traits: Their Influence on Oil Spill Vulnerability and Restoration Potential. 6th International Sea Duck Conference, San Francisco. Presentation.

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

Esler, D. 2015. Injury and recovery of sea otters and harlequin ducks following the *Exxon Valdez* oil Spill: a quarter-century perspective. Presentation to Prince William Sound Regional Citizens' Advisory Council, Anchorage. Presentation

Esler, D. 2015. Oil and wildlife don't mix: 25 years of lessons from the *Exxon Valdez* oil spill. Seminar at University of Quebec Rimouski. Presentation.

Esler, D., B. Ballachey, C. Matkin, D. Cushing, R. Kaler, J. Bodkin, D. Monson, G. Esslinger, and K. Kloecker. 2016. Long-term data provide perspective on ecosystem recovery following the *Exxon Valdez* oil spill. Oil Spill and Ecosystems Conference, Tampa. Presentation.

Esler, D., L. A. Sztukowski, D. H. Monson, S. A. Sethi, H. A. Coletti, B. P. Weitzman, K. A. Kloecker, and T. E. Hollmen. 2016. Barrow's goldeneye demographic responses to changing mussel conditions on wintering areas: A conceptual model exercise. Alaska Bird Conference, Cordova. Presentation.

Esslinger, G. G., H. A. Coletti, J. L. Bodkin, D. H. Monson, B. E. Ballachey, T. A. Dean, and D. Esler. 2017. Contrasting demography and behavior among sea otter populations in the northern Gulf of Alaska. Alaska Chapter of The Wildlife Society Annual Meeting, Fairbanks. Presentation.

Esslinger, G. G., H. A. Coletti, J. L. Bodkin, D. H. Monson, B. E. Ballachey, T. A. Dean, and D. Esler. 2017. Trends and equilibrium density vary among sea otter populations in the northern Gulf of Alaska. Sea Otter Conservation Workshop, Seattle. Presentation.

Fugate, C., M. R Lindeberg, J. M. Maselko, L. Holland, and M. G. Carls. 2016. Recent Survey Confirms Persistence of Lingering Oil 26 Years after the Exxon Valdez Oil Spill. Alaska Marine Science Symposium, Anchorage. Poster.

Heflin, B., M. L. Arimitsu, J. Piatt, S. Schoen, and E. Madison. 2016. Seabird and forage fish response to contrasting cold and warm years in Prince William Sound, Alaska. Pacific Seabird Group meeting, Honolulu. Poster.

Heintz, R. A., and M. G. Carls. 2016. Persistent Alaska North Slope crude oil: A quarter century of weathering. Ocean Sciences Meeting, New Orleans. Presentation.

Hoffman, K. 2012. Long-term monitoring program funded by the *Exxon Valdez* Oil Spill Trustee Council. Status report to the EVOSTC Public Advisory Commission, Anchorage. Presentation.

Hoffman, K. 2013. Have you seen them? The scientists of Gulf Watch Alaska. Ocean Fest, Cordova and Valdez. Presentation.

Holderied, K. 2013. Gulf Watch Alaska. Alaska Forum on the Environment, Anchorage. Presentation.

Holderied, K. 2013. Gulf Watch Alaska. Gulf of Alaska research program meeting, Anchorage. Presentation.

Holderied, K. 2013. Gulf Watch Alaska. Presentation to the Bureau of Ocean Energy Management, Anchorage. Presentation.

Holderied, K. 2015. How connected are Kachemak Bay and the Gulf of Alaska? And why it matters. Kachemak Bay Science Symposium, Homer. Presentation.

Holderied, K. 2016. Gulf Watch Alaska program overview. Prince William Sound Science Center Lecture science night lecture series, Cordova. Presentation.

Holderied, K., A. Doroff, and D. Hondolero. 2015. Seasonal variability in oceanography and ocean acidification in Kachemak Bay and lower Cook Inlet, Alaska. American Fisheries Society, Alaska chapter meeting, Homer. Poster.

Holderied, K., A. Doroff, and D. Hondolero. 2016. From cool to hot: 2012-2015 transition in Kachemak Bay and Cook Inlet Alaska waters. Alaska Marine Science Symposium, Anchorage. Poster.

Holderied, K., and D. Hondolero. 2016. Oceanographic and ecosystem response to the 2013-2015 Pacific Warm Anomaly in Kachemak Bay Alaska. Pacific Anomalies Workshop 2, Seattle. Poster.

Holderied, K., D. Hondolero, S. Kibler, W. Litaker, and A. Doroff. 2015. A web-based, paralytic shellfish poisoning risk assessment tool for Kachemak Bay Alaska. Coastal and Estuarine Research Federation Conference, Portland, OR. Poster.

Holderied, K., R. Hopcroft, T. Weingartner, S. Batten, R. Campbell, S. Danielson, and A. Doroff. 2015. 2014-2015 Oceanographic Anomalies in the Gulf of Alaska. Pacific Anomalies Workshop 1, Seattle. Presentation.

Holderied, K., M. McCammon, K. Hoffman, B. Ballachey, R. Hopcroft, M. Lindeberg, and T. Weingartner. 2014. Gulf Watch Alaska ecosystem monitoring highlights from the 2013 season. Alaska Marine Science Symposium, Anchorage. Poster.

Holderied, K., M. McCammon, K. Hoffman, B. Ballachey, R. Hopcroft, M. Lindeberg, T. Weingartner, and T. Neher. 2014. 2013 Gulf Watch Alaska ecosystem monitoring highlights. Alaska Marine Science Symposium, Anchorage. Presentation.

Holderied, K., M. McCammon, K. Hoffman, B. Ballachey, T. Weingartner, M. Lindeberg, and R. Hopcroft. 2015. Gulf Watch Alaska – Monitoring the pulse of the Gulf of Alaska's changing ecosystems: Alaska Marine Science Symposium, Anchorage. Presentation.

Holderied, K., M. McCammon, K. Hoffman, S. Rice, B. Ballachey, T. J. Weingartner, R. R. Hopcroft. 2013. Gulf Watch Alaska – Ecosystem monitoring at the intersection of spilled oil and climate change. Alaska Marine Science Symposium. Anchorage. Presentation.

Holderied, K., T. Neher, M. McCammon, K. Hoffman, M. Lindeberg, R. Hopcroft, T. Weingartner, B. Ballachey, H. Coletti, and D. Esler. 2016. Using integrated ecosystem observations from Gulf Watch Alaska to assess the effects of the 2014/2015 Pacific warm water anomaly in the Northern Gulf of Alaska. Ocean Sciences Conference, New Orleans. Poster.

Hollmen, T., and S. A. Sethi. 2013. Development of conceptual ecological models to support the Gulf Watch Alaska long-term monitoring program. PICES-2013, Nanaimo, British Columbia, Canada. Poster.

Hollmen, T., and S. A. Sethi. 2015. Conceptual models are flexible tools for research planning, prioritization, and communication. Alaska Marine Science Symposium, Anchorage. Presentation.

Hondolero, D. 2015. Kachemak Bay phytoplankton and harmful algal bloom patterns. Kachemak Bay National Estuarine Research Reserve Harmful Algal Bloom Workshop, Homer. Presentation.

Hondolero, D. 2015. Monitoring Phytoplankton in Kachemak Bay and lower Cook Inlet. Kachemak Bay Science Conference, Homer. Presentation.

Hondolero, D., and K. Holderied. 2016. Monitoring Phytoplankton in Kachemak Bay, Alaska. Alaska Marine Science Symposium, Homer. Poster.

Hondolero, D., K. Holderied, C. Pickens. 2014. Bloom and bust: Monitoring phytoplankton populations in Kachemak Bay. Alaska Marine Science Symposium, Homer. Poster.

Hondolero, D., S. Kibler, M. Vandersea, W. Litaker, and K. Holderied. 2015. Effects of Stratification and nutrient limitation on phytoplankton blooms in Kachemak Bay. American Fisheries Society, Alaska chapter meeting, Homer. Presentation.

Hopcroft, R. R. 2013, January. Measuring the pulse of the Gulf of Alaska: Seward Line, 1997-2012. Alaska Marine Science Symposium. Anchorage. Presentation.

Hopcroft, R. R. 2013. The Gulf of Alaska's salp bloom of 2011: Ignorance or harbinger of change? Alaska Marine Science Symposium. Anchorage. Poster.

Hopcroft, R. R. 2013. The Gulf of Alaska's salp bloom of 2011: ignorance or harbinger of change? ASLO meeting. New Orleans, LA. Presentation.

Hopcroft, R. R. 2016, March. Measuring the pulse of the Gulf of Alaska: Oceanographic observations along the Seward Line. Prince William Sound Science Center Seminar Series. Cordova, Cordova, AK. Presentation.

Hopcroft. R. R., and K. O. Coyle. 2012. Climate-related variability in abundance of mesozooplankton in the Northern Gulf of Alaska 1998-2009. Alaska Marine Science Symposium. Anchorage. Poster.

Hopcroft, R., and K. Coyle. 2014. Measuring the pulse of the Gulf of Alaska: 16 years of oceanographic observations along Seward Line, and in Prince William Sound. Alaska Marine Science Symposium, Anchorage. Presentation.

Hopcroft, R. R., and K. O. Coyle. 2014. Measuring the pulse of the Gulf of Alaska: 16 years of oceanographic observations along Seward Line, and within Prince William Sound. Ocean Sciences Meeting. Honolulu, HI. Presentation.

Hopcroft, R. R., K. O. Coyle, and C. Clarke-Hopcroft. 2015. Zooplankton temporal and spatial variability in the Gulf of Alaska: consequences to resource availability. Alaska Marine Science Symposium. Anchorage. Presentation.

Hopcroft, R. R., K. O. Coyle, S. L. Danielson, and S. L. Strom. 2016, February. Plankton verses the blob: Impact of the 2014/15 warm water anomaly on the Northern Gulf of Alaska Shelf. AGU Ocean Sciences. New Orleans, LA. Poster.

Hopcroft, R. R., M. Doyle, A. Matarese, C. W. Mordy, J. M. Napp, P. Stabeno, S. L. Strom. 2012. A broad-scale look at physics through plankton in the Coastal Gulf Of Alaska. Alaska Marine Science Symposium. Anchorage. Poster.

Hsu, B., M. A. Bishop, K. J. Kuletz, and R. Thorne. 2012. Linking hydroacoustic surveys for juvenile herring with winter seabird distribution in Prince William Sound. Alaska Bird Conference, Anchorage. Presentation.

Iken, K., and B. Konar. 2014. Strong local dynamics of intertidal communities in Kachemak Bay – a Gulf Watch Alaska program. Alaska Marine Science Symposium, Anchorage. Poster.

Iken, K., B. Konar, D. Esler, B. Weitzman, H. Coletti, D. Monson, B. Ballachey, T. Dean, and J. Bodkin. 2017. Spatial variability in mussel size frequency distribution in the Gulf of Alaska. Alaska Marine Science Symposium, Anchorage. Poster.

Klinger, T. 2014. What can we learn from long-term monitoring of intertidal habitats? Discovery lab public lecture, Homer. Presentation.

Kloecker, K. 2014. Women in science. Anchorage Public Schools presentation, Anchorage. Presentation.

Kloecker, K. A., D. H. Monson, B. Robinson, H. A. Coletti, B. E. Ballachey, and D. Esler. 2017. Correlates between sea otter diet and prey energetics in a mussel-specialist population. Sea Otter Conservation Workshop, Seattle. Presentation.

Konar, B., K. Iken, H. Coletti, T. Dean, and D. Monson. 2015. Influence of static habitat attributes on variability in rocky intertidal communities of the central Gulf of Alaska. Alaska Marine Science Symposium, Anchorage. Poster.

Konar, B., K. Iken, H. Coletti, T. Dean, D. Esler, B. Weitzman, K. Kloecker, and M. Lindeberg. 2017. Trends in intertidal seastar abundance and diversity across the Gulf of Alaska: looking for effects of seastar wasting. Alaska Marine Science Symposium, Anchorage. Poster.

Konar, B., S. Vanderwaal, and M. Rogers. 2015. Testing the use of unmanned aircraft systems for intertidal surveys—proof of concept. Alaska Marine Science Symposium, Anchorage. Poster.

Kuletz, K. J., D. A. Cushing, R. R. Hopcroft, S. L. Danielson, and E. A. Labunski. 2017. Running hot and cold: Shifts in seabird distribution in the northern Gulf of Alaska under different temperature regimes, based on Seward Line surveys, 2017-2015. Alaska Marine Science Symposium, Anchorage. Poster.

Kuletz, K., and E. Labunski. 2012. What's up and what's down: Seabird surveys in Kachemak Bay. Kachemak Bay Science Symposium, Homer. Presentation.

Kuletz, K., E. Labunski, M. Renner, and M. Bishop. 2013. The murrelet in winter –a review of marbled murrelet post-breeding distribution with a focus on Alaska. Pacific Seabird Group, Portland, OR. Presentation.

Kuletz, K. and J. Piatt. 2011. The plight of the 'glacier murrelet': What do receding glaciers have to do with the Kittlitz's murrelet? Wildlife Session, 'Classrooms for Climate' symposium, Chugach National Forest and University of Alaska Anchorage. Presentation.

Kuletz, K. J., H. Renner, R. Kaler, J. Parrish, B. Bodenstein, J. Piatt, and M. A. Bishop. 2016. Seabird Die-off events, 2014-2016. Alaska Marine Science Symposium. Workshop on Unusual Mortality Events, Anchorage. Presentation.

Lindeberg, M. R. 2015. Seaweeds, fishes, monitoring and more! Prince William Sound Science Center and Cordova Night Lecture Series, Cordova. Presentation.

Lenz, P. H., V. Roncalli, R. R. Hopcroft, and A. E. Christie. 2016, February. Control of diapause in calanid copepods: Identification of regulatory pathways using in silico data mining. AGU Ocean Sciences. New Orleans, LA. Poster.

Lindeberg, M. R. 2016. Lingering oil in Prince William Sound: What we know, past and present. Prince William Sound Regional Citizens Advisory Council Meeting, Anchorage. Presentation.

Lindeberg, M., M. Arimitsu, M. A. Bishop, D. Cushing, R. Kaler, K. Kuletz, C. Matkin, J. Moran, J. Piatt, and J. Straley. 2016. Response to top predators and prey to changes in the marine environment: Gulf Watch Alaska's pelagic monitoring program. Alaska Marine Science Symposium, Anchorage. Poster.

Lindeberg, M., K. Holderied, D. Aderhold, K. Hoffman, M. Arimitsu, H. Coletti, and R. Hopcroft. 2017. Gulf Watch Alaska: Results from five years of ecosystem monitoring in the northern Gulf of Alaska. Alaska Marine Science Symposium, Anchorage. Presentation.

Lujan, S., S. D. Newsome, H. Coletti, V. von Biela, D. Monson, B. Ballachey, and J. Bodkin. 2014. Importance of micro- vs. macro-algae to Alaska marine invertebrates. Western Society of Naturalists, Tacoma. Presentation.

Madison, E., J. Piatt, M. Kissling, D. Douglas, M. Arimitsu, E. Lance, K. Kuletz, G. Drew, and E. Cooper. 2012. Post-breeding movements of Kittlitz's Murrelet from the Gulf of Alaska and Aleutian Islands to the Arctic. Pacific Seabird Group, Oahu. Presentation.

Marcotte, E., and M. Lytle. 2015. Sea otter diet in Kachemak Bay 2015. Oral presentation in fulfillment of thesis research credits. University of Alaska, Kachemak Bay campus, Homer.

Marshall, K., A. Beaudreau, B. Brenner, M. Hunsicker, A. O. Shelton, and E. Ward. 2017. Twenty-five years after the *Exxon Valdez* oil spill: a synthesis of climatic, anthropogenic, and ecological drivers of Gulf of Alaska communities. Alaska Marine Science Symposium, Anchorage, AK. Presentation.

Matkin, C. 2014. Killer whale predation. Killer Whale Wildlife Wednesday, Juneau. Presentation.

Matkin, C. 2015. Alaskan killer whales from Ketchikan to the Pribilofs. UAA Lifelong Learning Class. Lecturer.

Matkin, C. 2015. Killer whales. Discovery lab public lecture, Kachemak Bay Research Reserve, Homer. Presentation.

Matkin, C. 2015. Latest killer whale research findings. Kenai Fjords Tourboat Operators Meeting, Seward. Presentation.

Matkin, C. 2015. Population dynamics of Alaskan killer whales. Southern Resident Killer Whale Health Meeting, Seattle. Presentation.

Matkin, C. 2016. Killer whales. KPC/UAA Biology Class, Homer. Guest lecturer.

Matkin, C. 2016. Migrations: A closer look at killer whale movements. Alaska SeaLife Center, Seward. Presentation.

Matkin, C., and E. Bradfield. 2016. A history of the threatened AT1 killer whale population. State University of New York. Presentation.

Matkin, C., D. Herman, G. Ellis, E. Saulitis, D. Burrows. 2014. Are recent changes in dietary patterns of southern Alaska resident killer whales leading to nutritional stress? Alaska Marine Science Symposium, Anchorage. Poster.

Matkin, C. O., and E. L. Saulitis. 2014. Into great silence. Week-long Seminar, St. Catherine University, Minneapolis. Presentations.

Matkin, C. O., and E. L. Saulitis. 2014. Into great silence. ORCA program for pre-college students, Everett, WA. Presentations.

Matkin, C. O., and E. L. Saulitis. 2014. Into great silence. Southern Resident Killer Whale Symposium, Friday Harbor. Presentations.

Matkin, C. O., G. W. Testa, G. M. Ellis, and E. L. Saulitis. 2015. Is the fate of southern Alaska resident (SAR) killer whales (*Orcinus orca*) tied to salmon? Life history and population dynamics of SAR killer whales. Alaska Marine Science Symposium, Anchorage. Poster.

McCammon, M., and K. Holderied. 2013. Gulf Watch Alaska: Ecosystem monitoring … at the intersection of spilled oil and climate change. Alaska Forum on the Environment, Anchorage. Presentation.

McCammon, M., K. Hoffman, K. Holderied, T. Neher, B. Ballachey, R. Hopcroft, M. Lindeberg, and T. Weingartner. 2015. Gulf Watch Alaska: Monitoring the pulse of changing ecosystems in the Gulf of Alaska. Alaska Marine Science Symposium, Anchorage. Presentation.

McCammon, M., K. Hoffman, K. Holderied, T. Neher, B. Ballachey, R. Hopcroft, M. Lindeberg, and T. Weingartner. 2015. Gulf Watch Alaska: Monitoring the pulse of changing ecosystems in the Gulf of Alaska. Coastal and Estuarine Research Federation Conference, Portland, OR. Presentation.

McCammon, M., K. Hoffman, K. Holderied, T. Neher, B. Ballachey, R. Hopcroft, M. Lindeberg, and T. Weingartner. 2015. Gulf Watch Alaska: Monitoring the pulse of changing ecosystems in the Gulf of Alaska. Kachemak Bay Science Conference, Homer. Presentation.

McCammon, M., K. Hoffman, K. Holderied, T. Neher, B. Ballachey, R. Hopcroft, M. Lindeberg, and T. Weingartner. 2016. Gulf Watch Alaska in hot water! Ecological patterns in the northern Gulf of Alaska under the Pacific 2014-2015 warm anomaly. Alaska Marine Science Symposium, Anchorage. Presentation.

McDonnell, A. M. P., R. R. Hopcroft, D. A. Stockwell, J. Turner, and T. Gordon. 2015. Using in situ optical instrumentation to investigate particle and plankton dynamics in Alaska's Coastal Waters. Alaska Marine Science Symposium. Anchorage. Poster.

Mearns, A. J., K. McLaughlin, R. Campbell, J. Bodkin, T. Dean, B. Ballachey, and J. Harper. 2013. Joint effort adds 24th year to long-term rocky intertidal photo-monitoring of western Prince William Sound. Alaska Marine Science Symposium, Anchorage. Poster.

Monson, D. H., T. A. Dean, M. R. Lindeberg, J. L. Bodkin, H. A. Coletti, D. Esler, K. A. Kloecker, B. P. Weitzman, and B. E. Ballachey. 2015. Inter-annual and spatial variation in Pacific blue mussels (*Mytilus trossulus*) in the Gulf of Alaska, 2006-2013. Alaska Marine Science Symposium, Anchorage. Poster.

Monson, D. H., B. P. Weitzman, K. A. Kloecker, D. Esler, L. A. Sztukowsi, S. A. Sethi, H. A. Coletti, and T. Hollmen. 2017. Understanding trophic relationships of sea otters and their effects on demographic attributes. Sea Otter Conservation Workshop, Seattle. Presentation.

Moran, J. 2012. Impact of humpback whale predation on Pacific herring populations in the Gulf of Alaska. Advisory Panel to the Western Pacific Fishery Management Council, Honolulu. Invited speaker.

Moran, J. 2012. Impact of humpback whale predation on Pacific herring populations in the Gulf of Alaska. 154th Meeting of the Western Pacific Fishery Management Council, Honolulu. Invited speaker.

Moran, J. 2012. Impact of humpback whale predation on Pacific herring populations in the Gulf of Alaska. Managing for Recovery of the North Pacific Humpback Whales, Honolulu. Invited speaker.

Moran, J. 2014. Living in a humpback world. How does an increasing humpback whale population affect humans? Prince William Sound Science Center weekly lecture series, Cordova. Presentation.

Moran, J. 2014. Living in a humpback whale world. University of Eastern Finland, Finland. Guest lecturer.

Moran, J. 2014. Challenges of photo ID during the Alaskan winter. Wildlife Photo-ID Workshop, Joensuu, Finland. Invited speaker.

Moran, J. 2015. Fisheries anomalies in the Gulf of Alaska, 2014 and 2015 highlights. Gulf of Alaska 2015 Anomalies Workshop, Anchorage. Presentation.

Moran, J. 2015. Sea birds as indicators of humpback whale prey. Juneau Marine Naturalist Symposium, Juneau. Presentation.

Moran, J. 2016. Hawaii's humpbacks: What are they doing in Alaska? Whale Tales event, Kapalua, Maui, Hawaii. Invited speaker.

Moran, J. 2016. Impacts of a recovering humpback whale population. University of Alaska Southeast guest lecture, Juneau. Guest lecturer.

Moran, J., K. Boswell, and J. Straley. 2017. Humpback whales ruin a perfectly good overwintering strategy for Pacific herring in Alaska. PICES - Drivers of Dynamics of Small Pelagic Fish Resources, Victoria, British Columbia, Canada. Poster.

Moran, J., M. O'Dell, D. Dickson, J. Straley, and M. L. Arimitsu. 2017. Seasonal distribution of Dall's porpoise in Prince William Sound, Alaska. Alaska Marine Science Symposium. Anchorage. Poster.

Moran, J., and J. Straley. 2016. Missing herring: Water temperature, relocation or dinner? Alaska Marine Science Symposium, Anchorage. Poster.

Moran, J. R., J. M. Straley, and M. Arimitsu. 2015. Humpback whales as indicators of herring movements in Prince William Sound. Alaska Marine Science Symposium, Anchorage. Poster.

Moss, J., S. Hinckley, R. R. Hopcroft, and O. Ormseth. 2012. The Gulf of Alaska Project: an Integrated Ecosystem Research Program. Alaska Marine Science Symposium. Anchorage. Presentation.

Mueter, F. J., R. R. Hopcroft, C. Ladd, O. Ormseth, and K. Shotwell. 2016. Gulf of Alaska Project: The gauntlet games - final showdown. Alaska Marine Science Symposium. Anchorage. Presentation.

Neher, T. H., K. Holderied, M. McCammon, K. Hoffman, T. Weingartner, R. Hopcroft, M. Lindeberg, and B. Ballachey. 2016. Gulf Watch Alaska: Monitoring the pulse of the Gulf of Alaska's changing ecosystems. Alaska Marine Science Symposium, Anchorage. Poster.

Neher, T., M. McCammon, K. Hoffman, K. Holderied, B. Ballachey, R. Hopcroft, M. Lindeberg, and T. Weingartner. 2016. Gulf Watch Alaska in hot water! Ecological patterns in the northern Gulf of Alaska under the Pacific 2014-2015 warm anomaly. Alaska Marine Science Symposium, Anchorage. Presentation.

Olsen, D.W. 2012. Killer whales of Alaska. KPC/UAA Biology Class, Homer. Guest lecturer.

Olsen, D. W. 2012. Killer Whales of Kenai Fjords National Park. Kenai Fjords National Park Service Interpreter Training, Seward. Presentation.

Olsen, D. W. 2013. Killer Whales of Coastal Alaska. Juneau Naturalist Symposium, Juneau. Presentation.

Olsen, D. W. 2014. Killer Whale Culture in Alaska. Juneau Naturalist Symposium, Juneau. Presentation.

Olsen, D. W. 2014. A comparison of satellite telemetry and photographic surveys in determining important foraging habitat for resident killer whales in the Gulf of Alaska. Alaska Coastal Rainforest Center Brown Bag Series, Juneau. Presentation.

Olsen, D. W. 2014. A comparison of satellite telemetry and photographic surveys in determining important foraging habitat for resident killer whales in the Gulf of Alaska. American Fisheries Society Annual Meeting, Juneau. Presentation.

Olsen, D. W. 2014. Killer whales of Alaska. UAS Biology Class, Juneau. Guest lecturer.

Olsen, D. W. 2014. Killer whale culture in Alaska. Wildlife Wednesday Series, Juneau. Presentation.

Olsen, D. W. 2015. Shifting hotspots: Core habitat use for resident killer whales in the Northern Gulf of Alaska. American Fisheries Society Student Chapter, Juneau. Presentation.

Olsen, D. W. 2015. Killer whale culture in Alaska. Seward Guide Training, Seward. Presentation.

Olsen, D. 2016. Family habits are hard to break: Killer whale culture in Prince William Sound. Prince William Sound Science Center community lecture series, Cordova. Presentation.

Olsen, D. W. 2016. Killer whale culture in Alaska. UAS Biology Class, Juneau. Guest lecturer.

Olsen, D. W. 2016. Killer whale culture in Alaska. KPC/UAA Biology Class, Homer. Guest lecturer.

Olsen, D. 2016. Killer whale culture in Alaska. Prince William Sound Science Center community lecture series, Cordova. Presentation.

Olsen, D. 2016. Killer whale culture in Alaska. Science after the spill: How are our ecosystems changing? Homer. Presentation.

Olsen, D. W. 2016. Mom knows best, killer whale culture in PWS. Prince William Sound Regional Citizens' Advisory Council, Anchorage. Presentation.

Olsen, D. W., C. M. Matkin, and R.D. Andrews. 2015. Shifting hotspots: Seasonal and pod-specific use of habitat by resident killer whales in the Northern Gulf of Alaska. Society for Marine Mammalogy Biennial Conference, San Francisco. Poster.

Olsen, D. W., C. M. Matkin, and R. D. Andrews, R.D. 2016. Shifting hotspots: Seasonal and pod-specific use of habitat by resident killer whales in the Northern Gulf of Alaska. Alaska Marine Science Symposium, Anchorage. Poster.

Ormseth, O., R. R. Hopcroft, C. Ladd, K. Shotwell, and F. J. Mueter. 2014. GOAIERP: Broad-scale investigations of the Gulf of Alaska ecosystem. Alaska Marine Science Symposium. Anchorage. Presentation.

Ormseth, O., R. R. Hopcroft, C. Ladd, F. J. Mueter, and K. Shotwell. 2015. GOAIERP: Into the home stretch. Alaska Marine Science Symposium. Anchorage. Presentation.

Pegau, W. S., M. L. Arimitsu, and M. Collins. 2015. Aerial surveys provide age-1 herring and forage fish indices for monitoring in Prince William Sound. Alaska Marine Science Symposium, Anchorage. Poster.

Piatt, J., G. Drew, M. Arimitsu, E. Madison, K. Kuletz, S. Zador. 2015. The glacier murrelet of Beringia: Pagophilia in the age of global warming. Pacific Seabird Group, San Jose. Presentation.

Pister, B., B. Ballachey, H. Coletti, T. Dean, K. Iken, B. Konar, M. Lindeberg, and B. Weitzman. 2016. Multi-agency efforts to monitor sea star wasting disease in Alaska: Results and recommendations for future efforts. Alaska Marine Science Symposium, Anchorage. Poster.

Questel, J. M., R. R. Hopcroft, L. Blanco-Bercial, and A. Bucklin. 2013. Distribution of *Pseudocalanus* spp. in the Pacific-Arctic as revealed by molecular markers. Alaska Marine Science Symposium. Anchorage. Poster.

Questel, J. M., R. R. Hopcroft, L. Blanco-Bercial, and A. Bucklin. 2013. Distribution of *Pseudocalanus* spp. in the Pacific-Arctic as revealed by molecular markers. ASLO meeting. New Orleans, LA. Poster.

Questel, J.M., R. R. Hopcroft, L. Blanco-Bercial, and A. Bucklin. 2014. Distribution of *Pseudocalanus* spp. in the Pacific-Arctic as revealed by molecular markers. Alaska Marine Science Symposium. Anchorage. Poster.

Questel, J.M., R. R. Hopcroft, L. Blanco-Bercial, and A. Bucklin. 2014. Distribution of *Pseudocalanus* spp. in the Pacific-Arctic as revealed by molecular markers. Ocean Sciences Meeting. Honolulu, HI. Poster.

Questel, J. M., R. R. Hopcroft, L. Blanco-Bercial, and A. Bucklin. 2015. Phylogeography and connectivity of sibling species of *Pseudocalanus* (Calanoida) in the North Pacific-Arctic as revealed by molecular markers. Alaska Marine Science Symposium. Anchorage. Presentation.

Questel, J. M., R. R. Hopcroft, L. Blanco-Bercial, and A. Bucklin. 2015. Phylogeography and connectivity of sibling species of *Pseudocalanus* (Calanoida) in the North Pacific-Arctic as revealed by molecular markers. ASLO meeting. Granada, Spain. Presentation.

Renner, H., K. Kuletz, D. Irons, R. Kaler, L. Labunski, J. Parrish, H. Burgess, B. Bodenstein, J. Piatt, S. Schoen, and M. Renner. 2016. The murre die-off. Alaska Marine Science Symposium, Anchorage. Presentation.

Robinson, B. H., L. M. Phillips, and A. N. Powell. 2016. Accelerated energy intake increases survival of black oystercatchers broods. Alaska Bird Conference, Cordova. Presentation.

Savage, K., B. Witteveen, J. Moran, S. Raverty, K. B. Huntington, D. Fauquier, K. Wynn, F. VanDolah, P. Cottrell, M. Migura, and A. Jensen. 2016. 2015 Gulf of Alaska Large Whale Unusual Mortality Event. National Marine Animal Health and Stranding Network Conference, Shepardstown. Presentation.

Schaefer, A. 2016. Winter seabirds of PWS. Prince William Sound Science Center community lecture series, Cordova. Presentation.

Straley, J., and J. Moran. 2016. Bird killers of Prince William Sound: A foraging strategy used by humpback whales to detect schooling fish. Alaska Marine Science Symposium, Anchorage. Poster.

Strom, S. L., and R. R. Hopcroft. 2016. Microzooplankton in the food web of the coastal Gulf of Alaska. 6th Zooplankton Production Symposium. Bergen, Norway. Presentation.

Sztukowski, L. A., D. H. Monson, D. Esler, S. A. Sethi, H. A. Coletti, B. P. Weitzman, K. A. Kloecker, and T. E. Hollmen. 2017. Nearshore marine consumer responses to changing prey conditions: Combining quantitative and qualitative model input into a conceptual framework. Alaska Marine Science Symposium, Anchorage. Presentation.

Sztukowski, L. A., S. A. Sethi, and T. E. Hollmen. 2016. Mesoscale ecosystem processes in the Gulf of Alaska. Alaska Marine Science Symposium, Anchorage. Poster.

Traiger, S. B., and B. Konar. 2015. Effects of glacial discharge on recruitment and succession in kelp bed communities. Alaska Marine Science Symposium, Anchorage. Poster.

Traiger, S. B., B. Konar, A. Doroff, and L. McCaslin. 2015. Distinguishing sources of foraging pits using pit dimensions and shell litter in nearshore substrates. Alaska Marine Science Symposium, Anchorage. Poster.

Trahanovsky, K., and T. E. Whitledge. 2014. Twelve+ years of observed spring nutrient levels in the Northern Gulf of Alaska along the Seward Line: 1998-2010. Ocean Sciences Meeting. Honolulu, HI. Poster.

Ward, C. L., R. E. Blake, M. Hunsicker, A. O. Shelton, A. Hollowed, E. Harvey, and O. L. Petchey. 2017. From local to regional: spatial scaling of long-term diversity and stability in the Gulf of Alaska groundfish community. Canadian Conference for Fisheries Research, Montreal, Canada. Presentation.

Weitzman, B. P., A. K. Fukuyama, G. Shigenaka, H. A. Coletti, T. A. Dean, J. L. Bodkin, K. A. Kloecker, G. G. Esslinger, D. H. Monson, D. Esler, B. Konar, K. Iken, and B. E. Ballachey. 2016. Happy as a clam? Variation in bivalve abundance throughout the northeastern Pacific. NPS Centennial Science Symposium, Fairbanks. Presentation.

Weitzman, B. P., D. Esler, H. A. Coletti, B. Konar, T. A. Dean, J. L. Bodkin, K. Iken, A. K. Fukuyama, G. Shigenaka, and D. Lees. 2017. Can you dig it? Patterns of variability in clam assemblages within mixed-sediment habitats across the Gulf of Alaska. Alaska Marine Science Symposium, Anchorage. Presentation.

Zador, S., S. K. Gaichas, and S. Kasperski. 2016. Linking ecosystem processes to communities of practice through commercially fished species in the Gulf of Alaska. MSEAS 2016: Understanding marine socio-ecological systems: including the human dimension in Integrated Ecosystem Assessments, Brest, France. Presentation.

Popular Articles, Books, and Interviews

Aderhold, D. 2016. Wreck. Pages 131 to 135 *in* S. Richardson and J. Roberts, editors, Driftfish: A Zoomorphic anthology. Zoomorphic, Brighton, UK.

Aderhold, D. 2017. Gulf Watch Alaska monitors ecosystem health. Delta Sound Connections newspaper, Cordova, AK, USA.

Arimitsu, M., J. Piatt, S. Schoen, and B. Heflin. 2017. Forage fish in hot water contribute to seabird die-off. Delta Sound Connections newspaper, Cordova, AK, USA.

Beeler, C. 2016. Warm ocean temps could be starving Alaskan seabirds. January 14. PRI's The World, Minneapolis, Minnesota, MN, USA.

Batten, S. 2013. Large ships, little critters. Delta Sound Connections newspaper, Cordova, AK, USA.

Bishop, M.A. 2014. At-sea seabird surveys. Delta Sound Connections newspaper, Cordova, AK, USA.

Bishop, M.A. 2016. Seabird die-off in Prince William Sound. The Cordova Times newspaper, January 8. Cordova, AK, USA.

Campbell, R. 2013. Oceanographic change. Delta Sound Connections newspaper, Cordova, AK USA.

Campbell, R. 2014. Long-term changes in the oceanography of Prince William Sound. Delta Sound Connections newspaper, Cordova, AK, USA.

Campbell, R. 2015. Recent climate change in PWS oceanography. Delta Sound Connections newspaper, Cordova, AK, USA.

Danielson, S., and T. Weingartner. 2016. Hot times in the Gulf of Alaska. Delta Sound Connections newspaper, Cordova, AK, USA.

Esler, D. 2015. Tidewater trends in nearshore ecosystems. Delta Sound Connections newspaper, Cordova, AK, USA.

Esler, D., B.E. Ballachey, M. LIndeberg, and M.G. Carls. 2016. The faint shadow of lingering oil. Delta Sound Connections newspaper, Cordova, AK, USA.

Farzan, S. 2017. Murre die-off linked to warm water temperatures. February 22. KBBI, Homer, AK, USA.

Fragoso, A. D. 2016. Thousands of starved dead birds wash up on Alaska's coasts, and climate change. January 15. Think Progress, Washington, D.C., USA.

Gorman, J. 2016. Animals die in large numbers, and researches scratch their heads. January 18. The New York Times, New York, NY, USA.

Hollander, Z. 2016. Dozens of starving seabirds grounded inland in southcentral Alaska. September 28. Alaska Dispatch News, Anchorage, AK, USA.

Hoover, H., T. H. Neher, K. Holderied. 2014. What is Gulf Watch Alaska? Delta Sound Connections newspaper, Cordova, AK, USA.

Joling, D. 2016. Warm ocean water triggered vast seabird die-off, experts say. February 10. Associated Press, New York, NY, USA.

Kaler, R., K. Kuletz, D. Dragoo, and H. Renner. Unusual observations of seabirds in the Gulf of Alaska following the 2015-2016 mass die-off. Delta Sound Connections newspaper, Cordova, AK, USA.

Kuletz, K., and R. Kaler. 2016. Seabird mortality mystery. Delta Sound Connections newspaper, Cordova, AK, USA.

Langlois, K. 2014. The toxic legacy of *Exxon Valdez*. March 25. High Country News, Paonia, CO, USA.

Learn, J. R. 2016. El Nino likely culprit of thousands of dead Alaska seabirds. January 13. The Wildlife Society, Bethesda, MD, USA

Matkin, C.O. 2013. 30 Years of tracking killer whales. Delta Sound Connections newspaper, Cordova, AK, USA.

Matkin, C.O. 2014. Killer whales and human communities: the salmon connection. Delta Sound Connections newspaper, Cordova, AK, USA.

Matkin, C. 2017. Tracking whales with remote hydrophones. Delta Sound Connections newspaper, Cordova, AK, USA.

Mercy, D. 2015. Wasting found in multiple Kachemak Bay sea stars. May 12. Press release posted to University of Alaska website. http://news.uaf.edu/seastar-may2015/.

McKittrick, E. 2016. Kachemak Bay has seen massive die-offs of sea stars and other species. What's going on? November 14. Alaska Dispatch News, Anchorage, AK, USA.

Newbern, E. 2016. Massive bird die-off puzzles Alaskan scientists. February 1. Live Science, New York, NY, USA.

O'Malley, J. 2016. In Alaska, warmer sea temperatures blamed for bird deaths. February 20. Al Jazeera America, New York, NY, USA.

Pfister, B., H.A. Coletti, B.E. Ballachey, T.A. Dean, K. Iken, B. Konar, M. LIndeberg, 2016. Sea star wasting disease. Delta Sound Connections newspaper, Cordova, AK, USA.

Polk, L. 2016. Following last year's massive die-off of Alaskan seabirds, scientists still looking for answers. February 14. KTUU, Anchorage, AK, USA.

Rosen, Y. 2016. Scientists think Gulf of Alaska seabird die-off is biggest ever recorded. January 29. Alaska Dispatch News, Anchorage, Alaska, USA.

Saulitis, E. L. 2013a. Into Great Silence. Beacon Press, Boston, MA, USA.

Saulitis, E. L. 2013b. Interview. The woman who loves orcas. OnEarth Magazine, March cover article. Natural Resources Defense Council, New York, NY, USA.

Schaefer, A. 2015. Fish, birds, whales – they're all connected. Delta Sound Connections newspaper, Cordova, AK, USA.

Shultz, F. 2015. Wild edge: Freedom to roam the Pacific coast. The Mountaineers Books, Seattle, Washington, USA.

Straley, J., and J. Moran. February 2015. Whales in Seymour Canal. Friends of Admiralty Island Newsletter. Issue no.19. Juneau, AK, USA.

Townsend, L. 2016. What's causing Alaska's sea bird die-off? Talk of Alaska, January 8. Alaska Public Media, Anchorage, AK, USA.