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

Nearshore Ecosystems in the Gulf of Alaska
Exxon Valdez Oil Spill Trustee Council Project 21120114-H
Final Report

Heather Coletti
National Park Service
Inventory and Monitoring Program, Southwest Alaska Network
240 West 5th Avenue
Anchorage, AK 99501

Dan Esler, Brenda Ballachey, Jim Bodkin, George Esslinger, Kim Kloecker, Dan Monson, Brian Robinson, and Sarah Traiger
U.S. Geological Survey
Alaska Science Center
4210 University Drive
Anchorage, Alaska 99508

Katrin Iken and Brenda Konar
University of Alaska Fairbanks
College of Fisheries and Ocean Sciences
2150 Koyukuk Drive
Fairbanks, AK 99775

Tom Dean
Coastal Resource Associates
1948 Kellogg Avenue
Carlsbad, California 92008

Mandy Lindeberg
National Oceanic and Atmospheric Administration
National Marine Fisheries Service, Alaska Fisheries Science Center
Ted Stevens Marine Research Institute - Auke Bay Laboratories
17109 Point Lena Loop Road
Juneau, Alaska 99801

Ben Weitzman
U.S. Fish and Wildlife Service
Marine Mammals Management
1011 E. Tudor Road
Anchorage, Alaska 99503

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Study History: The nearshore ecosystem monitoring protocols implemented in 2012, at the onset of the Gulf Watch Alaska program, are based on past work of the PIs and collaborators, allowing the continuation of valuable time series information about nearshore habitats in the Gulf of Alaska. Sampling protocols originally developed for the nearshore environment that included sea otters, nearshore marine birds, intertidal kelps, seagrasses, and invertebrates in Prince William Sound in 2003 were adopted by the National Park Service's Vital Signs Long-Term Monitoring Plan and implemented in Katmai National Park and Preserve in 2006 and in Kenai Fjords National Park in 2007. In 2010, *Exxon Valdez* Oil Spill Trustee Council Project 10100750 (J. Bodkin and T. Dean) was funded to implement a long-term nearshore monitoring plan in western Prince William Sound. Nearshore monitoring of rocky intertidal and seagrass habitats in Kachemak Bay was initiated in 2003 through the Census of Marine Life program (K. Iken and B. Konar). At the onset of Gulf Watch Alaska (2012), there were two Nearshore projects (16120114-R - Nearshore Benthic Systems in the Gulf of Alaska and 16120114-L - Ecological Trends in Kachemak Bay). The two projects worked closely from the beginning of Gulf Watch Alaska to ensure that data from all sites are as comparable as possible, allowing the strongest possible inferences about causative factors and the spatial extent of changes in nearshore systems. In 2017, the two nearshore projects integrated into a single, coordinated project (project 21120114-H) to enhance collaboration across Gulf Watch Alaska and expand upper trophic-level nearshore monitoring to Kachemak Bay. This coordinated and collaborative Nearshore Component has resulted in more than 46 peer reviewed publications, 49 reports, 97 presentations and several graduate student projects since 2012 that are either directly related to or leveraged by Gulf Watch Alaska. Numerous outreach products in the form of resource briefs, websites, social media posts and media articles also have been produced.

The nearshore ecosystem monitoring work described in this report builds on a long history of monitoring and research, some of which dates back more than 50 years. With these longer-term data streams, we have been able to document changes to nearshore marine environments and infer underlying causes earlier and with more confidence than if data had been collected during a short-term study. Importantly, these data streams are not continued in isolation, but are part of a carefully designed and coordinated nearshore monitoring program, described in detail by Dean et al. (2014) and Coletti et al. (2016), and briefly in the Introduction and Methods sections below.

Finally, it is critical to recognize the volume of *Exxon Valdez* Oil Spill Trustee Council-funded research addressing nearshore ecosystems since the time of the spill, which has contributed to the design of the nearshore ecosystem monitoring and provided critical background for identifying changes and understanding underlying mechanisms. These research efforts are too numerous to list individually but are summarized in recent reports and papers (e.g., Ballachey et al. 2014, Esler and Ballachey 2015, Esler et al. 2015, Coletti et al. 2016, Michel et al. 2016, Bodkin et al. 2018, Esler et al. 2018, Konar et al. 2019 and Weitzman et al. 2021).

Abstract: Nearshore ecosystem monitoring in western Prince William Sound, Kenai Fjords National Park, Kachemak Bay, and Katmai National Park and Preserve has been conducted as a single Nearshore Component of the Gulf Watch Alaska program over the past five years (2017-2021). This program builds on the previous five years and continues, in many cases, decades of preceding research and monitoring. During the 2017-2021 period of Gulf Watch Alaska, we successfully collected data on more than 200 nearshore metrics across all regions. These metrics were explicitly selected because of their value as trophically-connected features that offer insights into causes of changes through bottom-up and top-down forces within the nearshore food web. During these past 5 years, this study design has been applied to documenting and understanding several perturbations, including the Pacific Marine Heatwave and loss of sea stars due to sea star wasting. Continued monitoring will allow for a better understanding of change in nearshore ecosystems across the Gulf of Alaska and the status of spill injured resources, including greater perspective on oil spill effects and recovery relative to other types of perturbations. This information will be critical for anticipating and responding to ongoing and future changes in the region, as well as providing data for understanding global-scale variation in marine environments.

Key words: benthic invertebrates, black oystercatchers, Gulf of Alaska, intertidal, Kachemak Bay, Katmai National Park and Preserve, Kenai Fjords National Park, macroalgae, marine birds, monitoring, nearshore marine ecosystem, Prince William Sound, sea otters.

Project Data: The Nearshore Component has collected large quantities of data on a broad suite of nearshore ecosystem properties, species, and processes. Many of these data streams are extensions of data collection efforts that pre-date Gulf Watch Alaska. These data also reflect collaborative efforts by many agencies, entities, and individuals. As a result of these complexities, the data management challenges have been significant. During the 2017-2021 campaign, we created and instituted a revised data management plan that addressed the challenges of this complex data management task and resulted in a collection of data that are easy to find, well documented, and archived in perpetuity.

The re-vamped data management plan has a number of key elements to enhance availability and usefulness of Nearshore Component data. First, data are aggregated as much as possible. For example, data from all years and all locations are combined in a single file for a given metric, where practical. This avoids data users needing to search to find and combine all of the data that have been collected. It also assures that all of the data are in the same format, with a single metadata record that defines the contents. Notably, this includes combining data from Kachemak Bay and other Nearshore Component blocks, where possible; because Kachemak Bay started Gulf Watch Alaska as an independent project, following protocols from pre-Gulf Watch Alaska studies, not all data sets are combinable. However, even in those cases, data on the same metrics are housed under the same heading in the Gulf of Alaska data portal (see below) to facilitate their joint use. Also, in many cases, the publicly available and archived data sets include data that were collected prior to the onset of Gulf Watch Alaska in 2012; these longer data streams are particularly valuable for understanding long-term patterns in nearshore ecosystems.

Second, all Nearshore Component data are organized and presented coherently on the publicly available Gulf of Alaska data portal. Previously, year- and location-specific data for each metric were being loaded to the data portal individually and independently, making it difficult to find and use all data related to a metric of interest. Under the current data management process, all Nearshore data can be found within a discrete section of the Gulf of Alaska data portal: https://gulf-of-alaska.portal.aoos.org/#search?type_group=all&tag|tag=evos-gulf-watch-projects&tag|tag=nearshore&page=1.

Within this, data are organized under subheadings corresponding to the main monitoring elements (e.g., Intertidal Temperature, Rocky Communities, Sea Otters, etc). Data are updated annually after QA/QC processes and review.

Finally, Nearshore Component data are being archived with approved data repositories to ensure their availability in perpetuity. The locations of archived data files, and their associated metadata, are listed in Appendix A.

The data custodian is Carol Janzen, Director of Operations and Development, Alaska Ocean Observing System, 1007 W. 3rd Ave. #100, Anchorage, AK 99501, 907-644-6703. janzen@aoos.org.

Data are archived by Axiom Data Science, a Tetra Tech Company, 1016 W. 6th Ave., Anchorage, AK 99501 and USGS, Alaska Science Center, 4210 University Drive, Anchorage, AK 99508.

Citation:

Coletti, H., D. Esler, B. Ballachey, J. Bodkin, G. Esslinger, K. Kloecker, D. Monson, B. Robinson, S. Traiger, K. Iken, B. Konar, T. Dean, M. Lindeberg, and B. Weitzman. 2023. Gulf Watch Alaska: Nearshore Ecosystems in the Gulf of Alaska. *Exxon Valdez* Oil Spill Restoration Project 2017-2021 Final Report (Restoration Project 21120114-H), *Exxon Valdez* Oil Spill Trustee Council, Anchorage, Alaska.

TABLE OF CONTENTS

LIST OF FIGURES

EXECUTIVE SUMMARY

The nearshore ecosystem marine monitoring work described in this report was designed to detect changes in abundance and distribution of numerous nearshore species, and to lend insight into underlying drivers of that change, including the relative influences of oil spill injury versus other natural or anthropogenic effects. The Gulf of Alaska (GOA) nearshore ecosystem, while strongly influenced by both oceanic and terrestrial processes and biomes, is a distinct domain, with flora and fauna adapted for existence along the coastal fringes of the north Pacific. Nearshore ecosystems are subject to numerous physical, oceanographic, and biological sources of variation and are particularly sensitive to anthropogenic perturbations. The GOA nearshore ecosystem was severely affected by the *Exxon Valdez* oil spill, and many nearshore species showed evidence of acute and chronic injury as a result of the spill.

We conducted nearshore marine ecosystem monitoring in four regions within the spill-affected area of the northern GOA: western Prince William Sound (WPWS), Kenai Fjords National Park (KEFJ), Kachemak Bay (KBAY), and Katmai National Park and Preserve (KATM). The nearshore monitoring program focuses on sampling numerous ecosystem components in the GOA that are both numerically and functionally important, including kelps (and other marine algae), seagrasses, marine intertidal invertebrates, marine birds, black oystercatchers, sea otters, and physical properties. Our nearshore monitoring was carefully designed, with coordinated sampling of all metrics, to provide insights into drivers of change observed at different spatial and temporal scales. Our objectives were as follows:

- Determine status and detect patterns of change in a suite of nearshore species and communities.
- Identify temporal and spatial extent of observed changes.
- Identify potential causes of change in biological communities, including those related to climate change.
- Communicate these to the public and to resource managers to conserve nearshore resources.
- Continue restoration efforts to evaluate the current status of injured resources and identify factors potentially affecting present and future trends in population and ecosystem status.

During the 2017-2021 period of Gulf Watch Alaska (GWA) sampling, coupled with 2012-2016 GWA data and the data streams preceding GWA for some metrics, we observed many important and interesting patterns. For example, by mid-2014, the Pacific Marine Heatwave (PMH) was evident in intertidal waters of the northern GOA and persisted for multiple years. While pelagic marine ecosystems are known to respond to temperature anomalies, the response of nearshore ecosystems to this warming was unclear. Given that current climate change projections suggest increased frequency and duration of marine heatwaves, monitoring and understanding effects of heatwaves on nearshore habitats is important. The GWA Nearshore Component found that rocky intertidal community structure changed following the heatwave. Macroalgal foundation species declined and there was a region-wide shift to a filter-feeder dominated state. This suggests the PMH had Gulf-wide impacts to the structure of rocky intertidal communities, although effects were muted relative to dramatic effects seen in some elements of pelagic food webs. Strong, large-scale oceanographic events, like the PMH, may override local drivers to similarly influence patterns of intertidal community structure. These results are presented in a recent synthesis paper.

Amid the recent PMH, an outbreak of sea star wasting led to dramatic declines in sea star abundance throughout the northern GOA. Because some sea stars are important predators of mussels, we investigated 1) how mussel abundance changed since the onset of sea star wasting and 2) which sea star species and temperature metrics best explained variation in mussel abundance. The PMH and sea star wasting may have created synergistic effects, with declines in macroalgae due to warm temperatures creating space for mussels and reduced star predation relaxing top-down pressure on mussels, allowing for their increased abundance. In turn, increased mussel abundance may affect nearshore biodiversity and abundance or performance of nearshore vertebrates that consume mussels. These findings are highlighted in a recent paper.

As other studies have demonstrated, the PMH disrupted marine food webs and altered species' distributions, particularly in pelagic biomes. The Nearshore Component of GWA examined shifts in marine bird community composition by evaluating spatial and temporal variation in nearshore marine bird communities in KEFJ and KATM. Irrespective of the PMH, overall bird abundance was similar between summer and winter within regions, but community composition was different between seasons, with winter communities dominated by benthic foraging sea ducks and summer communities dominated by fish-consuming seabirds. We found variation in trends of some species at the regional scale, which suggests that drivers of abundance of marine birds were not coherent across the GOA. For other species, however, the lack of variation in trends across regions may indicate Gulf-wide drivers of abundance, such as the decline in piscivorous birds following the onset of the PMH. Taken holistically, contrasting trends in a variety of species and guilds can inform science and management as to the underlying factors driving individual species' abundance and distribution. This work is presented in a recently submitted paper.

As another example of the use of GWA long-term data, we are examining responses of sea otters to changing ocean conditions. Using foraging observations and fecal remains (spraint) collected since the early-mid 2000s, we found that sea otter diets varied by region, likely as a result of habitat differences across regions. In addition to spatial differences, temporal shifts in the proportions of prey in sea otter diets were evident in some regions and were likely related to recent shifts in prey abundance. Sea stars were sometimes a significant part of sea otter diets and reached annual maximums prior to sea star declines of 14% and 10% at KATM and WPWS, respectively. However, after the sea star wasting outbreak, sea stars comprised less than 2% of their diet in these regions. At KATM, mussels increased in observational diet data in 2015 concurrent with increased mussel abundance during the PMH. Decreased clam abundance in sea otter diets at KATM were coincident with decreasing clam biomass and increasing numbers of sea otters, suggesting that otters were near a food-dictated carrying capacity and had depleted their preferred prey. Monitoring both predator diets and prey abundance allows us to better understand nearshore ecosystem responses to perturbations across the GOA.

The spatial and temporal scales over which metrics vary provide insights on the potential drivers of observed patterns, as a consequence of the spatially-nested study design and long-term data collection. For example, intertidal community shifts were consistently observed across regions as a broad-scale response to the PMH. In contrast, sea otter density and population trends have been shown to be region-specific, due to local-scale differences in habitat quality, carrying capacity, and historical influences on sea otter populations. Our power to detect and understand variation in nearshore ecosystems increases as the timeline of data collection grows.

In addition to core monitoring work, we also have engaged in several collaborative research efforts to understand nearshore processes, leveraging the field presence facilitated by GWA. These collaborations include stable isotope analyses of nearshore communities, collection of mussels for contaminant analyses, evaluation of the prevalence of sea star wasting, and collection of clams as part of an evaluation of gene expression and other biomarkers as tools for monitoring health of nearshore ecosystems. We are working closely with researchers from Simon Fraser University on a black oystercatcher migration study, which is providing insight into seasonal movements and migration strategies. In addition to logistical support provided through the GWA program, these collaborative studies benefit from the perspective provided by long-term monitoring data. In turn, GWA benefits from clearer understanding of nearshore ecosystem processes resulting from directed research projects that are in addition to the monitoring program.

The improved understanding of nearshore ecosystem dynamics provided by our GWA monitoring has important and direct implications for natural resource management. For example, U.S. Fish and Wildlife Service has used our survey data for marine birds and mammals directly as part of risk assessments for vessel groundings and oil spills, both in drills and in real-world incidents. U.S. Fish and Wildlife Service Marine Mammals Management uses our sea otter distribution and abundance data in management documents for the species, such as stock assessments and species status assessments. The Nearshore Component annually contributes indices (such as nearshore temperature and sea star abundance anomalies) to National Oceanic and Atmospheric Administration Fisheries for the annual GOA Ecosystems Considerations Report to the North Pacific Fisheries Management Council. The NPS has incorporated our data into a number of their natural resource management instruments, including Resource Stewardship Strategies, Natural Resource Condition Assessments, State of the Park Reports, and upcoming Wilderness Character assessments. For many of their marine resources of management interest, our data are the only data that exist. In addition, data from the Nearshore Component have been used by the *Exxon Valdez* Oil Spill Trustee Council and trustee agencies to evaluate population recovery of injured species (e.g., sea otters and harlequin ducks). Finally, Nearshore Component data have been used to inform resource management activities well beyond the GOA, including the Deepwater Horizon case and risk assessments of pipelines and tanker traffic.

This Nearshore Component scientific productivity has been exceptional, resulting in more than 46 peer reviewed publications, 49 reports, 97 presentations and several graduate student projects since 2012 that are either directly related to or leveraged by GWA. During the reporting period, numerous outreach products in the form of resource briefs, websites, social media posts and media articles also have been produced.

INTRODUCTION

Nearshore marine ecosystems face significant challenges at local, regional, and global scales, with threats arising from both adjacent lands and oceans. An example of such threats was the 1989 grounding of the *T/V Exxon Valdez* in Prince William Sound (PWS) that affected marine systems across the northern Gulf of Alaska (GOA). An important lesson arising from this event, as well as similar events around the world, was that understanding the structure and function of the ecosystem and the composition and abundance of species across multiple spatial and temporal scales is essential to damage assessments as well as responding to and managing present and anticipated threats.

Nearshore ecosystems are broadly recognized to be sensitive to a variety of natural and human disturbances on a variety of temporal and spatial scales (reviewed in Valiela 2006, Bennett et al. 2006, Dean and Bodkin 2006, Wethey et al. 2011, Vinagre et al. 2016). For example, observed changes in nearshore systems have been attributed to such diverse causes as global climate change (e.g., Barry et al. 1995, Sagarin et al. 1999, Hawkins et al. 2008, Hoegh-Guldberg and Bruno 2010, Doney et al. 2012, Kaplanis et al. 2020), earthquakes (e.g., Baxter 1971, Noda et al. 2015), oil spills (e.g., Peterson 2001, Peterson et al. 2003, Bodkin et al. 2014), human disturbance and removals (e.g., Schiel and Taylor 1999, Crain et al. 2009, Fenberg and Roy 2012), and influences of invasive species (e.g., Jamieson et al. 1998, O'Connor 2014). As an example from the northern GOA, we recently described responses of rocky intertidal communities to a prolonged Pacific marine heatwave (PMH) (Weitzman et al. 2021). Nearshore systems are especially good indicators of change because organisms in the nearshore are relatively sedentary, accessible, and manipulable (e.g., Dayton 1971, Sousa 1979, Peterson 1993, Lewis 1996, Chemello et al. 2018). In contrast to other marine habitats, there is a comparatively thorough understanding of mechanistic links between species and their physical environment (e.g., Connell 1972, Paine 1974, 1977, Estes et al. 1998, Menge and Menge 2013, Menge et al. 2015) that facilitates understanding causes for change. Many of the organisms in the nearshore are sessile or have limited home ranges, providing a geographic context to sources of change. Nearshore habitats will undoubtedly have detectable levels of change in the future, and our monitoring design will allow us to discern local from regional sources of change, tease apart human induced from naturally induced changes, and provide opportunities for management actions to reduce human induced impacts or mitigate natural variation.

The overarching goal of the Nearshore Component of the Gulf Watch Alaska (GWA) long-term monitoring program has been to understand drivers of variation across the nearshore food web in the GOA (see Fig. 1). The foundational questions of the Nearshore Component include: (1) What is the current structure of the GOA nearshore ecosystems, and what are the spatial and temporal scales over which change is observed? (2) Are observed changes caused by broad-scale environmental variation, local perturbations, or both? (3) Does the magnitude and timing of changes in nearshore ecosystems correspond to those measured in pelagic ecosystems? The design features of the Nearshore Component include a rigorous site selection process that allows statistical inference over various spatial scales (e.g., GOA and regions within the GOA) as well as the capacity to evaluate potential impacts from more localized sources, and especially those resulting from human activities, including lingering effects of the *Exxon Valdez* oil spill (EVOS). In addition to detecting change at various spatial scales, design features incorporate both static (e.g., substrate, exposure, bathymetry) and dynamic (e.g., variation in oceanographic conditions, productivity, and predation) drivers as potential mechanisms responsible for change. More than 200 species dependent on nearshore habitats, many with well recognized ecological roles in the nearshore food web (Fig. 1), are monitored annually within four regional blocks in the GOA. Evaluation of change in those species over time in relation to well defined static and dynamic drivers allows accurate and defensible measures of change and supports management and policy needs addressing nearshore resources.

Harnessing the power of long-term datasets, several of the GWA Nearshore Component's data streams are continuations from preceding time series, some reaching as far back as 1971 (Calkins 1978). Building GWA monitoring on this legacy has resulted in many important insights and management-relevant findings thanks to longer time series. As an example, decades of data on sea otter population dynamics, including GWA data, have revealed patterns of change in abundance that differ among regions. Changes in sea otter abundance are driven largely by local conditions, although drivers may vary by location (e.g., recovery from the EVOS in PWS, recolonization following fur harvest in Katmai and Kachemak Bay, and prey availability in Kenai Fjords; Bodkin 2015, Coletti et al. 2016, Davis et al. 2019, Tinker et al. 2021). In contrast, our regionally explicit monitoring design allowed us to show that broader-scale drivers were important in other nearshore processes. Data on rocky intertidal communities indicated that static physical attributes did not differ markedly across regions, and neither did intertidal biota (Konar et al. 2016), findings that have subsequently been confirmed in other regions of the world (Hacker et al. 2019). Similarly, we observed losses of sea stars, important nearshore predators, and the emergence of sea star wasting coincided with onset of warming trends across all regions (Konar et al. 2019). During the recent PMH, our long-term monitoring data from the rocky intertidal indicated synchronous shifts in community structure across all four regions, indicating that the PMH perturbation was a stronger driver of community structure than local-scale factors

(Weitzman et al. 2021). The accumulated work of the GWA Nearshore Component shows that we have implemented a powerful monitoring program that is able to detect ecological impacts on relevant spatial and temporal scales. The conceptual framework for monitoring in the nearshore that was implemented in 2006 contains the following key elements:

1. Synoptic sampling of select physical parameters (e.g., temperature and salinity) over the GOA nearshore regions. This synoptic nearshore sampling is complemented by offshore measurements in the GOA through the Environmental Drivers Component of the GWA program.

2. Sampling of diverse species and a variety of specific biological parameters (e.g., abundance and size of intertidal organisms, abundance, productivity, and diet of selected marine birds and mammals) in all four GOA nearshore regions. Because nearshore habitats and species were disproportionately affected by the EVOS, this monitoring includes many resources that were injured by the EVOS, allowing perspective on natural variation relative to oil-spill injury.

3. The hierarchical sampling design allows us to test patterns on both temporal and spatial scales. For example, nearshore communities are sampled annually with replicates along various tidal strata at multiple sites within a region, and across four regions (Katmai National Park and Preserve [KATM], Kachemak Bay [KBAY], Kenai Fjords National Park [KEFJ], and western Prince William Sound [WPWS]).

4. The design is focused explicitly on the nearshore food web, where primary productivity originates largely in the kelps, other macroalgae and seagrass, is transferred to benthic invertebrates, and then to higher trophic levels (Fig. 1).

5. Coordination with externally funded, short-term (2-5 years) studies aimed at identifying important processes regulating, causing, or reflecting changes within a given system or subsystem.

Figure 1. Conceptual model of the nearshore food web with terrestrial and oceanic influences illustrated. In this model, sea otters, black oystercatchers, sea ducks and sea stars act as the top-level consumers in a system where primary productivity originates mostly from macroalgae and sea grass and moves through benthic invertebrates to top level consumers.

Building on historic data, including our first five years of GWA Nearshore monitoring, we continued to generate consistently collected, long-term ecological data during 2017-2021. The value to science, conservation, and resource management of extended, multispecies ecological time series is becoming increasingly apparent (Hughes et al. 2017). We capitalized on the first decade of available data on nearshore ecosystem structure by synthesizing existing data and conducting select process studies that explained biological and environmental relationships. We had a demonstrated record of leveraging our GWA work with other projects for added value and will continue to do so. The existing and continually accumulated information was synthesized with other components of GWA to identify potential causes and scales of change, including those related to EVOS and climate change. An excellent recent example of such synthesis is our Nearshore Component contribution to the GOA-wide synthesis on ecosystem changes resulting from the PMH (Suryan et al. 2021).

OBJECTIVES

1. To determine status and detect patterns of change in a suite of nearshore species and communities.

2. Identify temporal and spatial extent of observed changes.

3. Identify potential causes of change in biological communities, including those related to climate change.

4. Communicate these to the public and to resource managers to preserve nearshore resources.

5. Continue restoration monitoring in the nearshore in order to evaluate the current status of injured resources in oiled areas and identify factors potentially affecting present and future trends in population status.

METHODS

Sampling Areas

The design focuses on monitoring numerous components of the nearshore marine food web in KATM, KEFJ, WPWS, and KBAY (Fig. 2).

Most vital sign metrics are monitored on an annual basis; however, for some metrics less frequent sampling occurs. Sampling frequency was determined based on the expected extent of inter-annual variation for a given metric as well as cost and logistical constraints. For example, the species distribution and abundance of intertidal invertebrates that are known to exhibit high inter-annual variation are sampled either annually or bi-annually whereas less variable contaminant levels in mussel tissue are monitored every 7 to 10 years.

The number and location of sampling units differs among metrics, but in general the design calls for sampling at multiple sites within each region. The number of sampling locations and the rationale for this are specified in vital sign specific standard operating procedures (SOPs), but in general were guided by preliminary estimates of effort required to detect ecologically meaningful levels of change (e.g., Dean and Bodkin 2006). Sampling sites were selected to provide a random, spatially balanced distribution. The design allows for detection of large temporal or spatial-scale changes (e.g., changes that may occur over the entire region over time or among blocks). For some metrics (e.g., contaminants in mussels) the design will also allow for detection of changes that may occur on a more localized scale (e.g., at a site of heavy human influence).

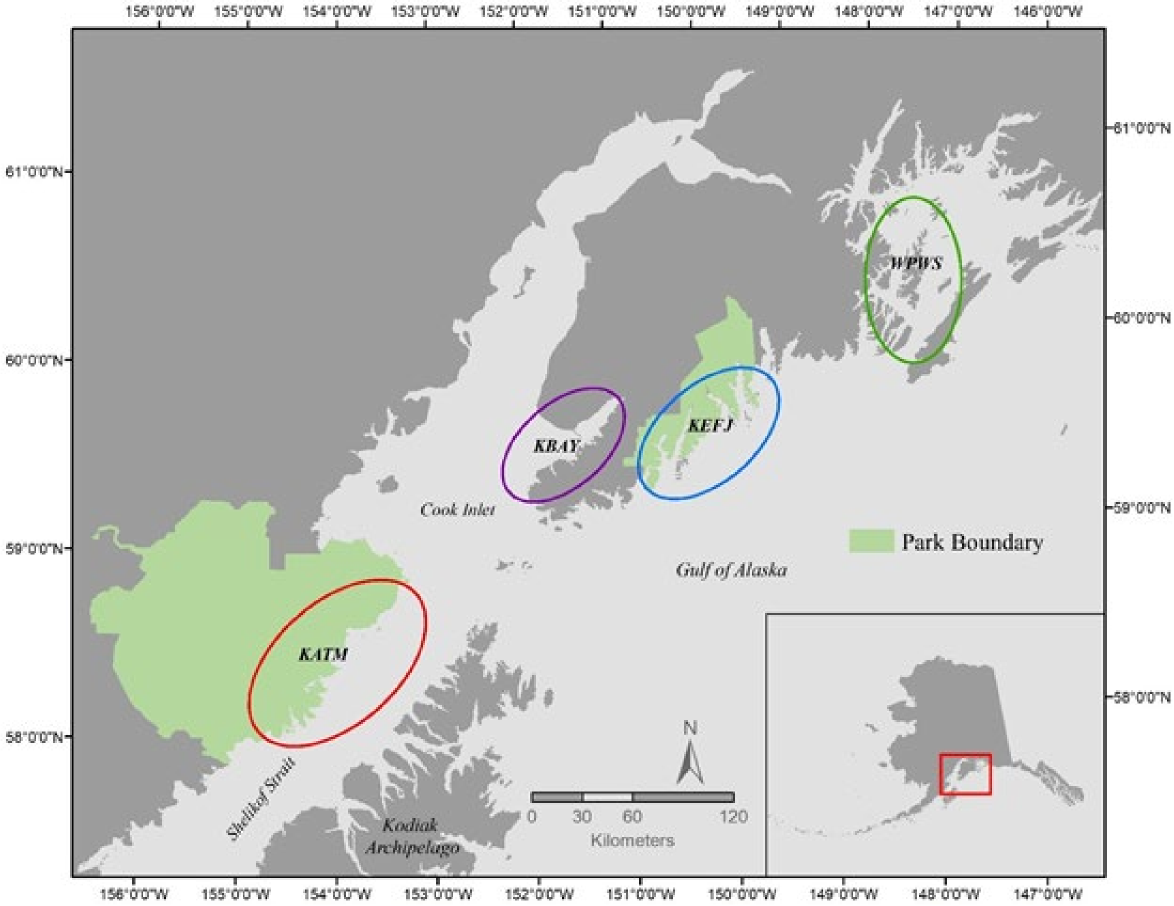

Figure 2. Map of the northern Gulf of Alaska (GOA) and the four study regions within the Nearshore Component: KATM (Katmai National Park and Preserve), KBAY (Kachemak Bay), KEFJ (Kenai Fjords National Park), and WPWS (western Prince William Sound).

Sampling Methods

Nearshore Component monitoring protocols (Dean and Bodkin 2006, Rigby et al. 2007, Iken and Konar 2012, Dean et al. 2014) describe the design and approach for sampling key components of the nearshore system in the GOA that are both numerically and functionally important to the system's health, including many that were injured by the EVOS, as well as several key environmental drivers. Components measured include kelps (and other marine algae) and seagrasses, marine intertidal invertebrates, marine birds, black oystercatchers, sea otters, and physical attributes of seawater. The rationale for focusing on these components of the nearshore is summarized below, with detailed descriptions in foundational documents (Bennett et al. 2006, Dean et al. 2014). Monitoring has followed the same SOPs that have been established from the onset of, and in many cases prior to, the GWA Nearshore program to ensure consistency of data streams. SOPs describe methods in greater detail than provided here, with links to published SOPs provided below each monitoring metric.

Objectives 1-3: Nearshore Component protocol narrative (Rigby et al. 2007, Iken and Konar 2012, Dean et al. 2014): https://irma.nps.gov/DataStore/DownloadFile/488741

1) Marine water chemistry and water quality, including temperature and salinity, are critical to intertidal fauna and flora and are likely to be important determinants of both long-term and short-term fluctuations in the intertidal biotic community. Basic water chemistry parameters, such as temperature, provide a record of environmental conditions at the time of sampling and are used in assessing the condition of biological assemblages. Water quality (including water temperature, salinity, and levels of contaminants such as heavy metals and organic pollutants) are also critical in structuring nearshore marine ecosystems and can cause both acute and chronic changes in nearshore populations and communities.

SOP for water quality monitoring (Dean and Bodkin 2011a):
https://irma.nps.gov/DataStore/DownloadFile/428529

Methods for water temperature monitoring (Weitzman et al. 2021):
https://www.frontiersin.org/articles/10.3389/fmars.2021.556820/full

2) Kelp, other algae, and seagrass are "living habitats" that serve as a nutrient filter, provide food, habitat, and physical structure for fish, clams, urchins, and other invertebrates, and provide spawning and nursery habitats for forage fish and juvenile crustaceans. Kelps and other algae are also the major primary producers in the marine nearshore and because they are located in shallow water they can be significantly impacted by human activities. These include spills of oil or other contaminants, dredging and disturbance from anchoring of vessels, and increased turbidity caused by runoff of sediments or nutrients.

SOP for rocky intertidal site monitoring in KEFJ, KATM and WPWS (Dean and Bodkin 2011a):
https://irma.nps.gov/DataStore/DownloadFile/428529

SOP for rocky intertidal site monitoring in KBAY (Rigby et al. 2007, Iken and Konar 2012):
https://workspace.aoos.org/published/file/fa30bafb-3fc8-439f-b144-1fc225be6ba7/SOP_EcologicalTrendsInKachemakBay.pdf?source=catalog&portalId=8

SOP for eelgrass bed monitoring in KBAY (Iken and Konar 2012):
https://workspace.aoos.org/published/file/fa30bafb-3fc8-439f-b144-1fc225be6ba7/SOP_EcologicalTrendsInKachemakBay.pdf?source=catalog&portalId=8

3) Marine intertidal invertebrates provide critical food resources for shorebirds, sea ducks, fish, bears, sea otters, and other marine invertebrate predators. Benthic invertebrates are ecologically diverse in terms of habitat, have a wide range of physiological tolerances, are relatively sedentary, and have varied life-histories. As a result, they are good biological indicators of both short-term (e.g., annual) and long-term (e.g., decadal scale) changes in environmental conditions.

SOP for rocky intertidal site monitoring in KEFJ, KATM and WPWS (Dean and Bodkin 2011a):
https://irma.nps.gov/DataStore/DownloadFile/428529

SOP for rocky intertidal site monitoring in KBAY (Konar and Iken 2012):
https://workspace.aoos.org/published/file/fa30bafb-3fc8-439f-b144-1fc225be6ba7/SOP_EcologicalTrendsInKachemakBay.pdf?source=catalog&portalId=8

SOP for mixed sediment invertebrate sampling in all 4 regions (Weitzman et al. 2017):
https://irma.nps.gov/DataStore/DownloadFile/577315

SOP for mussel bed sampling in all 4 regions (Bodkin et al. 2016):
https://irma.nps.gov/DataStore/DownloadFile/548246

4) Marine birds are predators near the top of marine nearshore food webs. Marine birds are long-lived, conspicuous, abundant, and widespread members of the marine ecosystem and are sensitive to change. Because of these characteristics marine birds are good indicators of change in the marine ecosystem. Studies have documented that their behavior, diet, productivity, and survival change as environmental conditions change. Public concern exists for the welfare of marine birds because they are affected by human activities like oil pollution and commercial fishing.

SOP for marine bird and mammal surveys (Bodkin 2011a):
https://irma.nps.gov/DataStore/DownloadFile/428463

5) Black oystercatchers specifically are well suited for inclusion into a long-term monitoring program of nearshore habitats because they are long-lived; reside and rely on intertidal habitats; consume a diet dominated by mussels, limpets, and chitons; and provision chicks near nest sites for extended periods. Additionally, as a conspicuous species sensitive to disturbance, the black oystercatcher would likely serve as a sentinel species in detecting change in the nearshore community resulting from human or other disturbances.

SOP for black oystercatcher data collection (Bodkin 2011b):
https://irma.nps.gov/DataStore/DownloadFile/428462

6) Sea otters are keystone species that can dramatically affect the structure and complexity of their nearshore ecological community. They cause well described top-down cascading effects on community structure by altering abundance of prey (e.g., sea urchins), which can in turn alter abundance of lower trophic levels (e.g., kelps). Sea otters generally have smaller home ranges than other marine mammals; eat large amounts of food; are susceptible to contaminants such as those related to oil spills; and have broad appeal to the public. Recent declines in sea otters have been observed in the Aleutian Islands. Currently declines are documented in areas approaching the western edge of our study area. As a result of these declines, the southwestern Alaska stock

of sea otters (which includes those in KATM), was federally listed as threatened in September 2005 under the Endangered Species Act.

SOP for Sea otter carcass surveys (Dean and Bodkin 2011b):
https://irma.nps.gov/DataStore/DownloadFile/428528

SOP for sea otter forage data collection (Bodkin 2011c):
https://irma.nps.gov/DataStore/DownloadFile/428470

SOP for sea otter abundance estimation (aerial surveys) (Bodkin 2011d):
https://irma.nps.gov/DataStore/DownloadFile/428467

RESULTS

Intertidal Water Temperature

Intertidal water temperature in all four Nearshore Component monitoring regions showed a warming trend beginning in 2014 and persisting across all regions through 2016; warming continued into 2017 in WPWS and KEFJ (Fig. 3). These results confirmed that the 2014-2016 marine heatwave in the Gulf of Alaska affected intertidal zones. While temperatures had appeared to cool and return to normal across all regions in late 2017 and 2018, 2019 indicated warmer than average water temperatures in the intertidal zone across all four study regions and a cooling during the early part of 2020, particularly in the western blocks of KBAY and KATM. Temperatures appeared to return to the long-term average across all regions early in 2021, followed by cooling across all regions into the summer months of 2021.

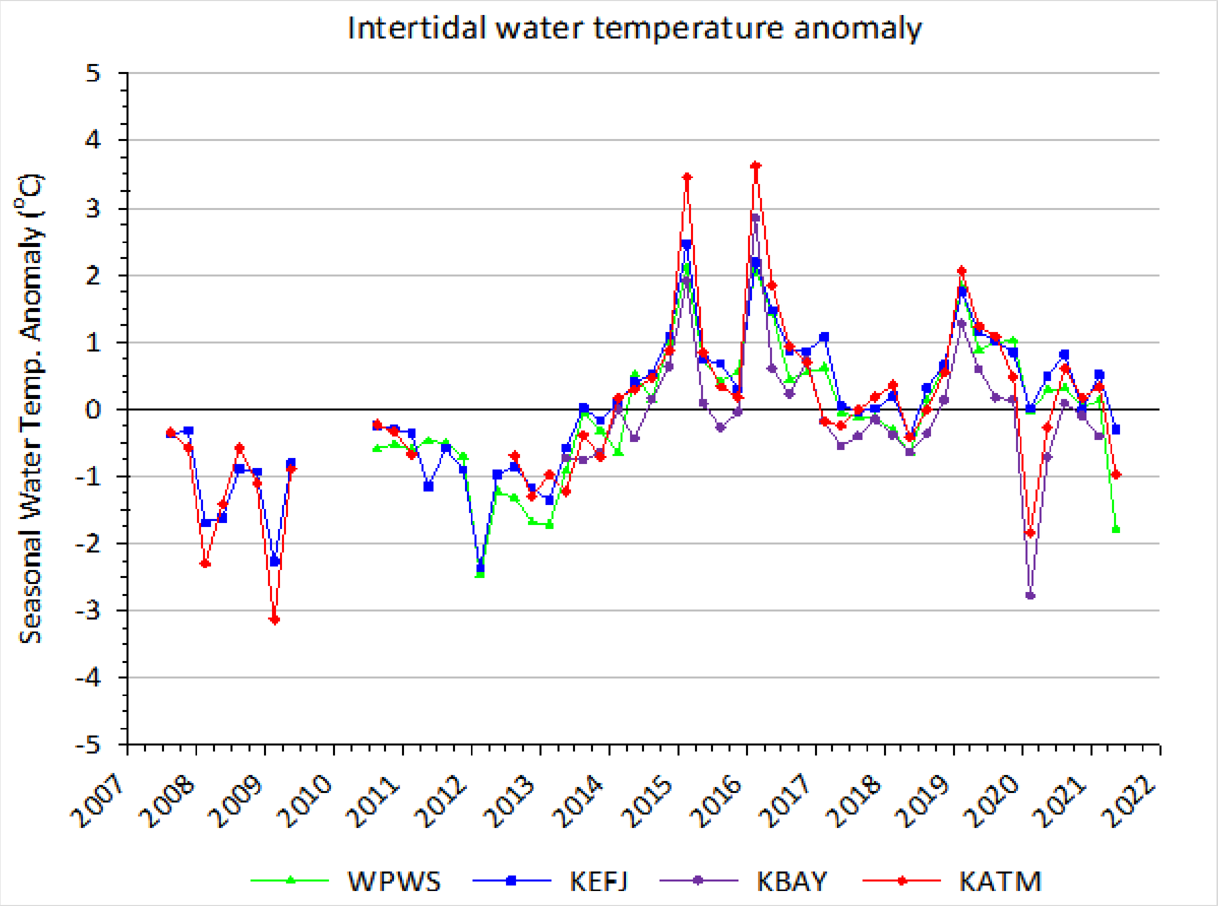

Figure 3. Seasonal intertidal water temperature anomalies at the 0.5 m tide level across western Prince William Sound (WPWS; 2011-2021), Kenai Fjords National Park (KEFJ; 2008-2021), Kachemak Bay (KBAY; 2013-2021), and Katmai National Park and Preserve (KATM; 2006-2021). Long tick marks indicate the start of the calendar year (January) while short tick marks are quarterly divisions within the year (April, July, October).

Contaminants in Mussel Tissue

In 2018, we collected mussels for analysis of a broad suite of contaminants across all four Nearshore Component monitoring regions. This work is not conducted annually but rather is slated to occur every 8 years unless a contaminant-specific issue emerges. In 2019, we received results from the laboratory analysis conducted by the National Oceanic and Atmospheric Administration (NOAA); we note that these analyses were conducted following protocols for the Mussel Watch program, ensuring comparability to other times and places. In fact, results from these analyses were combined with those from other locations in the northern GOA. Results indicate that there were no significant contaminant concerns within our study areas in 2018 (Rider et al. 2020).

Marine Algae and Invertebrates

We examined rocky intertidal community structure at 21 sites across our four regions, spanning 1,200 km of coastline. Sites were monitored annually at mid and low tidal strata. Before the PMH (2012-2014), community structure differed among regions. During and after the PMH (2015-2019), we found that macroalgal foundation species declined across the study regions. The GOA-wide shift from a macroalgal dominated rocky intertidal to a filter-feeder dominated state concurrent with the changing environmental conditions associated with a marine heatwave event suggests the PMH had Gulf-wide impacts to the structure of rocky intertidal communities. Similarities in community structure increased across regions, leading to a greater homogenization of these communities (Fig. 4). This was due to declines in macroalgal cover, driven mostly by a decline in the rockweed, *Fucus distichus*, and fleshy red algae in 2015, followed by an increase in barnacle cover in 2016, and an increase in mussel cover in 2017 (Figs. 5 and 6). Strong, large-scale oceanographic events, like the PMH, may override local drivers to similarly influence patterns of intertidal community structure at broader scales. These results are presented in a recent synthesis paper (Weitzman et al. 2021).

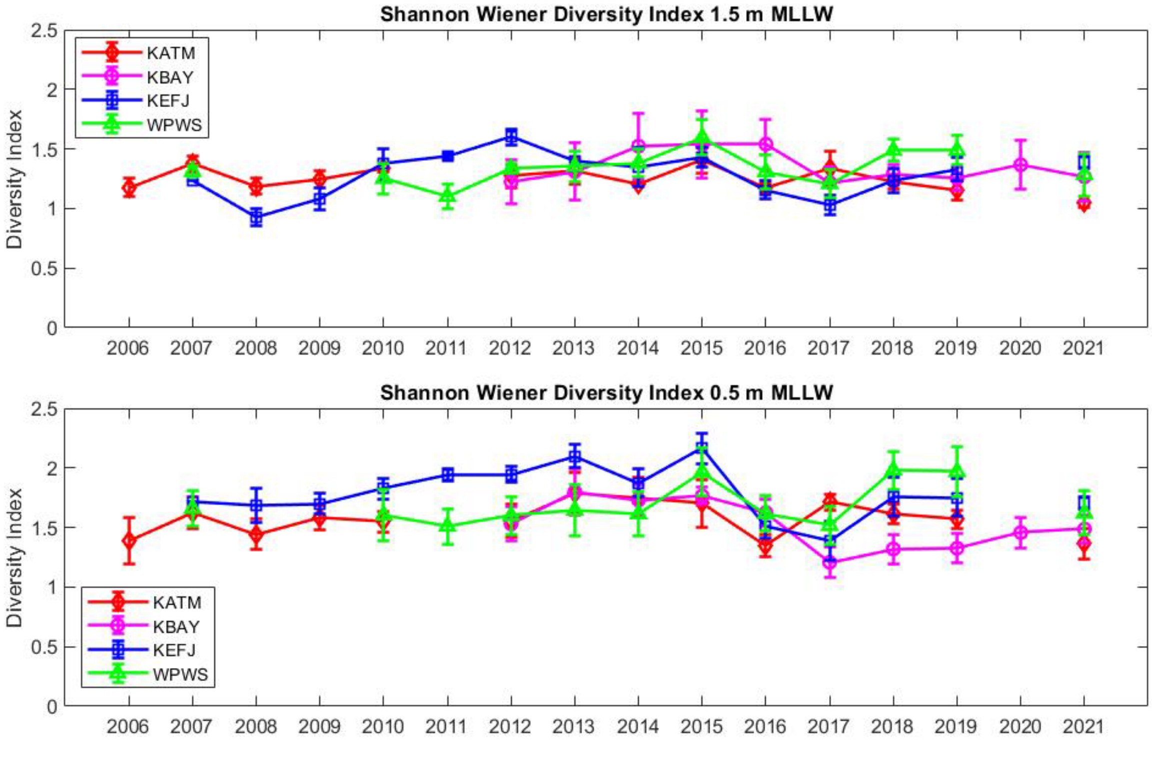

Figure 4. Shannon Wiener Diversity Index at the 1.5 m and 0.5 m tidal elevation relative to mean lower low water (MLLW) across the four Gulf Watch Alaska regions: Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), Kenai Fjords National Park (KEFJ), and western Prince William Sound (WPWS), 2006-2021. Error bars indicate ±1SE.

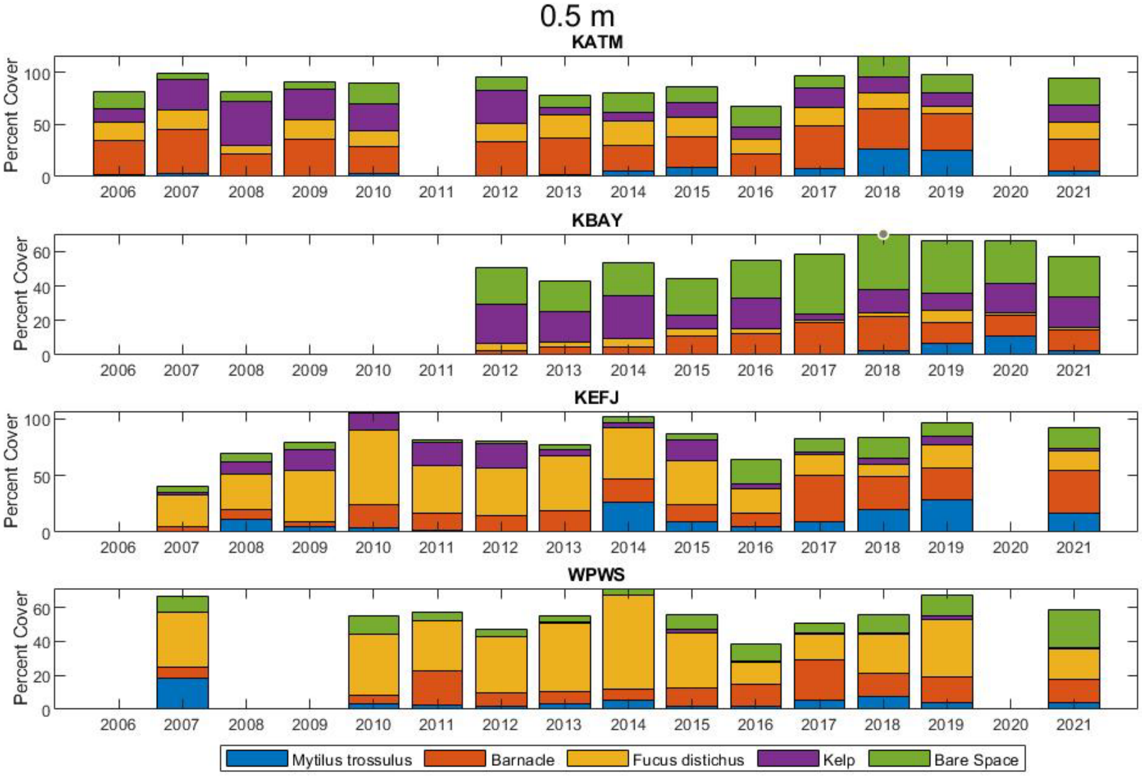

Figure 5. Percent cover of Mytilus trossulus*, barnacles,* Fucus distichus*, kelps, and bare substrate at the 0.5 m tidal elevation across the four Gulf Watch Alaska regions: Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), Kenai Fjords National Park (KEFJ), and western Prince William Sound (WPWS), 2006-2021.*

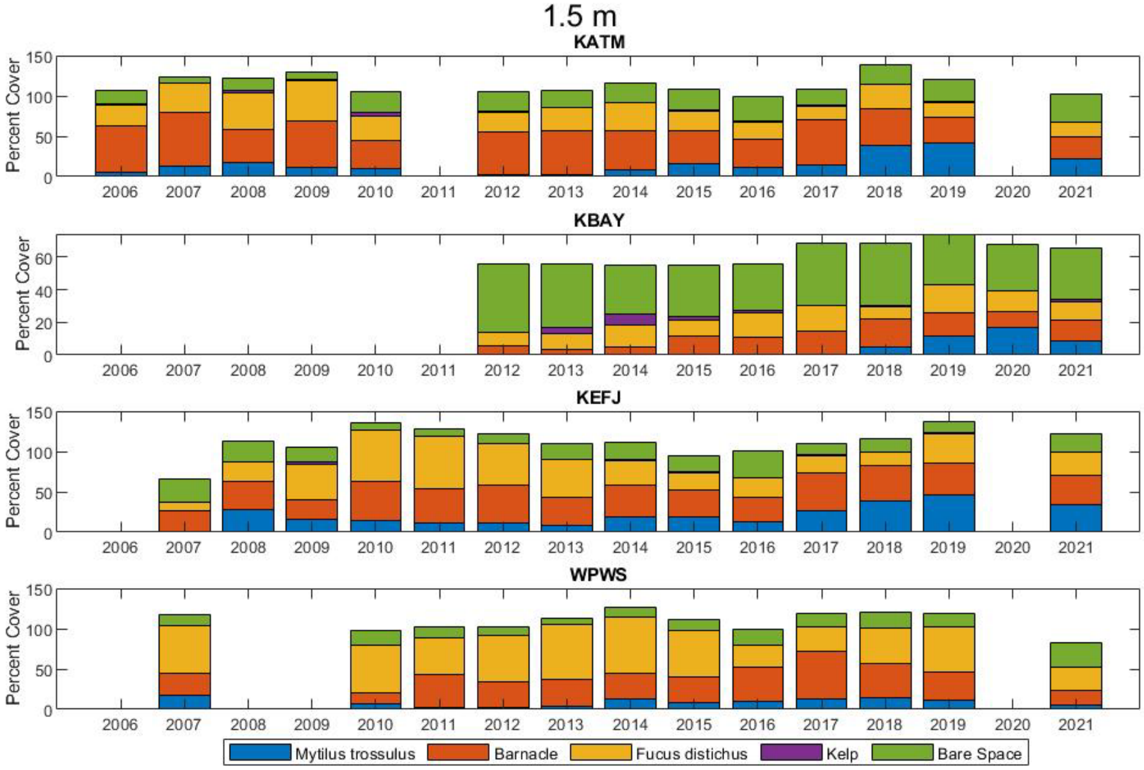

Figure 6. Percent cover of Mytilus trossulus*, barnacles,* Fucus distichus*, kelps, and bare substrate at the 1.5 m tidal elevation across the four Gulf Watch Alaska regions: Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), Kenai Fjords National Park (KEFJ), and western Prince William Sound (WPWS), 2006-2021.*

Lottia persona densities are estimated at a set "limpet line" which is established in the upper intertidal zone within 3 of the 4 regions at each randomly selected rocky intertidal site. *Lottia persona* density appeared stable across KEFJ and KATM, with more variability at WPWS (Fig. 7).

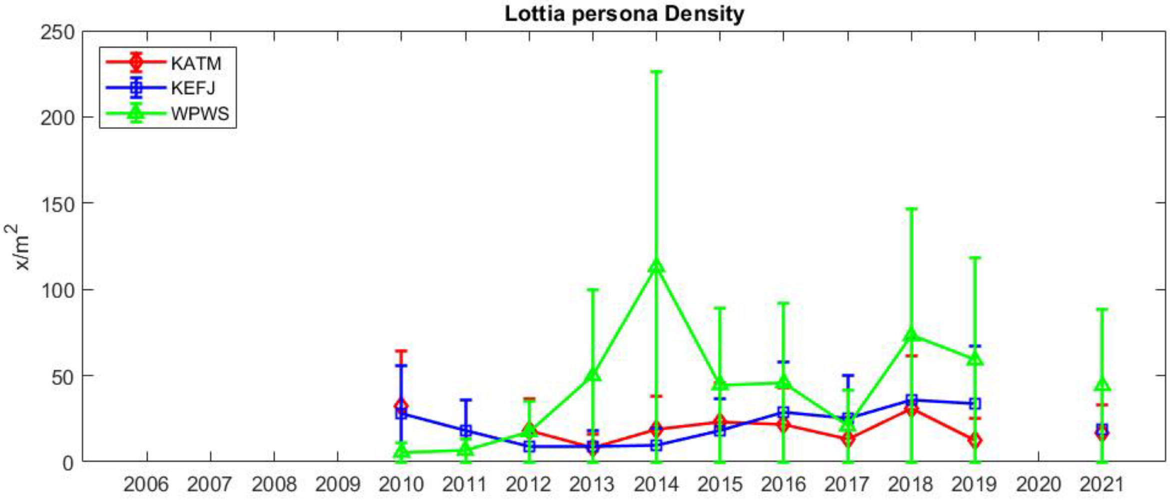

Figure 7. Lottia persona *density at the limpet line across three of the Gulf Watch Alaska regions: Katmai National Park and Preserve (KATM), Kenai Fjords National Park (KEFJ), and western Prince William Sound (WPWS), 2010-2021. Error bars indicate ±1SE.*

Sampling of rocky intertidal sites also includes estimating density of several mobile invertebrates along the 0.5 m and 1.5 m tidal elevations at all 4 regions and includes *Lottia* spp.*, Katharina tunicata, Lirabuccinum dirum,* and *Nucella* spp. Densities appear to vary by region, indicating that local-scale drivers may dictate motile invertebrate community structure (Figs. 8-11). Further work is being conducted by a graduate student at University of Alaska Fairbanks to analyze these data in response to sea star wasting and the PMH.

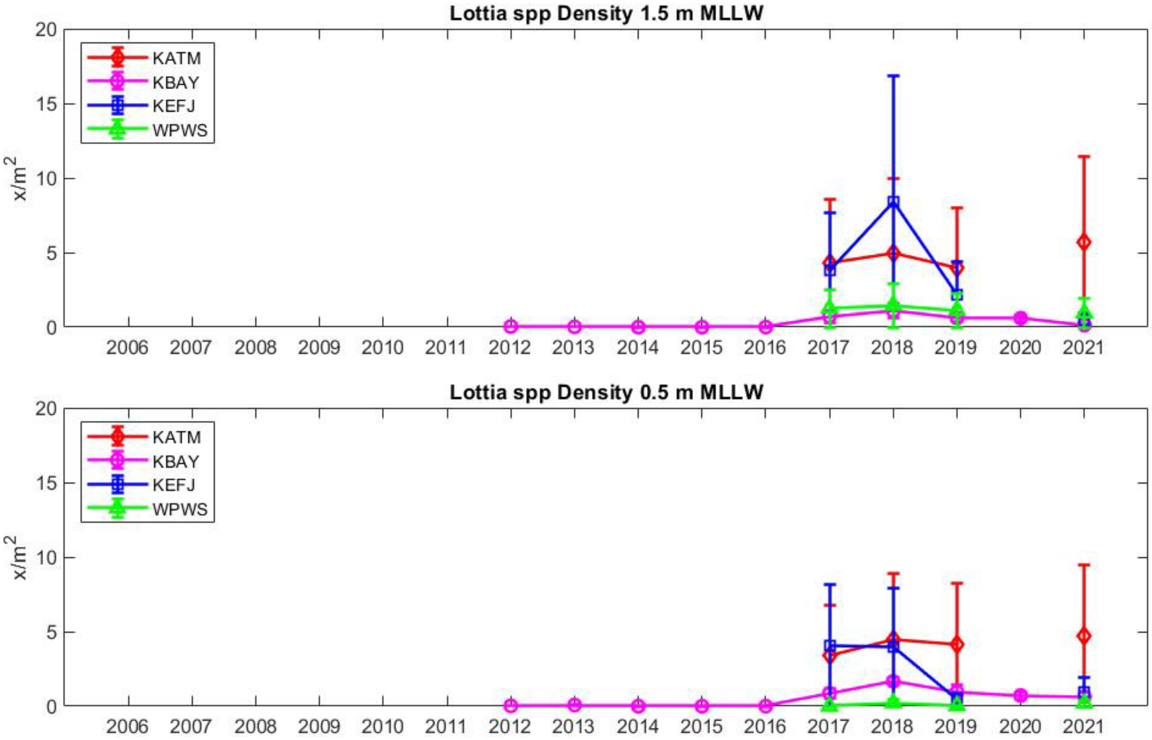

Figure 8. Lottia *spp. density at the at the 1.5 m and 0.5 m tidal elevation across the four Gulf Watch Alaska regions: Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), Kenai Fjords National Park (KEFJ), and western Prince William Sound (WPWS), 2006-2021. Error bars indicate ±1SE.*

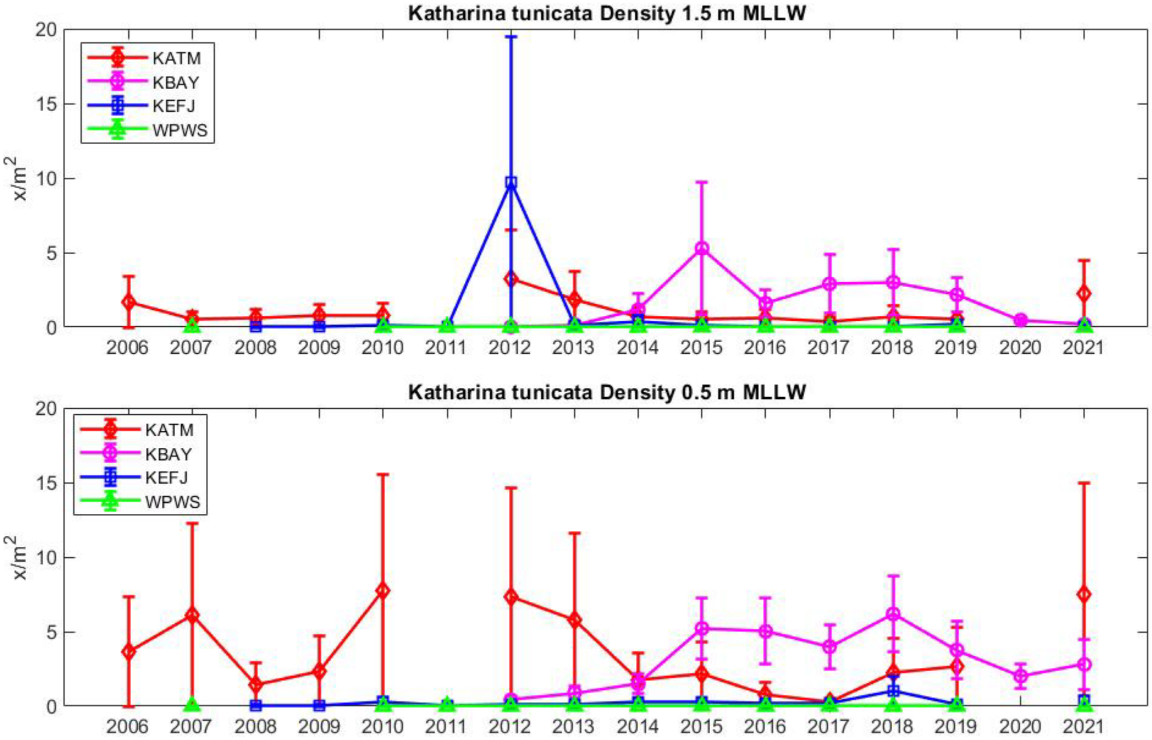

Figure 9. Katharina tunicata *density at the at the 1.5 m and 0.5 m tidal elevation across the four Gulf Watch Alaska regions: Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), Kenai Fjords National Park (KEFJ), and western Prince William Sound (WPWS), 2006-2021. Error bars indicate ±1SE.*

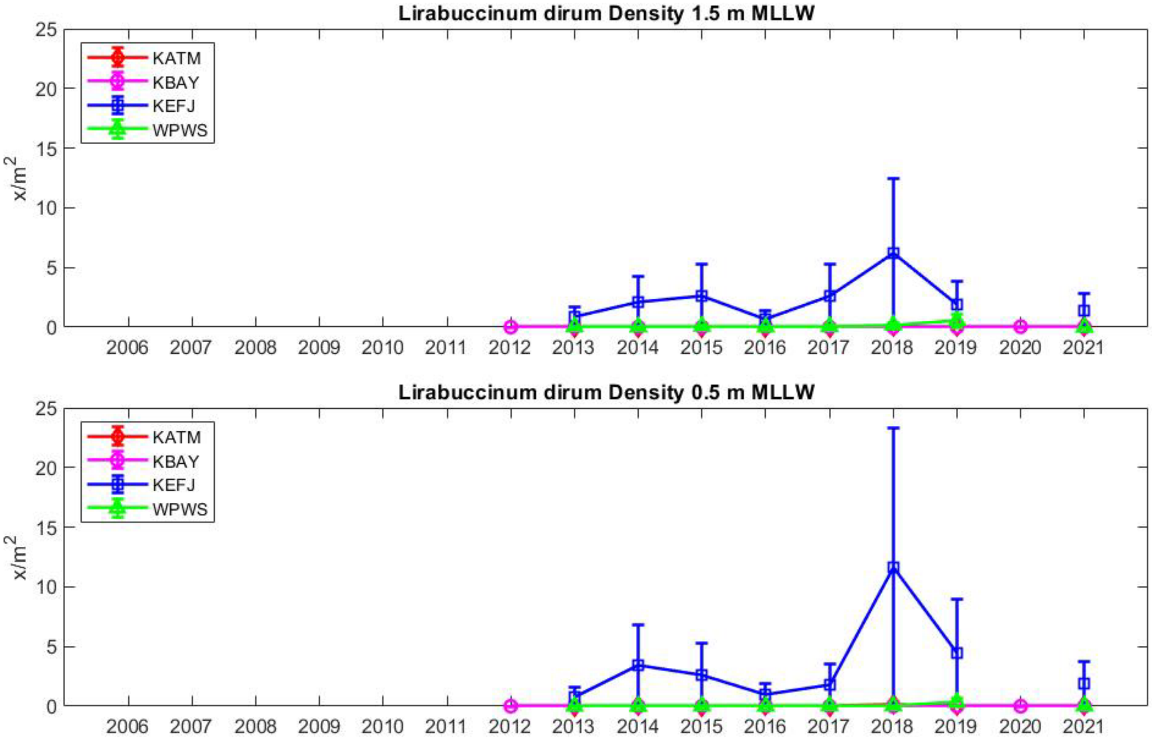

Figure 10. Lirabuccinum dirum *density at the at the 1.5 m and 0.5 m tidal elevation across the four Gulf Watch Alaska regions: Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), Kenai Fjords National Park (KEFJ), and western Prince William Sound (WPWS), 2006-2021. Error bars indicate ±1SE.*

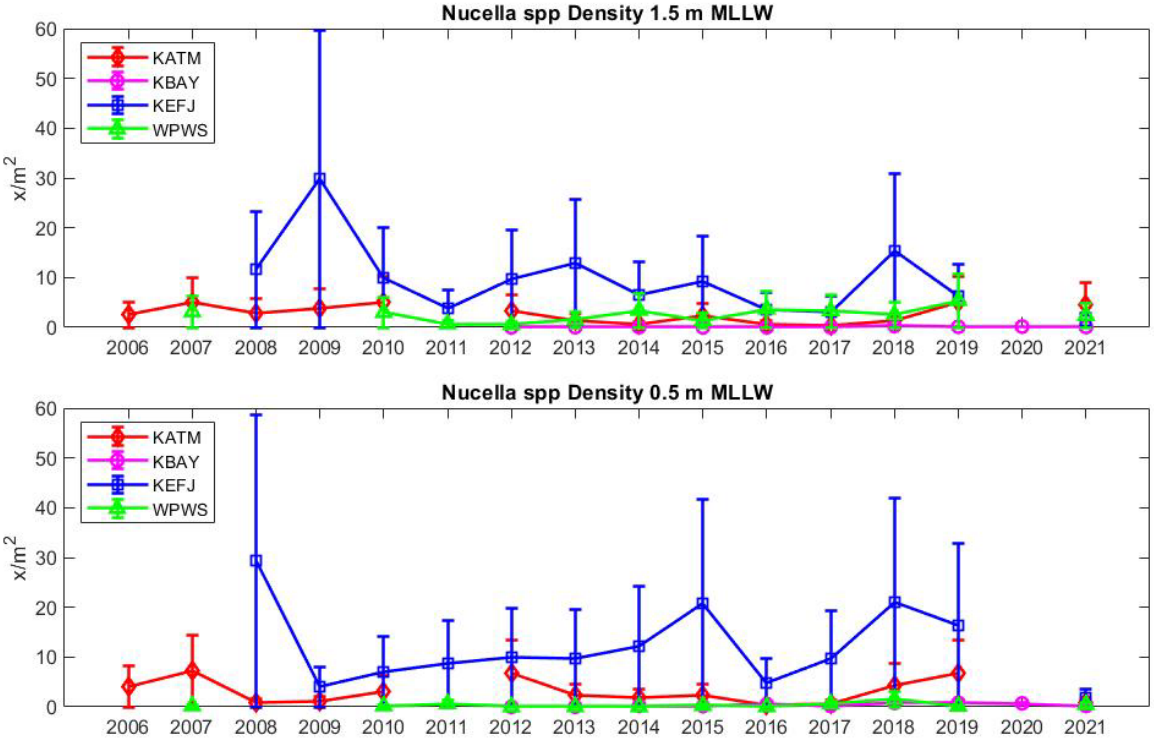

Figure 11. Nucella *spp. density at the at the 1.5 m and 0.5 m tidal elevation across the four Gulf Watch Alaska regions: Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), Kenai Fjords National Park (KEFJ), and western Prince William Sound (WPWS), 2006-2021. Error bars indicate ±1SE.*

Infaunal bivalves are sampled in intertidal mixed sediment habitats every other year in all regions. Estimates of clam biomass, density, and species distribution indicate that *Macoma* spp. numerically dominate the clam community across all four regions (Fig. 12). However, because of their much larger size, the less abundant *Saxidomous gigantea* contributes a significant portion of the overall clam biomass in KATM and to a lesser degree, KBAY (Fig. 13). Clams are generally more abundant at KATM and have higher biomass at KATM and KBAY than other regions (Figs. 12 and 13).

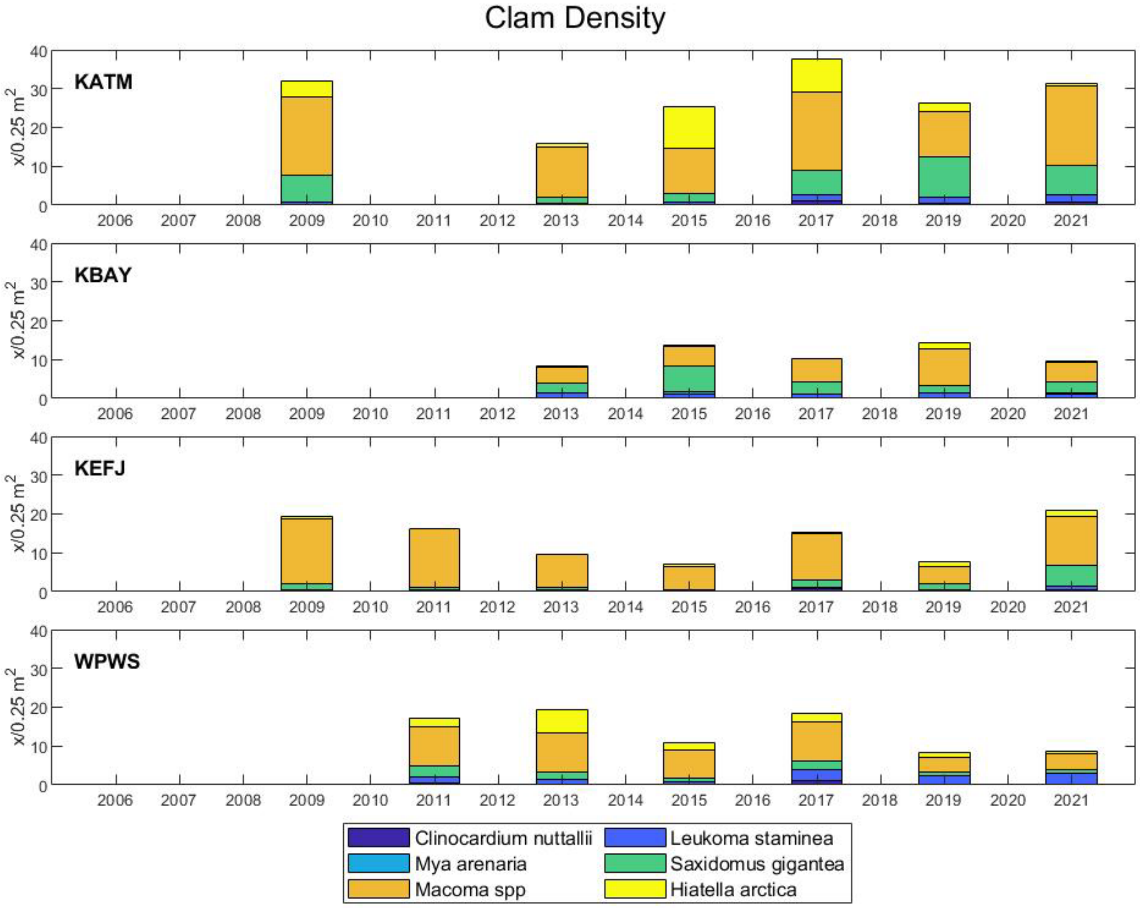

Figure 12. Clam density at the 0.0 m tidal elevation across the four Gulf Watch Alaska regions: Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), Kenai Fjords National Park (KEFJ), and western Prince William Sound (WPWS). Sampling is done every other year and began in 2009 in KATM and KEFJ (KATM was not sampled in 2011), in 2011 in WPWS and 2013 in KBAY.

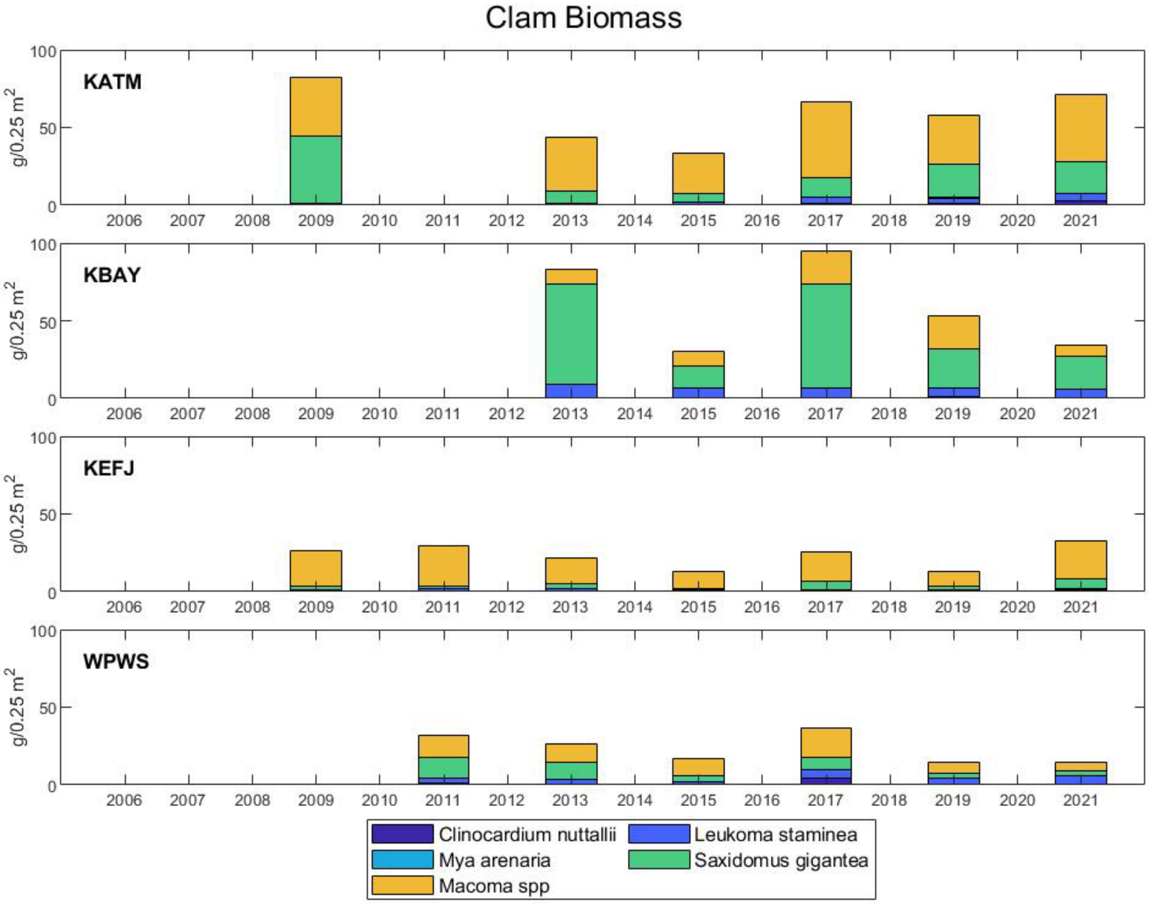

Figure 13. Clam biomass (grams of wet weight per 0.25 m^2) at the 0.0 m tidal elevation across the four Gulf Watch Alaska regions: Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), Kenai Fjords National Park (KEFJ), and western Prince William Sound (WPWS). Sampling is done every other year and began in 2009 in KATM and KEFJ (KATM was not sampled in 2011), in 2011 in WPWS, and 2013 in KBAY.

Specific mussel beds are sampled at each site within each region every year. Large mussel densities (≥ 20 mm) showed an overall positive trend across all regions consistent with timing of the marine heatwave through 2019 (Fig. 14). In 2021, it appears that large mussel density returned to the long-term average across all regions. Overall mussel density and density of 2-5 mm mussels, both indicators of recruitment, showed declines concurrent with the PMH with subsequent increases in recent years (Figs. 14 and 15). This is an opposite pattern to the large mussels, indicating that drivers of recruitment and survival may be operating at different spatial and temporal scales (Bodkin et al. 2018). Evaluation of drivers of mussel abundance, specifically variation in temperature and sea star abundance, was the subject of a recent Nearshore Component synthesis paper (Traiger et al. 2022).

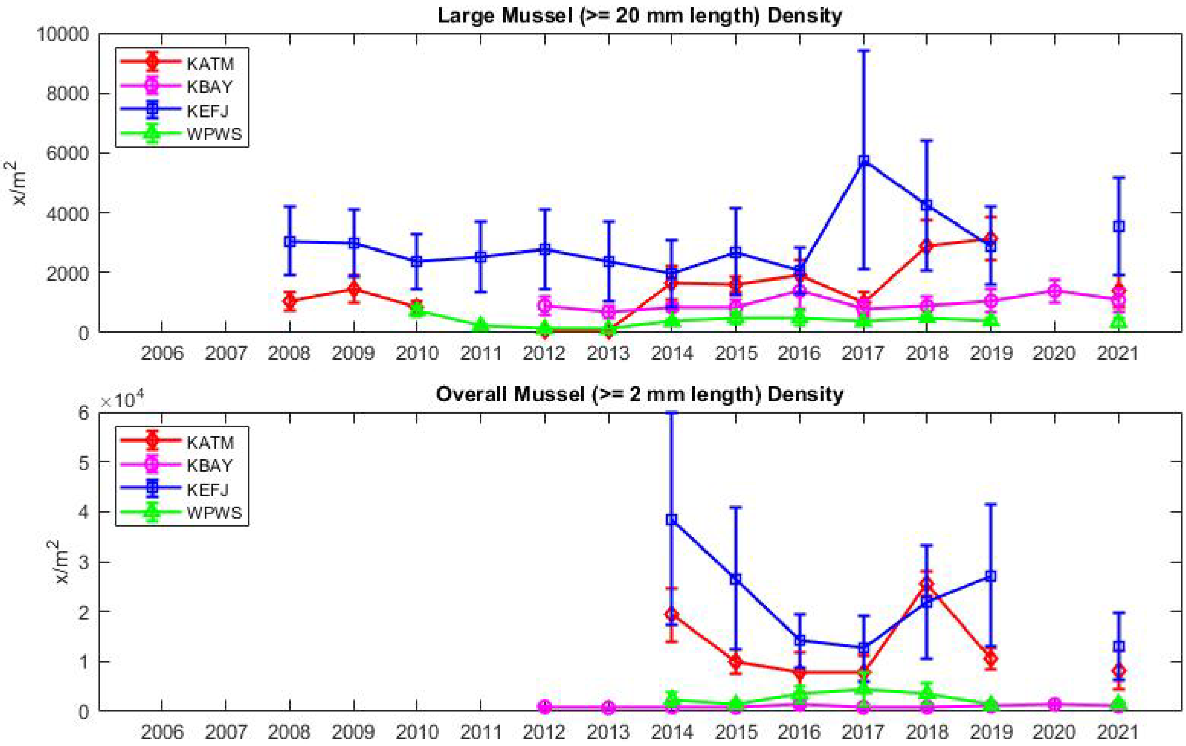

*Figure 14. Top graph illustrates large (>= 20 mm) mussel (*Mytilus trossulus*) density across four regions at mussel sites. The bottom graph illustrates the overall density (>= 2 mm). Note: The y-axis for the densities is different, with the overall density significantly larger (x10^{4}). Sampling started in 2008 in Kenai Fjords National Park (KEFJ), Katmai National Park and Preserve (KATM), and western Prince William Sound (WPWS). Kachemak Bay (KBAY) mussel bed sampling began in 2012. Error bars indicate ±1SE.*

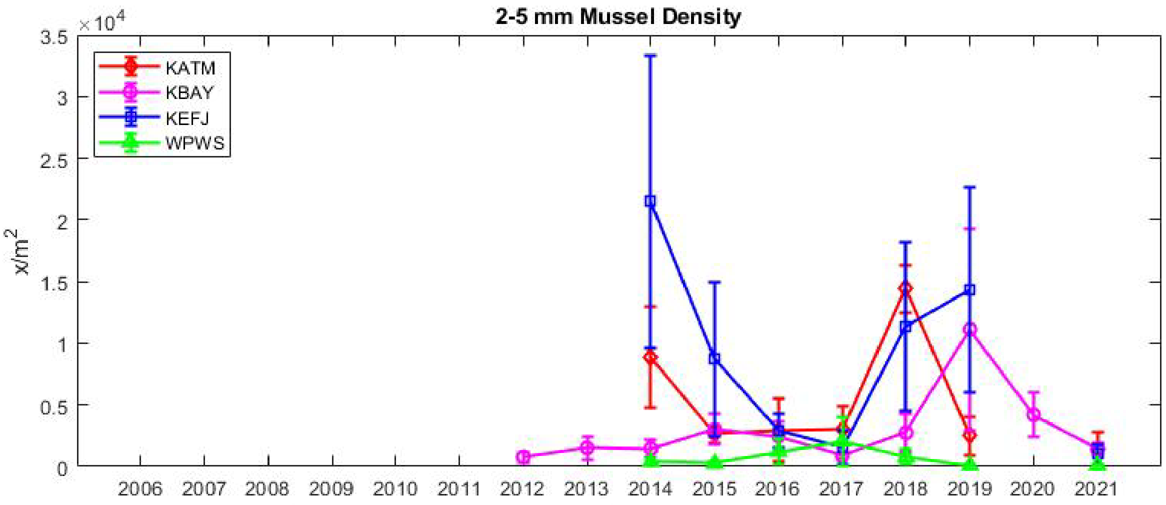

*Figure 15. Density of mussel (*Mytilus trossulus*) recruits (2-5 mm) across four regions at mussel sites. Note: The y-axis is (x10^4). Sampling started in 2008 in Kenai Fjords National Park (KEFJ), Katmai National Park and Preserve (KATM), and western Prince William Sound (WPWS). Kachemak Bay (KBAY) mussel bed sampling began in 2012. Error bars indicate ±1SE.*

Sea star abundance, density, and diversity varied greatly among regions through 2015. Between 2015 and 2017, abundance declined and remained low across all regions through 2018, likely due to sea star wasting (Konar et al. 2019). In 2019, there was some recruitment and recovery in WPWS, which persisted through 2020. However, the sea star species thought to be least affected by sea star wasting in the northern GOA (primarily *Henricia* and *Dermasterias*) continued to be present and accounted for the positive anomalies. The positive trend in WPWS and KEFJ during 2020 surveys was driven by high numbers of *Dermasterias* (81% and 88% of observed sea stars, respectively). The previously dominant sea stars (primarily *Pycnopodia, Evasterias,* and *Pisaster*) continued to be absent (or rare) in many of the Nearshore Component monitoring regions, although one site in WPWS in 2020 showed some recovery potential with many small *Pycnopodia*. However, in 2021 all regions except KATM again were trending downward (Fig. 16). The sea star species documented in KATM that accounted for the positive trends were primarily *Evasterias* (53%), *Pisaster* (35%) and *Pycnopodia* (10%), indicating a potential recovery of sea stars along the KATM coast but not elsewhere across the Gulf. This may help explain the slightly negative trend in large mussel density observed in KATM in 2021 (Fig. 14) but fails to explain this pattern elsewhere in the GOA.

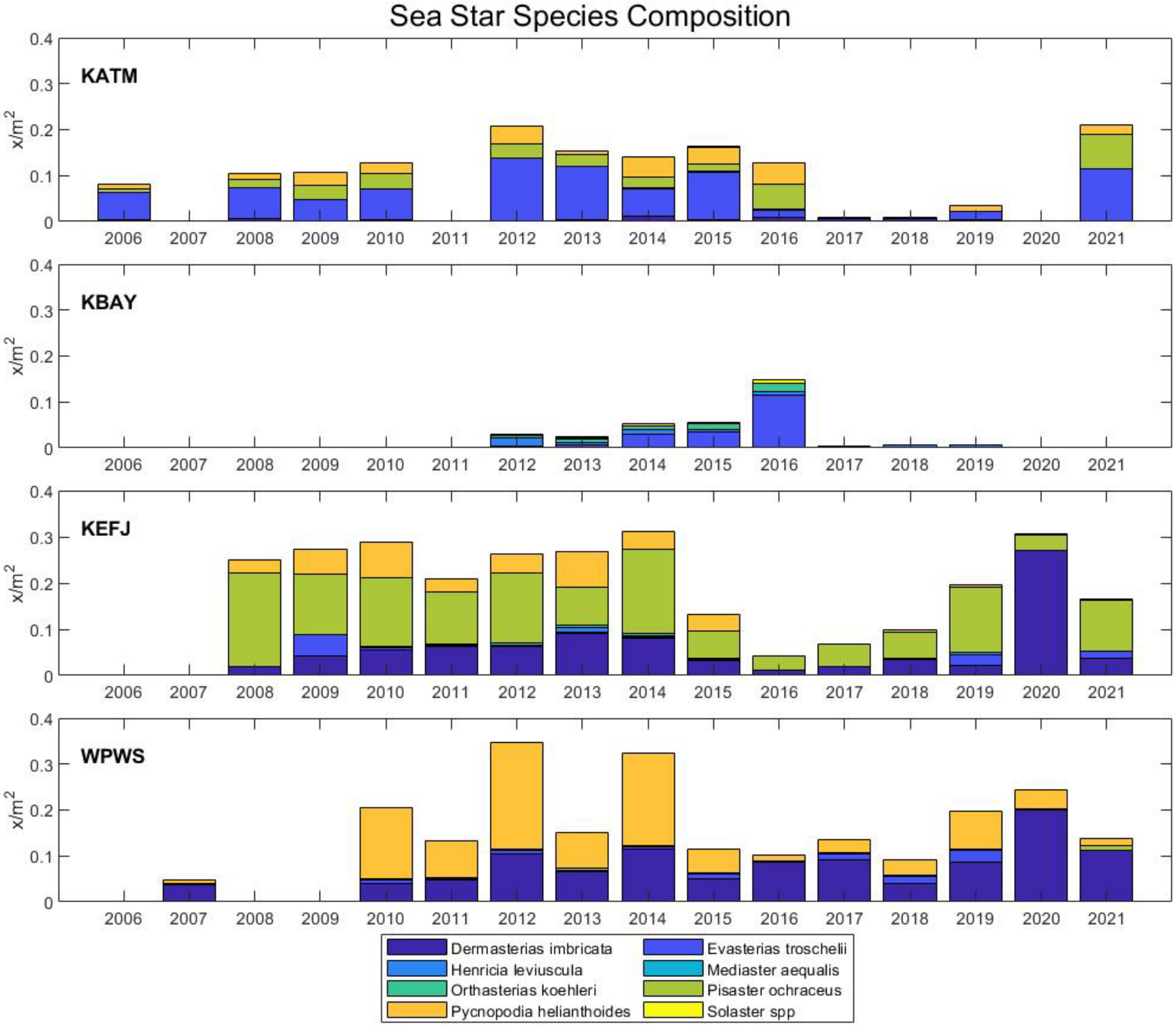

Figure 16. Sea star species composition and density across all four Gulf Watch Alaska regions: Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), Kenai Fjords National Park (KEFJ), and western Prince William Sound (WPWS).

Marine Birds and Mammals

Nearshore skiff surveys, conducted along transects that encompass 200 m swaths along shore, have generated long-term monitoring data since 2006 in KATM, 2007 in KEFJ, and 2018 in KBAY. For those birds and mammals that also regularly use habitats farther offshore, our results represent only the nearshore portion of their distribution. We present trends through 2021 in overall bird species richness (Fig. 17), overall marine bird density (Fig. 18) and a variety of marine bird and mammal species (Figs. 19-33). In general, bird abundance was similar between summer and winter within regions, but community composition was different between seasons with higher species richness at KEFJ in the summer. Winter coastal marine communities were characterized by a marked increase in benthic foragers and highlights the importance of nearshore coastal resources to sea ducks that primarily breed in the interior of Alaska but migrate to the coast in winter. Summer marine coastal communities were generally found to support large numbers of forage fish consumers as colonies, absent of marine birds in the winter, were occupied in the summer. We found variation in trends in density of some species at the regional scale, which suggests that drivers of abundance of marine birds are not coherent across the GOA. For other species, however, the lack of variation in trends in density across regions may indicate Gulf-wide drivers of abundance. Taken holistically, contrasting trends in a variety of species and guilds can inform as to the underlying factors driving individual species' abundance and distribution. A paper discussing seasonal, spatial, and temporal variation, including effects of the PMH, in marine bird communities of KEFJ and KATM is underway (Robinson et al. in review).

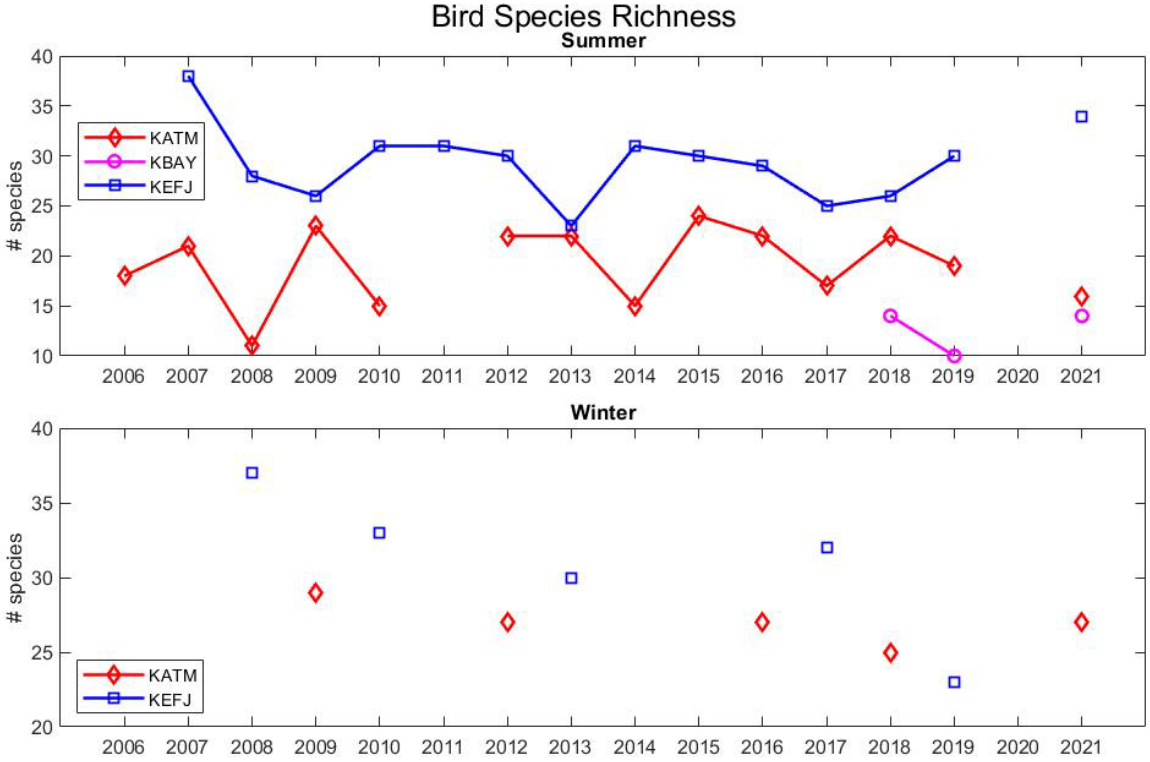

Figure 17. Overall bird species richness estimates in summer (top) in Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), and Kenai Fjords National Park (KEFJ) and winter (bottom) in KATM and KEFJ.

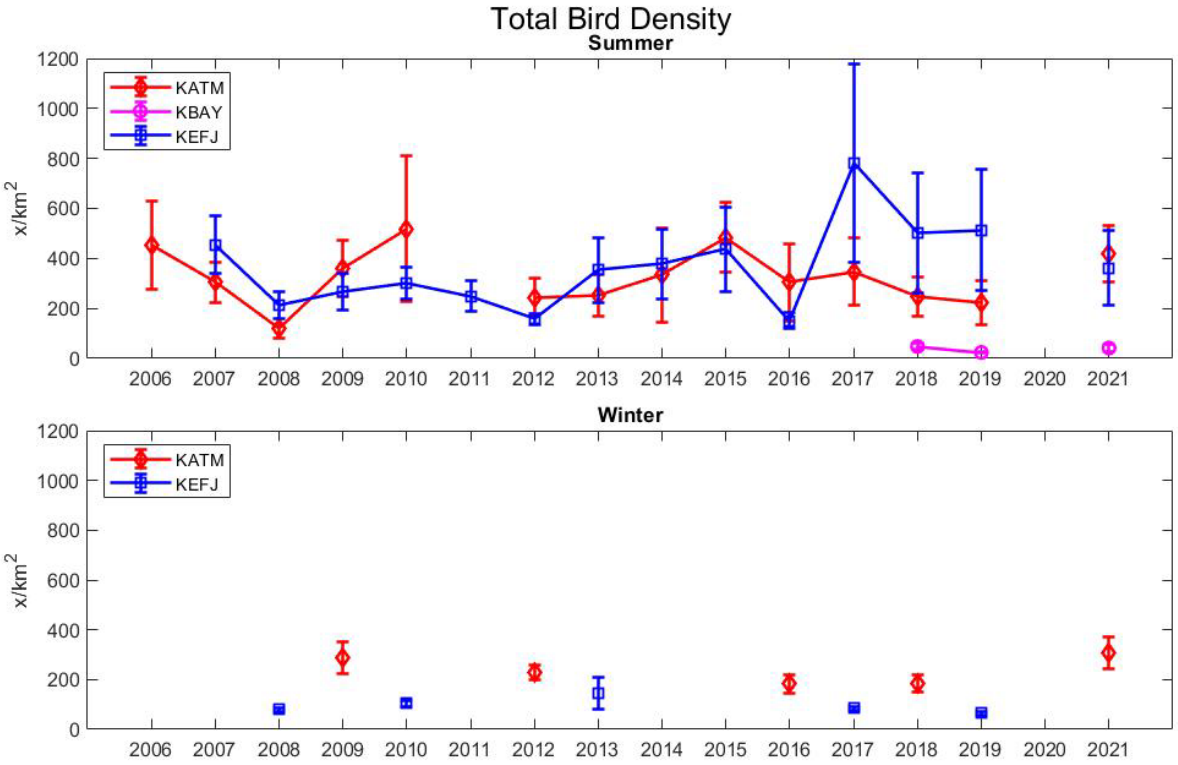

Figure 18. Overall bird species density estimates in summer (top) in Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), and Kenai Fjords National Park (KEFJ) and winter (bottom) in KATM and KEFJ. Error bars indicate ±1SE.

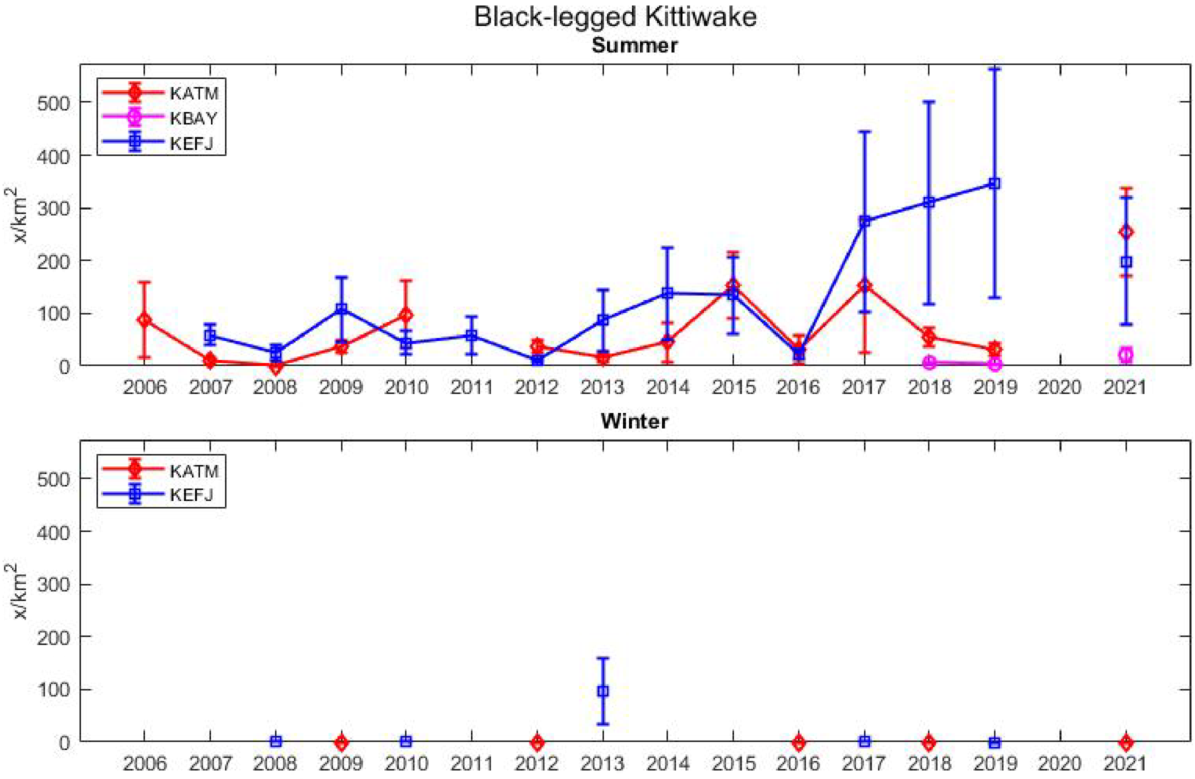

Figure 19. Black-legged kittiwake (Rissa tridactyla) *density estimates in summer (top) in Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), and Kenai Fjords National Park (KEFJ) and winter (bottom) in KATM and KEFJ. Error bars indicate ±1SE.*

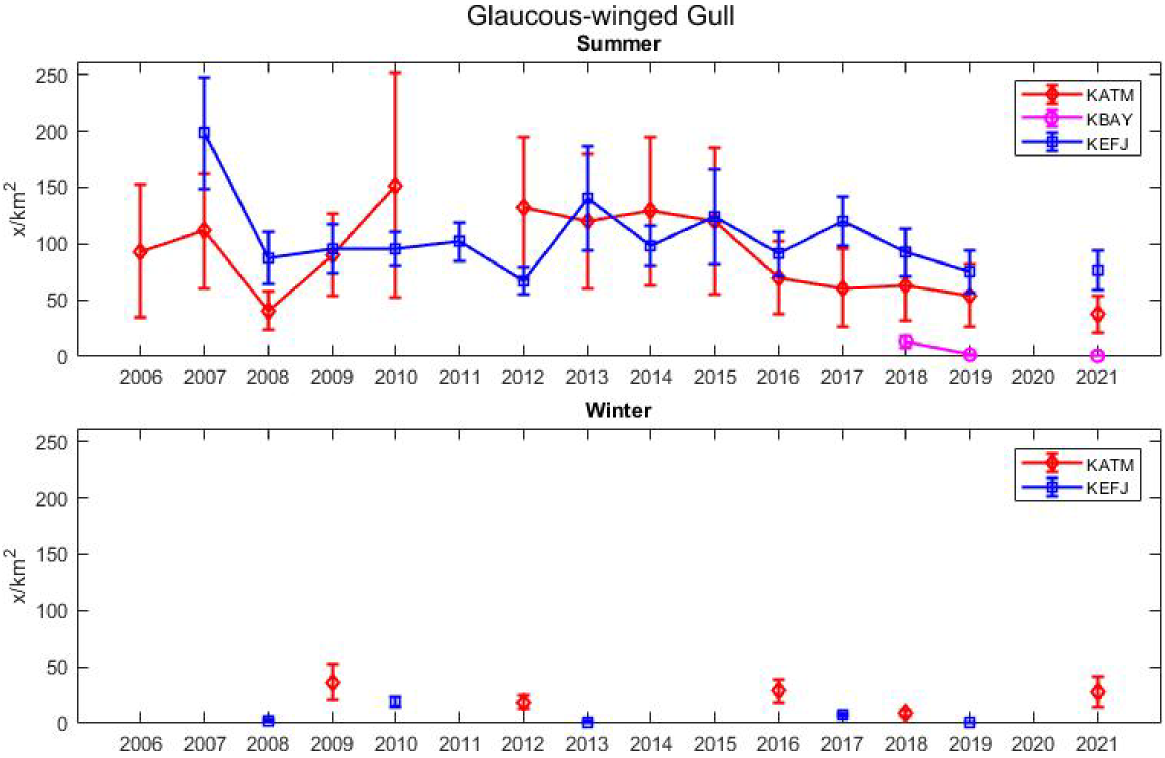

Figure 20. Glaucous-winged gull (Larus glaucescens) *density estimates in summer (top) in Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), and Kenai Fjords National Park (KEFJ) and winter (bottom) in KATM and KEFJ. Error bars indicate ±1SE.*

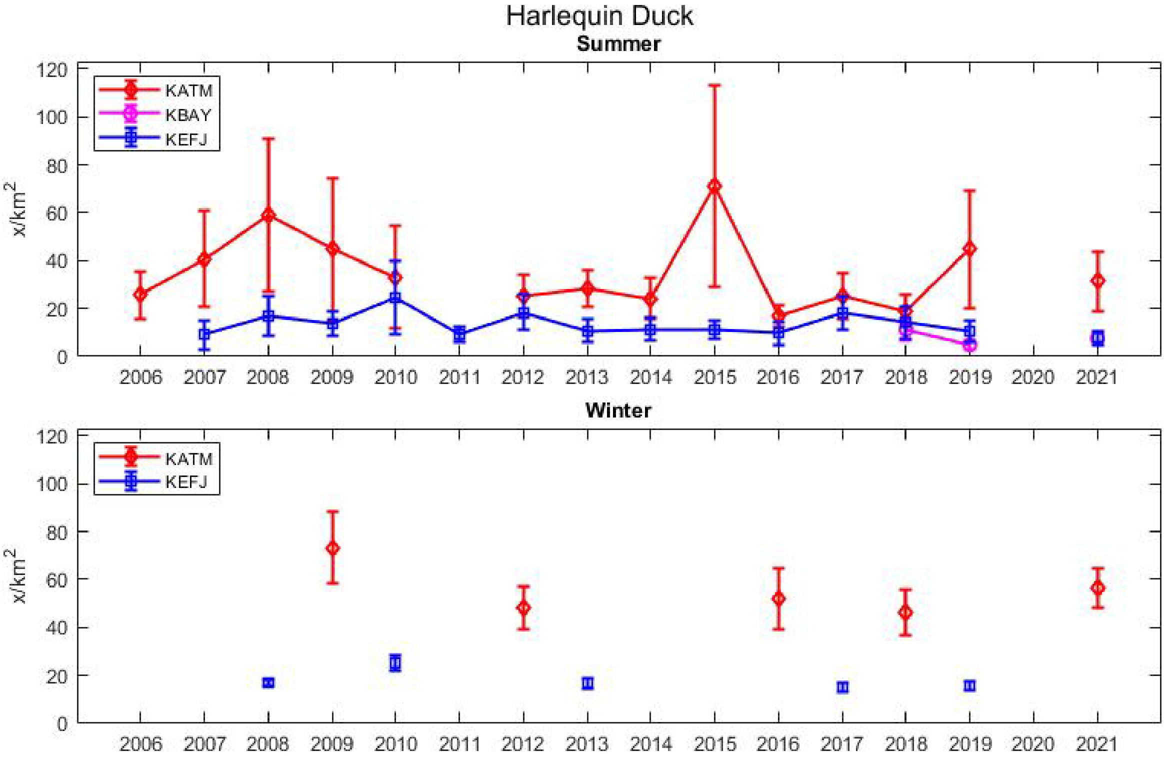

Figure 21. Harlequin duck (Histrionicus histrionicus) *density estimates in summer (top) in Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), and Kenai Fjords National Park (KEFJ) and winter (bottom) in KATM and KEFJ. Error bars indicate ±1SE.*

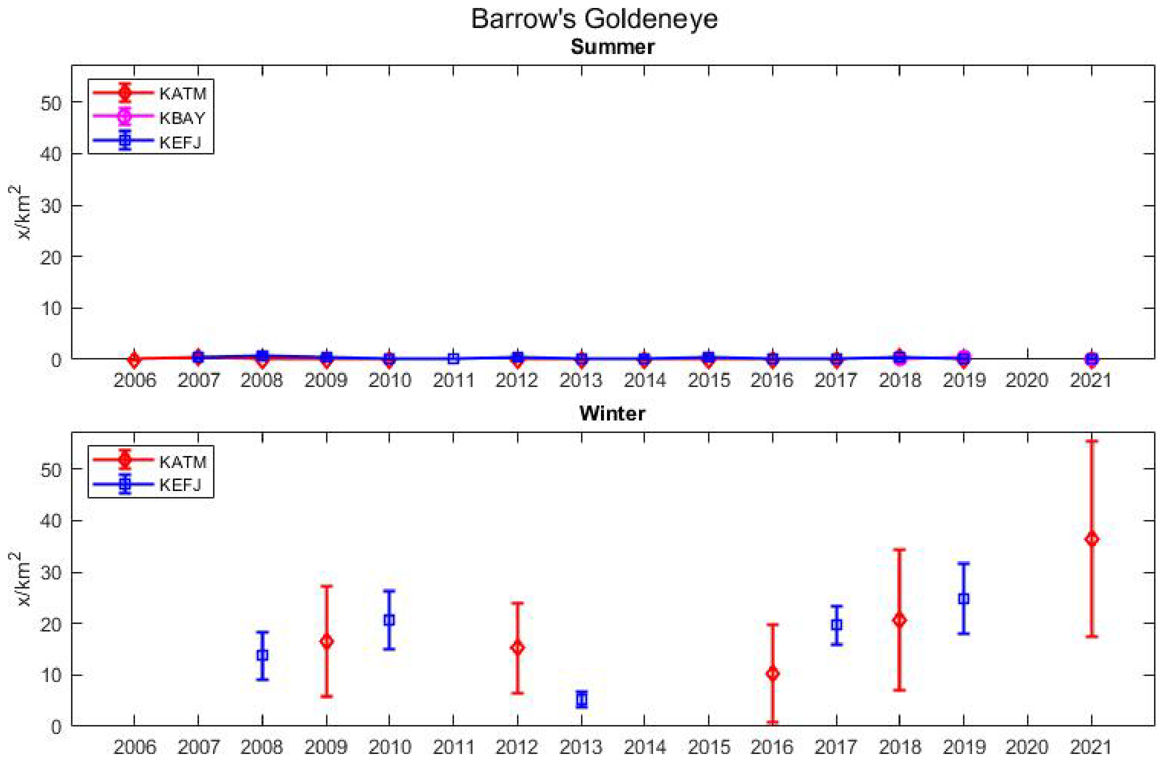

Figure 22. Barrow's goldeneye (Bucephala islandica) *density estimates in summer (top) in Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), and Kenai Fjords National Park (KEFJ) and winter (bottom) in KATM and KEFJ. Error bars indicate ±1SE.*

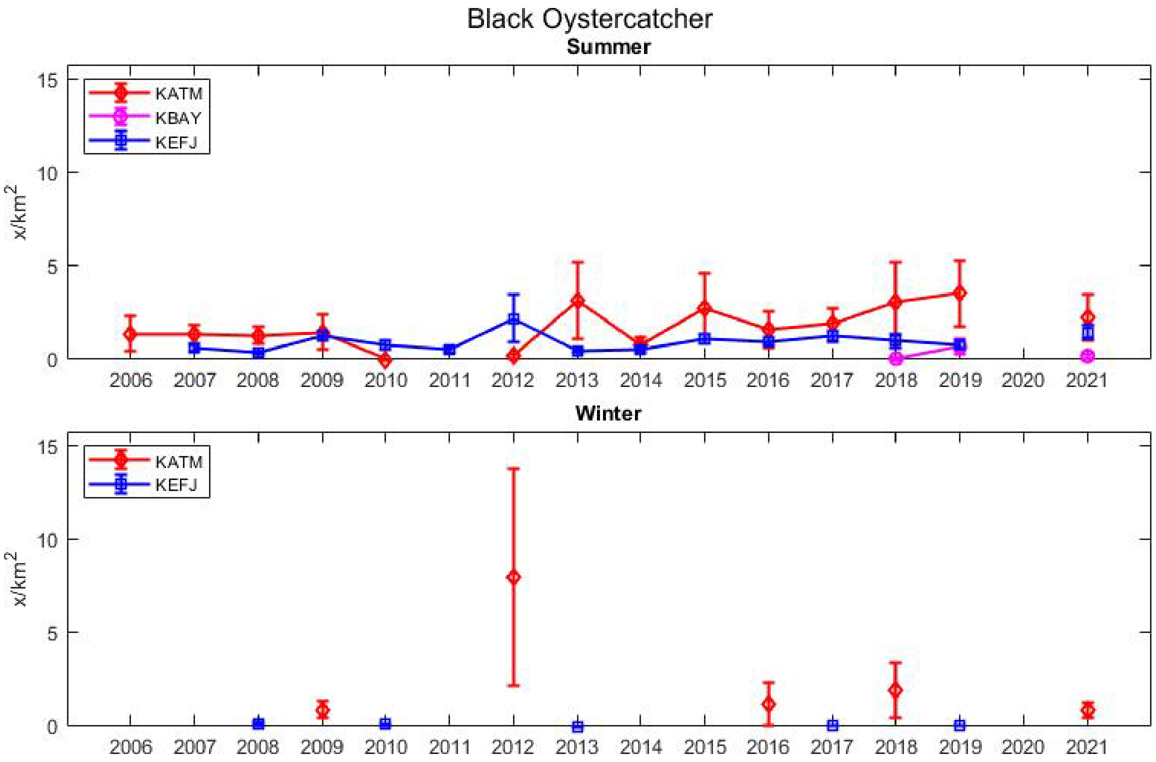

Figure 23. Black oystercatcher (Haematopus bachmani) *density estimates in summer (top) in Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), and Kenai Fjords National Park (KEFJ) and winter (bottom) in KATM and KEFJ. Error bars indicate ±1SE.*

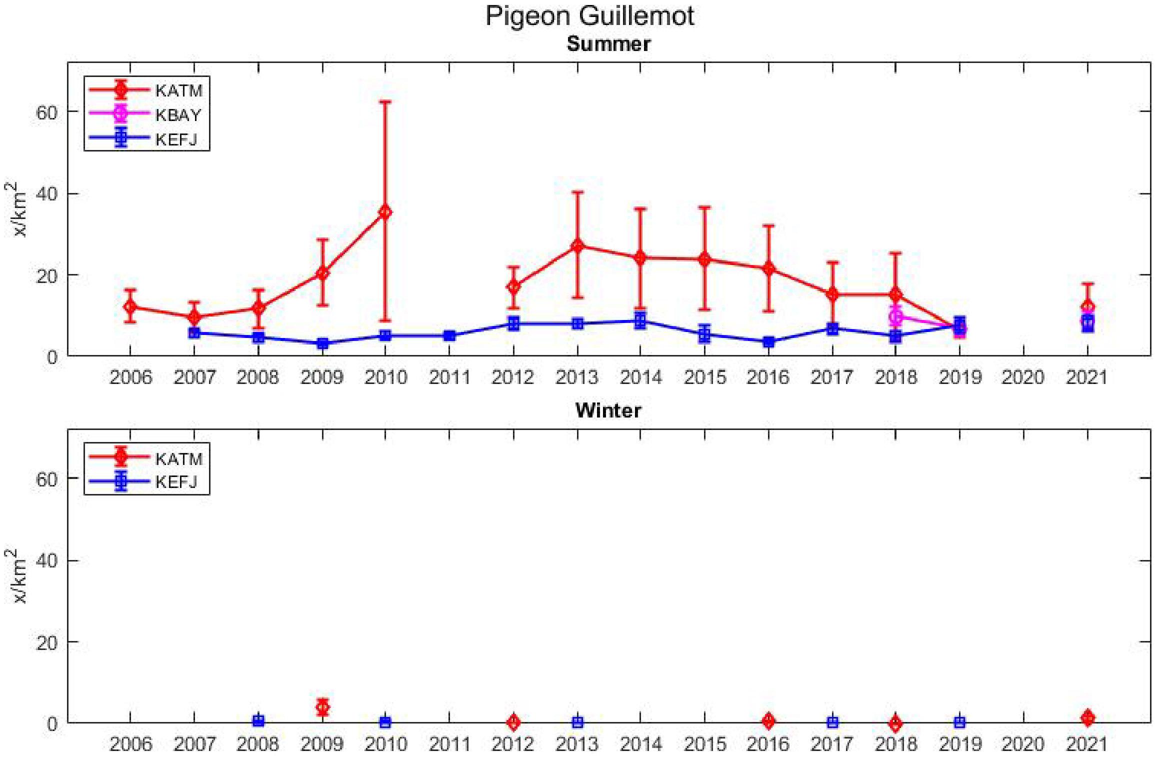

Figure 24. Pigeon guillemot (Cepphus columba) *density estimates in summer (top) in Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), and Kenai Fjords National Park (KEFJ) and winter (bottom) in KATM and KEFJ. Error bars indicate ±1SE.*

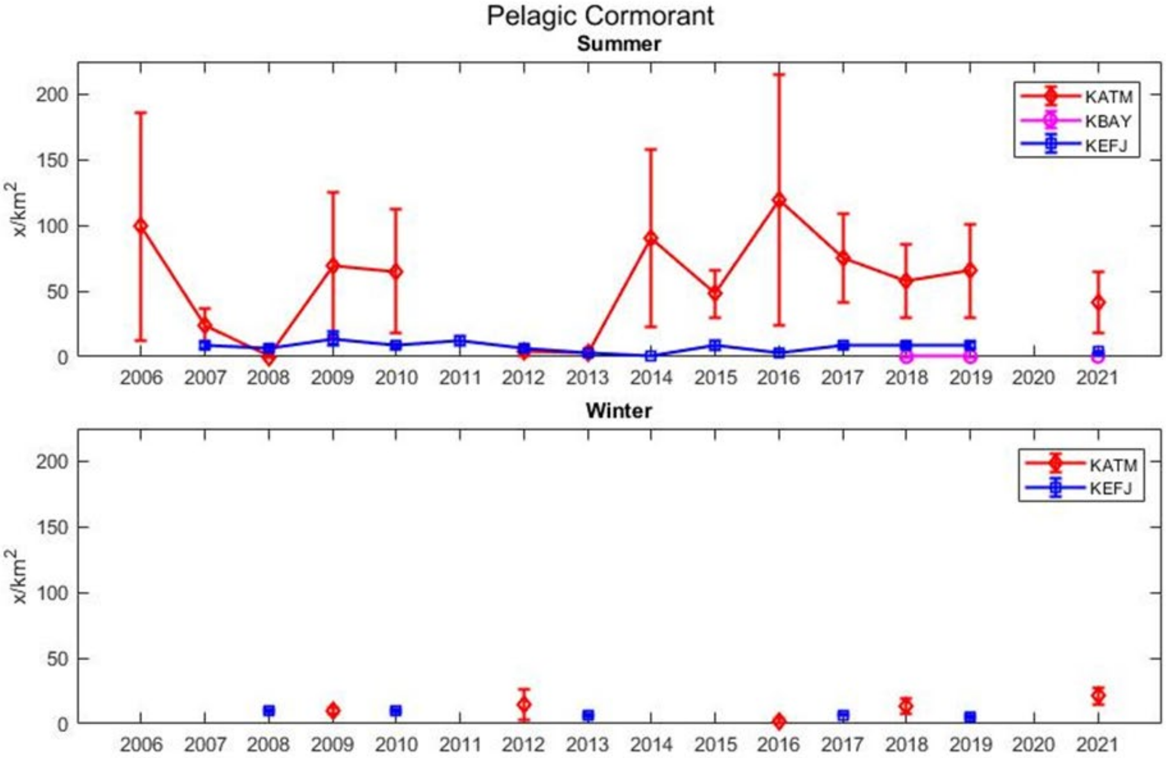

Figure 25. Pelagic cormorant (Phalacrocorax pelagicus) *density estimates in summer (top) in Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), and Kenai Fjords National Park (KEFJ) and winter (bottom) in KATM and KEFJ. Error bars indicate ±1SE.*

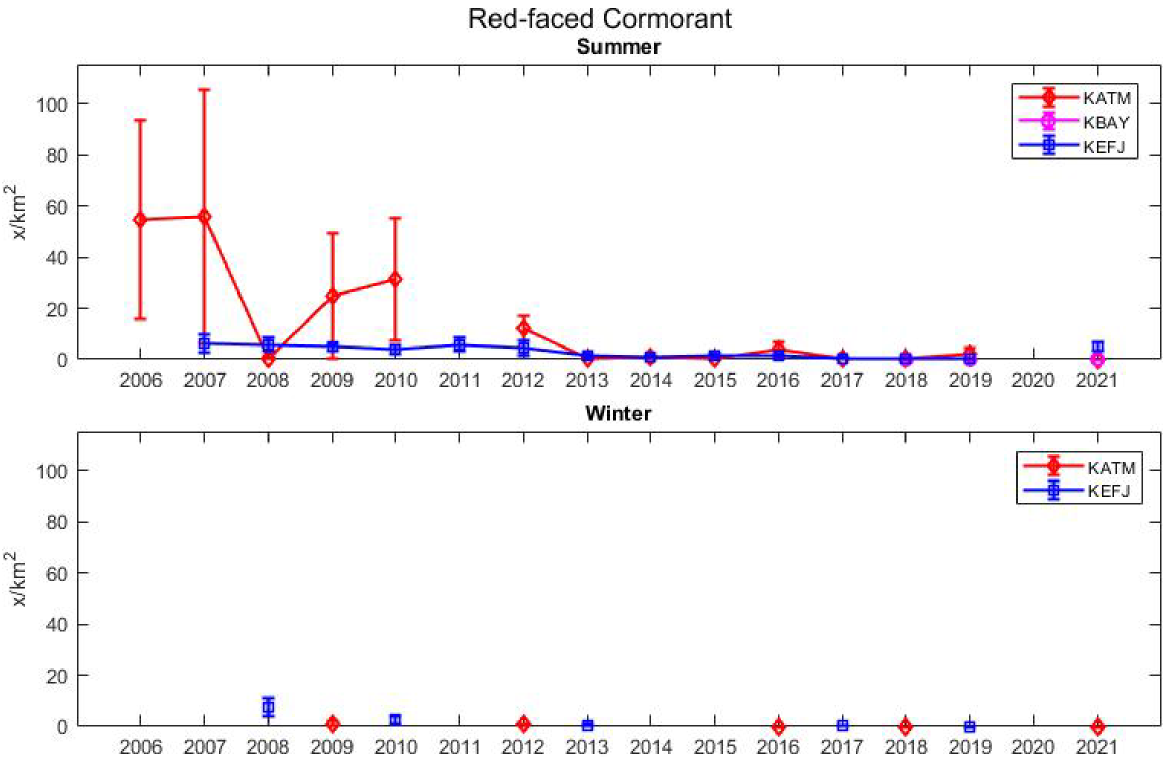

Figure 26. Red-faced cormorant (Phalacrocorax urile) *density estimates in summer (top) in Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), and Kenai Fjords National Park (KEFJ) and winter (bottom) in KATM and KEFJ. Error bars indicate ±1SE.*

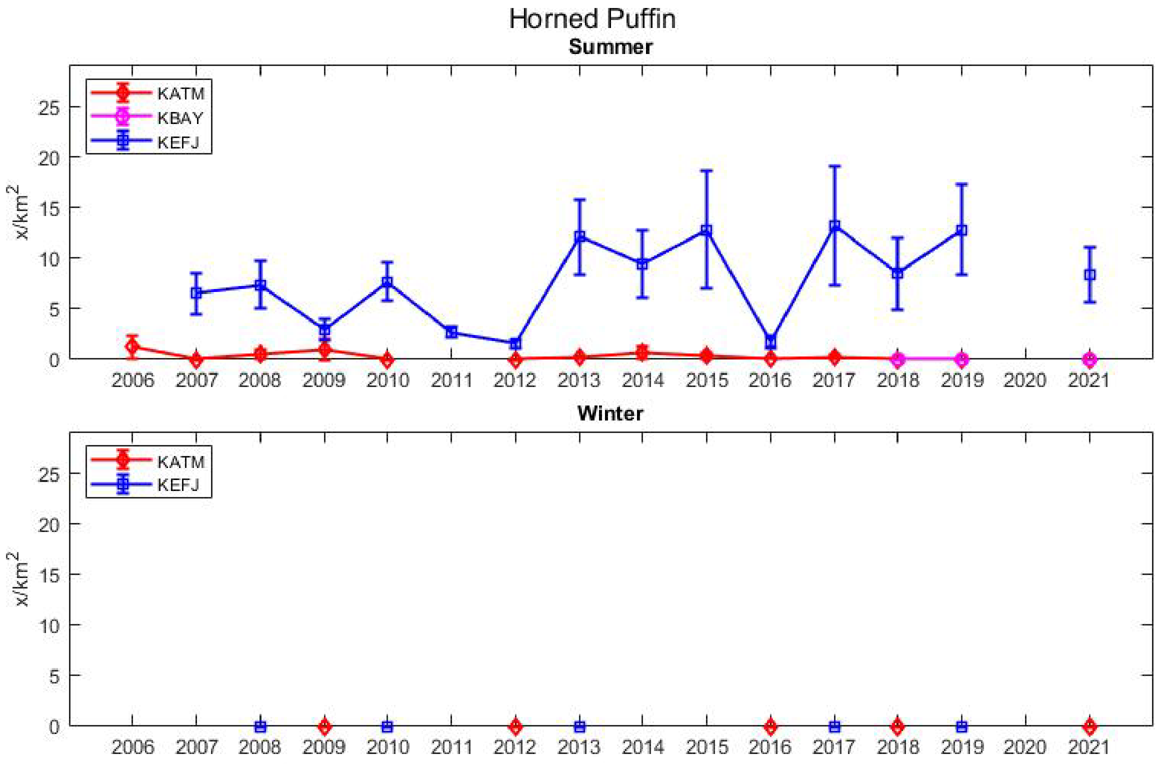

Figure 27. Horned puffin (Fratercula corniculata) *density estimates in summer (top) in Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), and Kenai Fjords National Park (KEFJ) and winter (bottom) in KATM and KEFJ. Error bars indicate ±1SE.*

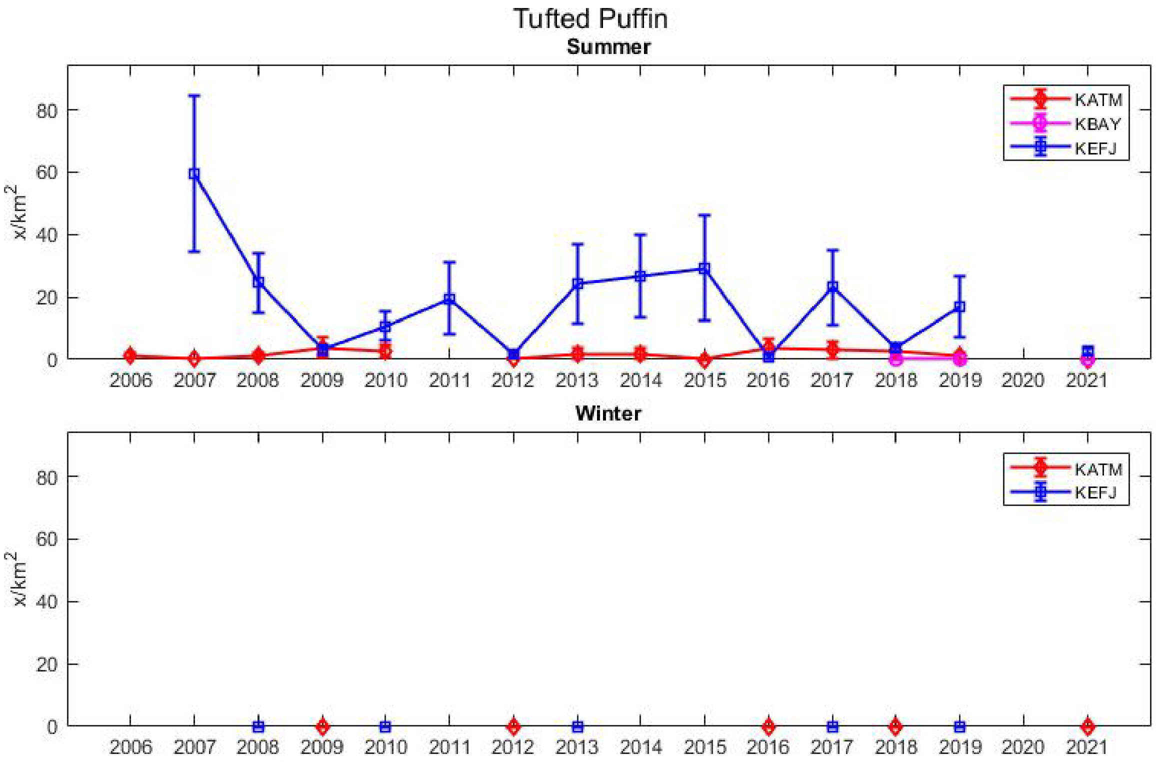

Figure 28. Tufted puffin (Fratercula cirrhata) *density estimates in summer (top) in Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), and Kenai Fjords National Park (KEFJ) and winter (bottom) in KATM and KEFJ. Error bars indicate ±1SE.*

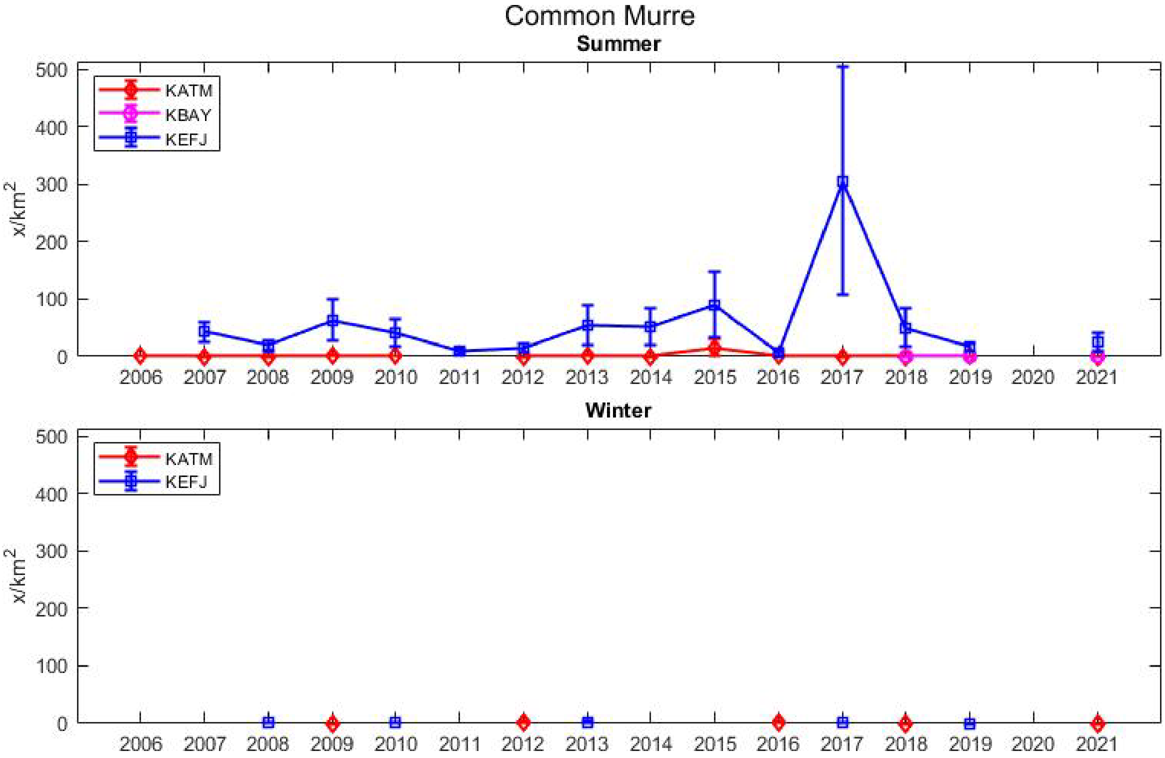

Figure 29. Common murre (Uria aalge) *density estimates in summer (top) in Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), and Kenai Fjords National Park (KEFJ) and winter (bottom) in KATM and KEFJ. Error bars indicate ±1SE.*

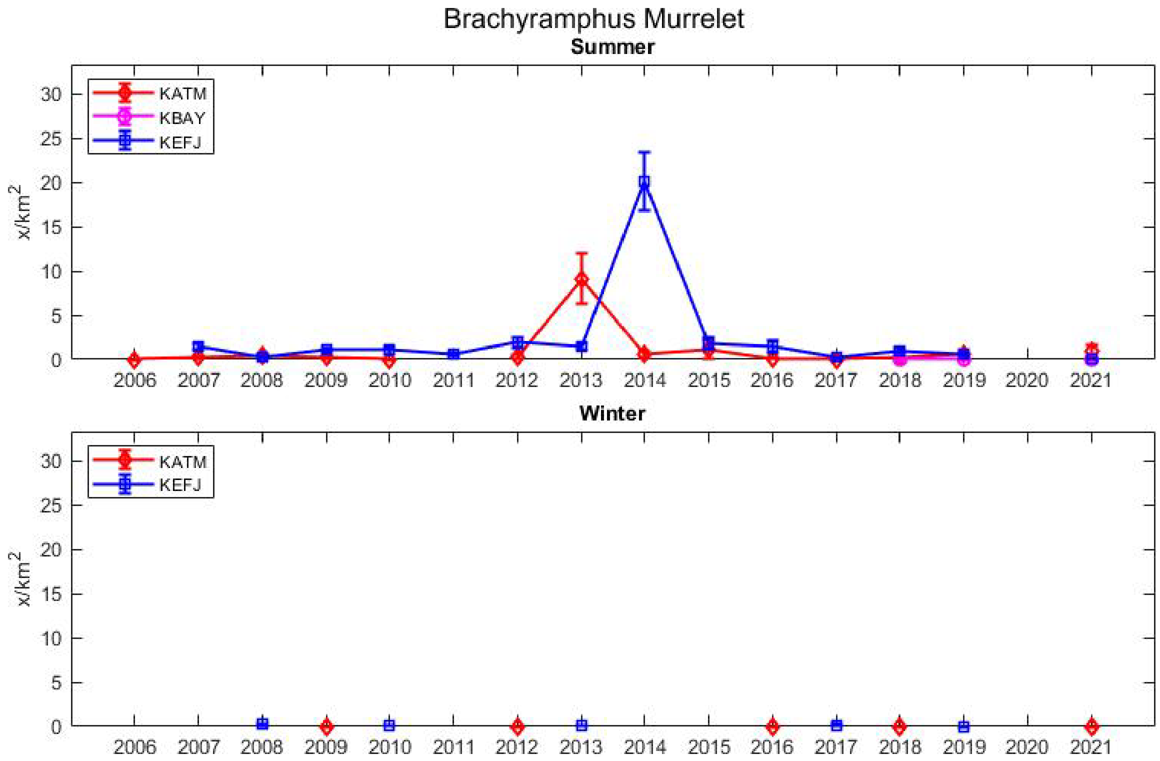

Figure 30. Brachyramphus murrelet (Brachyramphus spp.) *density estimates in summer (top) in Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), and Kenai Fjords National Park (KEFJ) and winter (bottom) in KATM and KEFJ. Error bars indicate ±1SE.*

The following figures are of marine mammals observed during our systematic skiff-based, shoreline surveys. These density estimates include counts from haulouts, when encountered. As with many of the bird species, regional differences exist (Figs. 31-33), likely driven by habitat. Sea otter density estimate differences between the skiff-based and aerial survey data are currently being explored that may help answer how and why populations vary in terms of density (Figs. 32 and 37).

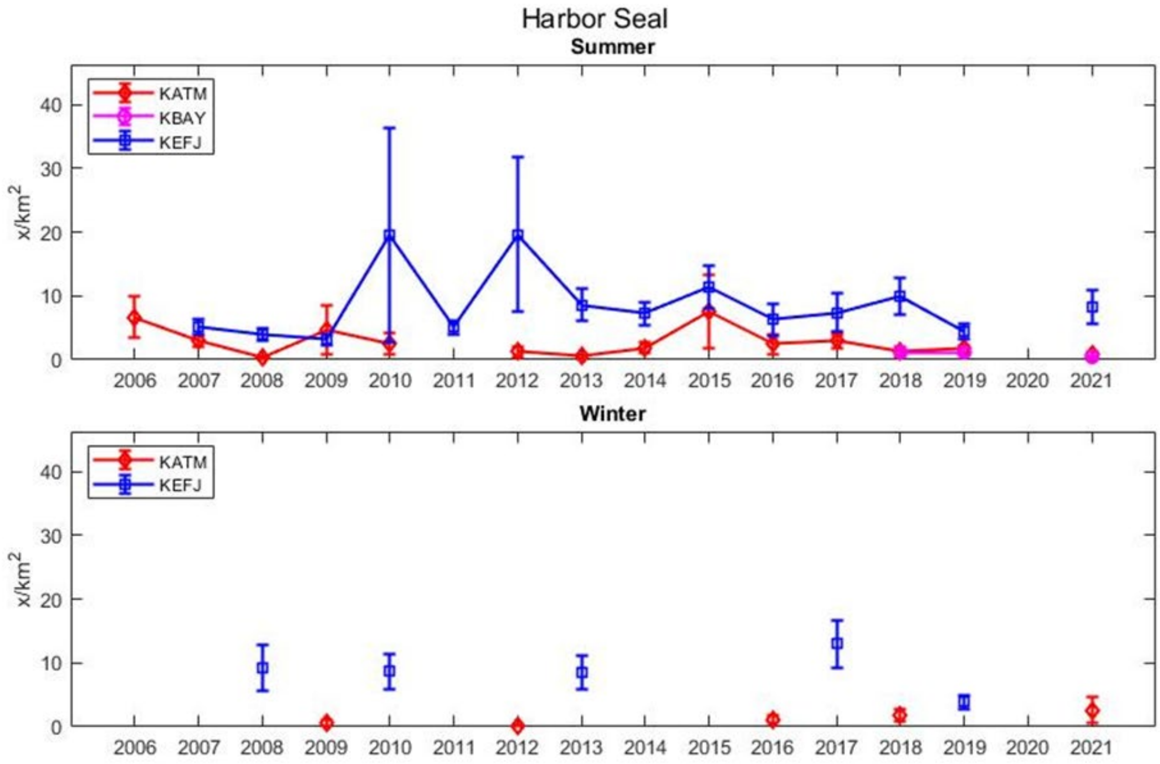

Figure 31. Harbor seal (Phoca vitulina) *density estimates in summer (top) in Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), and Kenai Fjords National Park (KEFJ) and winter (bottom) in KATM and KEFJ. Error bars indicate ±1SE.*

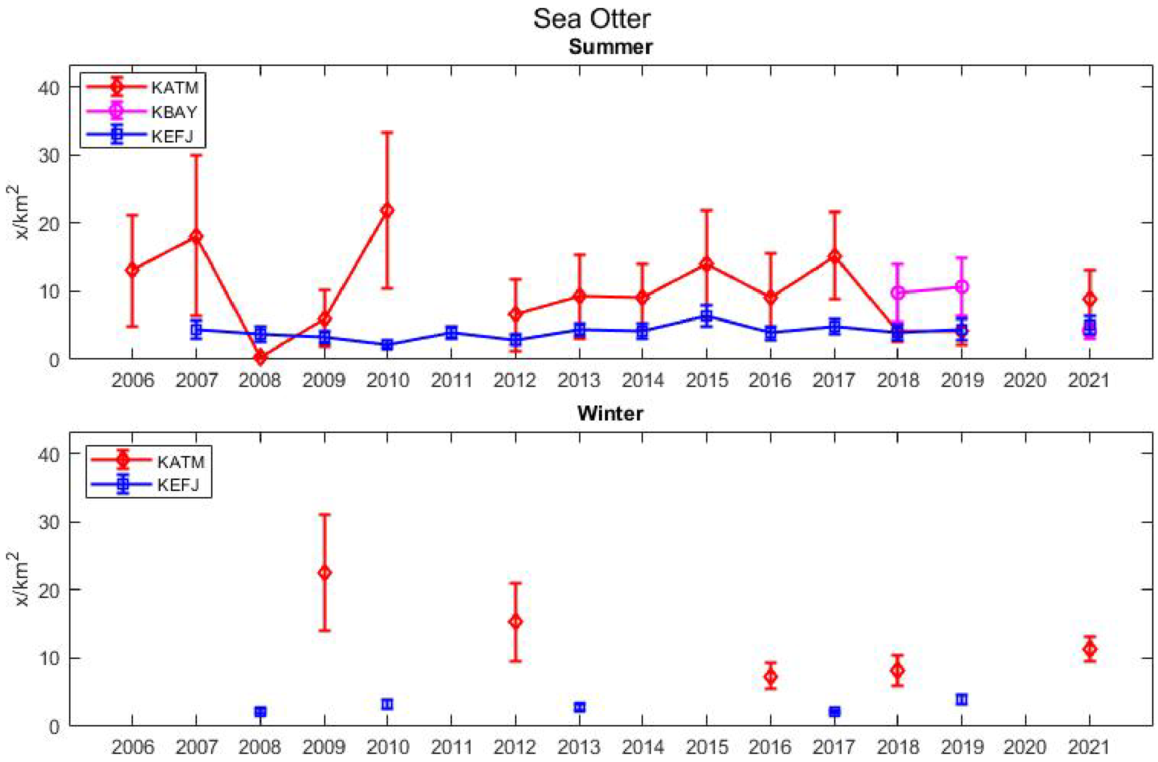

Figure 32. Sea otter (Enhydra lutris) *density estimates in summer (top) in Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), and Kenai Fjords National Park (KEFJ) and winter (bottom) in KATM and KEFJ. Error bars indicate ±1SE.*

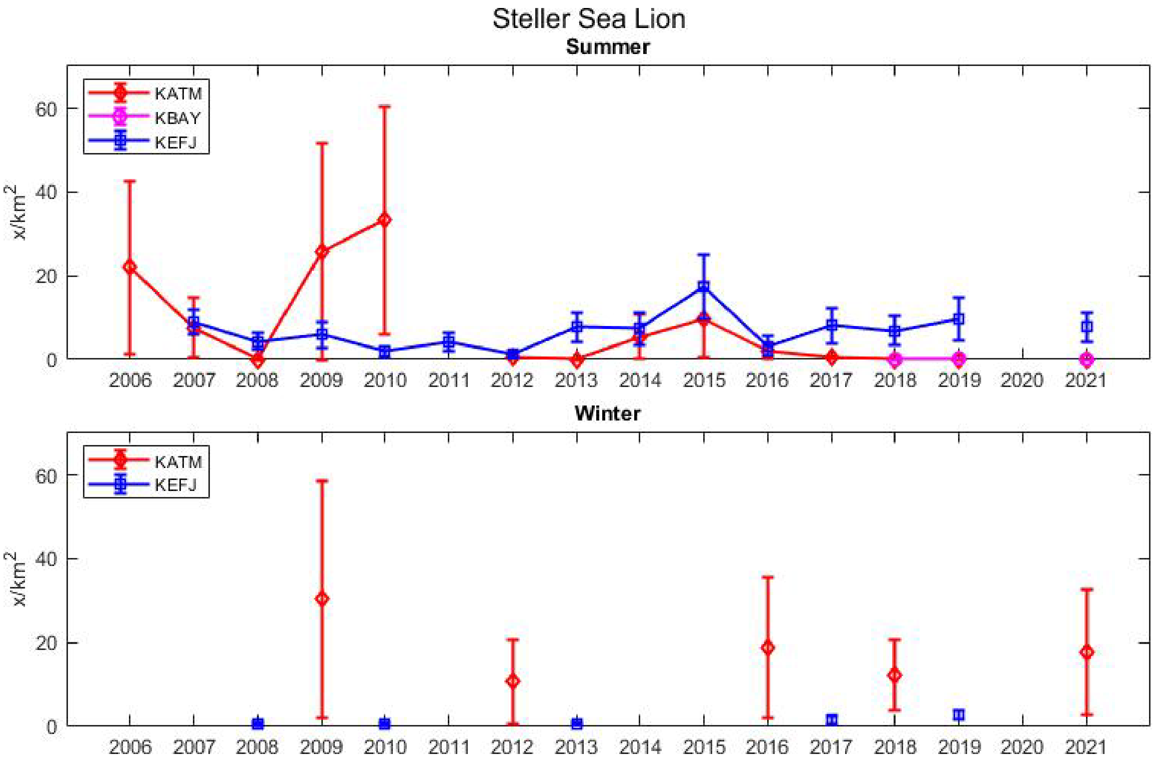

Figure 33. Steller sea lion (Eumetopias jubatus) *density estimates in summer (top) in Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), and Kenai Fjords National Park (KEFJ) and winter (bottom) in KATM and KEFJ. Error bars indicate ±1SE.*

Black Oystercatcher

Black oystercatcher *(Haematopus bachmani)* nest density appeared to be variable within and across all four regions with no discernable response to the PMH (Fig. 34), unlike the survey results from the marine bird and mammal surveys, which indicated a positive trend coincident with the PMH and increased prey availability (Fig. 21). We interpret this to suggest that establishment of nests is driven by factors other than food availability, such as availability of nest sites and environmental conditions during nonbreeding periods. This is further supported by the lack of response in the black oystercatcher diet to the PMH. Limpets continued to dominate diet of black oystercatcher chicks across all four regions (Fig 35).

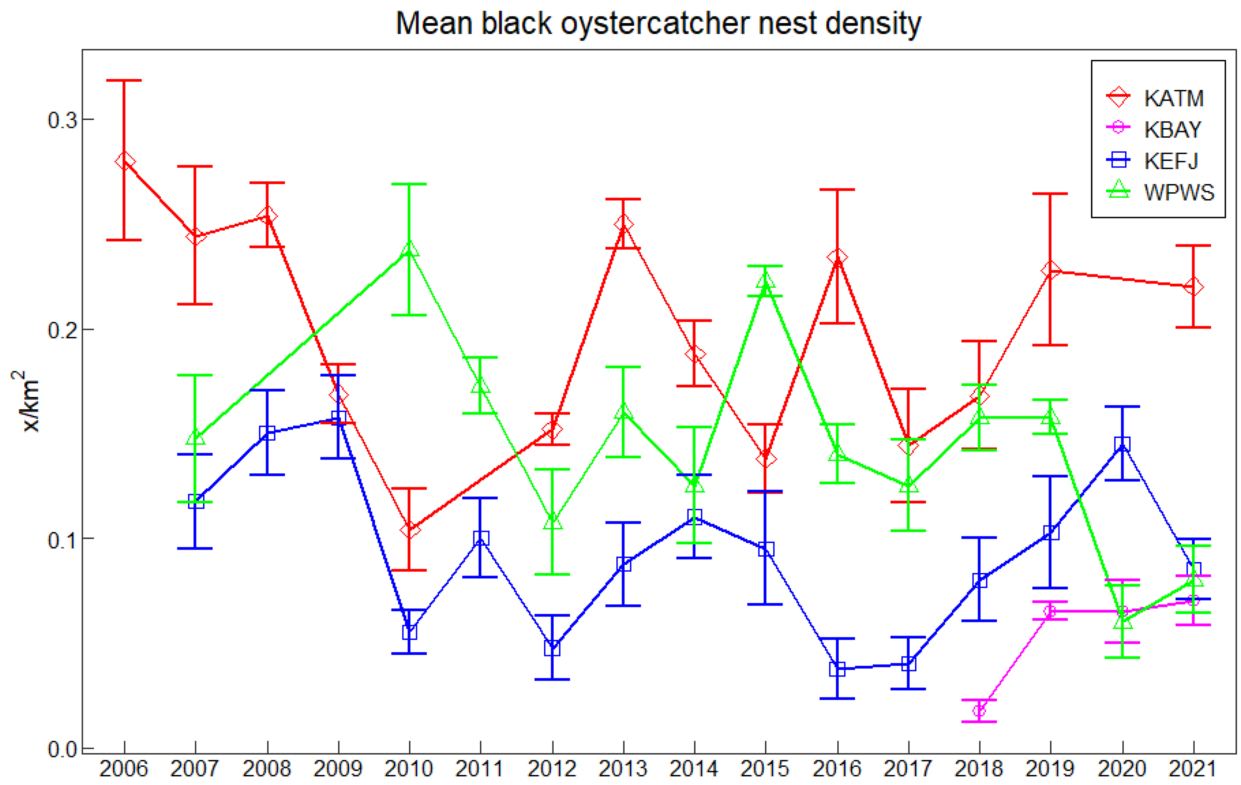

Figure 34. Black oystercatcher nest density estimates across all four Gulf Watch Alaska regions: Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), Kenai Fjords National Park (KEFJ), and western Prince William Sound (WPWS). Error bars indicate ±1SE.

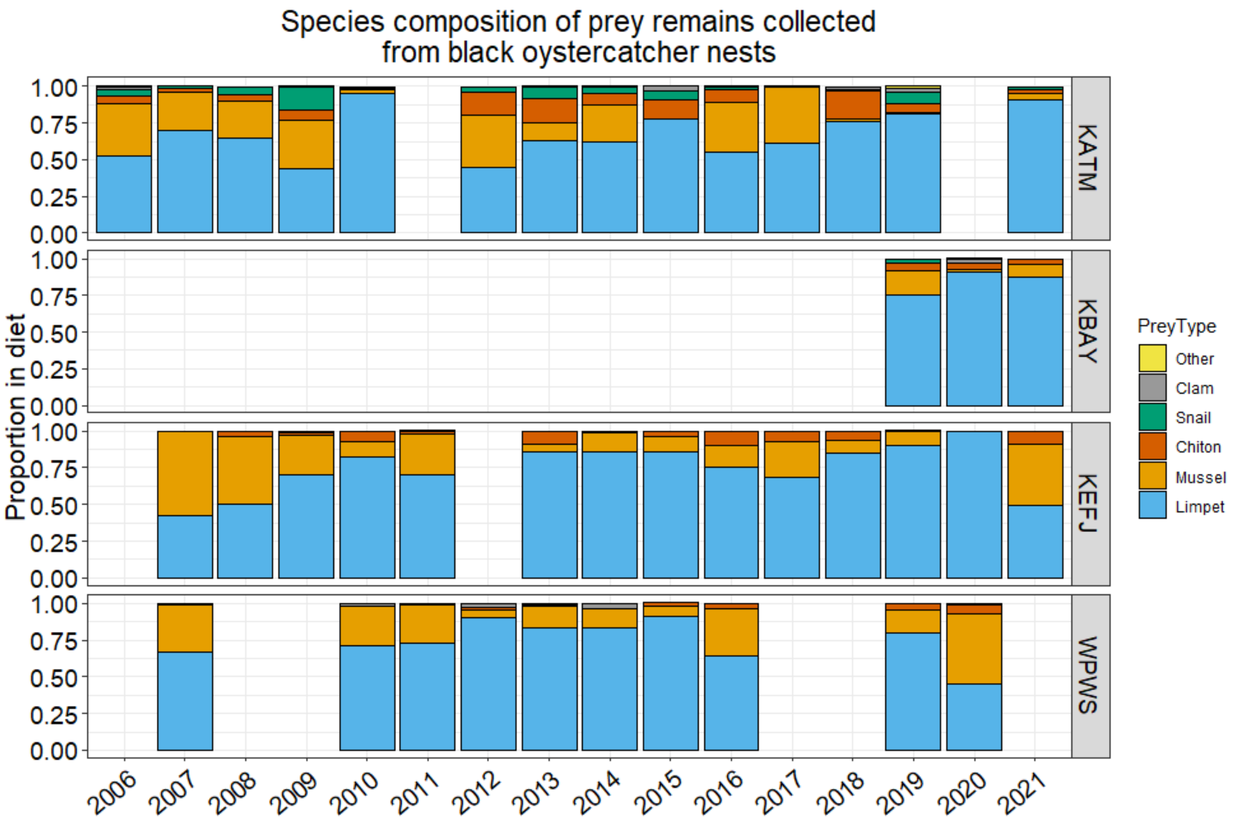

Figure 35. Species composition of prey remains collected at black oystercatcher nests across all four Gulf Watch Alaska regions: Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), Kenai Fjords National Park (KEFJ), and western Prince William Sound (WPWS).

Sea Otters

Sea otter *(Enhydra lutris)* abundance has been stable in KEFJ since 2006 and stable in KATM in recent years after achieving carrying capacity following re-occupation (Coletti et al. 2016). The sea otter population in KBAY also appears to have been stable since 2012, after a rapid increase in abundance since the early 2000s (Garlich-Miller et al. 2018). Survey data from WPWS show increasing trends through 2011, resulting from recovery from the EVOS, and generally stable numbers since (Esslinger et al. 2021) (Figs. 36 and 37).

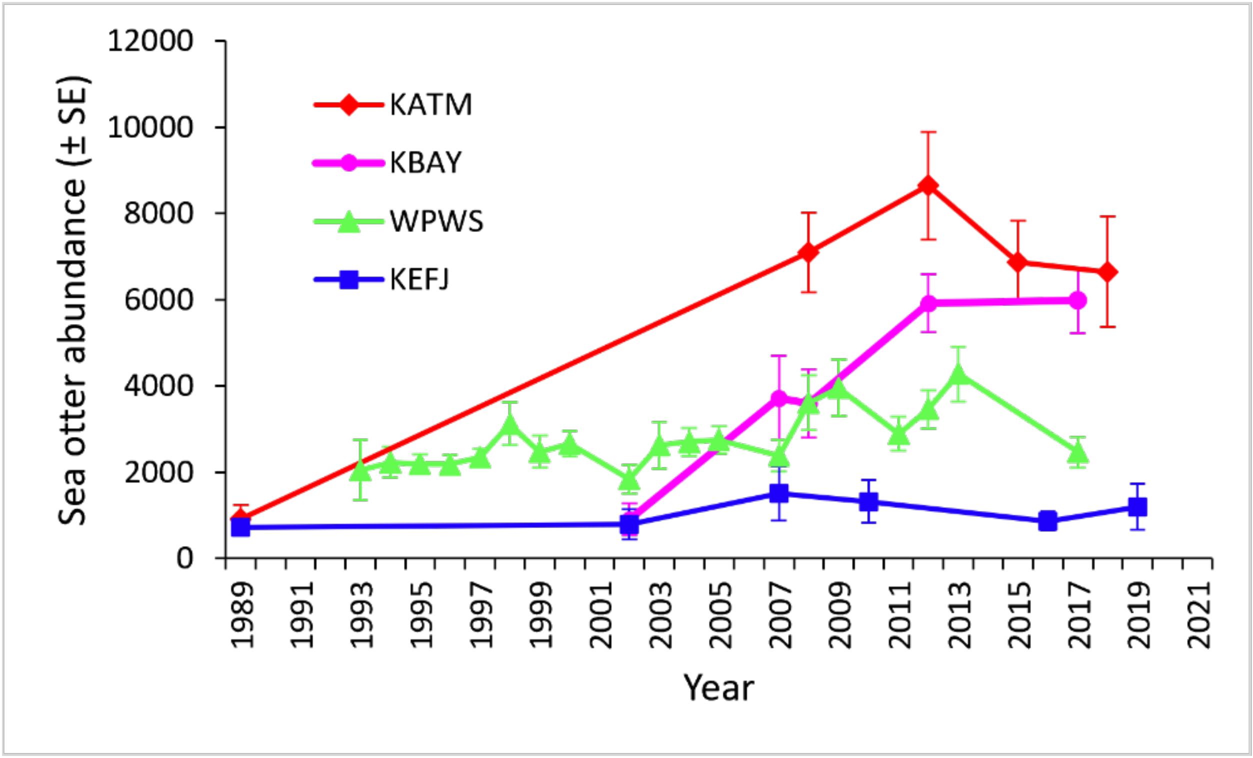

Figure 36. Sea otter abundance estimates across all four Gulf Watch Alaska regions: Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), Kenai Fjords National Park (KEFJ), and western Prince William Sound (WPWS). Error bars indicate ±1SE.

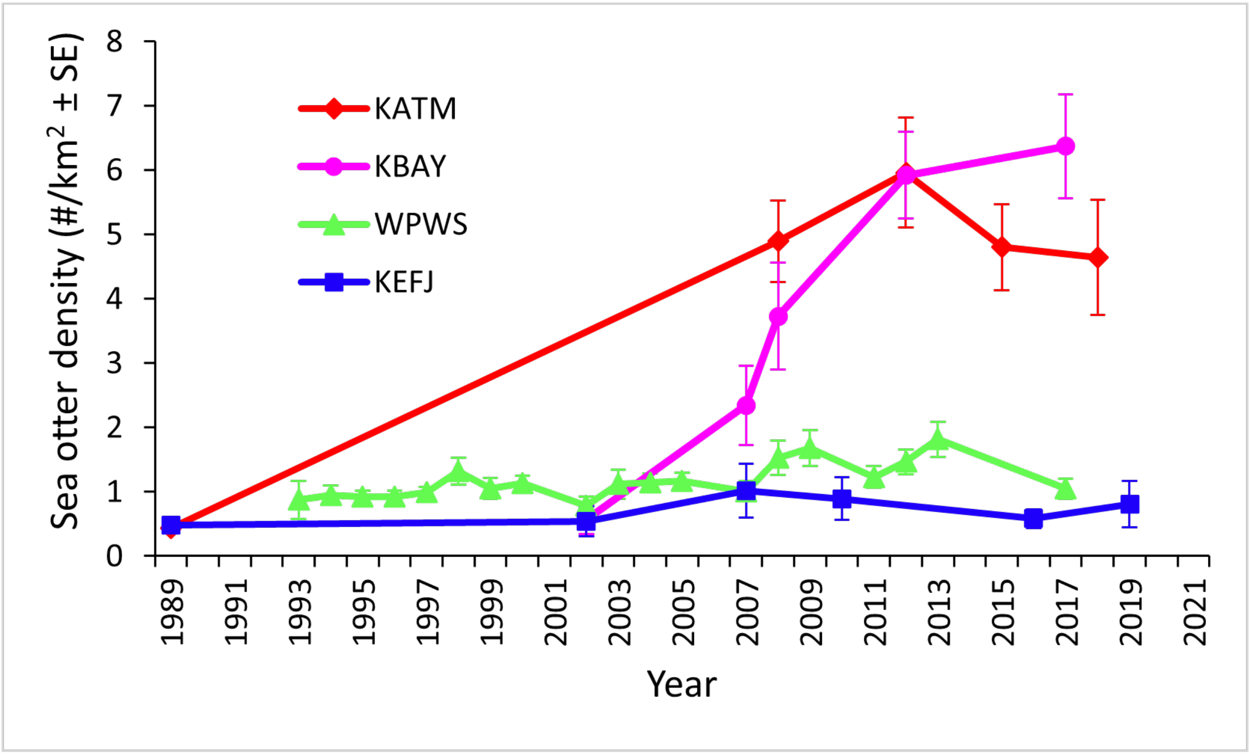

Figure 37. Sea otter density estimates across all four Gulf Watch Alaska regions: Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), Kenai Fjords National Park (KEFJ), and western Prince William Sound (WPWS). Error bars indicate ±1SE.

Sea otter responses to changing ocean conditions associated with the PMH may have resulted in shifts in diet but not in energy intake rates (EIR) (Fig. 38). Across the sea otter's range, numerous studies have documented that energy intake rates around 4-6 kcal/min are indicative of populations that are near a food-dictated carrying capacity. Across all four Nearshore Component study regions, EIR have stabilized at levels that suggest sea otters are at or near carrying capacity (Fig. 38). It is noteworthy that, despite EIR evidence of populations near carrying capacity in all regions, abundance and density estimates of sea otters differ widely among regions (Figs. 36 and 37). We interpret this as a consequence of differing habitat quality, likely resulting from differing bathymetry and substrate, and thus prey availability, across our different study regions (Coletti et al. 2016).

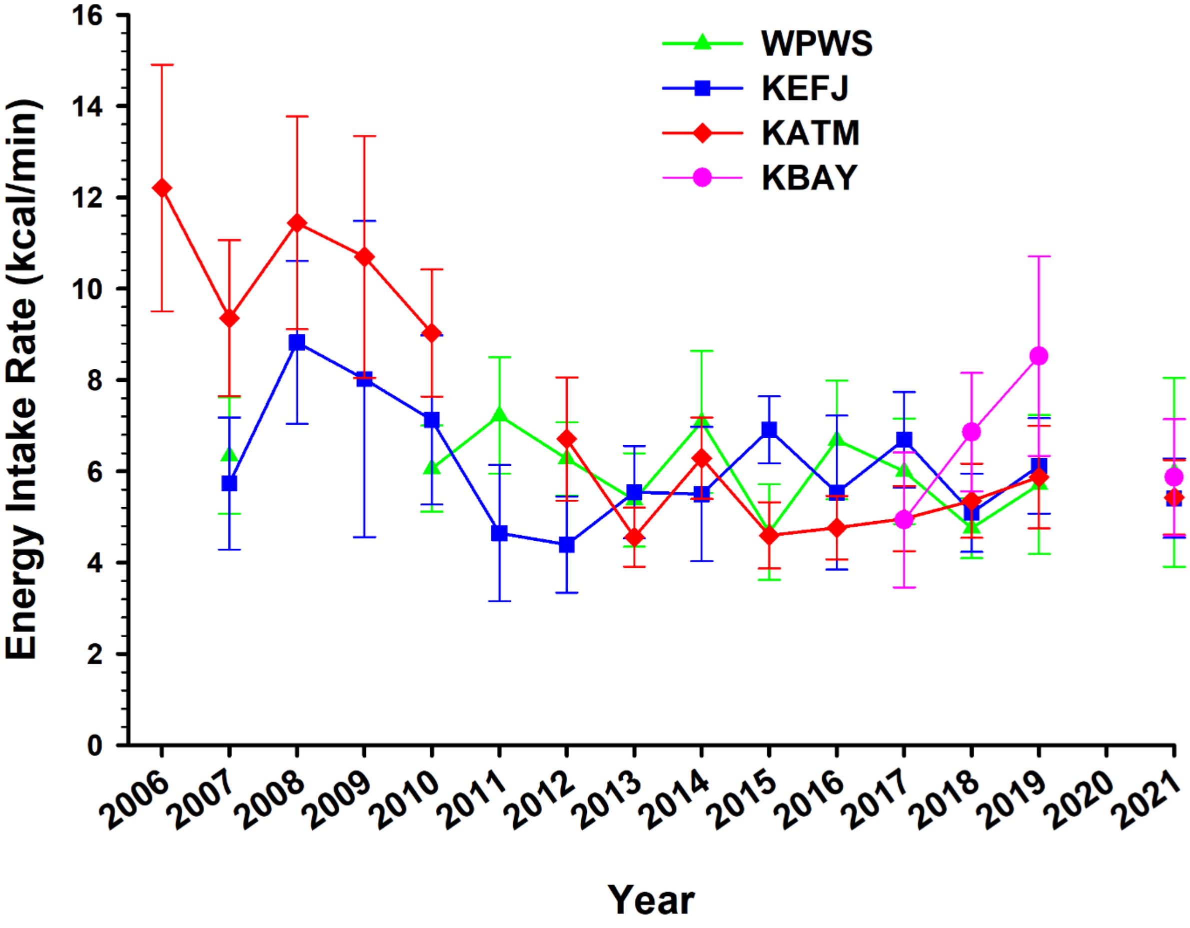

Figure 38. Sea otter energy intake rates across all four Gulf Watch Alaska regions: Katmai National Park and Preserve (KATM), Kachemak Bay (KBAY), Kenai Fjords National Park (KEFJ), and western Prince William Sound (WPWS). Error bars indicate ±1SE.

Monitoring both predator diets and prey abundance allows us to better understand nearshore ecosystem processes and responses to perturbations across the GOA. Foraging observations and fecal (spraint) composition data have been used to examine spatial and temporal variation in sea otter diet across the GOA since the early-mid 2000s. Based on foraging observations, clams dominated sea otter diet in KATM and WPWS, while in KEFJ mussels dominated. In KBAY, clam and mussel contributions were similar based on foraging observations. In addition to spatial differences, temporal shifts in the proportions of prey in sea otter diets were evident in some regions and were likely related to shifts in prey abundance. At KATM, mussels increased in observational data in 2015 concurrent with increased mussel abundance in the nearshore system. Decreased clams in sea otter diets at KATM were coincident with decreasing clam biomass and increasing numbers of sea otters, suggesting that otters were near a food-dictated carrying capacity (Figs. 38-42).

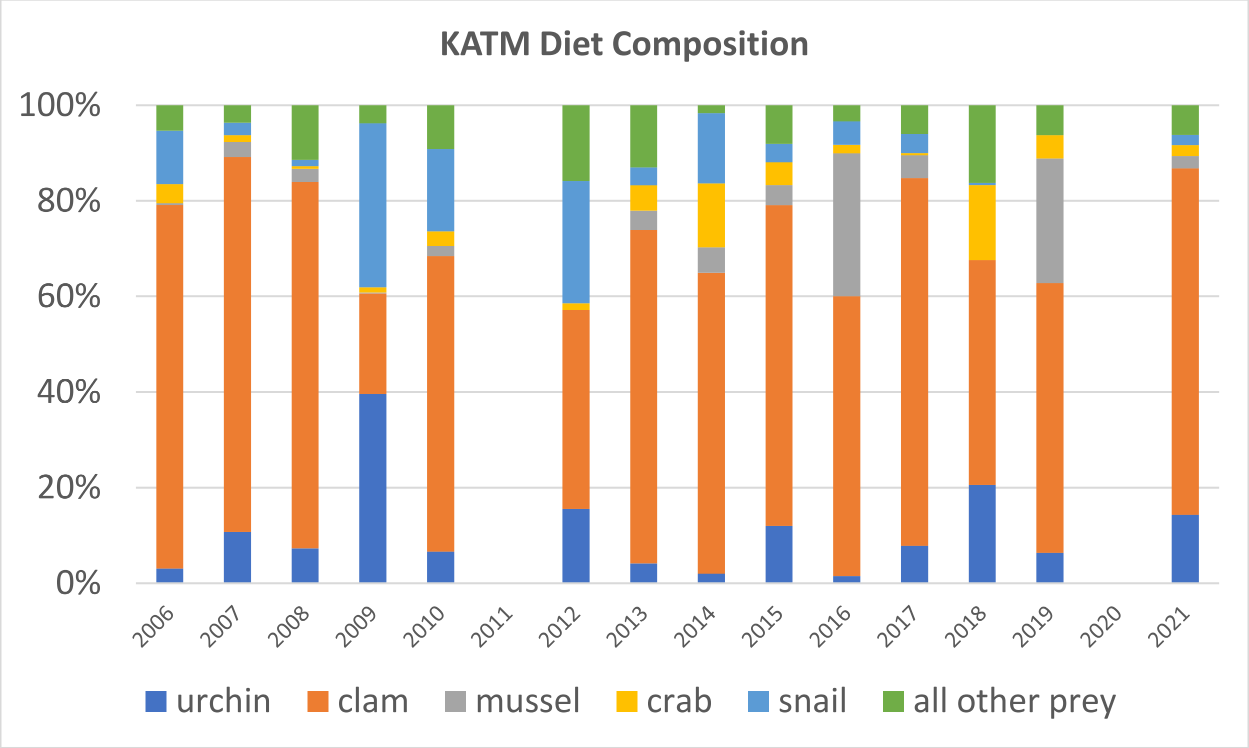

Figure 39. Species composition of sea otter prey from foraging observations in Katmai National Park and Preserve (KATM), 2006-2021.

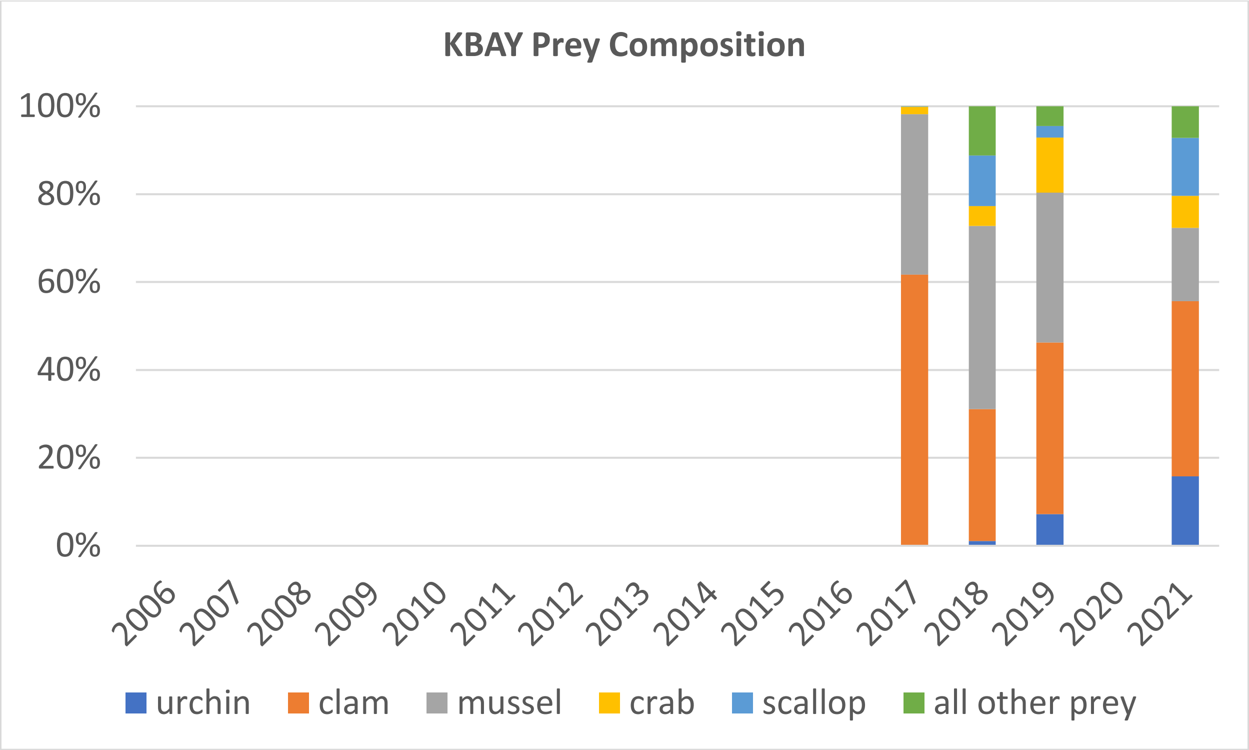

Figure 40. Species composition of sea otter prey from foraging observations in Kachemak Bay (KBAY), 2017-2021.

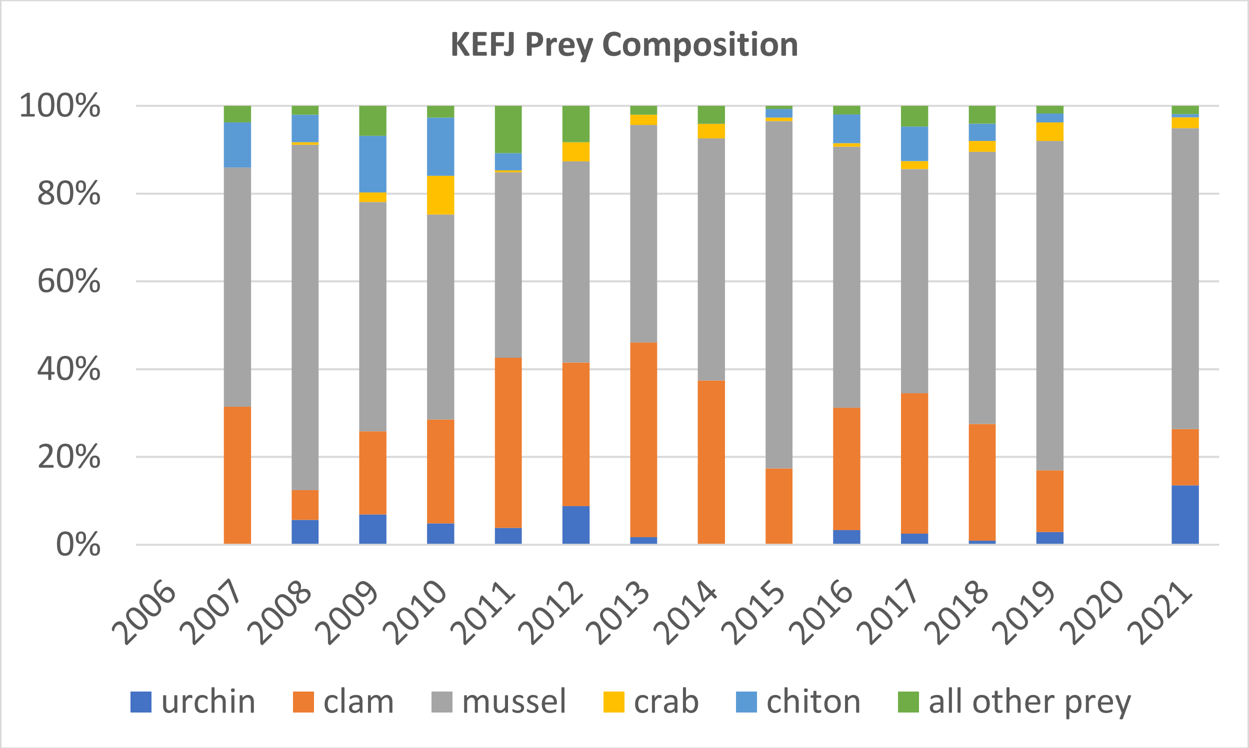

Figure 41. Species composition of sea otter prey from foraging observations in Kenai Fjords National Park (KEFJ) 2007-2021.

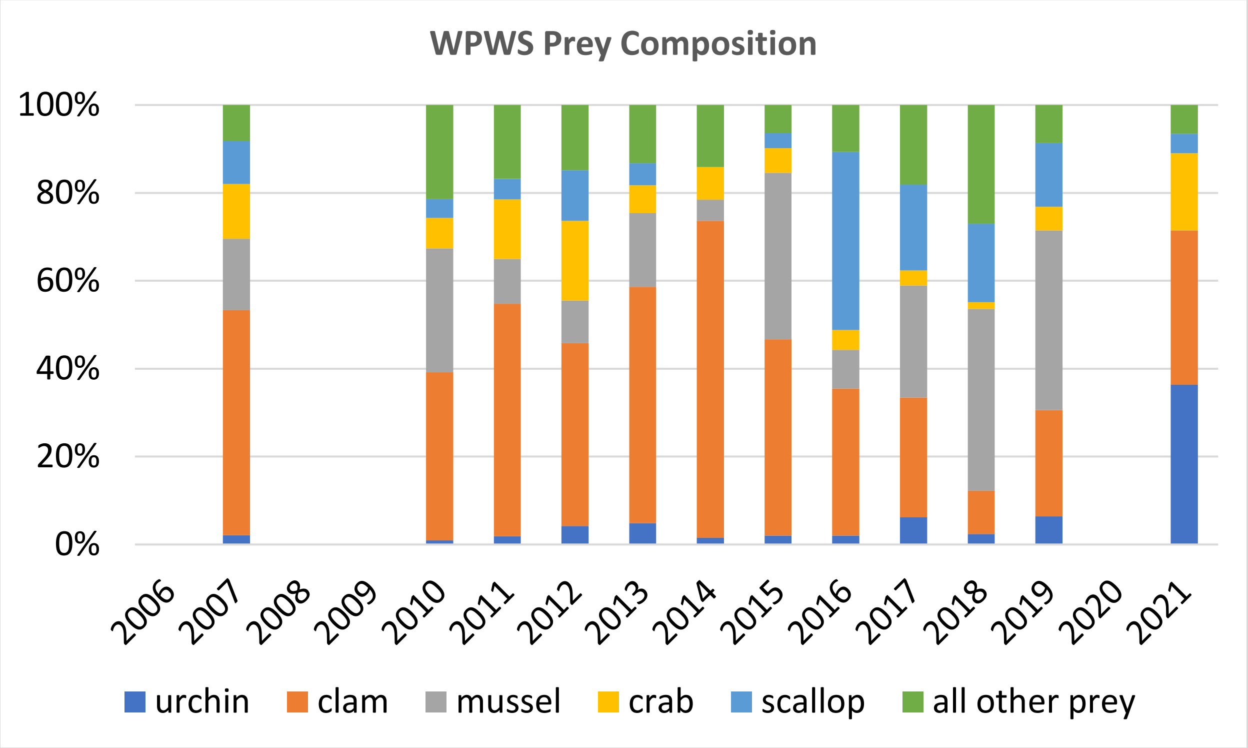

Figure 42. Species composition of sea otter prey from foraging observations in western Prince William Sound (WPWS), 2007-2021.

Spraint data, reflecting winter/spring diet offer a different window into sea otter diet composition. At KATM, clams predominate the diet of sea otters, reflected in their presence in 77% of spraint sampled. The presence of clams in spraint averaged 88% prior to 2014 and declined to 67% after the PMH. Concurrently, the presence of mussels increased from 22% to 59% during these same time periods, indicating a response to the change in mussel abundance (Fig. 43). At KEFJ mussels were the dominant prey type identified from spraint, averaging 80% presence over all years (Fig. 44). In WPWS, clams were the predominate prey in 16 of 20 years, averaging 60% presence. Mussels were the second most prevalent prey type, present on average in 53% of the spraint observed. Crab and urchin were also often detected in WPWS spraint, averaging 34% and 25% respectively, while urchins were rarely found in other regions (Fig. 45).

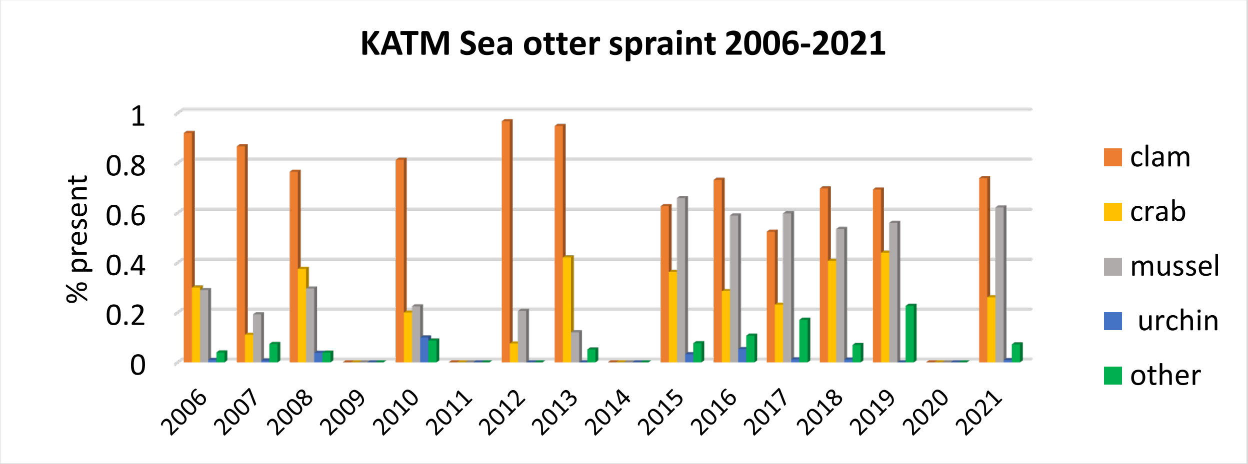

Figure 43. Species composition of sea otter spraint in Katmai National Park and Preserve (KATM), 2006-2021.

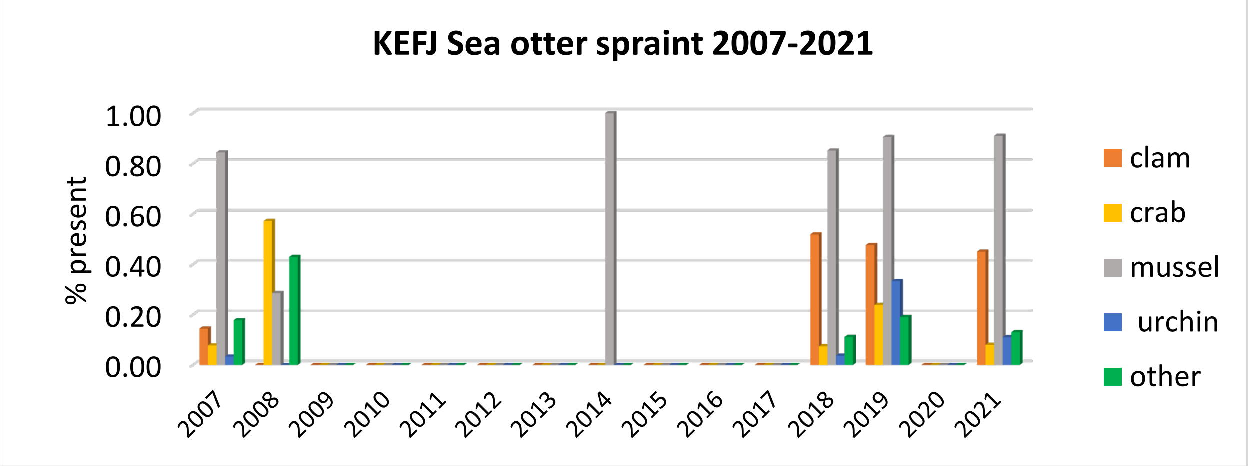

Figure 44. Species composition of sea otter spraint in Kenai Fjords National Park (KEFJ), 2007-2021.

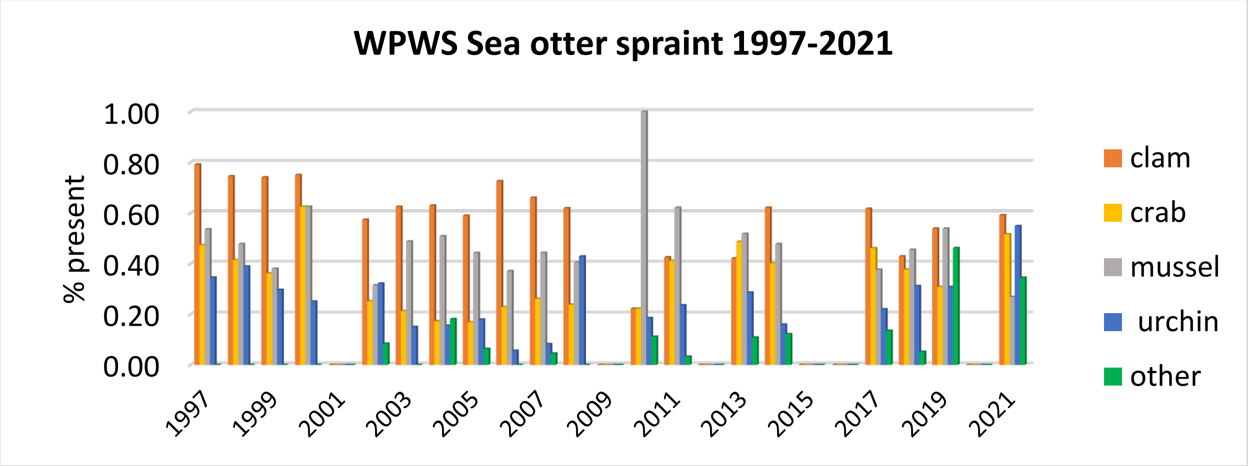

Figure 45. Species composition of sea otter spraint in western Prince William Sound (WPWS), 1997-2021.

Age-at-death data have been shown to be another useful metric for understanding sea otter population status (e.g., Monson et al. 2000). Data from KATM did not meet the expectation that typical "natural" sea otter mortality is age-dependent, with juveniles and older adults being the major components of the age-at-death structure of the population (Kenyon, 1969, Monson et al. 2000). Instead, data from KATM indicated high proportions of mortality among prime-aged animals based on carcass data (Figs. 46 and 47). With additional research, we found a non-age-specific mortality factor at work, specifically brown bear predation, resulting in a recent publication (Monson et al. 2022).

Figure 46. Proportion of the age of dying sea otters in Katmai National Park and Preserve (KATM) vs. western Prince William Sound (WPWS), 2006-2021. Blue bars represent age 0-1 (juveniles), orange bars represent age 2-8 (prime age), and grey bars represent 8+ year old animals (aged animals).

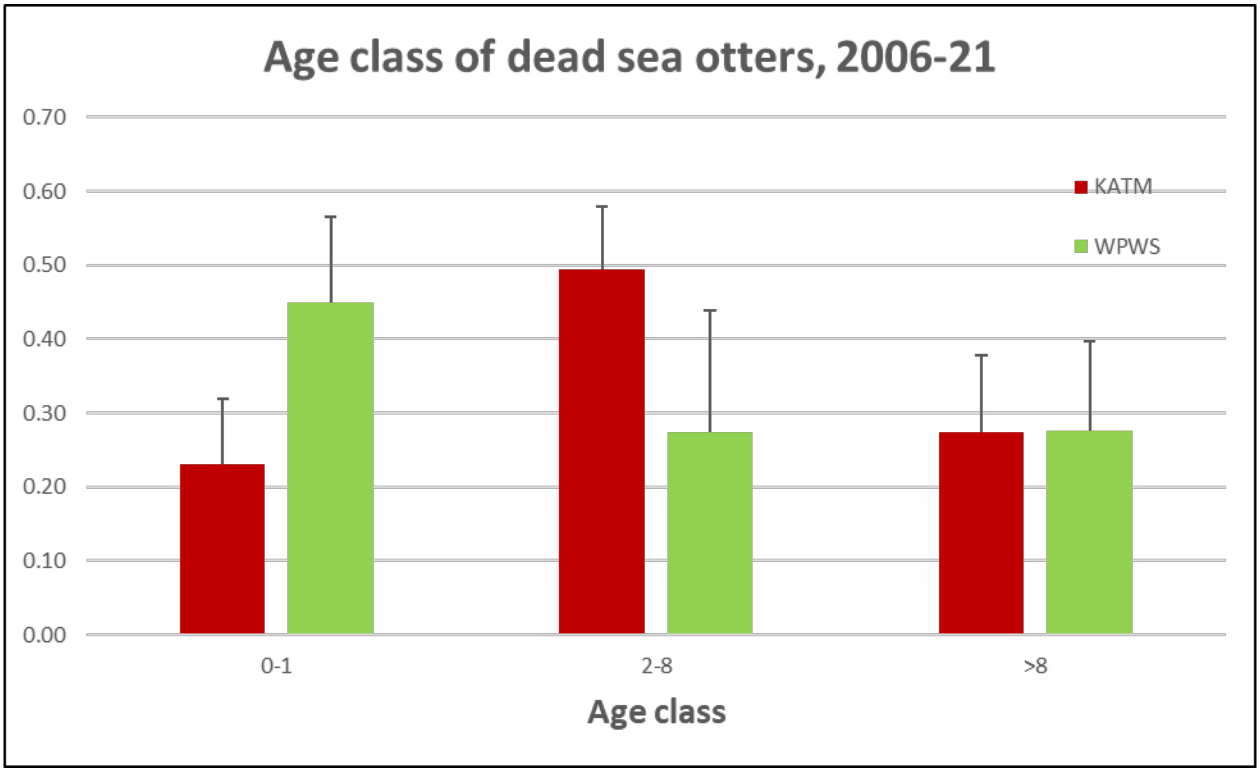

Figure 47. Proportional breakdown of age-class of the dying sea otter population in Katmai National Park and Preserve (KATM) and western Prince William Sound (WPWS), 2006-2021. Notice the high proportion of prime age animals in the KATM population.

DISCUSSION

Long-term data generated by the Nearshore Component of GWA have proven to be valuable for detecting and evaluating disturbances to marine ecosystems of the northern GOA, including the Pacific marine heatwave, sea star wasting, and recovery from the *Exxon Valdez* oil spill. Our findings provide important perspectives on factors affecting coastal marine communities that are important to the GOA ecosystem as well as to the human communities that depend on them. In addition, our improved understanding of nearshore marine ecosystems allows clearer predictions about how future variation, both anticipated (such as climate change) and unanticipated, may affect nearshore environments.

During 2017-2021, we successfully completed the Nearshore Component monitoring element of GWA. Importantly, this period was the first in which all Nearshore Component work was merged under a single project, combining work in KBAY with that of KATM, KEFJ, and WPWS regions. This helped continue and strengthen existing collaborations, resulting in even greater geographic coverage when considering factors influencing intertidal communities. In addition, higher-trophic level monitoring (e.g., marine bird and mammal surveys, black oystercatcher nest monitoring, sea otter foraging observations) that was regularly conducted in KATM, KEFJ, and WPWS also was instituted in KBAY during this period. The addition of higher-trophic level work allows for a full food-web consideration of factors that influence each region and greater power to evaluate causes and consequences of changes observed at the scale of the northern Gulf of Alaska.

Although the COVID-19 global pandemic affected our ability to conduct field work, particularly in summer 2020, we collected data throughout the period and have found that some data gaps can be compensated through the full timeline of data collection. Because many of the data streams pre-date GWA, resulting in longer timelines, the consequence of the loss of some data collection due to the pandemic is reduced.

We evaluated effects of a major and unanticipated phenomenon, the PMH, as part of the GWA Nearshore Component sampling and analysis efforts during the 2017-2021 period. Significant changes to the physical conditions of marine ecosystems are widely recognized to have bottom-up effects that transmit through pelagic and nearshore food webs (e.g., Anderson and Piatt 1999, Harley et al. 2006). Because of the magnitude of the PMH, marine monitoring should be expected to detect the physical phenomenon and subsequent biological responses; GWA generally and the Nearshore Component specifically met that expectation. Given that current climate change projections suggest increased frequency and duration of marine heatwaves (Frölicher et al. 2018), monitoring and understanding impacts of heatwaves on nearshore ecosystems is important.

Temperature increases associated with the PMH were documented in intertidal waters of the northern GOA and persisted for multiple years in all our study regions, as documented in a recent paper including Nearshore Component authors (Danielson et al. 2022). As one aspect of our considerations of subsequent biological effects, we examined rocky intertidal community structure across all Nearshore Component study regions. Before the PMH (2012-2014), community structure differed among regions, presumably reflecting region-specific static and dynamic drivers of intertidal community composition. During and after the PMH (2015-2019), we found that macroalgal species declined across all regions. Observed Gulf-wide shifts from an autotroph-macroalgal dominated rocky intertidal to a heterotroph- filter-feeder dominated state illustrate important changes that our monitoring program was able to detect. As a result of the coherent Gulf-wide changes to the structure of rocky intertidal communities, there was homogenization of these communities at relatively large scales. We conclude that strong, large-scale oceanographic events, like the PMH, may override local drivers to similarly influence patterns of intertidal community structure across regions. These results are presented in a recent synthesis paper (Weitzman et al. 2021).

Because of the food web-based design of the nearshore monitoring program, we were able to evaluate responses of upper trophic-level nearshore-reliant species (such as sea stars, sea otters and benthic-feeding marine birds) to observed shifts in community structure across the Gulf of

Alaska (Weitzman et al.2021). For example, sea stars are keystone predators in nearshore habitats, affecting communities through their predation on primary space holders such as mussels. Amid the recent PMH, an outbreak of sea star wasting (SSW) led to dramatic declines in sea star abundance throughout the northern GOA, documented through our Nearshore Component monitoring (Konar et al. 2019). Following up on results of Konar et al. (2019), we investigated 1) how mussel abundance changed since the onset of SSW and 2) which sea star species and temperature metrics best explain variation in mussel abundance. Star abundance, mussel percent cover, density of large mussels, and density of mussels of all sizes from core samples were surveyed approximately annually at KATM, KBAY, KEFJ, and WPWS. At KATM, KBAY, and KEFJ star abundance declined 40 – 100% after SSW. Mussel cover increased above the long-term mean 1-3 years after declines in star abundance at KATM, KBAY, and KEFJ, but not at WPWS. Large mussel abundance increased to 65% above the long-term mean at KATM after SSW. Large mussel abundance increased slightly at KBAY but did not increase at KEFJ or WPWS. Mussel abundance from cores, which included recruits, did not differ before and after the onset of SSW. *Pisaster ochraceus* and *Pycnopodia helianthoides* abundance and winter and spring temperatures together explained 22.4% of variation in the mussel metrics. The PMH and SSW outbreak may have created synergistic effects, with declines in macroalgae due to warm temperatures opening available space for mussels and then reduced star predation relaxed top-down pressure on mussels allowing for their increased abundance. These relationships are described in detail in a recent synthesis paper (Traiger et al. 2022). We note that, in turn, increased mussel abundance may affect nearshore biodiversity and abundance or performance of nearshore vertebrates that consume mussels (Bodkin et al. 2018).

As another example of Nearshore Component upper tropic level work that evaluates effects of the PMH, we used skiff survey data collected from 2006-2021 in KEFJ and KATM to examine shifts in marine bird community composition by evaluating spatial and temporal variation in nearshore marine bird communities. Specifically, we tested for differences in community composition between regions (KEFJ vs. KATM) and season (summer vs. winter) and evaluated nearshore marine bird community trends before and after the onset of the PMH. We also examined temporal trends across foraging guilds to examine whether effects of the PMH on birds were related to their prey type (e.g., forage fish versus benthic invertebrates). Overall, we found that bird abundance was similar between summer and winter within regions, but community composition was very different between seasons. For example, winter coastal marine bird communities were characterized by a marked increase in benthic foragers and highlights the importance of nearshore coastal resources to sea ducks that primarily breed in the interior of Alaska but migrate to the coast in winter. Summer marine bird communities were generally dominated by forage fish consumers at colonies. We found variation in abundance related to the PMH as an interaction with prey type. Specifically, we found that consumers of benthic invertebrates (e.g., black oystercatchers, sea ducks) had generally stable trends in abundance, consistent with the general stability in their prey base. However, birds that are members of the pelagic biome, consuming zooplankton or forage fish, tended to show differences in abundance associated with the PMH. These were in the form of either declines, which we interpreted as a result of lack of prey, or increases in nearshore habitats, which we interpreted as a side effect of greatly reduced colony attendance due to reproductive failure and subsequent occurrence in our nearshore transects during atypical foraging activities. These patterns are described in detail in a recently submitted paper by Nearshore Component authors (Robinson et al. in review).

Sea otter response to changing ocean conditions associated with the PMH may have resulted in shifts in diet but not in abundance. As described in the Results section, sea otters eat a large variety of invertebrate prey, with clams and mussels as important components of their diet, the proportions in the diet depending on habitat. In addition to spatial differences, temporal shifts in sea otter composition were evident in some regions and were likely related to recent shifts in prey abundance. Sea stars were sometimes a significant component of diets and reached maximums of 14% and 10% at KATM and WPWS, respectively. However, after the SSW outbreak, sea stars represented less than 2% of diet in these regions. Mussels increased after the Pacific Marine Heatwave (2014-2016) and the decline in sea star abundance (Traiger et al. 2022). At KATM, mussels increased in sea otter diets in 2015 concurrent with increased mussel abundance in the nearshore system. Decreased clams in sea otter diets at KATM were coincident with decreasing clam biomass and increasing numbers of sea otters, suggesting that otters were at or near a food-dictated carrying capacity. Monitoring both predator diets and prey abundance allows us to better understand nearshore ecosystem responses to perturbations across the GOA.

The PMH and our efforts to evaluate consequences to nearshore ecosystems are good examples and illustrations of the kinds of perturbations we can evaluate with our Nearshore Component monitoring. These allow us to understand not only which factors are important contemporary drivers of nearshore ecosystem dynamics, they also provide context on effects of EVOS and the status of spill-injured resources across various spatial and temporal scales. For example, we know that the oil spill had dramatic and relatively local effects on intertidal communities. More recently, we have been able to document the local, static drivers that generally dictate intertidal community structure (Konar et al. 2016) and how the PMH affected intertidal community structure at a larger scale (Weitzman et al. 2021), partially homogenizing community structure; these phenomena are now much more important drivers of intertidal communities than residual oil spill effects. Our Nearshore Component findings also allow contrasts between nearshore and pelagic biomes, through comparisons to research by our Pelagic Component colleagues. This is important for understanding the kinds of perturbations that disproportionately affect nearshore habitats and the associated biota (e.g., oil spills) and those that affect pelagic ecosystems (e.g., temperature regime shifts). The PMH is a good example. Although we detected variation associated with the PMH in nearshore habitats (Weitzman et al. 2021), these shifts were muted relative to those in the pelagic food web, where catastrophic changes to forage fish abundance and quality were observed (Piatt et al. 2020, Arimitsu et al. 2021, Suryan et al. 2021). As a result, we did not detect changes in upper trophic level abundance or distributions for those predators that consume benthic invertebrates in nearshore habitats, whereas some pelagic predators (e.g., whales and seabirds), showed large changes in condition, abundance, and distribution, perhaps the most dramatic of which was the major die-off of common murres (Piatt et al. 2020).

The spatial and temporal scales over which metrics vary are beginning to provide insights on the potential drivers of observed ecological patterns. This understanding will continue to improve as we increase the length of the data streams with continued annual sampling. In turn, this has broad application for management of marine habitats and species. For example, the differential responses observed between nearshore and pelagic biomes to the PMH allows some predictive capability and basis for risk assessment when considering which marine species are most likely to be affected by short-term temperature anomalies or persistent changes in global climate.

In addition to core monitoring work, we also have engaged in several collaborative research efforts to understand nearshore processes, leveraging the field presence facilitated by GWA. These collaborations have included stable isotope analyses of nearshore communities (von Biela et al. 2016, Siegert et al. 2022), collection of mussels for growth and energetics analyses, collection of mussels for contaminant analyses (Rider et al. 2020), evaluation of the prevalence of sea star wasting disease (Konar et al. 2019), and collection of clams as part of an evaluation of gene expression and other biomarkers as tools for monitoring health of nearshore ecosystems (Counihan et al. 2019, Bowen et al. 2020, Coletti et al. 2021). We also are working closely with researchers from Simon Fraser University on a black oystercatcher migration study, which is providing insight into the seasonal movements and migration strategies. In addition to logistical support, these collaborative studies benefit from the perspective provided by long-term monitoring data. In turn, GWA benefits from clearer understanding of nearshore ecosystem processes resulting from directed research projects.

The improved understanding of nearshore ecosystem dynamics provided by our GWA monitoring has important and direct application for natural resource management. For example, U.S. Fish and Wildlife Service (USFWS) has used our survey data for marine birds and mammals directly as part of risk assessments for vessel groundings and oil spills, both hypothetical in drills and in real-world incidents. USFWS Marine Mammals Management uses our sea otter distribution and abundance data in management documents for the species, such as stock assessments and species status assessments. The Nearshore Component regularly contributes indices to NOAA Fisheries for the annual GOA Ecosystem Status Report to the North Pacific Fisheries Management Council (Ferriss and Zador 2021). The National Park Service (NPS) has incorporated our data into a number of their natural resource management instruments, including Resource Stewardship Strategies (RSSs), Natural Resource Condition Assessments, State of the Park Reports, and upcoming Wilderness Character assessments. For many of their marine resources of management interest, our data are the only data that exist. Finally, data from the Nearshore Component have been used by the EVOS Trustee Council and Trustee agencies to designate population recovery of injured species (e.g., sea otters and harlequin ducks), and assess progress of species still listed as not recovered (e.g., pigeon guillemots and marbled murrelets). In addition, Nearshore Component data have been used to inform resource management activities well beyond the GOA including the Deepwater Horizon case and risk assessments of pipelines and tanker traffic.

CONCLUSIONS

The Nearshore Component has benefitted by the high degrees of coordination and integration across regions and among Principal Investigators, which was further enhanced during the 2017-2021 period by the formal integration of KBAY and the other study regions of KATM, KEFJ, and WPWS. We strongly feel that this integration and collaboration, along with the study design elements of spatial nesting and multi-trophic-level evaluation, provides an unprecedented broad-scale program for evaluating causes and consequences of variation in Alaska's nearshore ecosystems. Nearshore responses to the PMH provide an excellent example of the power of the Nearshore Component to detect effects at various spatial scales and within different parts of the food web. Our success can be measured by our high degree of productivity (see Other references section below), delivery of data (see Project Data section above), leveraging to facilitate numerous associated research projects, and relevance to management needs. We anticipate that this success and value will continue to grow with the addition of continued years of nearshore monitoring effort.

ACKNOWLEDGEMENTS

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APPENDIX A

The Nearshore component of the Gulf Watch Alaska program collects data on more than 200 species at four study regions (Katmai National Park and Preserve [KATM], Kachemak Bay [KBAY], Kenai Fjords National Park [KEFJ], and western Prince William Sound [WPWS] that were affected by the *Exxon Valdez* oil spill. Data are collected collaboratively by numerous federal agencies (National Park Service, US Geological Survey [USGS], US Fish and Wildlife Service, and National Oceanic and Atmospheric Administration [NOAA]) and the University of Alaska Fairbanks. Data are permanently archived based on requirements of the agency or organization responsible for primary data collection and/or analysis and the *Exxon Valdez* Oil Spill Trustee Council. The table below summarizes the permanently archived data. Detailed metadata for each dataset may be found at the data archive location.

Metric	**Permanent archive**	**Digital object identifier (doi)**	**Regions represented**	**Additional information**
Intertidal temperature	USGS data repository	https://doi.org/10.5066/F7WH2N3T	KATM, KBAY, KEFJ, WPWS	Intertidal air and water temperature data collected at all four study regions; dates range from 2006-2022; the doi includes one file for each year, region, and study block
Rocky intertidal	DataONE	https://doi.org/10.24431/rw1k1o	KBAY	Rocky intertidal data collected at study blocks in each of the four regions; start dates for data collection vary between 2006 and 2020 and end in 2022; data for the KBAY region are archived with DataONE and the other regions are archived with the USGS data repository; the archives each include data on intertidal seaweed cover, motile invertebrates, limpets, and sea stars
	USGS data repository	https://doi.org/10.5066/F7513WCB	KATM, KEFJ, WPWS	

Metric	Permanent archive	Digital object identifier (doi)	Regions represented	Additional information
Soft sediment bivalves	USGS data repository	https://doi.org/10.5066/F71834N0	KATM, KBAY, KEFJ, WPWS	Soft sediment bivalve data at study blocks in all four regions beginning in 2007 and ending in 2021; the archive includes data on soft sediment sites and bivalve species, size, and counts
Eelgrass	DataONE	https://doi.org/10.24431/rw1k1o	KBAY	Eelgrass bed data collected at study blocks in the Kachemak Bay region from 2012 to 2022; the archive includes data on eelgrass shoot density; eelgrass bed data collected 2008-2016 at other regions are not archived
Mussels	DataONE	https://doi.org/10.24431/rw1k1o	KBAY	Mussel bed data collected at study blocks in all four regions beginning in 2008 (KATM, KEFJ, and WPWS) or 2012 (KBAY) and ending in 2022; data for the KBAY region are archived with DataONE and the other regions are archived with the USGS data repository; the archives each include data on mussel bed sites and counts and sizes
	USGS data repository	https://doi.org/10.5066/F7FN1498	KATM, KEFJ, WPWS	
Mussel contaminants	NOAA data repository	https://doi.org/10.25923/dbyq-7z17	KATM, KBAY, KEFJ, WPWS	A suite of chemical contaminants measured in mussel tissue from all 4 study regions, collected during 2007 to 2018. Archived data are reported as tissue concentrations;

Metric	Permanent archive	Digital object identifier (doi)	Regions represented	Additional information
				report includes other areas in Alaska for contrasts.
Marine bird and mammal surveys	USGS data repository	https://doi.org/10.5066/F7416V6H	KATM, KBAY, KEFJ	Marine bird and mammal survey data collected in KATM, KBAY, and KEFJ beginning in 2006 (summer) or 2008 (winter) and ending in 2021; the archive includes data on summer and winter transects, species observations, and densities
Black oystercatchers	USGS data repository	https://doi.org/10.5066/F7WH2N5Q	KATM, KBAY, KEFJ, WPWS	Black oyster catcher data collected in all four regions 2006-2021; archive includes data on transects, nest details, egg stage, and chick diet
Sea otters	USGS data repository	https://doi.org/10.5066/F7H993CZ	KATM, KEFJ, WPWS	Sea otter mortality data collected in KATM, KEFJ, and WPWS, 2006-2021
		https://doi.org/10.5066/F7N29V4R	KATM, KBAY, KEFJ, WPWS	Sea otter foraging observations collected in all four regions, 2006-2021
		https://doi.org/10.5066/P9EDM6NL	KATM, KBAY, KEFJ, WPWS	Sea otter spraint data collected in all four regions, 2006-2021
		https://doi.org/10.5066/P9Q4DA3T	KBAY	Sea otter surveys conducted in lower Cook Inlet, including KBAY, in 2017

Metric	Permanent archive	Digital object identifier (doi)	Regions represented	Additional information
		https://doi.org/10.5066/F7930SG7	KATM	Sea otter surveys conducted in KATM, 2008-2019
		https://doi.org/10.5066/F7CJ8BN7	KEFJ	Sea otter surveys conducted in KEFJ, 2002-2016
		https://doi.org/10.5066/P9OG6SR5		Sea otter survey conducted in northern and eastern Prince William Sound in 2014
		https://doi.org/10.5066/P9TTJVBC	KEFJ	Sea otter survey conducted in outer Kenai Peninsula, including KEFJ, in 2019
		https://doi.org/10.5066/P9KNKOG1	WPWS	Sea otter survey conducted in WPWS in 2017