ATTACHMENT B. Annual Project Report Form (Revised 11.21.19)

1. Project Number:

20120114-H

2. Project Title:

Nearshore Ecosystems in the Gulf of Alaska

3. Principal Investigator(s) Names:

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Mandy Lindeberg, National Oceanic and Atmospheric Administration
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Brian Robinson, U.S. Geological Survey, Alaska Science Center
Sarah Traiger, U.S. Geological Survey, Alaska Science Center
Ben Weitzman, National Oceanic and Atmospheric Administration

4. Time Period Covered by the Report:

February 1, 2020-January 31, 2021

5. Date of Report:

March 2021

6. Project Website (if applicable):

https://gulfwatchalaska.org/monitoring/nearshore-ecosystems-4/

7. Summary of Work Performed:

Nearshore monitoring in the Gulf of Alaska (GOA) provides ongoing evaluation of status and trends of more than 200 species, including many of those injured by the 1989 *Exxon Valdez* oil spill. The monitoring design includes spatial, temporal, and ecological features that support inference regarding drivers of change. Continued monitoring will lead to a better understanding of variation in the nearshore ecosystem across the GOA and a more thorough evaluation of the status of spill-injured resources. This information has been used in a number of management contexts and will be critical for anticipating and responding to ongoing and future perturbations in the region, as well as providing for global contrasts. Monitoring metrics include marine invertebrates, macroalgae, birds, mammals, and physical parameters such as temperature. In addition to taxon-specific metrics, monitoring includes recognized important ecological relations such as predator-prey dynamics, measures of nearshore ecosystem productivity, and contamination. **In FY20, due to the COVID-19 global pandemic, normal field operations were significantly reduced or cancelled.** Minimal sampling was conducted in Kenai Fjords National Park (KEFJ) and western Prince William Sound (WPWS), while none was completed in Katmai National Park and Preserve (KATM). Most intertidal work was completed in Kachemak Bay (KBAY), but upper trophic level surveys were significantly reduced there (see Table 1). We are planning for normal proposed field operations for FY21. Due to the reduction in field costs in FY20, we have allocated some of those funds to support a graduate student at the University of Alaska Fairbanks (UAF) to examine variation in carbon sourcing to nearshore consumers across all four nearshore component regions, using samples collected in recent years, which will contribute to interpretation of monitoring data.

*Table 1. Nearshore component metrics measured by location and year, 2017-2021. Completed activities for 2020 are represented by a bolded **X**, while completed activities (2017 - 2019) and planned activities in future years (2021) are not. Other symbol designations include: **C** = cancelled due to COVID-19 and **P** = partially completed, due to constraints of COVID-19.*

Location and Metric	**2017**	**2018**	**2019**	**2020**	**2021**
Western PWS, intertidal invertebrates and algae	x	x	x	**P**	x
Western PWS, intertidal kelps and sea grass	x	x	x	**P**	x
Western PWS, black oystercatchers	x	x	x	**X**	x
Western PWS, contaminants/water quality		x			
Western PWS, sea otter carcass recovery	x	x	x	**C**	x
Western PWS, sea otter spraint observations	x	x	x	**C**	x
Western PWS, sea otter foraging observations	x	x	x	**C**	x
Western PWS, water/air temperature	x	x	x	**X**	x
Kenai NP, intertidal invertebrates and algae	x	x	x	**P**	x
Kenai NP, intertidal kelps and sea grass	x	x	x	**P**	x
Kenai NP, black oystercatchers	x	x	x	**P**	x
Kenai NP, contaminants/water quality		x			
Kenai NP, sea otter carcass recovery	x	x	x	**C**	x
Kenai NP, sea otter spraint observations			x	**C**	x
Kenai NP, sea otter foraging observations	x	x	x	**C**	x
Kenai NP, water/air temperature	x	x	x	**P**	x
Kachemak Bay, intertidal invertebrates and algae	x	x	x	**X**	x
Kachemak Bay, intertidal kelps and sea grass	x	x	x	**X**	x
Kachemak Bay, black oystercatchers		x	x	**X**	x
Kachemak Bay, contaminants/water quality		x			
Kachemak Bay, sea otter spraint observations	x	x	x	**C**	x
Kachemak Bay, sea otter foraging observations		x	x	**C**	x
Kachemak Bay, water/air temperature	x	x	x	**X**	x
Katmai NP, intertidal invertebrates and algae	x	x	x	**C**	x
Katmai NP, intertidal kelps and sea grass	x	x	x	**C**	x
Katmai NP, black oystercatchers	x	x	x	**C**	x

Location and Metric	2017	2018	2019	2020	2021
Katmai NP, contaminants/water quality		x			
Katmai NP, sea otter spraint observations	x	x	x	**C**	x
Katmai NP, sea otter carcass recovery	x	x	x	**C**	x
Katmai NP, sea otter foraging observations	x	x	x	**C**	x
Katmai NP, water/air temperature	x	x	x	**C**	x
Western PWS, sea otter aerial survey	x			**C**	
Kenai NP, sea otter aerial survey			x		
Kachemak Bay, sea otter aerial survey*	x				
Katmai NP, sea otter aerial survey		x			x
PWS Nearshore marine bird survey**		x		**C**	
Kenai NP nearshore marine bird survey	x	x	x	**C**	x
Kachemak Bay nearshore marine bird survey		x	x	**C**	x
Katmai NP nearshore marine bird survey	x	x	x	**C**	x

*Funded by U.S. Fish and Wildlife Service in 2017
**Under Pelagic component Restoration Project 18120114-M

While data collection was greatly reduced in 2020, here we present highlights of recent findings (see also FY21 workplan and the FY19 Annual Report). These include: (1) trends submitted to the 2020 National Oceanic and Atmospheric Administration (NOAA) Ecosystems Status Report for the Gulf of Alaska, (2) intertidal community response to the marine heatwave, (3) initial findings examining mussel response to decline in sea stars across the GOA, and (4) an update to the black oystercatcher migration study that the Gulf Watch Alaska (GWA) nearshore component has been conducting in partnership with Simon Fraser University.

1. NOAA Ecosystems Status Report

Monitoring of intertidal and subtidal communities across the GOA provides ongoing evaluation of status and trends of more than 200 nearshore species. The spatial extent of sampling includes 21 sites distributed across the northern GOA from WPWS, KEFJ, KBAY, and KATM. Due to the COVID-19 global pandemic, field sampling was significantly reduced in 2020. Most intertidal work was completed in KBAY; however, minimal sampling was conducted in KEFJ and WPWS, while none was completed in KATM. For the past two years, as part of GWA contributions to the annual NOAA Ecosystems Status Report, we have reported one physical indicator (intertidal water temperature) and three biological indicators that represent key nearshore ecosystem components of primary production (algal cover), prey abundance (mussel density), and predator abundance (sea star density). Our algal cover indicator is percent cover of rockweed (*Fucus distichus*) sampled in quadrats at the mid intertidal level (1.5 m). Intertidal prey is represented by density estimates of large (≥ 20 mm) Pacific blue mussels (*Mytilus trossulus*) sampled quantitatively within mussel beds. Nearshore predator abundance is density of the most abundant sea stars, estimated along a 50 m x 4 m transect at each rocky intertidal site in the GOA. Intertidal water temperature and mussel density data, while collected at some sites in 2020, are not currently available due to COVID-19 laboratory health restrictions constraining sample analysis. Rockweed percent cover was collected only in KBAY, while sea star densities were documented at all sites in KBAY and WPWS. Biological indicators are presented as annual anomalies compared to the long term mean of the data record by site through the most recent year of data availability.

Intertidal Water Temperatures

In summary, nearshore water temperature trends in all four intertidal zones from Prince William Sound to the Alaska Peninsula show warming beginning in 2014 (Fig. 1), corresponding to the large marine heatwave phenomenon ("the Blob") detected by more pelagic sensors (Danielson et al. 2020). Our data confirm that the physical manifestations of this large-scale oceanographic event were expressed in nearshore ecosystems. A science synthesis paper was prepared in collaboration with the Environmental Drivers component of GWA evaluating coherence of water temperatures across the central GOA, including how Gulf-scale temperature trends measured in the pelagic realm manifest in nearshore waters (Danielson et al. 2020).

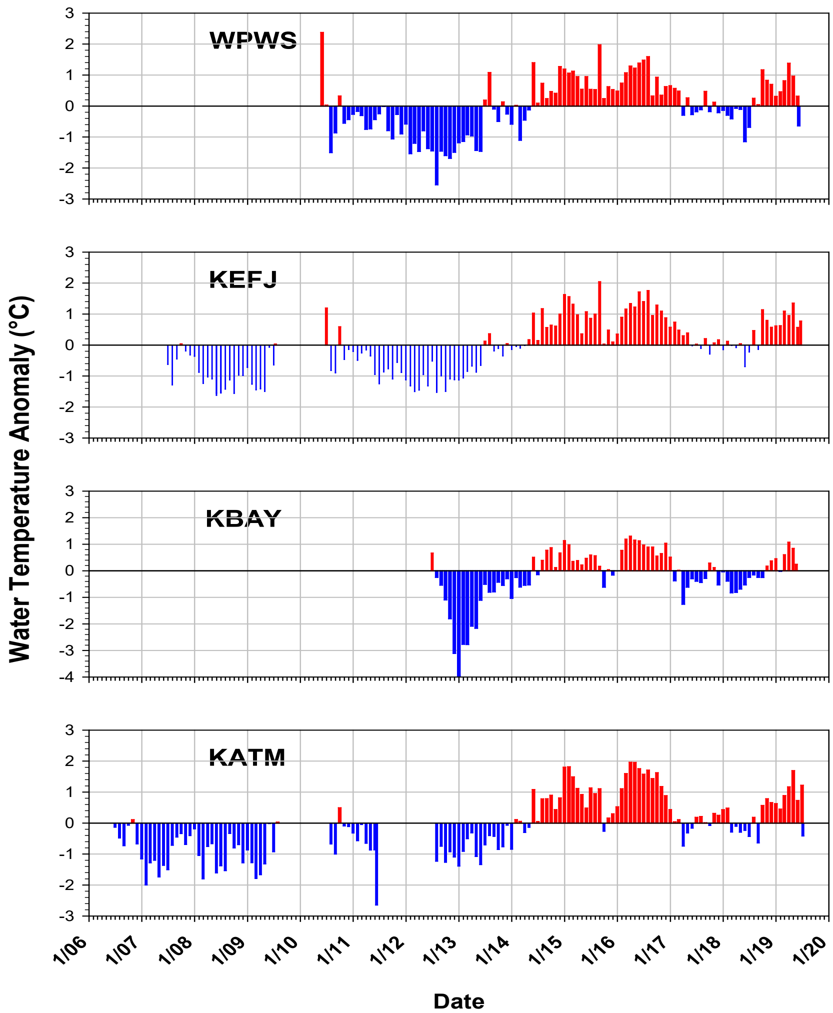

Figure 1. Intertidal water temperature anomalies by month at the 0.5 m tide level four regions of the western Gulf of Alaska (west of 144°W), western Prince William Sound (WPWS; 2011-2019), Kenai Fjords National Park (KEFJ; 2008-2019), Kachemak Bay (KBAY; 2013-2019), and Katmai National Park and Preserve (KATM; 2006-2019).

Algal Cover

We used percent cover of the perennial intertidal, dominant alga *Fucus distichus* as a metric of trends in a primary producer. Despite considerable variability in percent cover among sites and generally positive anomalies through 2014, KATM and KEFJ sites showed consistently negative values during the recent marine heatwave, continuing through 2019 (Fig. 2). KBAY has continued to have roughly average Fucus cover without a noticeable response to the heatwave through 2020. Anomalies in WPWS had become slightly positive in 2019 and may indicate recovery from the heatwave effects after temperatures cooled in 2018. Percent cover in WPWS, KEFJ and KATM was not measured in 2020. *F. distichus* is known to cycle in abundance at local scales; the broad, consistent patterns in our data suggest that a large-scale phenomenon, presumably the marine heatwave, was acting on this metric at the scale of the northern GOA. Variation in *F. distichus* abundance is included as part of a science synthesis paper (Weitzman et al. 2020, 2021) evaluating intertidal community responses to the marine heatwave.

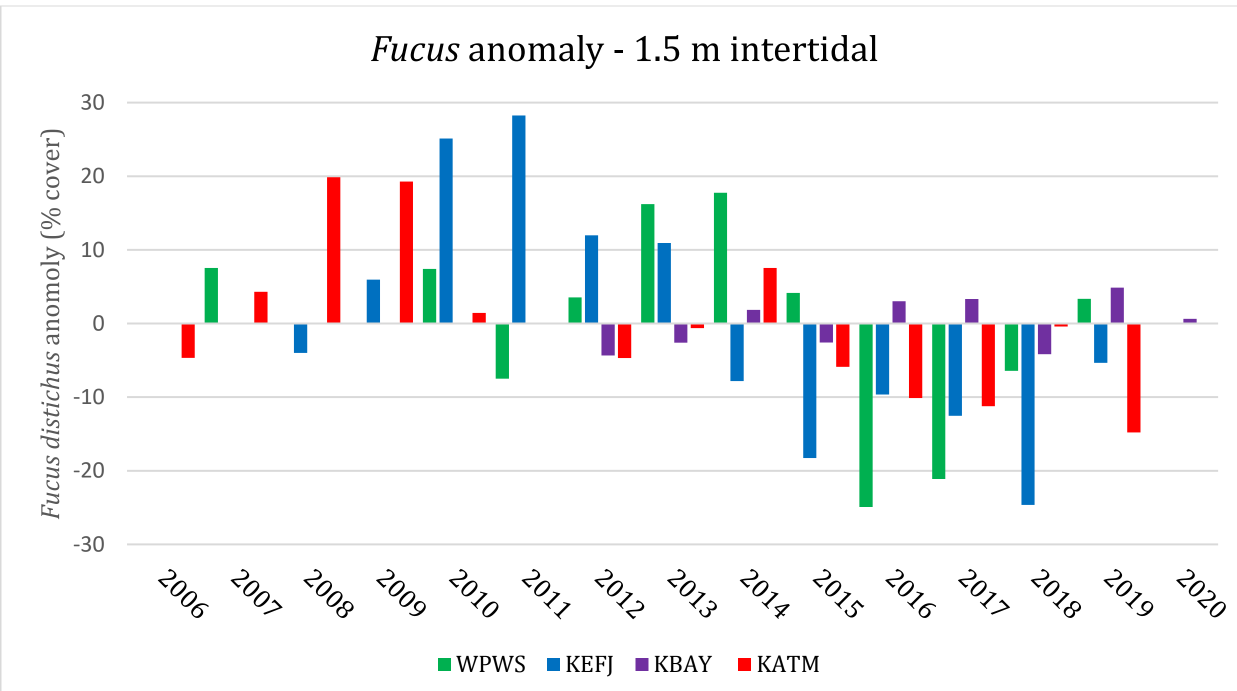

*Figure 2. Percent cover anomalies for rockweed (*Fucus distichus*) in four regions of the western Gulf of Alaska, western Prince William Sound (WPWS; 2007, 2010-2019), Kenai Fjords National Park (KEFJ; 2008-2019), Kachemak Bay (KBAY; 2012-2020), and Katmai National Park and Preserve (KATM; 2006-2010, 2012-2019).*

Mussel Density

The Nearshore Component of GWA has examined trends in abundance of the mussel *Mytilus trossulus*, a ubiquitous invertebrate filter feeder, as a common nearshore prey species that transfers primary production to higher trophic levels, including various sea stars, annually. However, mussel site sampling was greatly reduced in 2020, therefore this metric was not included in the NOAA 2020 Ecosystems Status Report. In summary, densities of large mussels (≥ 20 mm, Fig. 3) show a strong trend across all regions consistent with timing of the marine heatwave, but in this case switching from generally negative to positive anomalies – an opposite response compared to *F. distichus* and sea stars (Figs. 2 and 4). Variation in mussel abundance through 2017 was described in detail in a recent paper (Bodkin et al. 2018) and percent cover data up to 2019 are included as part of a science synthesis paper evaluating intertidal community responses to the marine heatwave (Weitzman et al. 2020, 2021). Mussel sites were sampled in KBAY in 2020 but data analysis is pending. Mussel sites in WPWS, KEFJ and KATM were not sampled in 2020.

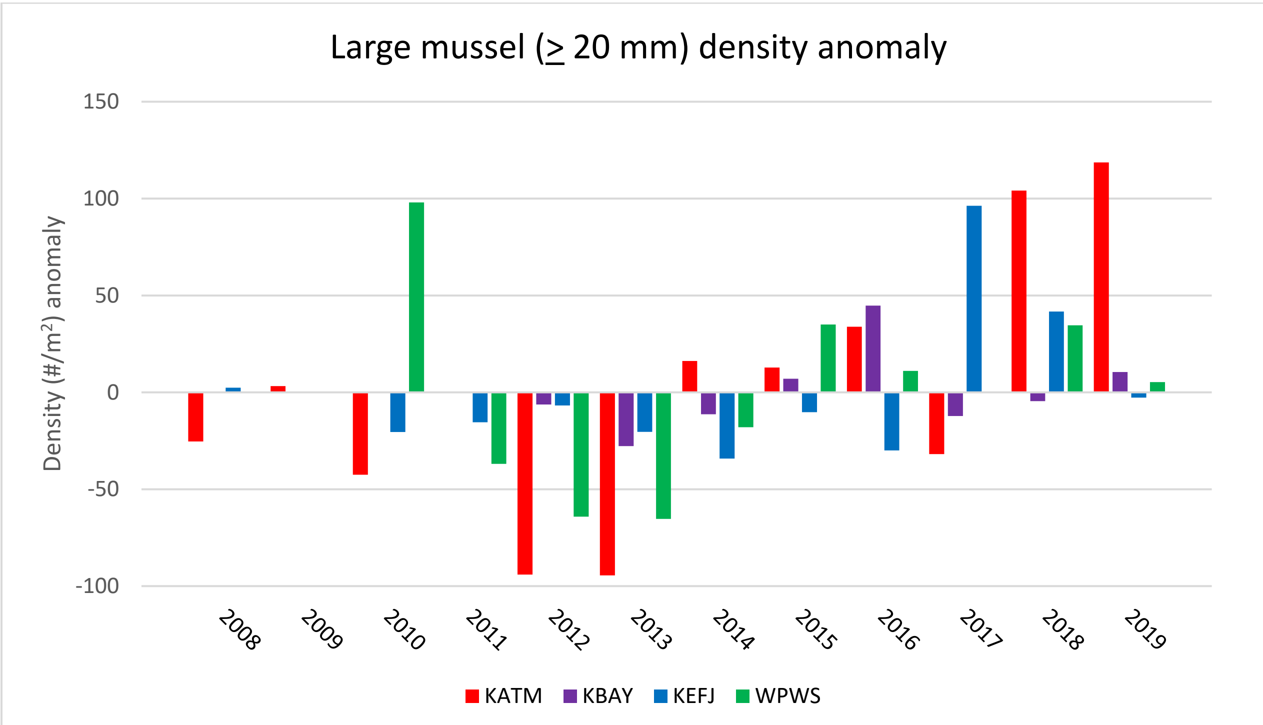

*Figure 3. Density anomalies for large (> 20 mm) mussels (*Mytilus trossulus*) in four study regions spanning the northern Gulf of Alaska, western Prince William Sound (WPWS; 2010-2019), Kenai Fjords National Park (KEFJ; 2008-2019), Kachemak Bay (KBAY; 2012-2019), and Katmai National Park and Preserve (KATM; 2008-2010, 2012-2019).*

Sea Star Abundance

As an important predator in structuring nearshore communities (including mussel populations), we present trends in sea star abundance. For sea star abundance, variability in density, diversity, and dominance of individual sea star species varied greatly among regions through 2015. Between 2015 and 2017, abundance declined and remained strongly negative across all regions through 2018, likely due to sea star wasting disease (Konar et al. 2019). In 2019, there was some recruitment and recovery in WPWS and to a lesser degree in KATM, although anomalies were still negative. However, KBAY continues to show no signs of recovery through 2020 (Fig. 4). There could be some lag in recovery in KBAY as sea star wasting disease seemed to move across the GOA from east to west, with first records in WPWS, then KEFJ, and then KBAY (Konar et al. 2019). In 2020, the sea star species thought to be unaffected by sea star wasting disease in the northern GOA (primarily *Henricia leviuscula* and *Dermasterias imbricata*) continued to be present. The positive anomaly in WPWS during 2020 surveys was driven by high numbers of *D. imbricata* (81%; Fig. 4). At the two sites sampled in KEFJ in 2020, 88% of observed sea stars were *D. imbricata*. The once more dominant sea stars (primarily *Pycnopodia helianthoides, Evasterias troschellii, and Pisaster ochraceus*) continue to be absent (or rare) in many of the GWA sites sampled in 2020, although one site in WPWS showed some recovery potential with many small *P. helianthoides*.

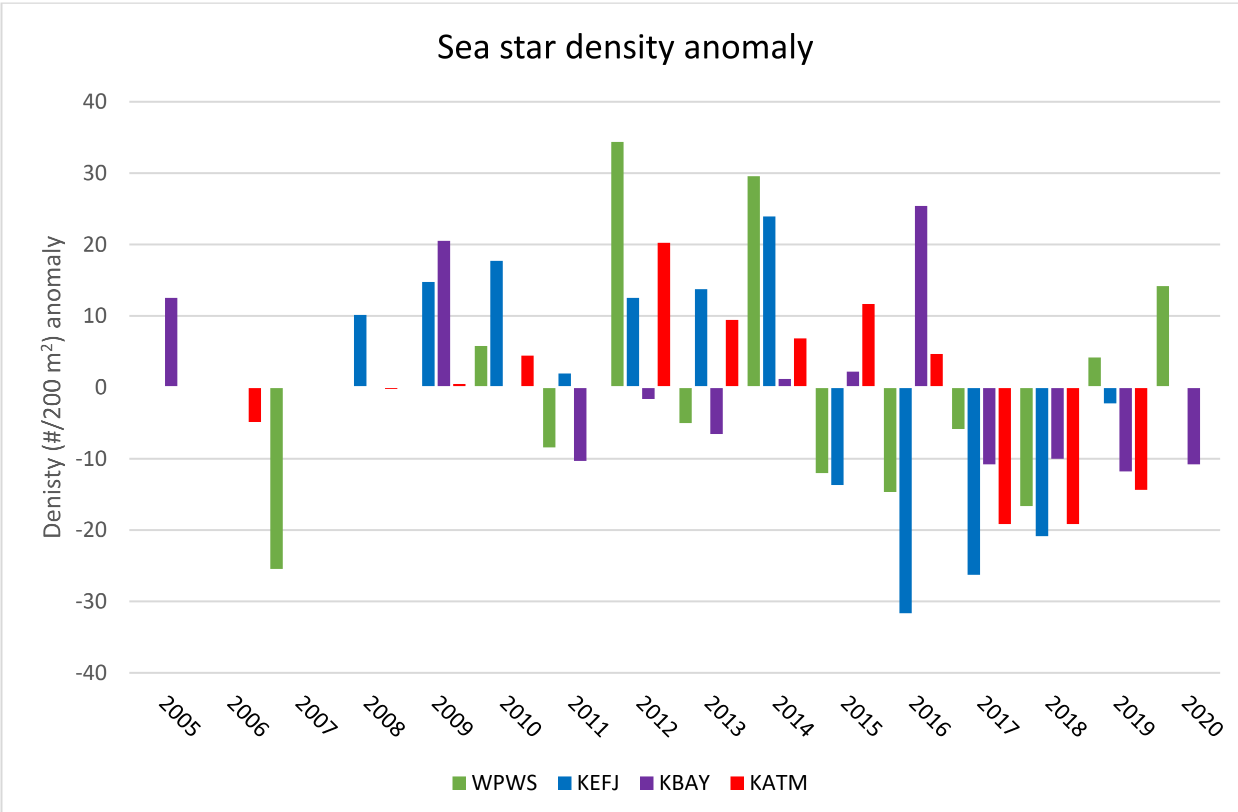

Figure 4. 4. Density anomalies of sea stars (primarily Dermasterias imbricata, Evasterias troschelii, Pisaster ochraceus *and* Pycnopodia helianthoides*) in four study areas spanning the northern Gulf of Alaska, western Prince William Sound (WPWS; 2007, 2010-2020), Kenai Fjords National Park (KEFJ; 2008-2019), Kachemak Bay (KBAY; 2005, 2009, 2011-2020), and Katmai National Park and Preserve (KATM; 2006, 2008-2010, 2012-2019).*

Inter-species Interactions and Interpretation of NOAA Ecosystem Status Metrics

The negative anomalies of rockweed in three of the four regions and sea stars across all regions were coincident with warm water temperatures in nearshore areas. The decline in sea star abundance across the Gulf was likely due to sea star wasting disease (Konar et al. 2019), first detected south of Alaska in 2014 and generally thought to be exacerbated by warm water temperature anomalies (Eisenlord et al. 2016). Positive anomalies during 2015-2019 for large mussels are consistent with a response to reduced predation pressure precipitated by the decline of sea stars. Sea stars are known to have strong top-down effects on intertidal communities, including mussels specifically (Paine 1974), so this inter-specific interaction is a plausible explanation for observed patterns. Further, we speculate that other nearshore predators, including sea otters, sea ducks, and black oystercatchers, may benefit from increased abundance of large mussels when sea stars decline.

Collectively, these indicators demonstrate consistent, large scale perturbations of nearshore ecosystems throughout much of the western GOA, including areas both inside (WPWS, KBAY) and outside (KEFJ and KATM) of protected marine waters. Two of the three indicators with data from 2020 signal community level effects correlated with changing water temperatures and ecological processes of the 2014-2016 marine heatwave, with effects persisting into 2020. The decline in *F. distichus* may result in habitat loss for settlement of new mussel recruits but also decreased competition for space with larger mussels. *F. distichus* trends also reflect a reduction in their contribution to nearshore sources of primary productivity.

Intertidal and nearshore ecosystems provide valuable habitat for early life stages of various commercially important species in the Gulf of Alaska, including Dungeness crab, Pacific cod, salmonids, and several species of rockfish. Though our sampling was spatially limited in 2020, our indicators suggest that some nearshore biological responses to the heatwave appear to continue into 2020 and could possibly affect future recruitment and survival of species whose life stages rely on nearshore habitat. Cornwall (2019) suggested that a new 'marine heatwave' forming in the Pacific will affect these coastal ecosystems, which our data support. With these perturbations, we also expect to see responses of nearshore-reliant, upper trophic level species (such as sea otters and sea ducks) to shifts in prey availability from changing ocean conditions across the GOA.

2. Intertidal Community Response to the Marine Heatwave

Marine heatwaves are global phenomena that can have major impacts on the structure and function of coastal ecosystems. By mid-2014, the Pacific Marine Heatwave (PMH) was evident in intertidal waters of the northern GOA and persisted for multiple years. While offshore marine ecosystems are known to respond to these warmer waters, the response of rocky intertidal ecosystems to this warming is unclear. Intertidal communities link terrestrial and marine ecosystems and their resources are important to marine and terrestrial predators and to human communities for food and recreation, while simultaneously supporting a growing coastal tourism industry. Given that current climate change projections suggest increased frequency and duration of marine heatwaves, monitoring and understanding the impacts of heatwaves on intertidal habitats is important. As part of the GWA Long-Term Monitoring program, we examined rocky intertidal community structure at 21 sites across four regions spanning 1,200 km of coastline: WPWS, KEFJ, KBAY, and KATM. Sites were monitored annually from 2012 to 2019 at mid and low tidal strata. Before-PMH (2012-2014), community structure differed among regions. We found macroalgal foundation species declined during this period mirroring patterns observed elsewhere for subtidal habitat formers during heatwave events. The region-wide shift from an autotroph-macroalgal dominated rocky intertidal to a heterotroph-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. During/after-PMH (2015-2019), similarities in community structure increased across regions, leading to a greater homogenization of these communities, due to declines in macroalgal cover, driven mostly by a decline in the rockweed, *Fucus distichus,* and other fleshy red algae in 2015, followed by an increase in barnacle cover in 2016, and an increase in mussel cover in 2017. 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 synthesis paper (Weitzman et al. 2021).

3. Mussel Response to Decline in Sea Star Abundance

Sea stars are keystone predators in rocky intertidal habitats, affecting communities through their predation on primary space holders such as mussels. Amid the recent PMH, an outbreak of sea star wasting syndrome (SSWS) led to dramatic declines in sea star abundance throughout the northern GOA. We investigated 1) how mussel abundance changed since the onset of SSWS 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 SSWS. 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 SSWS. 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 SSWS. *Pisaster ochraceus* and *Pycnopodia helianthoides* abundance and winter and spring temperatures together explained 22.4% of variation in the mussel metrics. The PMH and SSWS outbreak may have created synergistic effects, with declines in macroalgae due to warm temperatures opening available space to mussels and then relaxed top-down pressure on mussels allowing for increased abundance. In turn, increased mussel abundance may affect intertidal biodiversity and abundance or performance of nearshore vertebrates that consume mussels. These results are being prepared for submission as a manuscript (Traiger et al. in prep).

4. Black Oystercatcher Migration Study

The time series of marine bird and mammal survey data generated by the GWA nearshore component reveal important patterns within individual species. For example, black oystercatcher (*Haematopus bachmani*) densities show different seasonal patterns in KATM and KEFJ. In KATM, black oystercatchers occur at similar densities during summer and winter, suggesting that either KATM breeders are non-migratory or that different individuals move into KATM post-breeding. In contrast, black oystercatchers in KEFJ occur regularly during the breeding season but are absent, or nearly so, during winter, indicating that breeders there migrate elsewhere post-breeding. These contrasting patterns have been useful for a tag-on project initiated in FY19 in collaboration with Simon Fraser University. This work is using geolocator and GPS tags to understand links between black oystercatchers breeding in all four nearshore regions (KBAY, KATM, KEFJ, and WPWS) and their subsequent wintering areas. This study will help determine why some individuals migrate and others are resident, as well as the individual and environmental factors that influence different strategies. Although the field work planned for FY20 was affected by COVID-19, we did conduct some activities. In WPWS, KEFJ, and KBAY, we recaptured 10 individuals that were marked last summer and removed the attached instruments, which is necessary to download data and determine annual cycle movements. We also deployed new GPS tags on nine black oystercatchers, which will add high-resolution data for addressing movements and migration strategies. This project will continue in FY21, with the intent of recapturing individuals marked in 2019 and 2020 and deploying additional instruments.

8. Coordination/Collaboration:

A. Long-term Monitoring and Research Program Projects

1. Within the Program

The Nearshore Component of GWA is a highly coordinated effort involving multiple principal investigators (PIs) with expertise on various aspects of nearshore ecosystems; the overall design and coordination are critical for drawing inference about factors affecting the nearshore. Beginning in 2012 under GWA, 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 have worked closely over the past several years to ensure that data from all sites are comparable when possible, allowing the strongest possible inferences about the causative factors and spatial extent of changes in nearshore systems. In 2017, the two nearshore projects integrated into a single, coordinated project to enhance collaboration across the GWA. For example, nearshore data sets were combined across projects for analyses that resulted in two peer reviewed journal articles to date (Konar et al. 2016 and 2019) as well as contributions to three chapters of the science synthesis report to the *Exxon Valdez* Oil Spill Trustee Council (Danielson et al. 2020, Suryan et al. 2020b, and Weitzman et al. 2020). The synthesis of rocky intertidal data (Weitzman et al. 2020, 2021) revealed that, after the marine heatwave, intertidal communities became more similar among study regions and generally, that rocky intertidal habitats shifted from a macroalgal dominated community to a community dominated by filter-feeding invertebrates, such as mussels. The intertidal synthesis manuscript marks the third publication written that synthesizes data between the two nearshore projects and the first publication for the nearshore group to begin incorporating data from the Environmental Drivers component. Additional collaboration includes component-wide collaboration involving a MSc graduate student (Katie Corliss) at UAF starting in January of 2021. The focus of the student's thesis will be to examine variation in the sources of carbon (phytoplankton vs. macroalgae) to nearshore lower and mid-level trophic consumers and how that variation may manifest itself in organismal responses (for example: growth rates). This information will provide important understanding of the drivers of annual changes that we detect from monitoring.

The Nearshore component has coordinated sampling of mussels, offshore and nearshore particulate organic matter (POM) and select macroalgae to discern the role of carbon produced by macro-algae in the nearshore food web using stable isotope analyses across all four regions. Mussels serve as a model organism for this project as they are an abundant and characteristic species of the nearshore environment that plays a critical role in linking pelagic to nearshore environments and also are a key prey for many species at higher trophic levels. In several of the sampling regions, collections reach back as far as 2014, but a concerted and coordinated effort across regions was initiated in 2017. Preliminary data from 2017 show that mussels likely consume some proportion of macroalgal detritus and additional macroalgal samples collected in 2019 are soon ready to be analyzed for stable isotope values. A regional comparison of carbon and nitrogen stable isotope values across all years (2014-2018) showed that mussels in KEFJ and WPWS were on average depleted in ^{13}C isotopes compared with those from KATM and KBAY. This may indicate that mussels in KATM and KBAY feed on a higher proportion of macroalgae or could reflect an inherent regional difference in inorganic carbon sources. POM and macroalgal samples collected in 2019 and 2020 in all regions and 2020 in some regions will help us shed more light on these alternative hypotheses.

An educational collaboration also exists within this project. There are two UAF field courses usually taught by Konar and Iken at the Kasitsna Bay Lab that assist with data collection for this program. Although these courses were not run this year due to COVID-19, both courses will resume in FY21. Students get valuable experience and training from participating in the project, and the project benefits from having these students. In addition, the KBAY portion of this project provides summer funding for one graduate student who can dedicate more time to assist in the sampling, sample processing, and outreach.

In addition, we have worked closely with the other GWA components (Environmental Drivers and Pelagic) to identify data sets and logistical synergies that can be shared. For example, Environmental Drivers data were used extensively in an analysis of mussel trends across the GOA, presented in the GWA Science Synthesis report (Monson et al. 2015). More recently, we collaborated on two synthesis chapters for the draft report submitted to the *Exxon Valdez* Oil Spill Trustee Council (EVOSTC; Suryan et al. 2020a): we collaborated with the Environmental Drivers component to evaluate whether temperature changes in nearshore systems correlate with oceanographic conditions (Danielson et al. 2020) and we collaborated with the Pelagic component to assess how the synchronous collapse of forage species disrupted trophic transport during the marine heatwave (Arimitsu et al. 2020, Arimitsu et al. in press). Also, we are working with the killer whale project of the Pelagic component, providing logistical support to deploy a hydrophone in Kachemak Bay and UAF student time to process hydrophone data. In general, the geographic scale of our study (GOA-wide) will continue to provide greater ability to discern both potential linkages across these diverse components, as well as among the study areas within the Nearshore component, allowing us to evaluate variability and relations among the nearshore resources. Overall, the Nearshore component contributed to all of the FY17-21 science synthesis products produced by GWA (Suryan et al. 2020a).

Two Pelagic component projects of the overall GWA program of particular importance to the nearshore are surveys of nearshore marine birds in Prince William Sound (PWS), including summer (20120114-M) and fall-winter (20120114-E) marine bird population trend projects (for additional long-term data sets of marine birds, see Irons et al. 2000, Stocking et al. 2018). The nearshore project conducts comparable surveys in KEFJ and KATM, with surveys added to KBAY in 2018. Contrasting the changes occurring in the pelagic and nearshore environments during the recent years when GOA waters have warmed by several degrees (https://alaskapacificblob.wordpress.com/2016/02/09/subsurface-warmth-persists/) may be particularly illuminating.

A cross-component (Nearshore and Pelagic) effort continues (projects 20120114-C, E, H, L, M, and O) with the intent to integrate bird survey data to examine spatial and temporal trends in a variety of species and guilds across the northern Gulf of Alaska. The Pelagic and Nearshore components worked with ABR Inc. to create a survey tool (SeaLog) and a processing tool (QAQSea) for rapid QA/QC as well as automating the processing required to upload survey data into the North Pacific Pelagic Seabird Database (NPPSD) maintained by the U.S. Geological Survey (USGS). Previous efforts compiled Nearshore survey data from all four regions and provided to USGS for the NPPSD v3 release in 2020 (Drew and Piatt 2015). Incorporation of all GWA marine bird survey data into NPPSD will allow for larger scale analyses of marine bird trends throughout the Gulf of Alaska over time. Further collaboration between the Nearshore and Pelagic components is highlighted in chapter 3 of the synthesis effort (Arimitsu et al. 2020, Arimitsu et al. in press) which utilized GWA nearshore marine bird survey data from KATM. Nearshore marine bird survey data were also used in the GWA science synthesis chapter 4 (Suryan et al. 2020b, Suryan et al. in press).

The Nearshore Component of GWA historically has been closely linked with the Lingering Oil component, given that lingering oil occurs in nearshore habitats and affects nearshore species. Although the EVOSTC has treated Lingering Oil as a separate program in the current 5-year period, we understand that it will be considered a component under the GWA program in the future. The conceptual and collaborative linkages with the nearshore component remain. Data collected by the Nearshore Component are relevant for understanding ecosystem recovery with respect to the Lingering Oil Program; for example, sea otter abundance, energy recovery rate, and age-at-death data have been used to evaluate population recovery to this point (Bodkin et al. 2014, Ballachey et al. 2014). Contaminant samples (mussels) collected during the 2018 field season were analyzed for a broad suite of compounds, including hydrocarbons. This analysis, led by NOAA's Mussel Watch program, culminated in a report that combined results other locations as well as historic results in the northern GOA in a report (Rider et al. 2020). Results indicate that there are no contaminants concerns at this time within our study areas. We look forward to potential Lingering Oil collaborations in the future.

2. Across Programs

a. Herring Research and Monitoring

The Nearshore component does not have any collaborations to date with the Herring Research and Monitoring program, but discussions are in progress with respect to coastal herring spawning habitat.

b. Data Management

This project coordinates with the data management program by submitting data and preparing metadata for publication on the Gulf of Alaska Data Portal and DataONE within the timeframes required.

3. Individual Projects

There are many projects for which collaboration with the Nearshore component has provided conceptual overlap, shared expertise, logistical support, an opportunity for sample collection, or an extension of GWA goals. Several examples follow below.

In collaboration with researchers at University of Alaska Anchorage (UAA) and University of Alaska Southeast (UAS), Nearshore GWA PIs (Konar and Iken) have received funding from the National Science Foundation Established Program to Stimulate Competitive Research (EPSCoR) program to examine how the timing, duration, and character of the freshwater flux from precipitation vs glacial melt influences nearshore biological communities. This five-year project (titled Fire and Ice) will examine an array of sites from Lynn Canal in southeast Alaska to Kachemak Bay. GWA and EPSCoR are sharing environmental data (temperature, salinity) and some biological data. One EPSCoR graduate student, Amy Dowling, is using the KBAY GWA sites as oceanic endpoints in her MS research, which is examining mussel size frequency histograms along a glacial gradient.

In collaboration with other UAF researchers, GWA PIs (Konar and Iken) received a Field Station and Marine Laboratories Award from the National Science Foundation. An array of SeapHOx sensors in Kachemak Bay to monitor pH, oxygen, salinity, and temperature at multiple sites and an experimental system to manipulate ocean variables to determine responses in marine organisms was installed at the Kasitsna Bay Marine Lab in 2019. These data will be available for all GWA PIs.

In collaboration with GWA PIs (Esler, Coletti, and Robinson), a study was initiated with Simon Fraser University to determine connectivity between breeding areas and non-breeding areas of black oystercatchers in the north Pacific. We recognize that migration strategies and large-scale movements of the black oystercatcher may play a role in their overall condition, in addition to the diet monitoring conducted by GWA. By using GPS and geolocator technology, this work will elucidate the migration strategies and identify the overwintering locations of Alaskan breeding birds. Black oystercatchers were captured and tagged in all four Nearshore regions in 2019 and three regions in 2020. Recaptures and new captures are planned to occur at all four regions in 2021. Taken together this work will highlight the times and places when and where conservation action can directly benefit black oystercatchers that breed in Alaskan coastal parks and will serve to facilitate risk assessment to a key wildlife species throughout the year.

GWA PI Kim Kloecker has been working with professors and students at Alaska Pacific University, seeking opportunities for undergrad projects that utilize GWA Nearshore component data. For example, an undergrad (Emily Reynolds) will be looking at relationships between mussel size class structure and temperature from our study sites. These are mutually beneficial ventures, with students getting access to robust data sets and scientific expertise, and the Nearshore component gets focused analysis on data that we otherwise would not have time to pursue.

B. With Trustee or Management Agencies

In addition to the logistical, administrative, and in-kind support that the NPS, USGS, NOAA, and UAF have provided to ensure success of the GWA Nearshore Component, there are several additional projects with trustee and management agencies that the Nearshore Component of GWA has collaborated with. Below are several recent examples. We expect to continue these kinds of related projects.

NOAA Fisheries

The Nearshore Component contributed nearshore indices to NOAA Fisheries for the annual Gulf of Alaska Ecosystems Considerations Report to the North Pacific Fisheries Management Council (Coletti et al. 2020, Ferriss and Zador et al. 2020). The health of nearshore ecosystems informs managers on essential fish habitat and sensitive early life stages of federally managed fish species mandated through the Magnuson-Stevens Act.

NPS sea otters in KEFJ

In 2013, building on GWA findings indicating that sea otters in KEFJ consume mussels at much higher frequencies than at other areas, we initiated a study of annual patterns in mussel energetics and sea otter foraging at KEFJ, funded by NPS and USGS. The field portion of the study was completed in 2016. Lab analyses have been completed. Initial data analyses indicate that mussel energy density varies seasonally, likely corresponding to spawning condition. Further, we found that mussel consumption by otters varied seasonally in association with varying mussel energy density, but overall mussel consumption was high in KEFJ across seasons.

NPRB sea otter study

Nearshore GWA PIs (Bodkin, Ballachey, Coletti, Esslinger, Kloecker, Konar, Monson and Weitzman) contributed to an international study supported in part by the North Pacific Research Board (NPRB Project 717) to delineate the cause and constraints to recovery of a declining sea otter population listed under the Endangered Species Act as "Threatened" across the North Pacific. Our GWA nearshore data from KATM and WPWS contributed sea otter abundance, diet, and energetics data, which was combined with data obtained from sites at the Commander Islands in the west to PWS in the eastern Pacific. Contrasts across areas identified the range of decline and identified predation as the likely cause and constraint to recovery (Estes et al. 2010, Tinker et al. in press). Results identify KATM and WPWS as beyond the area of decline in 2011. These data and results are shared with the U.S. Fish and Wildlife Service, Marine Mammals Management, the agency responsible for sea otter management.

NPS Changing Tides

Nearshore GWA PIs (Ballachey, Bodkin, and Coletti) are working with NPS on the 'Changing Tides' Project. This study examines the linkages between terrestrial and marine ecosystems and is funded by the National Park Foundation. Field work was initiated in July 2015 with in-kind support from our GWA KATM vessel charter. National Parks in Southwest Alaska are facing a myriad of management concerns that were previously unknown for these remote coasts, including increasing visitation, expanded commercial and industrial development, and environmental changes due to natural and anthropogenic forces. These are concerns because of their potential to significantly degrade and potentially impair resources in coastal systems. The Changing Tides project has three key components: (1) brown bear fitness and use of marine resources, (2) health of bivalves (clams and mussels), and (3) an integrated outreach program. We (GWA Nearshore Component) assisted with the collection of a variety of bivalve species from the coast of KATM. Specimens were kept live in small aquarium-like containers, and condition and performance metrics were assessed in the laboratory by Alaska SeaLife Center collaborators Tuula Hollmen and Katrina Counihan. Additional specimens were used for genetic transcription diagnostics (gene expression) to measure the physiologic responses of individuals to stressors, in collaboration with Liz Bowen and Keith Miles of USGS. Several papers have been published stemming from this work including three focused on the bivalve portion (Counihan et al. 2019, Bowen et al. 2020, Coletti et al. in prep). This project will increase our understanding of how various stressors may affect both marine intertidal invertebrates and bear populations at multiple spatial and temporal scales.

Building on the Changing Tides work and earlier EVOSTC studies (Bowen et al. 2018), GWA PIs (Coletti and Ballachey) are collaborating with L. Bowen (USGS) and A. Love (Prince William Sound Regional Citizens Advisory Council) to develop genetic transcription diagnostics (gene expression) to measure responses of individuals to stressors in *Mytilus trossulus*. Results on mussels sampled in in 2019 in PWS (various sites in Port Valdez) have been summarized and suggest gene transcription assays in mussels will be a useful additional tool for monitoring of contaminants; this collaboration is anticipated to continue (Bowen et al. 2019).

Further building on GWA and Changing Tides work, in the summer of 2019, we (Coletti and Ballachey) collaborated with Maya Groner (PWSSC), Maureen Purcell, and Paul Hershberger (USGS Western Fisheries Research Center) on their study of the bacterial gill pathogen NIX in razor clams. Razor clams are economically and ecologically important along coastlines in Alaska, as well as in Washington and Oregon where they are known to be affected by NIX disease. However, NIX is not thought to affect razor clams in Alaska; we provided razor clams from the KATM coast for the NIX study as a negative control sample (Travis et al. 2021). We also provided additional sample of razor clam tissue to the Alaska Department of Fish and Game for genetic and morphometric analyses.

Additional work examining the interaction between bears and marine mammals was added in 2016 (initiated by D. Monson). Previously, it was believed that bears generally utilize marine mammals via scavenging of beached carcasses. This project has shed light on the importance of marine mammals (primarily sea otters and harbor seals) as live prey taken on offshore islands along the Katmai coast (Monson et al. in review).

BOEM Nearshore community assessments

Nearshore Component PIs (Coletti, Iken, Konar, and Lindeberg) have completed recommendations to the Bureau of Ocean Energy Management (BOEM) for nearshore community assessment and long-term monitoring (Jones et al. 2020). The BOEM Proposed Final Outer Continental Shelf (OCS) Oil and Gas Leasing Program included proposed Lease Sale 258 in the Cook Inlet Planning Area in 2021. Until this leasing program, an OCS Cook Inlet Lease Sale National Environmental Policy Act (NEPA) analysis had not been undertaken since 2003. Updated nearshore information was needed to support the environmental analyses associated with the planned lease sale. The overall objective of this study was to provide data on habitats and sensitive species to support environmental analyses for NEPA documents, potential future Exploration Plans, and Development and Production Plans. Throughout this process, a goal has been to utilize existing nearshore monitoring protocols already developed through GWA when possible to ensure data comparability across all regions. All data are being provided to the Alaska Ocean Observing System Gulf of Alaska Data Portal.

CMI Nearshore food webs in Cook Inlet

Funded through the Coastal Marine Institute (CMI), a partnership between BOEM and UAF, GWA PIs Iken and Konar worked with a student on analyzing food web structure in western Cook Inlet (above-mentioned BOEM project) and at GWA sites in Kachemak Bay by using carbon and nitrogen stable isotope analyses. Intertidal taxa at western Cook Inlet are clearly adapted to utilizing some of the more terrestrial material available from river and glacial discharge than the more marine production-feeding taxa in Kachemak Bay. This adds valuable information about the energetic links among the species that are analyzed for their abundance and distribution through GWA. A final report has been submitted to CMI and BOEM and a manuscript has been submitted to the Gulf of Alaska Special Issue in Deep-Sea Research II and is currently under review (Siegert et al. in review). A student within the EPSCoR Fire and Ice program is currently investigating nearshore food web structure in glacially influenced watersheds in Kachemak Bay, which will provide a complementary dataset to the above-mentioned work at the GWA sites under an expanded environmental setting.

Drones to collect monitoring data

Nearshore GWA PIs (Iken and Konar) tested the use of unmanned aircraft systems (UASs) for various aspects of coastal biological monitoring in KBAY. With BOEM funding, UASs were compared to traditional methods of rocky intertidal and seagrass sampling with some success and suggestions for future work (Konar and Iken 2018). After this success, UASs were tested to determine their feasibility to complete sea otter foraging observations in KBAY with USGS funding (Monson and Weitzman).

In August 2019, GWA PIs (Hondolero and Weitzman) with an academic collaborator (Tom Bell – University of California Santa Barbara) used a UAS to map canopy kelp and eelgrass habitats in Kachemak Bay with support from NOAA – Kasitsna Bay Lab. The pilot effort proved successful, resulting in a poster at the 2020 Alaska Marine Science Symposium. The Kasitsna Bay Laboratory intends to pursue more UAS mapping of kelp and other nearshore habitats in 2021.

In collaboration with NPS, during recent nearshore monitoring trips on the Katmai coast, the GWA Nearshore project (GWA PI Monson and NPS collaborator Martyn) tested the use of a small UASs to map intertidal sites. The elevation data collected by the UAS will allow us to track changes in topography over time and enable us to correlate species presence and abundance with elevation in the intertidal zone. The high-resolution elevation data may also be critical for future assessments of ecosystem change due to sea-level rise, earthquakes, or other natural phenomena. Collection of UAS based aerial imagery for each site allows for documentation of physical disturbances, which can be valuable when trying to interpret variation in community structure within sites. Data collected from 2017-2019 are currently being analyzed. UAS flights in KATM will not take place in 2021 as the Department of Interior has issued a ‘stand down’ of all NPS UAS operations.

The Pacific nearshore project

In kind support from GWA and NPS was provided to the USGS Pacific Nearshore Project (https://pubs.usgs.gov/fs/2010/3099/) that investigated methods to assess overall health of nearshore ecosystems across the north Pacific. In particular, samples were collected during GWA trips to KATM and WPWS to examine the sources of primary productivity to two fish species that differed in their feeding mode (kelp greenling/nearshore benthic vs. black rockfish/pelagic). Stable isotope analyses showed that both benthic foraging and pelagic foraging fish species derive their energy from a combination of macro- (kelps) and micro-algae (phytoplankton) sources (von Biela 2016a). Initial stable isotope analyses from across the GOA of a variety of nearshore invertebrates supports the concept that kelps are a primary contributor of carbon to nearshore ecosystems in the GOA (unpublished data). Further work was completed by von Biela et al. (2016b), with support from GWA, examining the role of local and basin-wide ocean conditions on growth rates of benthic foraging and pelagic foraging fish species. In 2018, we initiated a pilot study to build on the Pacific Nearshore Project by sampling fish and mussels across all four regions. Objectives are to 1) examine relative contributions of macroalgae and phytoplankton to nearshore intertidal mussels and subtidal fishes over space and time, 2) examine variation in the relative contributions of primary producers and determine if that variation is related to growth performance, and 3) assess annual growth rates of mussels and fish to determine if they are synchronous with other GWA environmental drivers or indicators of productivity in nearshore or pelagic ecosystems. Sample collection is on-going throughout all four regions of the Nearshore component. This project forms the foundation of the new MS student projects starting in 2021, supported by NPS and carry over dollars not expended due to COVID-19.

Nearshore ecosystem responses to glacial inputs

Nearshore GWA PIs (Esler, Coletti, Robinson, Weitzman), in collaboration with NPS, have initiated work aimed at documenting variation in nearshore physical oceanography in relation to tidewater glacial input, and quantify biological responses to that variation across trophic levels in KEFJ. This work will allow prediction of changes in nearshore ecosystems in the face of ongoing glacier mass loss and retreat from the marine environment. This proposed work relies heavily on GWA nearshore monitoring data and will build on our understanding of nearshore marine processes.

9. Information and Data Transfer:

A. Publications Produced During the Reporting Period

1. Peer-reviewed Publications

Arimitsu, M., J. Piatt, R.M. Suryan, S. Batten, M.A. Bishop, R.W. Campbell, H. Coletti, D. Cushing, K. Gorman, S. Hatch, S. Haught, R.R. Hopcroft, K.J. Kuletz, C. Marsteller, C. McKinstry, D. McGowan, J. Moran, R.S. Pegau, A. Schaefer, S. Schoen, J. Straley, and V.R. von Biela. In press. Synchronous collapse of forage species disrupts trophic transfer during a prolonged marine heatwave. Global Change Biology.

Bowen, L., K. Counihan, B. Ballachey, H. Coletti, T. Hollmen, B. Pister and T. Wilson. 2020. Monitoring Nearshore Ecosystem Health Using Pacific Razor Clams (*Siliqua patula*) as an Indicator Species. PeerJ 8:e8761 DOI 10.7717/peerj.8761

Coletti H., L. Bowen, B. Ballachey, T. Wilson, M. Booz, K. Counihan, T. Hollmen, and B. Pister. In prep. Gene transcription profiles in two razor clam populations: discerning drivers of population status.

Coletti, H.A. In press. Sea Otter Behavior and Its Influence on Littoral Community Structure. In R.W. Davis and A. Pagano (Eds) The Ethology of Marine Mammals: Polar Bears and Sea otters. Springer.

Davis, R.W., and J.L. Bodkin. In Press. Sea otter foraging behavior. In R.W. Davis and A. Pagano (Eds) The Ethology of Marine Mammals: Polar Bears and Sea otters. Springer.

Monson D., R. Taylor, G. Hilderbrand, J. Erlenbach, H. Coletti, and J. Bodkin. In Review. Brown Bears and sea otters along the Katmai coast: Terrestrial and nearshore communities linked by predation. Journal of Mammalogy.

Piatt, J.F., J.K. Parrish, H.M. Renner, S. Schoen, T. Jones, K. Kuletz, B. Bodenstein, M. Arimitsu, M. García-Reyes, R. Duerr, R. Corcoran, R. Kaler, G. McChesney, R. Golightly, H. Coletti, R. M. Suryan, H. Burgess, J. Lindsey, K. Lindquist, P. Warzybok, J. Jahncke, J. Roletto, W. Sydeman. 2020. Mass mortality and chronic reproductive failure of common murres during and after the 2014-2016 northeast Pacific marine heatwave. PLOS One https://doi.org/10.1371/journal.pone.0226087

Siegert, D., B. Konar, M.R. Lindeberg, S. Saupe, and K. Iken. In review. Trophic structure of rocky intertidal communities in two contrasting high-latitude environments. Deep-Sea Research II.

Suryan, R.M., M. Arimitsu, H. Coletti, R.R. Hopcroft, M.R. Lindeberg, S. Batten, M.A. Bishop, R. Brenner, R. Campbell, D. Cushing, S. Danielson, D. Esler, T. Gelatt, S. Hatch, S. Haught, K. Holderied, K. Iken, D. Irons, D. Kimmel, B. Konar, K. Kuletz, B. Laurel, J.M. Maniscalco, C. Matkin, C. McKinstry, D. Monson, J. Moran, D. Olsen, S. Pegau, J. Piatt, L. Rogers, A. Schaefer, J. Straley, K. Seeeney, M. Szymkowiak, B. Weitzman, J. Bodkin, and S. Zador. In press. Ecosystem response to a prolonged marine heatwave. Scientific Reports.

Tinker, T.M., J.L. Bodkin, L. Bowen, B.E. Ballachey, G. Bentall, A. Burdin, H.A. Coletti, G.E. Esslinger, B.B. Hatfield, M.C. Kenner, K.A. Kloecker, A.K. Miles, D.H. Monson, M.J. Murray, B. Weitzman, and J.A. Estes. In press. Sea otter population collapse in southwest Alaska: assessing ecological covariates, consequences, and causal factors. Ecological Monographs.

Weitzman, B., B. Konar, K. Iken, H. Coletti, D. Monson, R. Suryan, T. Dean, D. Hondolero, and M. Lindeberg. 2021. Changes in rocky intertidal community structure during a marine heatwave in the northern Gulf of Alaska. Frontiers in Marine Science 8:556820. doi: 10.3389/fmars.2021.556820

2. Reports

Arimitsu, M., J. Piatt, R.M. Suryan, S. Batten, M.A. Bishop, R.W. Campbell, H. Coletti, D. Cushing, K. Gorman, S. Hatch, S. Haught, R.R. Hopcroft, K.J. Kuletz, C. Marsteller, C. McKinstry, D. McGowan, J. Moran, R.S. Pegau, A. Schaefer, S. Schoen, J. Straley, and V.R. von Biela. 2020. Chapter 3 Synchronous collapse of forage species disrupts trophic transfer during a prolonged marine heatwave. In M.R. Suryan, M.R. Lindeberg, and D.R. Aderhold, eds. The Pacific Marine Heatwave: Monitoring During a Major Perturbation in the Gulf of Alaska. Gulf Watch Alaska Long-Term Monitoring Program Draft Synthesis Report (*Exxon Valdez* Oil Spill Trustee Council Program 19120114). *Exxon Valdez* Oil Spill Trustee Council, Anchorage, Alaska.

Coletti, H., D. Esler, B. Konar, K. Iken, K. Kloecker, D. Monson, B. Weitzman, B. Ballachey, J. Bodkin, T. Dean, G. Esslinger, B. Robinson, and M. Lindeberg. 2020. Gulf Watch Alaska: Nearshore Ecosystems in the Gulf of Alaska. *Exxon Valdez* Oil Spill Restoration Project Annual Report (Restoration Project 19120114-H), *Exxon Valdez* Oil Spill Trustee Council, Anchorage, Alaska.

Coletti, H., J. Bodkin, T. Dean, D. Esler, K. Iken, B. Ballachey, K. Kloecker, B. Konar, M. Lindeberg, D. Monson, B. Robinson, R. Suryan and B. Weitzman. 2020 Intertidal Ecosystem Indicators in the Northern Gulf of Alaska in Ferriss, B. and S. G. Zador. 2020. Ecosystem Status Report 2020: Gulf of Alaska. Report to the North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99301.

Danielson, S.L., T.D. Hennon, D.H. Monson, R.M. Suryan, R.W. Campbell, S.J. Baird, K. Holderied, and T.J. Weingartner. 2020. Chapter 1 A study of marine temperature variations in the northern Gulf of Alaska across years of marine heatwaves and cold spells. In M.R. Suryan, M.R. Lindeberg, and D.R. Aderhold, eds. The Pacific Marine Heatwave: Monitoring During a Major Perturbation in the Gulf of Alaska. Gulf Watch Alaska Long-Term Monitoring Program Draft Synthesis Report (*Exxon Valdez* Oil Spill Trustee Council Program 19120114). *Exxon Valdez* Oil Spill Trustee Council, Anchorage, Alaska.

Ferriss, B., and S.G. Zador. 2020. Ecosystem Status Report 2020: Gulf of Alaska. Report to the North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Rider, M., D.A. Apeti, A. Jacob, K. Kimbrough, E. Davenport, M. Bower, H. Coletti, and D. Esler. 2020. A Synthesis of Ten Years of Chemical Contaminants Monitoring in National Park Service - Southeast and Southwest Alaska Networks. A collaboration with the NOAA National Mussel Watch Program. NOAA Technical Memorandum NOS NCCOS 277. Silver Spring, MD. 110 pp. DOI 10.25923/dbyq-7z17 https://repository.library.noaa.gov/view/noaa/25520

Suryan, R.M., M. Arimitsu, H. Coletti, R.R. Hopcroft, M.R. Lindeberg, S. Batten, M.A. Bishop, R. Brenner, R. Campbell, D. Cushing, S. Danielson, D. Esler, T. Gelatt, S. Hatch, S. Haught, K. Holderied, K. Iken, D. Irons, D. Kimmel, B. Konar, K. Kuletz, B. Laurel, J.M. Maniscalco, C. Matkin, C. McKinstry, D. Monson, J. Moran, D. Olsen, S. Pegau, J. Piatt, L. Rogers, A. Schaefer, J. Straley, K. Seeeney, M. Szymkowiak, B. Weitzman, J. Bodkin, and S. Zador. 2020. Chapter 4 Ecosystem response to a prolonged marine heatwave in the Gulf of Alaska. In M.R. Suryan, M.R. Lindeberg, and D.R. Aderhold, eds. The Pacific Marine Heatwave: Monitoring During a Major Perturbation in the Gulf of Alaska. Gulf Watch Alaska Long-Term Monitoring Program Draft Synthesis Report (*Exxon Valdez* Oil Spill Trustee Council Program 19120114). *Exxon Valdez* Oil Spill Trustee Council, Anchorage, Alaska.

Weitzman, B., B. Konar, K. Iken, H. Coletti, D. Monson, R.M. Suryan, T. Dean, D. Hondolero, and M.R. Lindeberg. 2020. Chapter 2 Changes in rocky intertidal community structure during a marine heatwave in the northern Gulf of Alaska. In M.R. Suryan, M.R. Lindeberg, and D.R. Aderhold, eds. The Pacific Marine Heatwave: Monitoring During a Major Perturbation in the Gulf of Alaska. Gulf Watch Alaska Long-Term Monitoring Program Draft Synthesis Report (*Exxon Valdez* Oil Spill Trustee Council Program 19120114). *Exxon Valdez* Oil Spill Trustee Council, Anchorage, Alaska.

3. Popular articles

Coletti, H. 2020. Refuge Notebook: What happened when the ocean warmed. Peninsula Clarion. July 30.

Traiger, S. 2021. Mussels are thriving: Thank your (un)lucky stars. Delta Sound Connections. Prince William Sound Science Center.

B. Dates and Locations of any Conference or Workshop Presentations where EVOSTC-funded Work was Presented

1. Conferences and Workshops

Arimitsu, M., J. Piatt, R.M. Suryan, S. Batten, M.A. Bishop, R.W. Campbell, H. Coletti, D. Cushing, K. Gorman, S. Hatch, S. Haught, R.R. Hopcroft, K.J. Kuletz, C. Marsteller, C. McKinstry, D. McGowan, J. Moran, R.S. Pegau, A. Schaefer, S. Schoen, J. Straley, and V.R. von Biela. 2021. Heatwave-induced synchrony within forage fish portfolio disrupts energy flow to top pelagic predators. Poster Presentation. Alaska Marine Science Symposium, January.

DeCino, K., K. Holderied, B. Weitzman, and M. Renner. 2021. State of Kachemak Bay: A tool for understanding and reporting change. Poster presentation. Alaska Marine Science Symposium January.

Dowling, A., B. Konar, and K. Iken. 2021. Size distribution variability in Pacific blue mussels (*Mytilus trossulus*) in glacially influenced estuaries. Poster presentation. Alaska Marine Science Symposium, January.

Dowling, A., B. Konar, and K. Iken. 2020. Size distribution variability in Pacific blue mussels (*Mytilus trossulus*) in glacially influenced estuaries. Poster presentation. World Conference on Marine Biodiversity, December.

Hasan, L., B. Konar, T. Jones, and H. Coletti. 2021. Subtidal habitat mapping in Cook Inlet for current and predictive sea otter habitat associations. Poster Presentation. Alaska Marine Science Symposium, January.

Holderied, K., M. Renner, A. Jyzk, D. Hondolero, and B. Weitzman. 2021. Speed dating through meroplankton? Linking ocean and nearshore ecosystems in Kachemak Bay, Alaska. Poster. Alaska Marine Science Symposium, January.

Lindeberg, M., R. Suryan, D. Aderhold, K. Hoffman, R. Hopcroft, H. Coletti, Y. Arimitsu. 2021. Gulf Watch Alaska: Building Partnerships to Understand Ecosystem Change. Poster Presentation. Alaska Marine Science Symposium, January.

Mearns, A., D. Janka, S. Pegau, and B. Robinson. 2021. Inter-Annual and longterm variability of rocky intertidal biota at selected sites in Prince William Sound, 1989 to 2020. Alaska Marine Science Symposium, January.

Traiger, S.B., J.L. Bodkin, H.A. Coletti, B. Ballachey, T. Dean, D. Esler, K. Iken, B. Konar, M.R. Lindeberg, B. Robinson, R.M. Suryan, B. Weitzman. 2021. How the mighty have fallen: Indirect effects of sea star wasting syndrome on mussel abundance in the Northern Gulf of Alaska. Alaska Marine Science Symposium, January.

Traiger, S.B., J.L. Bodkin, H.A. Coletti, B. Ballachey, T. Dean, D. Esler, K. Iken, B. Konar, M.R. Lindeberg, B. Robinson, R.M. Suryan, and B. Weitzman. 2020. How the mighty have fallen: Indirect effects of sea star wasting syndrome on mussel abundance in the Northern Gulf of Alaska. Western Society of Naturalists, November.

2. Public presentations

Lindeberg, M. and J. Bodkin. 2020. Gulf Watch Alaska: Program Overview and Highlights and Monitoring Upper Trophic Consumers in the Nearshore. Oral Presentation. Virtual MARINe Annual Workshop, March 13, 2020.

C. Data and/or Information Products Developed During the Reporting Period, if Applicable

In 2020, the NPS created a Story Map based on the Piatt et al. 2020 article: Mass mortality and chronic reproductive failure of common murres during and after the 2014-2016 northeast Pacific marine heatwave. PLOS One. NPS also maintains a seabird dis-off webpage that is updated regularly. Seabird Die-Offs - Alaska Nature and Science (U.S. National Park Service) (nps.gov)

In 2020, Nearshore component PIs updated all the Gulf Watch Alaska webpages to reflect the current status of the project as well as provide the latest findings. Nearshore Ecosystems | Gulf Watch Alaska

D. Data Sets and Associated Metadata that have been Uploaded to the Program's Data Portal

Coletti, H., J. Bodkin, B. Ballachey, D. Monson, D. Esler, M. Lindeberg, T. Dean, B. Weitzman, K. Kloecker, G. Esslinger, K. Iken, and B. Konar. 2020. Gulf Watch Alaska Nearshore Component: Black oystercatcher data from Prince William Sound, Katmai National Park and Preserve, Kachemak Bay, and Kenai Fjords National Park. 2019 Data. *Exxon Valdez* Oil Spill Trustee Council Long-Term Monitoring program. Gulf of Alaska Data Portal.

Coletti, H., J. Bodkin, B. Ballachey, D. Monson, D. Esler, M. Lindeberg, T. Dean, B. Weitzman, K. Kloecker, G. Esslinger, K. Iken, and B. Konar. 2017-2021. Gulf Watch Alaska Nearshore Component: Monitoring Site Locations from Prince William Sound, Katmai National Park and Preserve, Kachemak Bay, and Kenai Fjords National Park. *Exxon Valdez* Oil Spill Trustee Council Long-Term Monitoring program. Gulf of Alaska Data Portal.

Coletti, H., J. Bodkin, B. Ballachey, D. Monson, D. Esler, M. Lindeberg, T. Dean, B. Weitzman, K. Kloecker, G. Esslinger, K. Iken, and B. Konar. 2020. Gulf Watch Alaska Nearshore Component: Intertidal Mussel Site Data from Prince William Sound, Katmai National Park and Preserve, Kachemak Bay, and Kenai Fjords National Park. 2019 Data. *Exxon Valdez* Oil Spill Trustee Council Long-Term Monitoring program. Gulf of Alaska Data Portal.

Coletti, H., J. Bodkin, B. Ballachey, D. Monson, D. Esler, M. Lindeberg, T. Dean, B. Weitzman, K. Kloecker, G. Esslinger, K. Iken, and B. Konar. 2020. Gulf Watch Alaska Benthic Component: Intertidal Rocky Shore Limpet Size Data from Prince William Sound, Katmai National Park and Preserve, Kachemak Bay, and Kenai Fjords National Park. 2019 Data. *Exxon Valdez* Oil Spill Trustee Council Long-Term Monitoring program. Gulf of Alaska Data Portal.

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10. Response to EVOSTC Review, Recommendations and Comments:

Science Panel Comment (FY21): The SP appreciates the plan to fund a MS student with savings associated with cancelled surveys and other sources.

GWA PI Response (FY21): The nearshore component appreciates the support of the Science Panel regarding our plan to support a MS student with savings associated with modified field efforts during the COVID-19 pandemic during 2020.

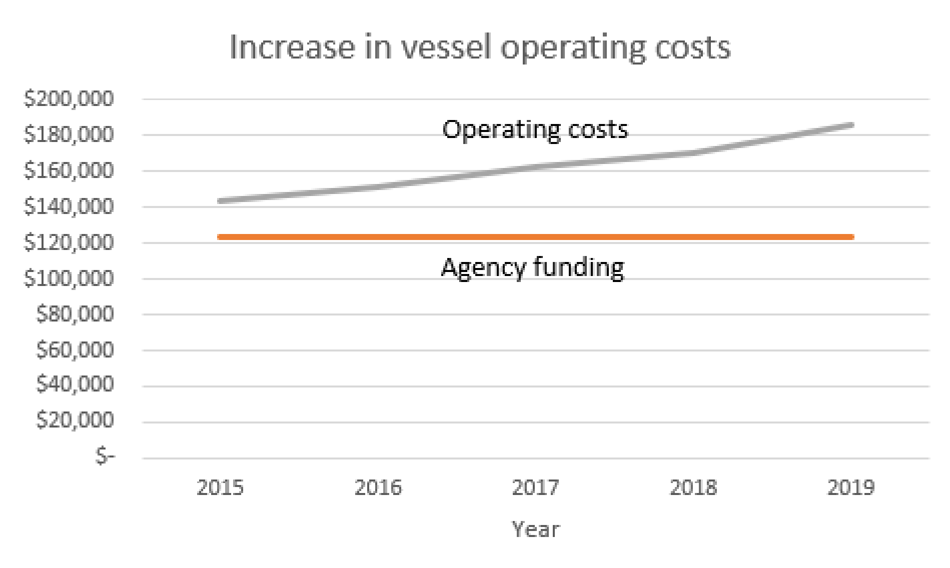
Science Panel Comment (FY21): The Science Panel appreciates the creative measures taken to accomplish field work and surveys during the Covid pandemic. We may see more of the same pandemic-related restrictions on field work and access to labs, which will require alternative plans that were not stated in the program and project proposals. Each project should address the following questions. What are the program and project contingency plans for FY21 in regard to accomplishing goals and field activities? The SP understands that it may be challenging to develop extensive and detailed contingency plans for the future, but some planning is required. Will any unused funds for FY21 be repurposed for additional lab and/or data analyses? Or are they requested to rollover to FY22 (pending proposal approval)? Other ways to accomplish field work - i.e., other vessels that could be used or other projects that can be leveraged?

GWA PI Response (FY21): The nearshore component of GWA is planning a full field season for FY21. The primary goal of the nearshore component is to complete all spending in FY21. However, in the event that COVID-19 restricts field activities, we have the following contingency plans:

- As in FY20, we will conduct as much field work as we safely can. We expect that much of the work scheduled for Kachemak Bay in FY21 could be completed, following FY20 activities and precautions. Also, small skiff and crew configurations were used to conduct limited sampling in WPWS and KEFJ in FY20 and also would be implemented in FY21. As needed, we will coordinate with vessel operators (contracted and USGS) to consider use of smaller, core crews to collect data in areas beyond skiff range.
- Any cost savings resulting from reduced FY21 field work will be:
  a. Used to support the MS student through an existing agreement with UAF.
  b. Used to support additional prioritized lab analyses not covered under the current agreement with UAF (such as compound-specific isotope analysis and otolith aging).
  c. Used for staff time toward additional data analyses expanding science products, including marine bird community analyses, evaluating trends in under-analyzed species (e.g., predatory snails, limpets), and evaluating spatial and temporal variation in sea otter diets.
  d. Used to fund an extension of the current post doc appointment to produce additional synthesis products such as: contrasts of Gulf Watch Alaska data to marine monitoring findings from the lower 48 and evaluating marine predator characteristics and how they influence vulnerabilities to different types of perturbations (e.g., oil spills versus marine heat waves).
  e. If needed, a detailed request will be made in the Work Plan schedule to carry over funds into FY22 to finish options pursued in a-d.

Science Panel Comment (FY20): The Panel would like to see more detail on the increase in operating costs. Is the additional request for $24K for previous costs or for this year's increase in operating costs? Will this be an annual request?

GWA PI Response (FY20): The costs of operating the US Geological Survey (USGS) research vessel Alaskan Gyre are increasing through time, while the base contribution of USGS facilities money has remained static (Fig. 1). The base contribution from USGS still allows the boat to be used at a fraction of the cost of charter vessels (see estimates below); however, this does not cover as much of the total operating costs as in past years. USGS has prepared a business plan for operating and maintaining the Alaskan Gyre, which resulted in the need to increase costs to projects. These



increased costs are being required of all users of the Alaskan Gyre, not just Gulf Watch Alaska projects.

Figure 1. Annual costs of operating the USGS research vessel Alaskan Gyre relative to the agency funding allocation.

The increase in overall operating costs reflects increases in nearly all of the specific costs of running the Alaskan Gyre. However, a sizeable proportion of the increased costs are associated with a few specific items, including personnel (captain salary and benefits), maintenance (shop rates and material costs are increasing), and harbor fees. All of these costs are essential for safely and effectively operating the vessel. The budget request for FY20 is for costs anticipated in that fiscal year, not previous years' costs. We also are requesting funds for FY21, anticipating that operating costs will not go down. If additional funding is not approved, field time on the Alaskan Gyre could be reduced by as many as 19 days.

Charter boats used for nearshore sampling have ranged from $3600 to $5000 per day. Our request for additional funds, assuming at least 50 days of Gulf Watch Alaska use annually, is less than $500 per day. Moreover, some of the Gulf Watch Alaska work involves trawling for forage fish and the Alaskan Gyre has been specifically outfitted to do this work.

Science Panel Comment (FY20): In FY19 we requested the exploration of the relationships among species. The PIs did not address this inquiry. We note the PIs responded with an example that mussel density has increased, and Fucus and sea stars have declined but no other interpretations were offered or reported in the FY18 annual report. The Panel requests PIs address this and present possible mechanisms for this change. This certainly should be included in the synthesis paper(s). We appreciate the listed collaborations with a wide variety of groups.

GWA PI Response (FY20): We agree with the science panel that understanding inter-specific relationships is important and that the nearshore component is particularly well-suited for evaluating those, given the large number of species monitored across multiple trophic levels and the sampling design in which all data streams are spatially coordinated. Below we describe our efforts to date along these lines, as well as plans for additional exploration in the near future.

The Nearshore program is the lead on two of the Gulf Watch Alaska synthesis manuscripts currently in progress. One of the these manuscripts is specifically focused on inter-species and community relationships and titled "Synchronous Region-wide Responses in Intertidal Community Structure to a Marine Heat Wave in the Gulf of Alaska." This synthesis product will focus on changes in intertidal community structure at long-term monitoring sites that stretch across the Gulf of Alaska from Prince William Sound to the Katmai Peninsula over the period from 2006 through 2018, with emphasis on changes that occurred during the 2014-2016 marine heatwave. We are examining site specific changes in intertidal temperature as well as changes in percent cover of intertidal algae and invertebrates during this period. Preliminary analyses indicate that differences in community structure exist across sites; however, synchronous trends across sites in heatwave years over very large spatial scales suggest influence of large-scale oceanographic events. While mean water temperatures differ across sites and regions (i.e., Katmai generally colder), all regions exhibited anomalous warming during heatwave years indicating that the heatwave may be driving these synchronous responses of the biological community in the intertidal.

We also will be continuing to explore inter-specific relationships within the nearshore component and across components. The USGS postdoc position, recently funded by the EVOSTC, will support an early-career scientist as they work with Gulf Watch Alaska principal investigators to evaluate interspecific relationships as part of synthesis efforts.

Additional species-environmental relationships are in our FY18 Annual Report (Coletti et al. 2019), as well as in the annual NOAA Gulf of Alaska Ecosystem Status Report (Coletti et al. 2018), we identified warming water temperatures (heatwave) as a possible driver for coincident responses of several species, representing various trophic levels, across the nearshore environment in the northern Gulf of Alaska. These include both direct responses of warming surface temperatures and also indirect effects through interspecific interactions. We documented negative anomalies of rockweed in three of the four regions and sea stars across all regions coincident with warm water temperatures. We hypothesized that the decline in sea star abundance was likely due to sea star wasting disease (Konar et al. 2019), which was first detected in 2014 and is generally associated with warm water temperature anomalies (Eisenlord et al. 2016). We documented positive anomalies during 2015-2019 for large mussels. This is likely due, in part, to a response to the reduced predation pressure given the synoptic decline of sea stars. Continued positive anomalies of large mussels in Katmai National Park and, to a lesser degree, in Kachemak Bay coincide with continued negative anomalies of sea stars in these two regions. A decline in small mussel density (an indicator of recruitment) was also observed during the 2015-2017 period, possibly because of the decrease in Fucus as available settlement habitat or some reduction in primary productivity.

We also published a paper specific to the sea star decline to document pre- and post-heatwave community structure and examined possible static drivers of those communities (Konar et al. 2019). Sea star wasting disease and then subsequent declines in sea stars resulted in a sea star assemblage that is responding to different environmental variables and has drastically altered ecological function by the reduction of species composition and loss of large predatory sea stars. Understanding the delicate interplay of environmental variables that influence sea star assemblages could expand knowledge of the habitat preferences and tolerance ranges of important sea star species within the northern Gulf of Alaska.

In 2016, a paper was published in Ecosphere (Coletti et al. 2016) highlighting the overall nearshore monitoring program while simultaneously providing examples of linkages across metrics to detect and infer causes of change. In one example specific to Kenai Fjords National Park, we documented changes in the proportion of various prey types in the sea otter diet that coincided with changes in the abundance of the mussel, *Mytilus trossulus*. This is likely a bottom-up driven interaction as mussel abundance in Kenai Fjords is very high while sea otter abundance is considered low, but stable and likely at carrying capacity for this region.

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11. Budget:

For FY20, funds were shifted among budget categories; for example, personnel costs have increased while contractual costs have decreased, reflecting the transition from contracted PIs to agency staff. Also, we requested and received EVOSTC approval for an additional $23,980 (including 9% GA) for FYs 20 and 21. These funds will cover some of the costs of operating the RV *Alaskan Gyre*, which have increased substantially and were unanticipated at the time of the original proposal.

In FY20 (due to COVID-19 restrictions) we are redirecting funding that was unused for field operations to support a MSc student at UAF to conduct a project evaluating stable isotope variation in nearshore food webs and associated effects on productivity of nearshore flora and fauna. These changes are reflected in the FY21 budget. We are making a 2-year commitment to a student, which goes beyond the currently funded GWA 5-year block, but we are confident we can acquire the necessary funds for FY22. We will be requesting the reallocation of some FY21 funds to support the student, which are described in the FY21 nearshore Work Plan.

***EXXON VALDEZ* OIL SPILL TRUSTEE COUNCIL**
PROJECT BUDGET PROPOSAL AND REPORTING FORM

Budget Category:	Proposed FY 17	Proposed FY 18	Proposed FY 19	Proposed FY 20	Proposed FY 21	TOTAL PROPOSED	ACTUAL CUMULATIVE
Personnel	$228.8	$229.1	$229.4	$250.7	$250.9	$1,188.9	$822.6
Travel	$17.4	$17.5	$17.6	$10.7	$10.8	$74.0	$58.9
Contractual	$83.1	$125.5	$83.1	$73.1	$72.7	$437.5	$331.3
Commodities	$23.9	$23.0	$23.0	$44.0	$44.0	$157.9	$47.9
Equipment	$5.0	$10.0	$14.0	$2.0	$2.0	$33.0	$24.4
Indirect Costs (*will vary by proposer*)	$10.5	$10.3	$10.3	$10.4	$10.5	$52.0	$26.7
SUBTOTAL	$368.7	$415.4	$377.4	$390.9	$390.9	$1,943.3	$1,311.7
General Administration (9% of subtotal)	$33.2	$37.4	$34.0	$35.2	$35.2	$174.9	N/A
PROJECT TOTAL	$401.9	$452.7	$411.4	$426.1	$426.1	$2,118.2	
Other Resources (Cost Share Funds)	$410.0	$410.0	$410.0	$389.6	$389.6	$2,009.2	

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