1. Project Number:

17120114-J

2. Project Title:

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

3. Principal Investigator(s) Names:

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4. Time Period Covered by the Report:

February 1, 2017-January 31, 2018 (Year 6)

5. Date of Report:

March 2018

6. Project Website (if applicable):

www.gulfwatchalaska.org

7. Summary of Work Performed:

The overall project goal is to continue and enhance time-series of oceanographic data from shipboard surveys and shore-based stations in lower Cook Inlet and Kachemak Bay that provide information on seasonal, inter-annual, and spatial trends and variability of marine conditions, to help understand of variations in nearshore and pelagic food webs. We also put these observations in the context of other ongoing physical and biological oceanographic studies occurring in Prince William Sound, the outer Kenai Peninsula, and the Gulf of Alaska under the Gulf Watch Alaska (GWA) program, as well as other ongoing state and federal agency studies in the region. Our data will be used to better understand how the coastal region responds to climate variability and change. Specific project objectives include:

1. Determine the thermohaline structure of Kachemak Bay and the southeastern Cook Inlet entrance at seasonal and longer time scales.
2. Determine long-term trends and variability from daily to interannual time scales in Kachemak Bay oceanography.
3. Determine seasonal patterns of phytoplankton and zooplankton species abundance and community composition within Kachemak Bay and southeastern Cook Inlet.
4. Assess interannual changes in oceanographic structure and phytoplankton/zooplankton species composition across the Cook Inlet entrance.

5. Assess seasonal patterns in oceanography, macronutrients, and plankton between Kachemak Bay, southeastern Cook Inlet and the adjacent shelf (collaboration with Seward Line and Continuous Plankton Recorder (CPR) projects).
6. Determine temporal patterns and linkages in oceanographic conditions and plankton communities between lower Cook Inlet and Kachemak Bay and the Gulf of Alaska continental shelf (GAK1, Seward Line, CPR projects), and Prince William Sound (Prince William Sound oceanography and Seward Line projects).
7. Provide environmental forcing data for correlation with biological data sets in the nearshore benthic project component and pelagic components of GWA.
8. Provide Alaska Department of Fish and Game (ADF&G), National Oceanographic and Atmospheric Administration (NOAA) and U.S. Fish and Wildlife Service (USFWS) resource managers with assessment of oceanographic trends and seasonal conditions.

During 2017, under the lower Cook Inlet/Kachemak Bay oceanographic monitoring project, we collected year-round oceanographic, zooplankton and phytoplankton data, completed taxonomic identification for zooplankton samples collected in 2016, delivered quality-controlled data to the Research Workspace before program deadlines, and conducted data analyses with project time series data from 2012-2017. The project is part of Environmental Drivers component of the *Exxon Valdez* Oil Spill Trustee Council (EVOSTC) GWA program, and provides data to help assess the impacts of nearshore oceanographic variability on nearshore and pelagic species injured by the spill. Sampling completed in this period included conducting oceanographic surveys and plankton sampling in lower Cook Inlet (Transects 3, 6, and 7) and Kachemak Bay (Transects 4 and 9) (Fig. 1) and continuous oceanographic sampling at nearshore stations. As proposed, we focused shipboard sampling on the east side of lower Cook Inlet and included monthly sampling of an along-bay transect in Kachemak Bay to better characterize seasonal changes in estuary-shelf oceanographic gradients. For FY17-21, cross-inlet sampling is now only done in the spring at the Cook Inlet entrance transect (Transect 6), and provides data on cross-estuary patterns at a time aligned with spring sampling of other Environmental Drivers projects (Seward Line and CPR). Oceanographic data were collected vertically at stations using conductivity-temperature-depth (CTD) profilers (shown as dots on Fig. 1). Zooplankton and phytoplankton sampling was conducted at up to three stations along each transect (red dots in Fig. 1). Sample collection dates and locations from 2012-2017 are summarized in Table 1. In addition to shipboard surveys, higher frequency data were obtained with continuous, year-round oceanographic measurements and monthly nutrient and chlorophyll measurements at Kachemak Bay National Estuarine Research Reserve (KBNERR) System Wide Monitoring Program (SWMP) water quality stations at the Seldovia and Homer harbors, as well as in ice-free months from a mooring near the head of Kachemak Bay in Bear Cove (Fig. 1). Analyses of 2017 oceanographic data showed a shift toward a cooler and saltier water column, returning toward more average conditions from the warming/freshening conditions seen in 2014-2016 in Kachemak Bay/lower Cook Inlet. An initial correlation between environmental variables and zooplankton community species composition in Kachemak Bay identified temporal (by year), but not spatial (by transect) responses to oceanographic variations.

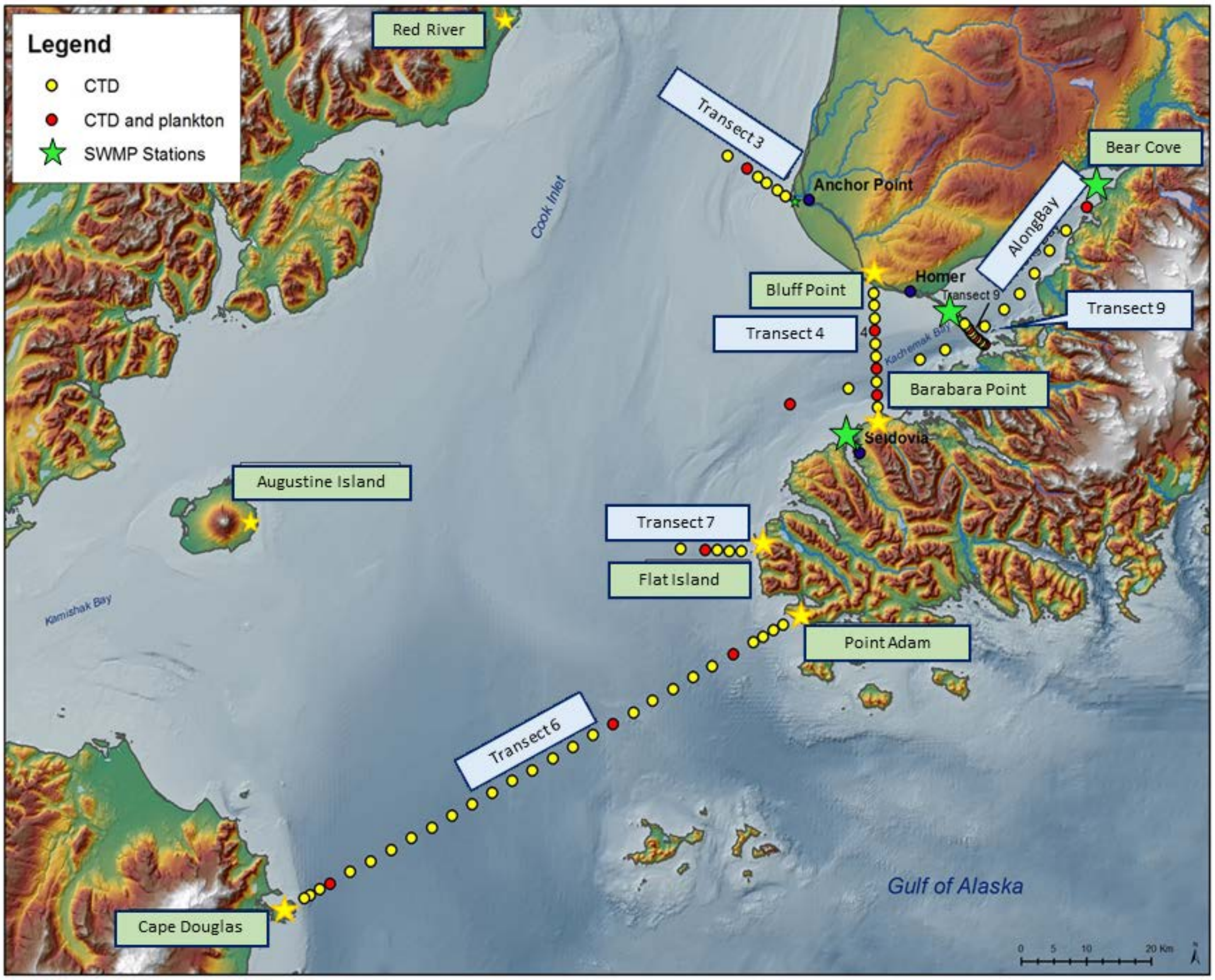


Figure 1. Sampling locations for the lower Cook Inlet and Kachemak Bay project in 2017. Stations shown for shipboard oceanography (all dots) and phytoplankton and zooplankton sampling (red dots). Kachemak Bay NERR continuous sampling water quality stations are marked with green stars. Yellow stars show geographical locations of start and endpoints of transects, with place names shown in boxes.

Table 1. Sampling frequency of Kachemak Bay and lower Cook Inlet transects from 2012-2017. Blue color denotes that samples were collected. AB stands for the AlongBay transect.

		CTD						PHYTOPLANKTON						ZOOPLANKTON						WATER SAMPLES					
		Transect No.						Transect No.						Transect No.						Transect No.					
	Month	AB	3	4	6	7	9	AB	3	4	6	7	9	AB	3	4	6	7	9	AB	3	4	6	7	9
2012	January																								
2012	February						X																		
2012	March						X																		
2012	April						X						X						X		X	X	X	X	
2012	May		X	X	X		X		X	X	X	X	X		X	X	X	X	X		X	X	X	X	X
2012	June			X			X			X			X			X			X			X	X	X	X
2012	July		X	X	X	X	X		X	X	X	X	X		X	X	X	X	X		X	X	X	X	X
2012	August	X		X			X			X									X						
2012	September						X						X						X						
2012	October		X	X	X	X	X		X		X	X	X		X		X	X	X			X	X	X	
2012	November																								
2012	December																								
2013	January						X						X						X						
2013	February	X		X			X			X			X			X			X			X			
2013	March						X						X						X						X
2013	April		X	X	X	X	X		X	X	X	X	X		X	X	X	X	X		X	X	X	X	X
2013	May						X						X						X						X
2013	June	X		X			X			X			X						X						X
2013	July		X	X	X	X	X		X	X	X	X	X		X	X	X	X	X				X	X	
2013	August						X						X						X						
2013	September						X						X						X						
2013	October			X			X			X			X			X			X						X
2013	November		X		X				X		X				X		X								
2013	December						X						X						X						
2014	January						X						X						X						
2014	February		X	X		X	X		X	X		X	X		X	X		X	X						
2014	March	X					X						X						X						
2014	April		X	X	X	X	X		X	X	X	X	X		X	X	X	X	X						
2014	May	X					X						X						X						X
2014	June						X						X						X						
2014	July		X	X	X	X	X		X	X	X	X	X		X	X	X	X	X		X	X	X	X	X
2014	August	X		X			X			X			X			X			X						
2014	September						X						X						X						
2014	October		X	X	X	X	X		X	X	X	X	X		X	X	X	X	X		X	X	X	X	X
2014	November						X						X						X						
2014	December						X						X						X						
2015	January						X																		
2015	February		X	X	X	X	X		X	X	X	X	X		X	X	X	X	X		X		X		
2015	March						X						X						X						
2015	April		X	X	X	X	X		X	X	X	X	X		X	X	X	X	X					X	
2015	May						X						X						X						
2015	June						X						X						X						
2015	July	X					X						X						X						
2015	August	X		X	X	X	X																		
2015	September			X			X			X			X						X						
2015	October			X			X			X			X			X			X			X			X
2015	November		X	X			X		X	X			X		X	X			X		X	X			X
2015	December			X			X			X			X			X			X						
2016	January	X					X						X						X						
2016	February		X	X	X	X	X		X	X	X	X	X		X	X	X	X	X		X	X	X	X	X
2016	March																								
2016	April		X	X	X		X		X	X	X		X		X	X	X		X		X	X	X		X
2016	May	X					X			X		X	X			X		X	X			X		X	X
2016	June	X					X						X						X						X
2016	July	X		X			X			X			X			X			X			X			X
2016	August		X		X	X			X		X	X			X		X	X			X		X	X	
2016	September						X						X						X						X
2016	October			X			X			X			X			X			X			X			X
2016	November						X						X						X						X
2016	December			X	X	X																			
2017	January	X					X						X	X					X						X
2017	February	X					X						X						X						X
2017	March	X					X	X					X	X					X	X					X
2017	April	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X
2017	May	X					X						X						X	X					X
2017	June	X					X	X					X	X					X	X					X
2017	July	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2017	August	X					X						X						X						X
2017	September	X					X	X					X	X					X						X
2017	October	X		X			X	X		X			X	X		X			X			X			X
2017	November	X			X	X	X	X			X	X	X	X			X	X	X	X			X		X
2017	December	X					X						X						X						X

Field Sampling

Field sampling activities for 2017 were completed in accordance with our proposal and with the detailed sampling protocols available on the Alaska Ocean Observing System (AOOS) Research Workspace. Shipboard oceanographic and plankton sampling was conducted monthly in Kachemak Bay (Transect 9, AlongBay transect) and quarterly in outer Kachemak Bay (Transect 4) and southeast Cook Inlet (Transects 3, 6 and 7). Logistical challenges caused by inclement weather resulted in some data gaps in the Cook Inlet sampling (see Table 1), as well as slight differences in the times of seasonal sampling relative to prior years, but we were able to characterize seasonal and along-estuary conditions in detail. In addition to project field sampling, we were able to leverage the GWA shipboard surveys and data to support an intensive harmful algal bloom (HAB) research project, focusing on temporal and spatial patterns in the phytoplankton species, *Alexandrium,* which produce saxitoxins and cause paralytic shellfish poisoning. *Alexandrium* cell abundances and shellfish toxicity were examined in detail for several sub-bays in Kachemak Bay during the summer of 2017. For this experiment, we placed Pacific oysters (*Mallana gigas*) in mesh cages suspended below buoys at several sites near the Kasitsna Bay Laboratory. Oysters were placed in the cages for one-week intervals and then collected to determine shellfish tissue toxicity patterns over the summer season, in conjunction with water quality data at the same sites, along with water samples that were filtered to count cells and determine *Alexandrium* cell abundances. The EVOSTC project oceanographic data provided context for seasonal and interannual changes in marine conditions for the HAB field research and some HAB monitoring results are included in this report.

Recent Results and Scientific Findings

Oceanography sampling results: Waters in Kachemak Bay were cooler throughout the water column and saltier at depth in 2017 than in the previous year, which was a return towards more average conditions. The Cook Inlet/Kachemak Bay region experienced a transition from anomalously cold water temperatures in 2012 to persistent warm temperature anomalies starting in late 2013 and lasting through 2014-2016, then followed by cooling in 2017. The observed warming was part of a large scale warm period across the Gulf of Alaska and northeast Pacific Ocean associated with Pacific marine heat wave (“Blob”) and El Niño climate events. Time series data from shipboard surveys (Fig. 2) and shore stations (Fig. 3) are used here to illustrate the transition to warmer than average temperatures that occurred in late fall 2013/early winter 2014, as well as the return to near-average conditions in 2017.

Fig. 2 shows a time series of vertical temperature and salinity profiles from February 2012 to December 2017 from monthly sampling at the middle CTD station along the mid-Kachemak Bay survey line (Transect 9, station 6). The transition to warmer water temperatures starting in late 2013 and early 2014 was dramatic, with much warmer surface temperatures observed in the summers of 2014, 2015 and 2016, and subsequent cooling in 2017 (Fig. 2, top). In winter, the coldest water temperatures were observed in 2012 (<2 degrees Celsius (˚C)) and 2015-2016 temperatures were the warmest (> 6 ˚C), before winter temperatures cooled in 2017 (<4 ˚C). Water column salinities varied seasonally, with variability dominated by the annual cycle, but also varied by year and by depth. In summer, surface salinities in the mid-bay appeared to respond mostly to seasonal changes and precipitation events, rather than to the interannual climate events, but in winter, surface waters were fresher in the winters of 2015 and 2016, with a return to saltier conditions in 2017, consistent with more freshwater input to the bay during the warmer winters. Below the pycnocline, deeper waters freshened in all seasons in 2015-2016 and then became saltier in 2017 (Fig. 2), which may reflect the influence of freshening in Alaska Coastal Current waters during warm winters, which then entered the deeper portions of the bay.

Longer-term data (2004-2017) from the near-bottom sensor at the Seldovia Harbor SWMP station are used to provide additional temporal context for the recent warm event and clearly show the transition to warmer than average conditions in late fall 2013 and persistence of warmer and fresher than normal conditions through 2016 (Fig. 3). Warmest water temperature anomalies (relative to 2005-2014 monthly means) were observed in the winters of 2014-2015 and 2015-2016, with monthly averaged anomalies of up to 3 degrees C, followed by near-average conditions for most of 2017 with the exception of >1 ˚C warm anomalies in September and December 2017 (Fig. 3, top). Salinity data at Seldovia also shows a clear annual signal most years, with higher salinities in winter due to reduced freshwater input as air temperatures drop below freezing and then decreasing salinity in spring through late summer with freshwater inputs from precipitation, snowpack melt and glacier melt. Fall salinity conditions were more variable, depending on storm tracks and precipitation events. However, this annual pattern was disrupted in 2015 and 2016, with fresher conditions and more variability in both winters, and persistently fresher than normal monthly average salinities in 2014-2016, before returning to more normal conditions in 2017 (Fig. 3, bottom).

In addition, continuous monitoring of near-surface water quality at the Seldovia, Homer, and Bear Cove SWMP stations provided time series along the estuarine gradient in Kachemak Bay. Monthly averaged values for near-surface water temperature, salinity and dissolved oxygen at all three sites for 2012-2017 are shown in Fig. 4 (noting for comparison that Fig. 3 shows data from the near-bottom sensor at Seldovia). Surface water temperatures at each site showed close similarities in their seasonal patterns, but had different temperature ranges, with the lowest winter surface water temperatures observed at the Homer site, and highest summer temperatures found at the Bear Cove site (Fig. 4). Temperatures were consistently warmer than average in 2014-2016, with closer to average temperatures observed in 2017, consistent with our other observations. Salinities were lowest and most variable near the head of Kachemak Bay at Bear Cove and least variable at the Seldovia site (Fig. 4), which reflects greater influence of local freshwater input at the Bear Cove and Homer sites. The timing of summer freshening also varied between the sites, with Seldovia lagging the other two sites, which reflects the influence from Gulf of Alaska waters. Distinct annual variations in salinity were observed in all years at the Homer and Bear Cove sites, but the annual pattern was disrupted at Seldovia in 2015 and 2016 with more winter freshening (Fig. 4), which is consistent with mid-bay CTD observations. The surface salinity patterns at these stations did not change consistently during the marine heat wave (Fig. 4), unlike the persistently freshening observed at the deeper Seldovia station sensor during that period (Fig. 3). Salinity observations at the shore stations and from the CTD surveys indicate that salinities at the surface and in the inner bay responded more to changes in freshwater input from storms, precipitation patterns and snowpack melt, than to larger climate patterns, while salinities in deeper waters varied more with larger climate patterns. However, changing climate patterns also affect precipitation and snowpack, as well as wind mixing, so these factors are not independent. Dissolved oxygen concentrations exhibited an annual cycle with highest values in spring, with similar ranges of values and timing of seasonal changes between sites and little interannual variability (Fig. 4, middle).

To provide an example of patterns observed in lower Cook Inlet, in Fig. 5 we provide along-transect vs depth contours of temperature and salinity which show seasonal (spring, summer, fall) and interannual variability along the Cook Inlet entrance (Transect 6). Conditions were most mixed in spring, with freshwater from the upper Inlet showing up on the very western side of the transect. Spring conditions in 2016 were warmer by 1.5 - 2˚C and fresher than in 2012, 2014 and 2017 and in August of 2016 we observed the warmest, freshest and most stratified conditions of any survey (Fig. 5). In 2017, conditions on the eastern side of the entrance in summer and fall months were similar to 2014 and relatively mixed compared to some of the earlier years (Fig. 5). The Cook Inlet entrance is influenced by variability in transport and intrusions of the Alaska Coastal Current, and we plan future comparisons to satellite sea surface temperature time series to help interpret oceanographic patterns.

Zooplankton Results: From 2012 to 2016, two hundred and fifteen discrete zooplankton samples from shipboard surveys have been analyzed by researchers (R. Campbell group) at the Prince William Sound Science Center, which resulted in the identification of species from 168 taxa across 12 phyla. Identification is ongoing for samples collected in 2017. Abundance data were log transformed to stabilize variance. Using Ward's agglomerative method, a hierarchical cluster analysis (HCA) produced distinct groups based on species assemblages. These groups were used in the Indicator Species Analysis (ISA) to examine which species were indicative of each group. We summarized temporal variation in zooplankton community composition for each transect (combining results from three plankton stations along the transect) in a stacked histogram of the relative proportion of zooplankton species category by sampling date (Figs. 6, 7, 8); rare or intermittently observed categories (≤ 1% across most sampling periods) were combined in the "other" category. Spatial and seasonal variability across the study area is further illustrated in Fig. 9, which combines data by station and season from all years. Zooplankton density was highest in spring or summer at all sampling locations and lowest in fall or winter (Fig. 9). *Pseudocalanus* was the most abundant taxon in most seasons at all locations. Inner Kachemak Bay and to a lesser degree outer Kachemak Bay differ from the remaining Cook Inlet stations in showing a more diverse zooplankton community, where *Acartia longerimis*, *Parasagitta elegans*, and Barnacle nauplii were also common. *Neocalanus plumcrus* distributions had a north-south gradient, being rare to absent in the northern part of lower Cook Inlet and the most abundant species in southern Cook Inlet during spring (Fig. 9).

Based on the zooplankton indicator species analysis from 2012-2016 for all sampling areas combined, it was determined that early spring periods were characterized by ostracods, cumacea, and the copepod *Scolechithricella minor* ($p < 0.05$) (Figs. 6, 7, and 8). Late spring months were primarily identified by the concurrent presence of all three species of *Neocalanus* in more than

60% of samples ($p < 0.05$); fish eggs were also an important factor of this group. The summer period included one copepod, *Tortanus discaudatus*, as the defining species ($p < 0.05$) (Figs. 6, 7, and 8). Species that categorized the late fall were dominated by copepods including *Mesocalanus tenuicornis*, *Calanus pacificus*, and *Clausocalanus* sp. ($p < 0.05$) (Figs. 6, 7, and 8). Taxonomic groups from Kachemak Bay (Transects 4 and 9) were defined by meroplanktonic larvae such as barnacle cyprids, shrimp and crab zoea ($p < 0.05$) in the summer (Figures 6 and 7).

During this study period, we also used the five year (2012-2016) zooplankton and oceanographic time series to begin analyzing patterns of variability in the zooplankton community, and the role of environmental variables in driving the observed biological patterns. Biological variability in the zooplankton community was analyzed with data from the spring months (March – May) in Kachemak Bay (Transects 4 and 9). Using a Bray-Curtis similarity matrix in PRIMER on 4^{th} root transformed data and a similarity percentages (SIMPER) analysis, we identified *Acartia spp*., barnacle nauplii, crab zoea, unidentified egg, *Neocalanus spp*., and *Pseudocalanus spp*. as the top six taxa that contributed to interannual variability for all years (2012 – 2016). A 4th root transformation was used to downplay the influence of overly abundant species and increase the significance of rarer species. The SIMPER analysis breaks down the contribution of each species (or other variable) to the observed similarity (or dissimilarity) between samples. Fig. 10 shows the temporal and spatial variability of those six species in Kachemak Bay. In 2012, unidentified eggs were abundant, with barnacle nauplii becoming more important after 2012 and *Pseudocalanus spp*. increasing in abundance in 2016 (Fig. 10). To determine which variables (density, dissolved oxygen, PAR, salinity, temperature, and fluorescence) correlated best with the zooplankton community composition for each year, we ran a principal components analysis (PCA) in PRIMER, finding that PC1 and PC2 explained 69.9% of the variability in the data. The data did not cluster spatially (by transect/location), but it did cluster temporally (by year) with separation between 2012, 2013, 2014 and 2015/2016 (Fig. 11). The two variables that best describe the patterns seen in the zooplankton community are temperature and chlorophyll (details not shown here, but are available in poster presented at 2018 Alaska Marine Science Symposium).

Phytoplankton Results: Results from phytoplankton sampling on EVOSTC shipboard surveys are discussed here, along with the results from more frequent (approximately weekly in summer) sampling conducted at the NOAA Kasitsna Bay Laboratory dock (supported by NOAA/National Centers for Coastal Ocean Science [NCCOS]). The more detailed time series provide valuable information on temporal variability in plankton abundance and species composition, while the EVOSTC project ship survey data provide better information on spatial variability in the phytoplankton community. Samples from Kachemak Bay/ lower Cook Inlet were generally dominated by diatoms, usually *Chaetoceros* spp*.,* except for a few fall samples that were dominated by dinoflagellates (Figs. 12 and 13). Spring and summer samples also showed high abundances of other diatoms, including *Pseudo-nitzschia* spp*., Rhizosolenia* spp., and *Thalassiosira* spp. There were no consistent patterns in phytoplankton abundances and composition between cold (2012) and warm (2014) years in outer Kachemak Bay and lower Cook Inlet transects, except that seasonal patterns were more similar across the area in 2014 (low in spring, high in summer with dominance by *Chaetoceros* spp) (Fig. 12). Samples near Anchor Point (just north of Kachemak Bay) also had relatively high cell abundances in both spring and summer, for both cold and warm years.

The intensive phytoplankton sampling data from Kasitsna Bay were used to create more detailed seasonal time series of relative species composition (Fig. 13) and total phytoplankton cell abundance (Fig. 14). Unfortunately, the Kasitsna Bay phytoplankton samples from 2016 were processed improperly, so we do not have data from that year. The Kasitsna Bay samples were dominated by diatoms, usually *Chaetoceros* spp., with low abundances of dinoflagellates seen throughout the year (Fig. 13). Total cell abundances of dinoflagellates and diatoms showed the same general pattern each year with a spring bloom of diatoms beginning in late April or early May, peaking in July, and continuing through August when numbers begin to decline and remain near zero from November through March (Fig. 14). One striking difference in 2017, relative to 2012-2015, is the reduced contribution of *Chaetoceros* spp and increased relative abundance of "other diatoms" (Fig. 13), along with a reduction in total cell abundance in 2017 (Fig. 14). Other diatom species such as *Leptocylindrus spp.* and *Lauderia spp.* were proportionally more dominant in 2017 as a result of lower abundances of *Chaetoceros spp.* throughout the summer, with the absolute abundances of the other species staying comparable to what they had been in previous years. To investigate spatial and seasonal variability, we also combined phytoplankton data from all years, by location and season (Fig. 15). The highest phytoplankton abundances were consistently seen in Kachemak Bay, with the next highest on the eastern side of lower Cook Inlet and the lowest abundances found on the western side of Cook Inlet (Fig. 15). While *Chaetoceros* spp were frequently the most dominant species across the study area, *Thalassiosira* spp were a higher percentage of the community in the Inlet than in Kachemak Bay and species composition was most variable in the northern part of lower Cook Inlet (Transect 3). Relative abundances of *Pseudonitzschia* spp. also increased in fall months at many stations in the bay and inlet.

Data analyses were conducted in 2017 to examine spatial and temporal variability in *Alexandrium* spp. cell concentrations as part of NCCOS supported harmful algal bloom research studies. The increase in these toxic phytoplankton and paralytic shellfish poisoning events in Kachemak Bay in 2014 and 2015, associated with warmer water events, prompted us to conduct an intensive sampling project throughout Kachemak Bay in 2016 for *Alexandrium* spp. cells and to monitor shellfish toxicity more intensively in time. The results indicated that *Alexandrium* cells were present in all of the Kachemak Bay sub-bays, although abundances differed throughout the summer and among sub-bays (Fig. 16), with the highest abundances observed in early September and concentrations rising to almost 10,000 cells/liter. For comparison, we expect to see toxicity in shellfish when *Alexandrium* spp. cell concentrations get above approximately 500 cells/liter. A time series of shellfish toxicity levels from caged oysters, mussels and clams (Fig. 17) showed the same general pattern as for the *Alexandrium* spp. cell abundances, with toxicity differing among sub-bays, but showing a similar seasonal pattern of rising slowly rose throughout the late spring and summer and reaching a peak in early September (Fig. 17). Highest toxicities observed in 2016 were above 200 micrograms of saxitoxin per 100 grams of tissue, well over the regulatory limit for human shellfish consumption of 80 micrograms per 100 grams of tissue. With a clear relationship established between cell concentrations and toxicity, we can use a five year time series of cell concentrations developed from quantitative polymerase chain reaction (qPCR) analysis of phytoplankton samples from 2012-2016 to assess changes in paralytic shellfish poisoning risk over our initial project study period. *Alexandrium* cell concentrations exhibited consistent seasonal patterns each year, with a late spring or early summer rise in cell abundances peaking around the same time in August or September and declining to near zero cells in winter (Fig. 18). In 2014-2016, cell concentrations in Kachemak Bay increased relative to 2012-2013, rising above the 500 cells/liter level in each of those warmer than average summers (noting that the abundance scale on Fig. 18 is logarithmic). We established a clear association of warmer summer temperatures, increased cell concentrations and increased toxicity over 2012-2016, and going forward, we plan to examine the potential role of warmer winter temperatures in affecting *Alexandrium* cysts and complete analysis of 2017 plankton data, which had closer to average water temperatures. The results will be incorporated into improved HAB risk assessment tools, such as the Kachemak Bay HAB Information System (www.aoos.org/k-bay-hab/), in collaboration with other NOAA offices, Alaska Department of Environmental Conservation, Alaska Department of Fish and Game and Alaska Department of Health and Social Services.

Result Figures:

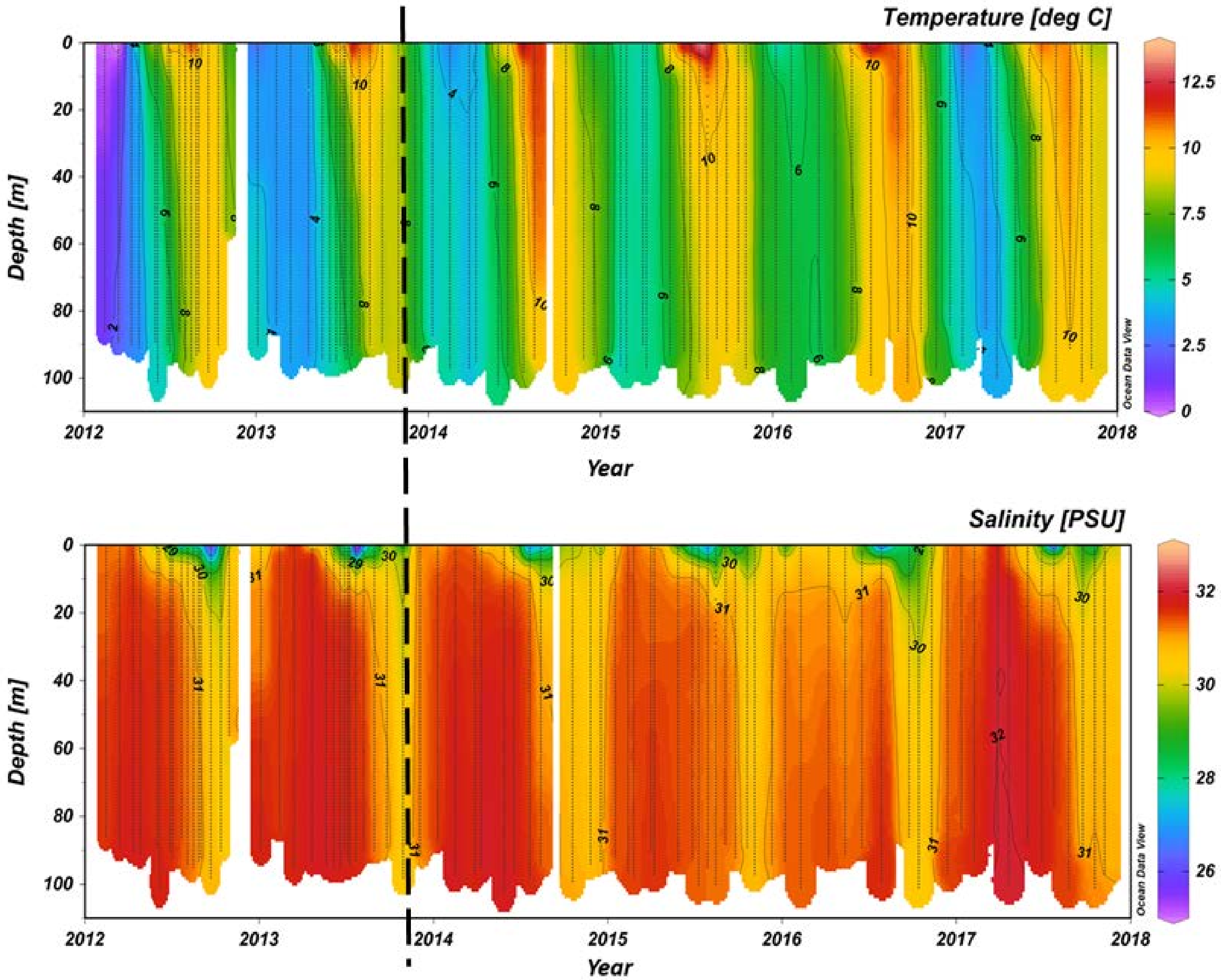
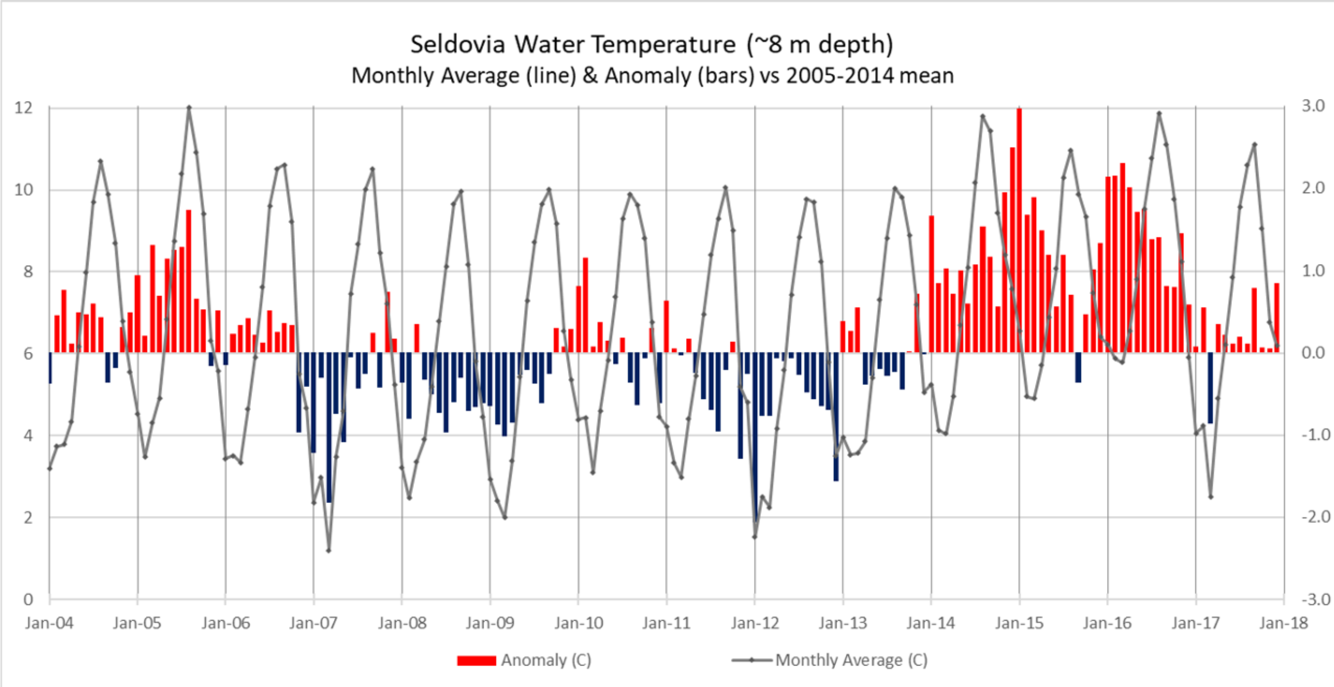


Figure 2. Time series of vertical profiles of water column temperature (top, degrees C) and salinity (bottom, PSU) from 2012-2017 collected from monthly CTD casts at a mid-Kachemak Bay station (station 9-6). The dashed black line marks the transition to warmer conditions in late 2013, with warmer than average temperatures observed throughout the water column in 2014-2016 and a return to cooler conditions in 2017. Surface salinity patterns did not vary consistently between warmer and cooler periods, but a slight freshening of deeper waters was observed in deeper waters in 2015-2016, especially in winter months, with a return to saltier conditions in 2017.



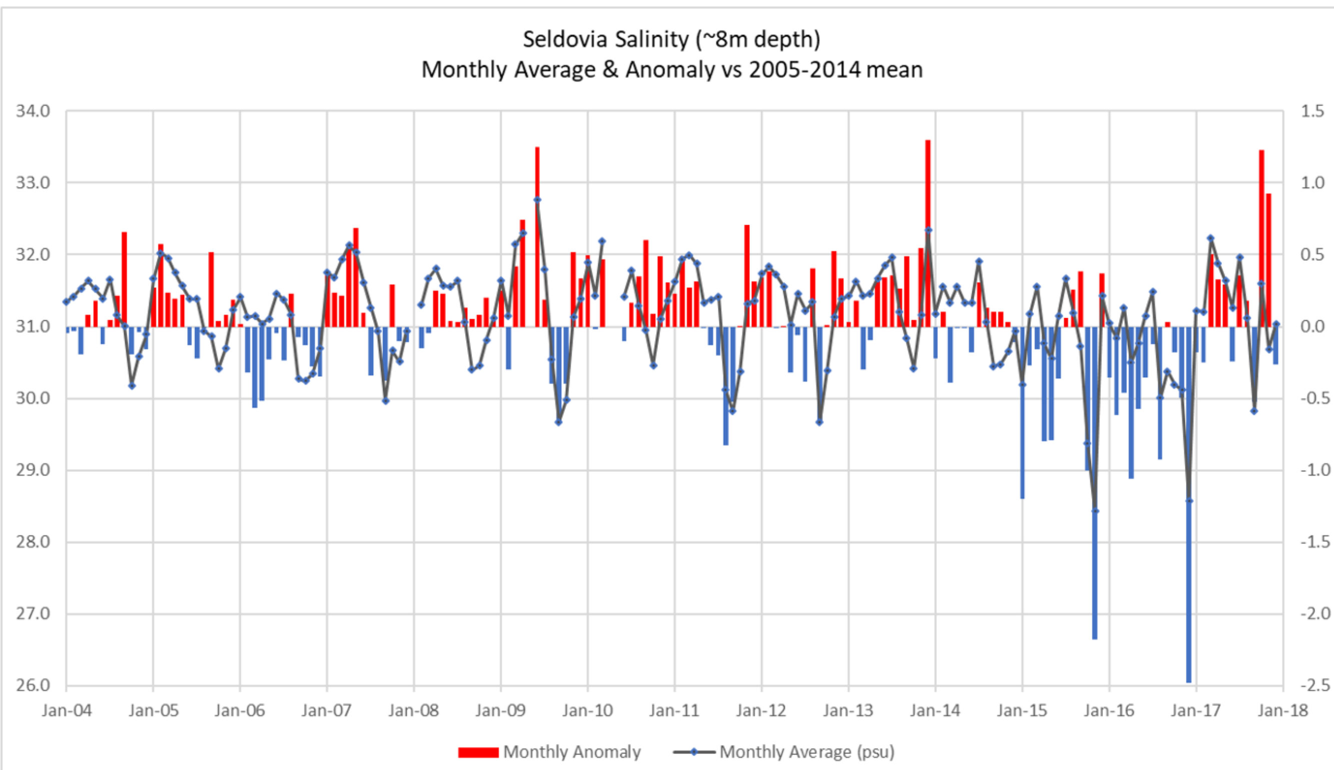


Figure 3. Time series of monthly average (line) and monthly anomaly (bars) water temperatures (top) and salinities (bottom) at KBNERR monitoring station in Seldovia during 2004 – 2017. These NERR SWMP station data are collected from a sensor package 1 meter above sea bottom. Red bars indicate positive (warm/salty) anomalies and blue bars indicate negative (cold/fresh) anomalies.

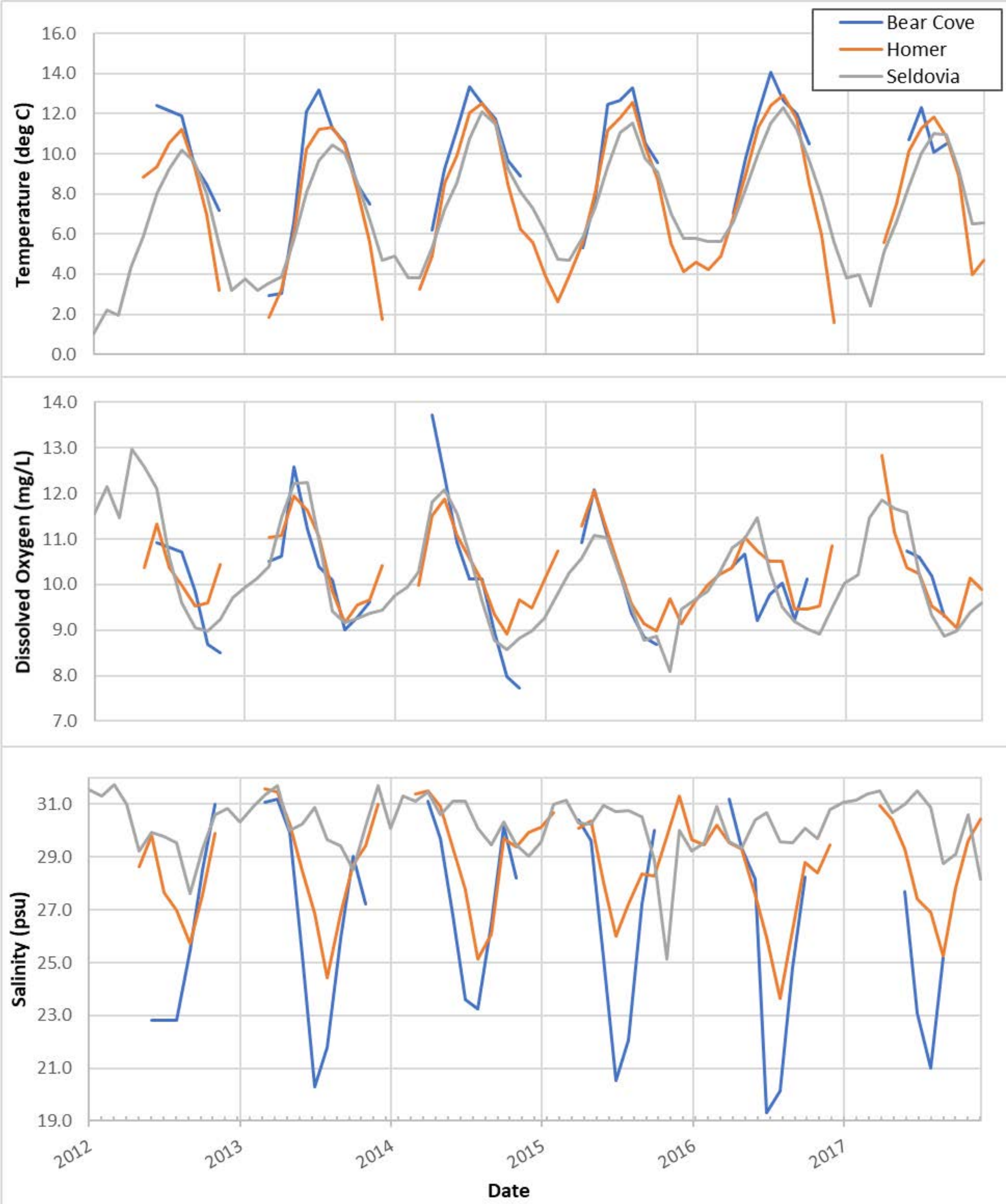


Figure 4. Monthly-averaged environmental data recorded at KBNERR monitoring stations in Seldovia, Homer, and Bear Cove during 2012 – 2017. These NERR SWMP station data are collected from a sensor package 1 meter below the sea surface. The Homer surface and Bear Cove mooring are not deployed in winter due to ice, and other data gaps are due to missing sensor data or data rejection during QA/QC process.

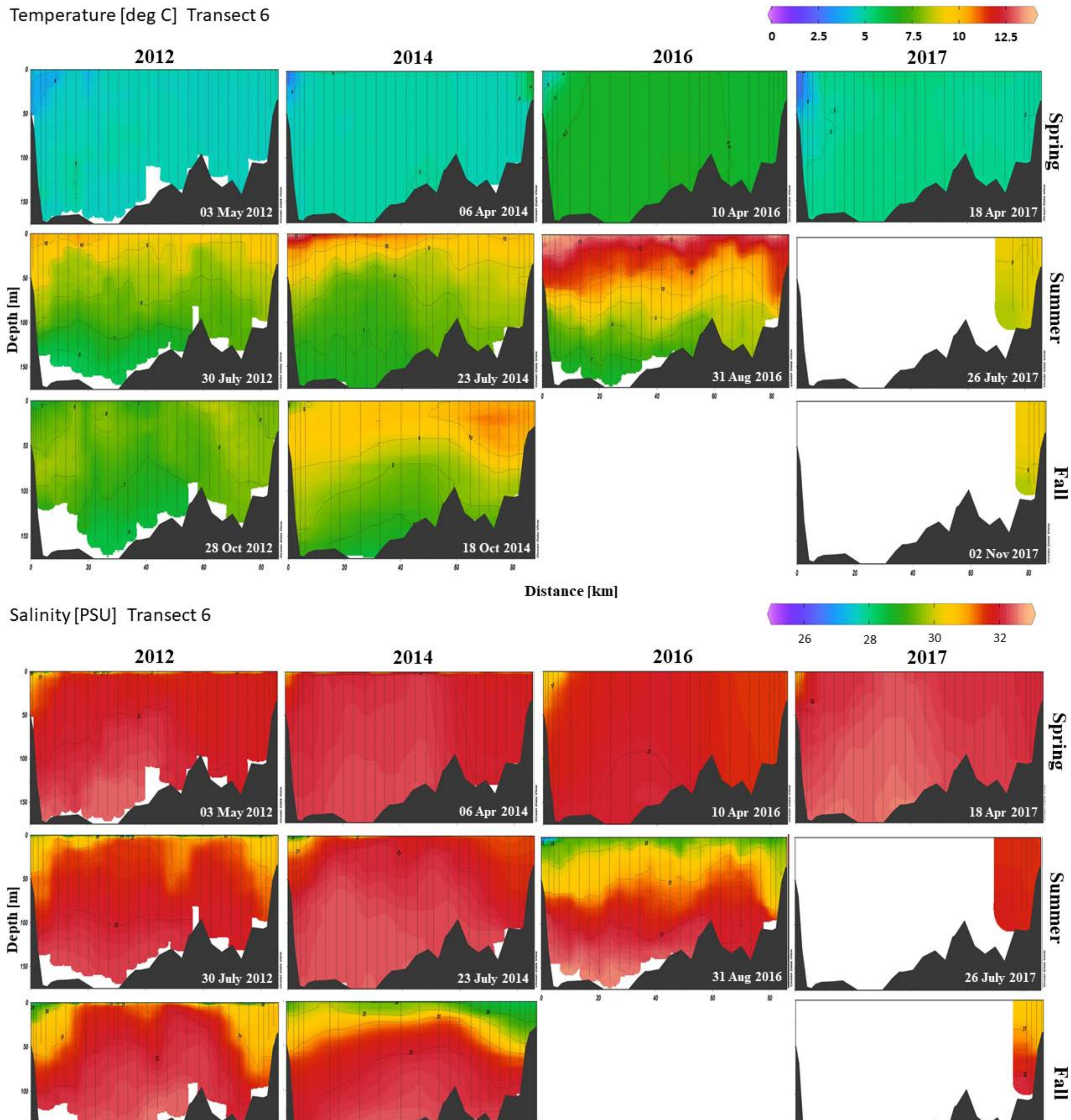


Figure 5. Comparison of seasonal variation in temperature and salinity from vertical oceanographic profile data across the lower Cook Inlet entrance (Transect 6) for the years 2012, 2014, 2016, and 2017. Columns represent years and rows represent seasons. For 2017-2021, the full entrance transect is only sampled in spring, with the east side sampled quarterly. Note that the 2016 summer sampling was in August, not July.

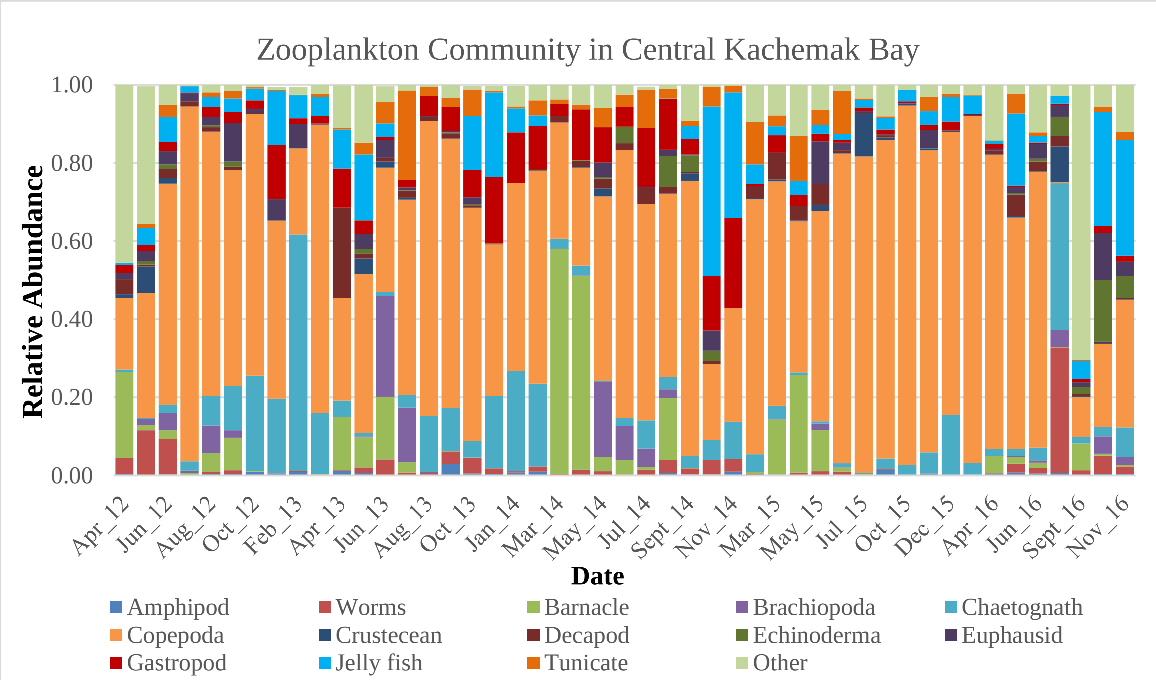


Figure 6. Proportion of zooplankton in central Kachemak Bay samples collected at stations 1, 6, and 9 along Transect 9 during 2012-2016. Rare or intermittently observed species (≤ 1% across most sampling periods) were combined in the "Other" category.

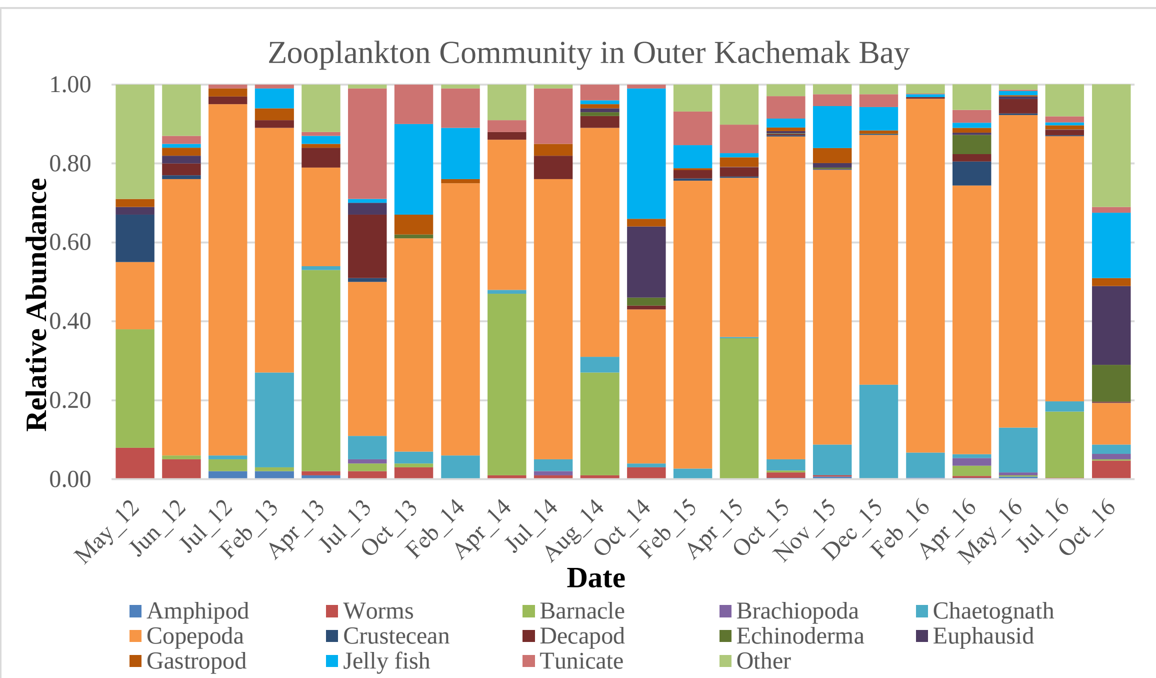


Figure 7. Proportion of zooplankton in outer Kachemak Bay samples collected at stations 2, 4, and 7 along Transect 4 during 2012-2016. Rare or intermittently observed species (≤ 1% across most sampling periods) were combined in the "Other" category.

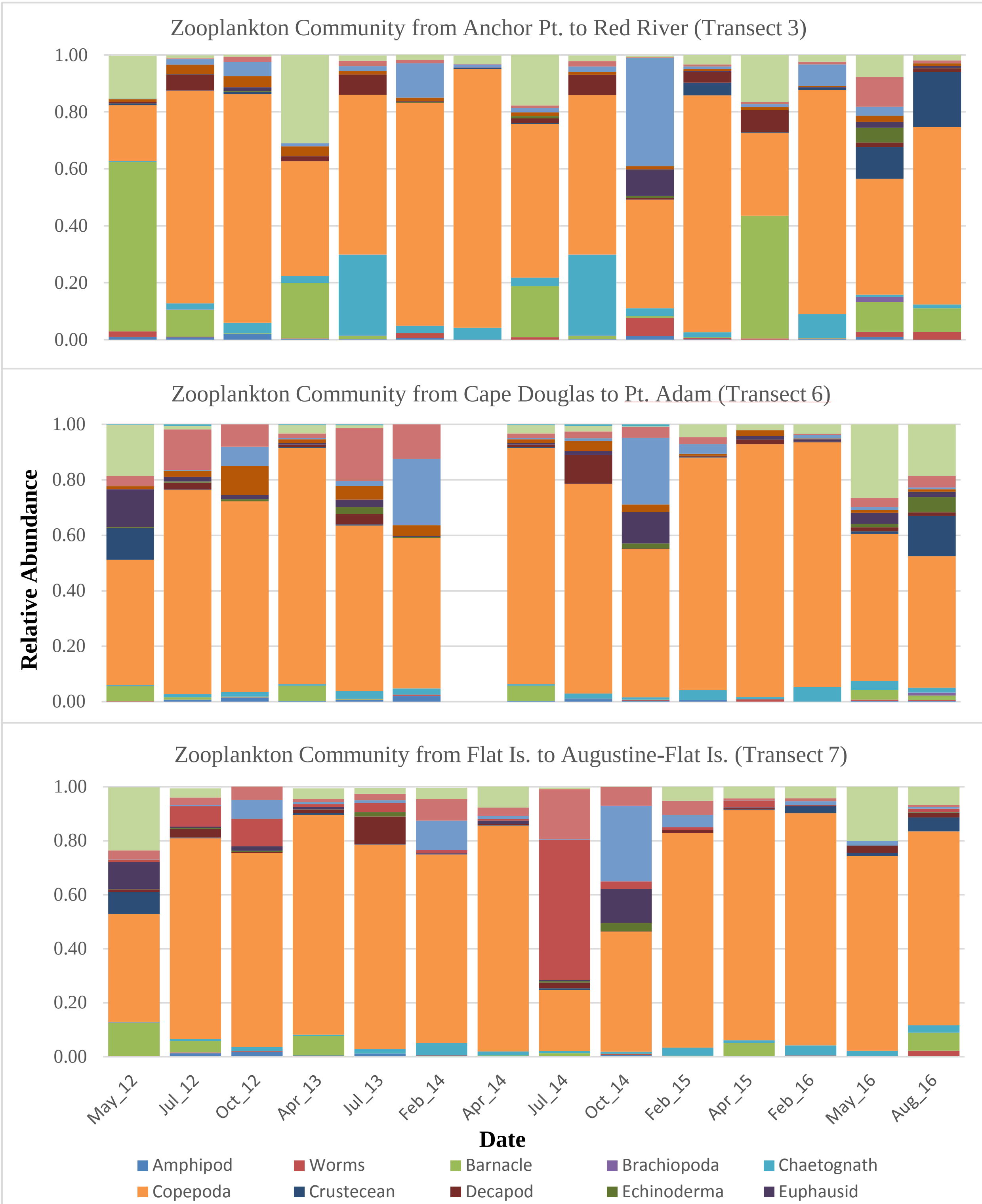


Figure 8. Proportion of zooplankton species categories in lower Cook Inlet samples collected during 2012-2016 from combined plankton stations on shipboard surveys (north to south) along Transect 3 (top – Anchor Pt to Red River), Transect 7 (middle – Flat Island to Augustine Volcano), and Transect 6 (bottom – Pt. Adam to Cape Douglas). Rare or intermittently observed species (≤ 1% across most sampling periods) were combined in the "Other" category.

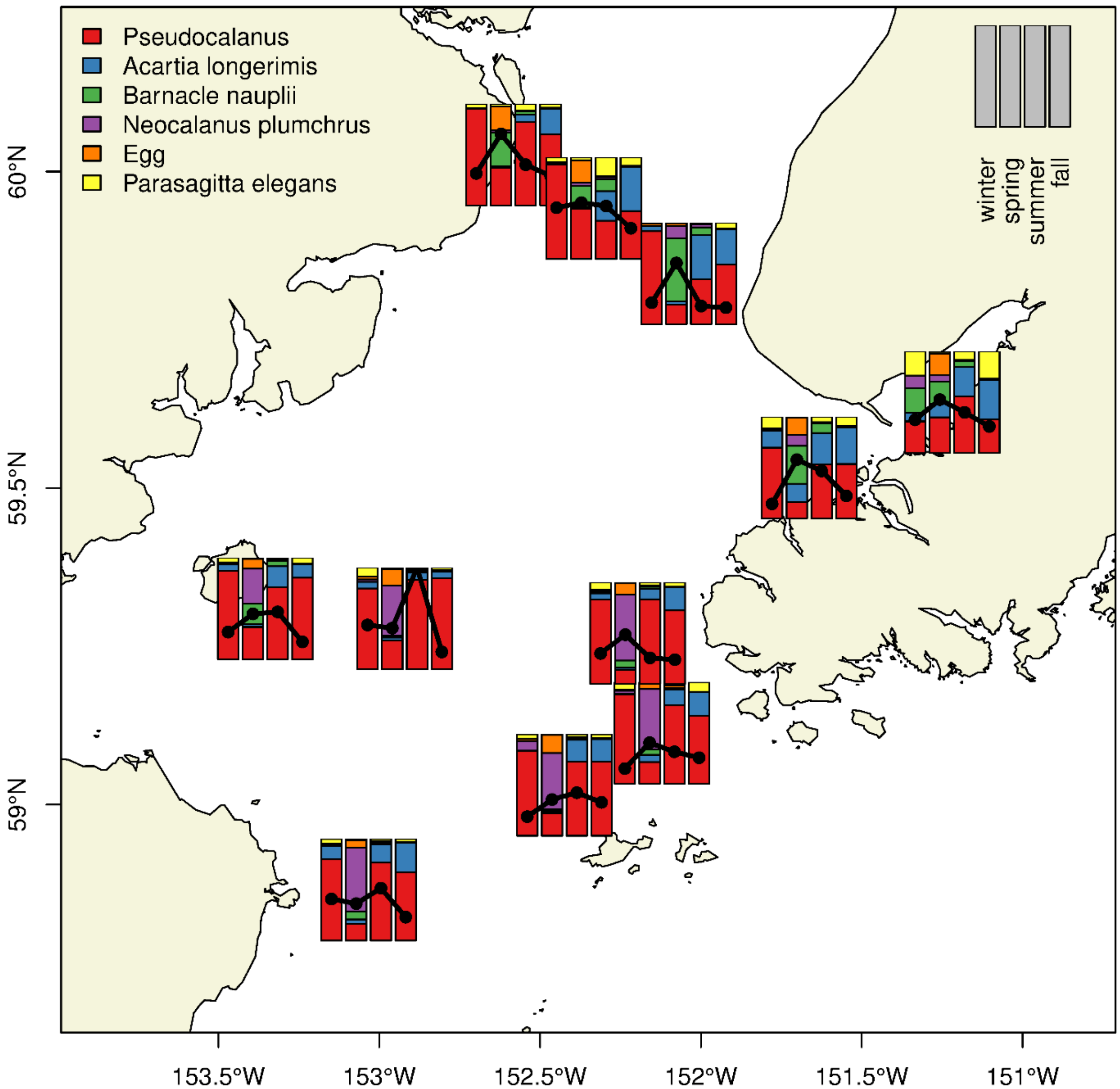
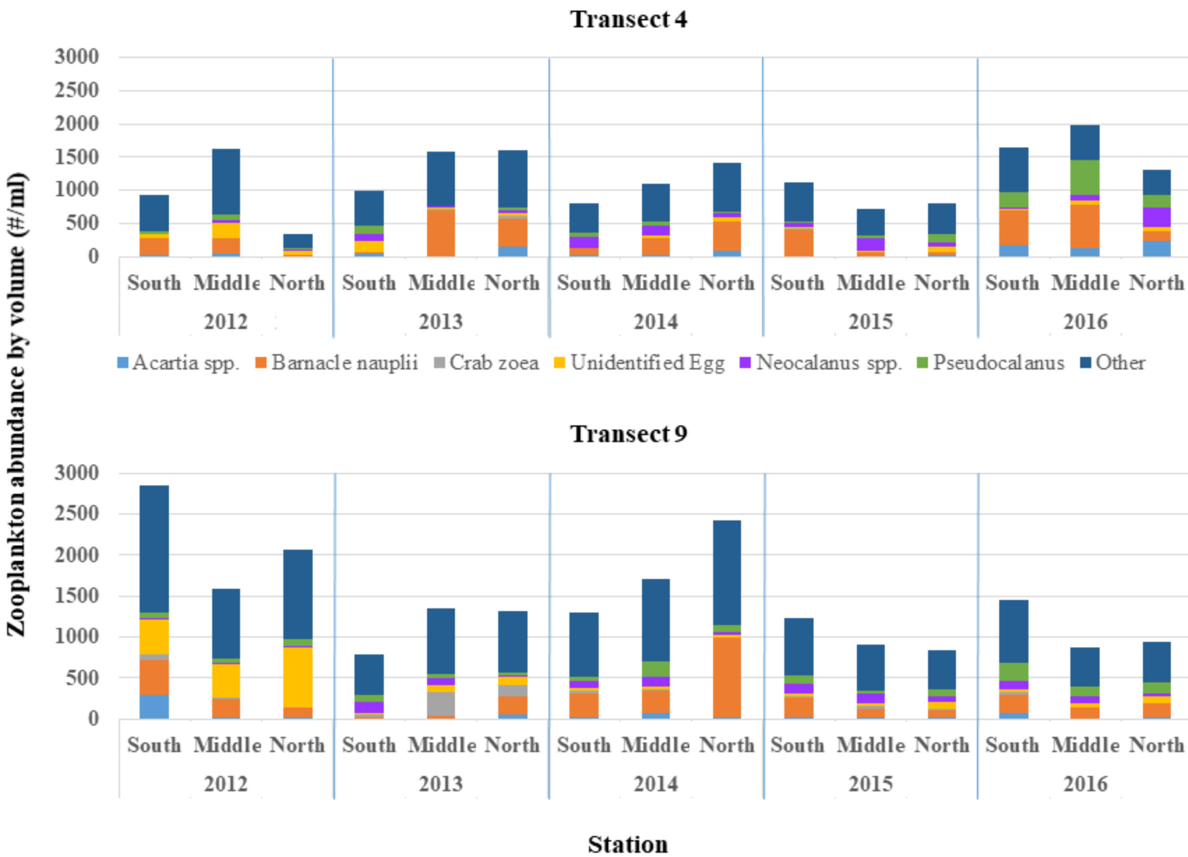


Figure 9. Geographic and seasonal patterns of abundance and species-composition of the zooplankton community in lower Cook Inlet. Shown are the relative abundance of the six most common species overall at each sampling site, with separate bars for each season. The black lines overlaid across the bars represent the overall density of all zooplankton taxa combined, by season.



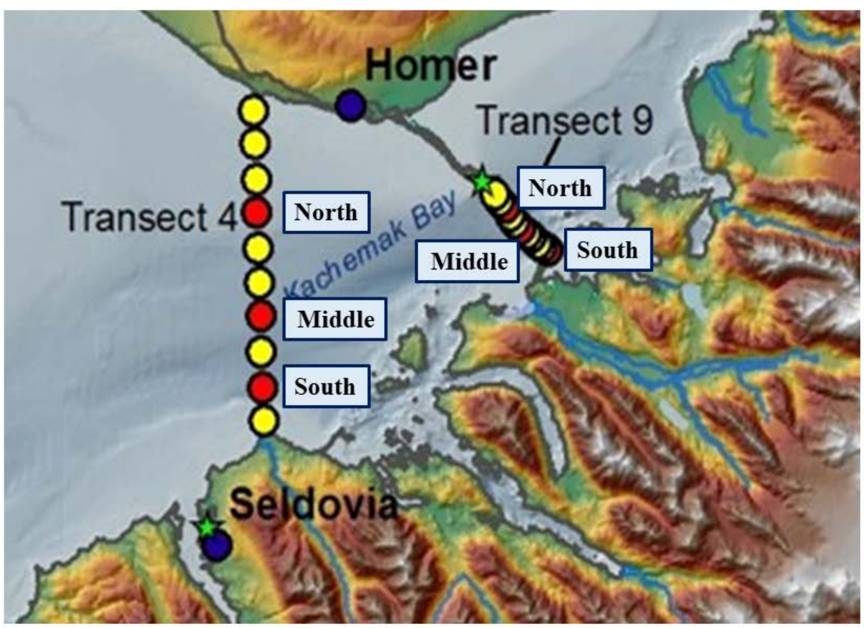


Figure 10. The abundance of the top six zooplankton species that contribute most to interannual variability over the spring months (March – May) study period 2012 – 2016. Map depicts plankton station locations along Transects 4 and 9.

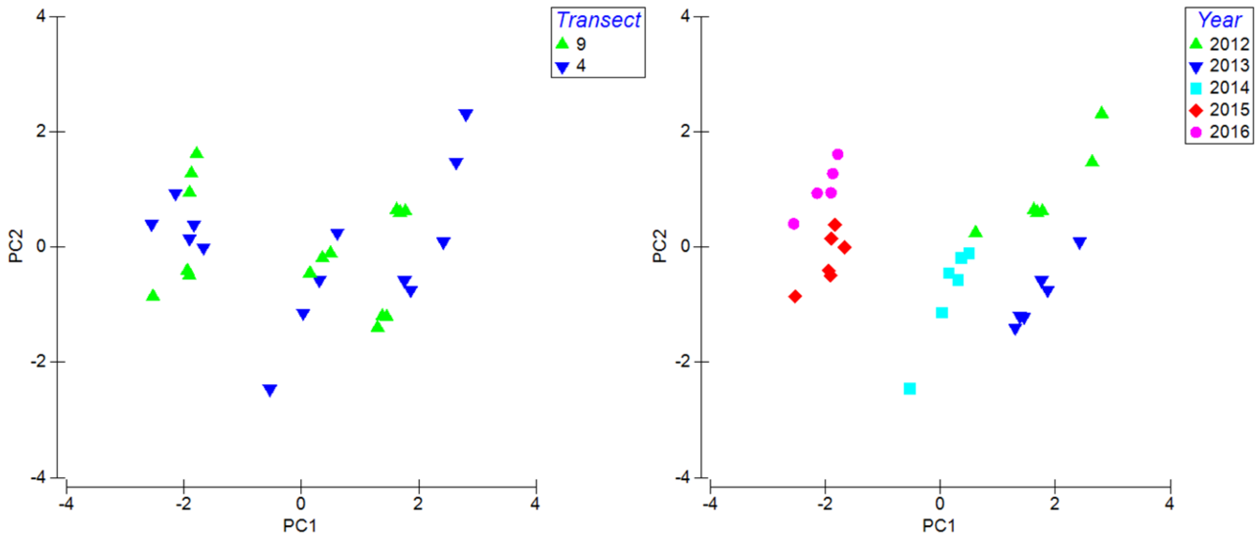


Figure 11. Principal components analysis (PCA) plot of environmental variables (not shown) explaining variance for the spring zooplankton community in Kachemak Bay. PC 1 and 2 explain 69.9% of the variability in the zooplankton community. Clusters indicate greater similarity and the data cluster more closely by year than by location.

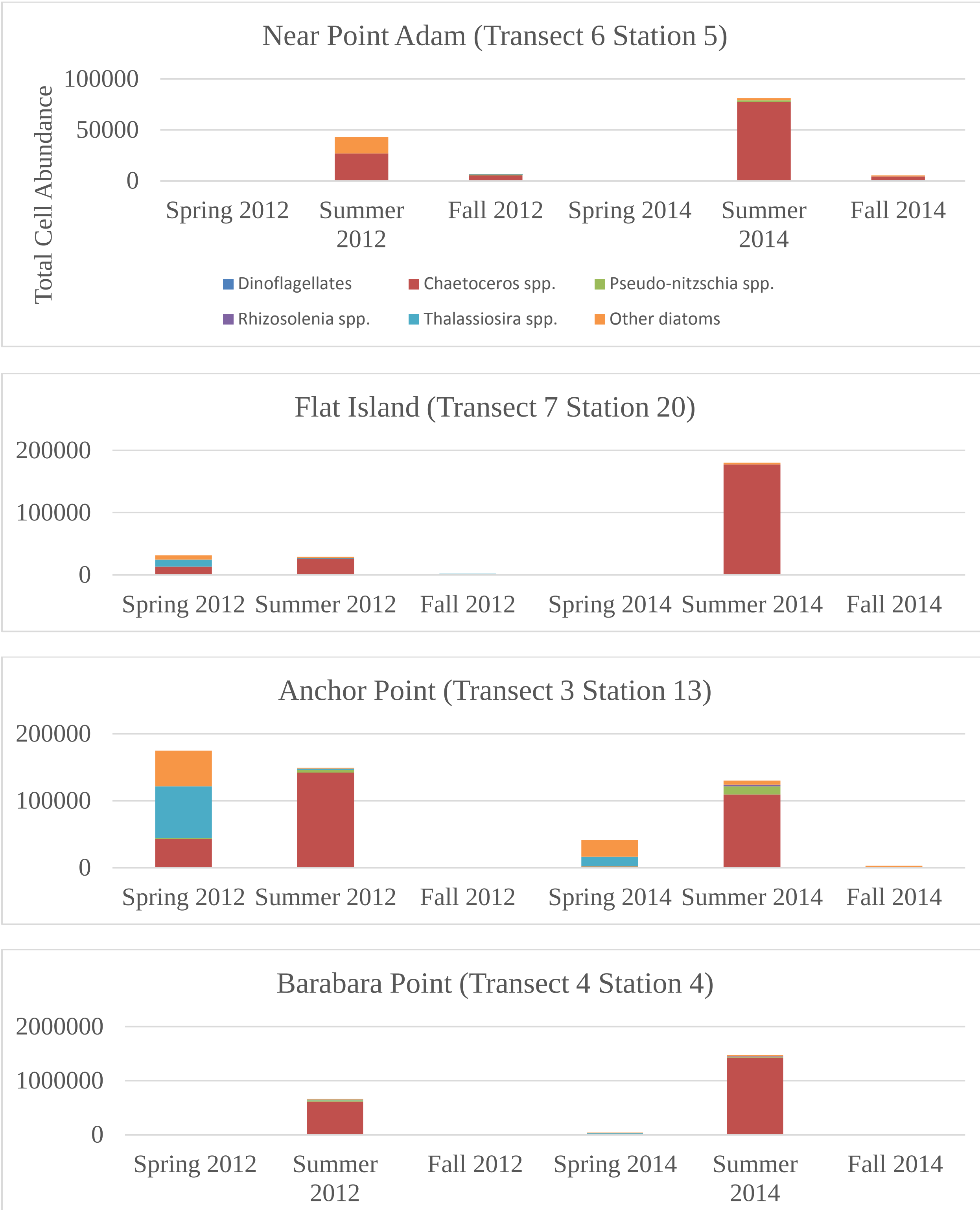


Figure 12. Total cell abundance and taxonomic composition of Kachemak Bay and Cook Inlet phytoplankton samples from Transects 3, 4, 6, 7, and 9 comparing an anomalously cold year in 2012 and an anomalously warm year in 2014. Winter samples were excluded due to low cell abundances. Taxa were grouped into 6 categories: Dinoflagellates, *Chaetoceros* spp. (diatom), *Pseudo-nitzschia* spp. (diatom), *Rhizosolenia* spp. (diatom), *Thalassiosira* spp. (diatom), and "Other diatoms". Note that the y-axis scale of the top graph is different from the others.

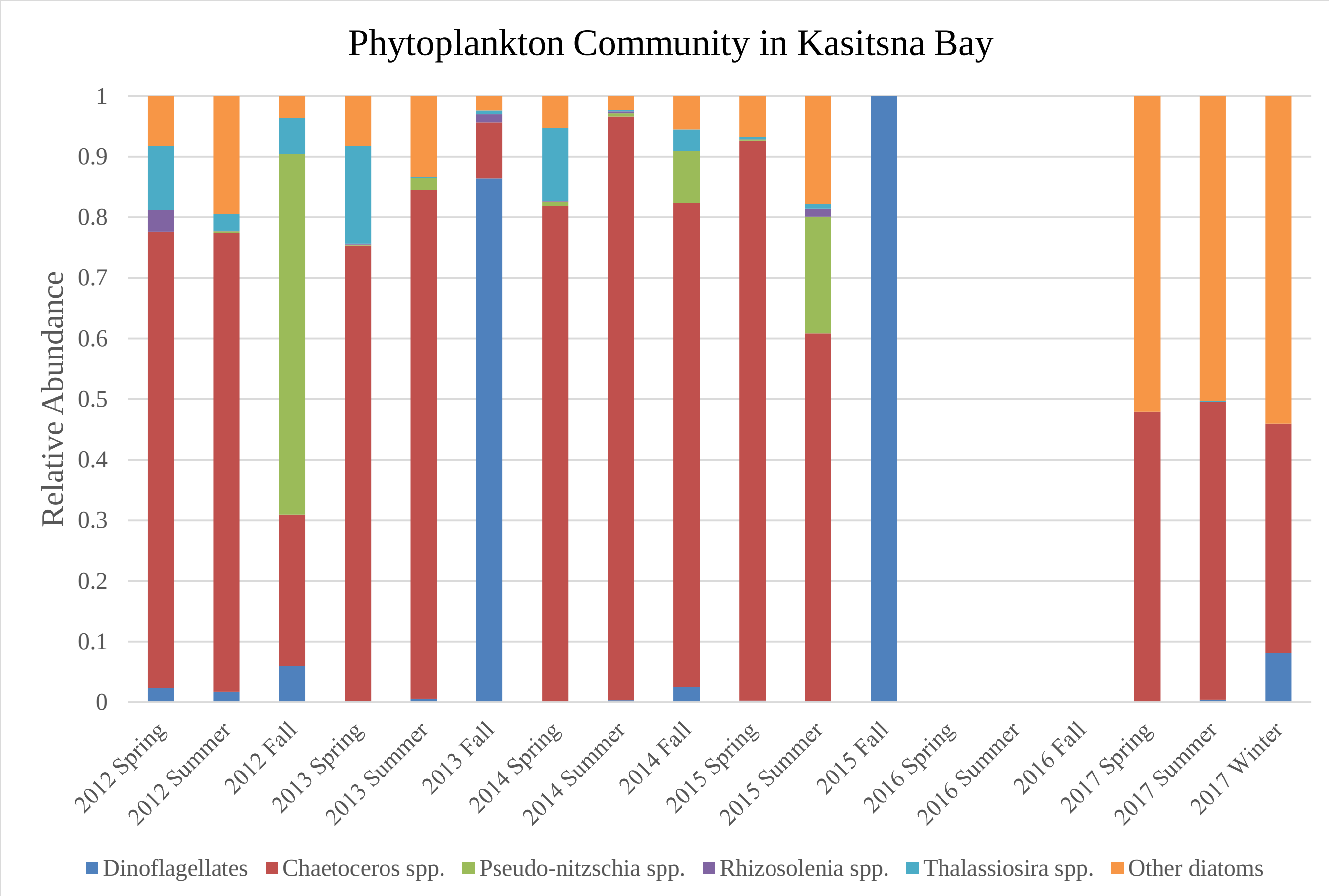


Figure 13. Relative abundance of phytoplankton samples from Kasitsna Bay. Winter samples were excluded because of low abundances of cells and data are not available for 2016. Taxa were grouped into 6 categories: Dinoflagellates, *Chaetoceros* spp. (diatom), *Pseudo-nitzschia* spp. (diatom), *Rhizosolenia* spp. (diatom), *Thalassiosira* spp. (diatom), and "Other diatoms". Compositions for taxa are shown as a percentage of total cell abundance.

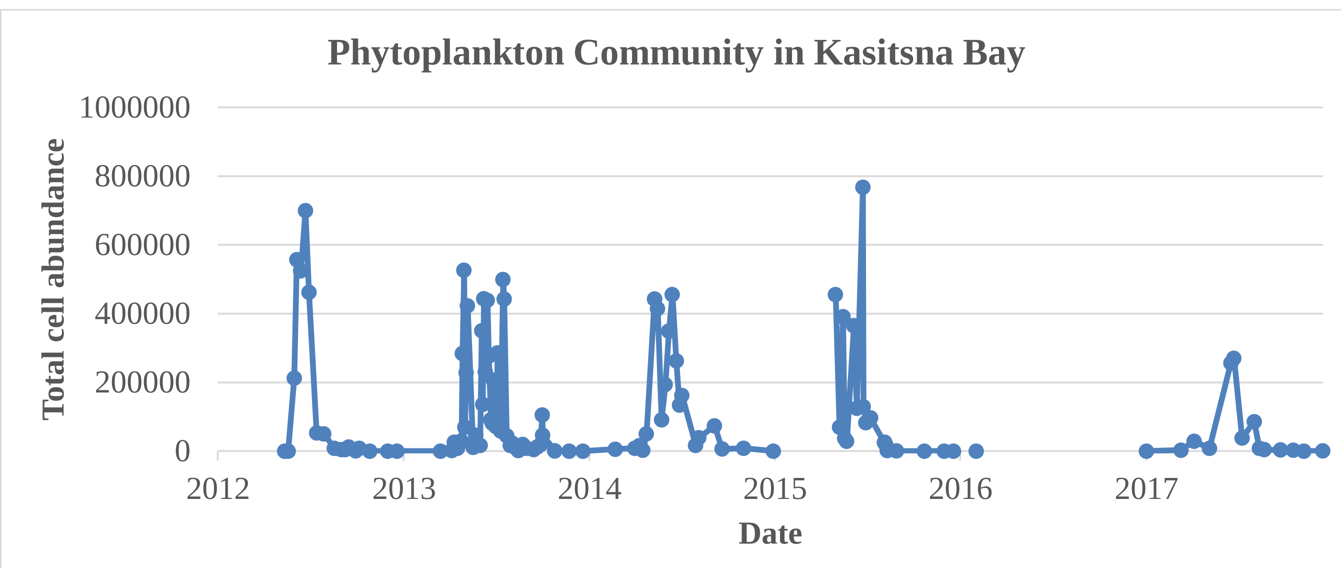


Figure 14. Total phytoplankton cell abundance from samples collected at the Kasitsna Bay Laboratory dock from May 2012 through December 2015. Data are not available for 2016.

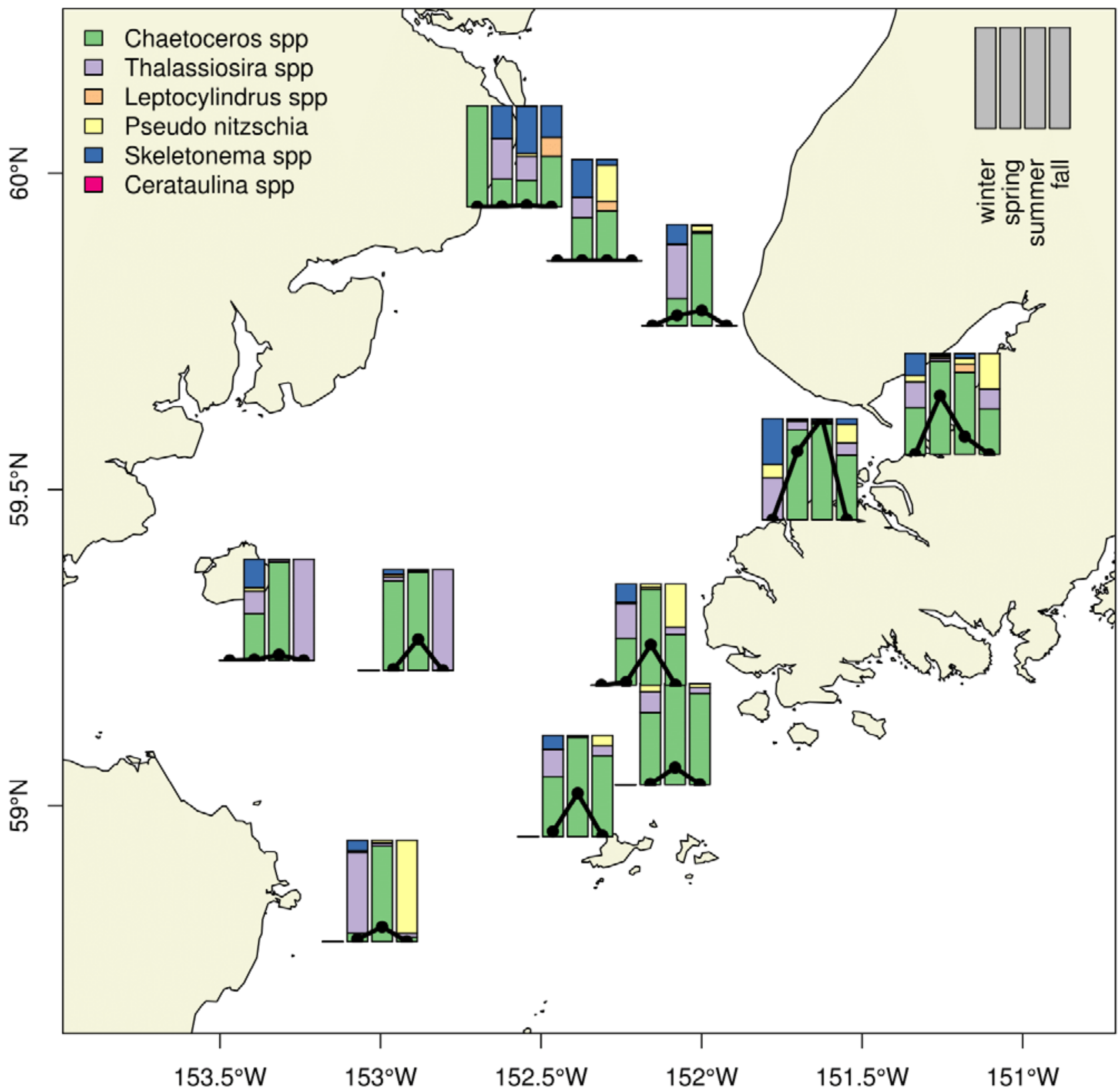


Figure 15. Geographic and seasonal patterns of abundance and species-composition of the phytoplankton community in lower Cook Inlet. Shown are the relative abundance of the six most common diatom species overall at each sampling site, with separate bars for each season and no bar for very low abundances. The black lines overlaid across the bars represent the overall density of all diatom taxa combined, by season.

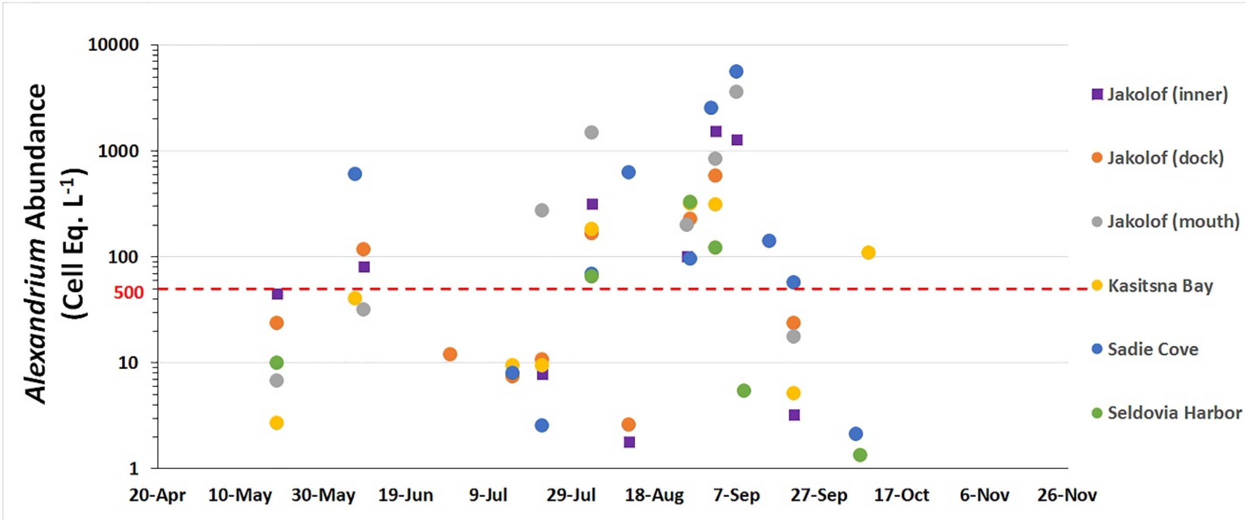


Figure 16. *Alexandrium* spp. cell abundances from several sites in Kachemak Bay, estimated using qPCR. All samples were from May-October, 2016. The approximate cell concentration corresponding to the FDA toxicity limit is shown as a red dashed line. The abundance is shown on a logarithmic scale.

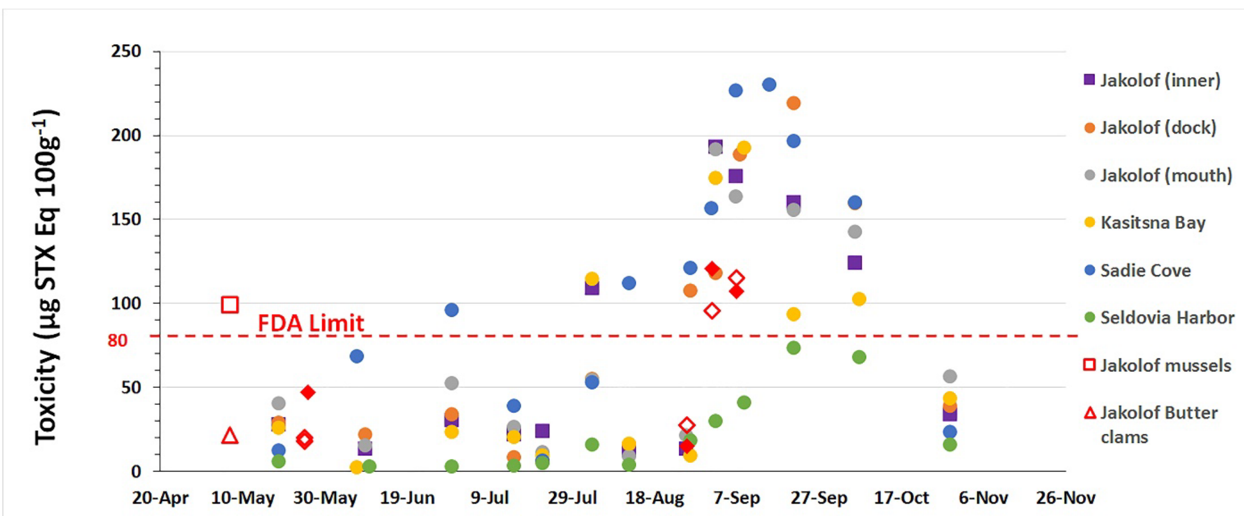


Figure 17. Toxicity of oyster, mussel, and butter clam tissue samples from several sites in Kachemak Bay. The FDA limit for saxitoxin is shown as a red dashed line (80 micrograms/100grams of tissue).

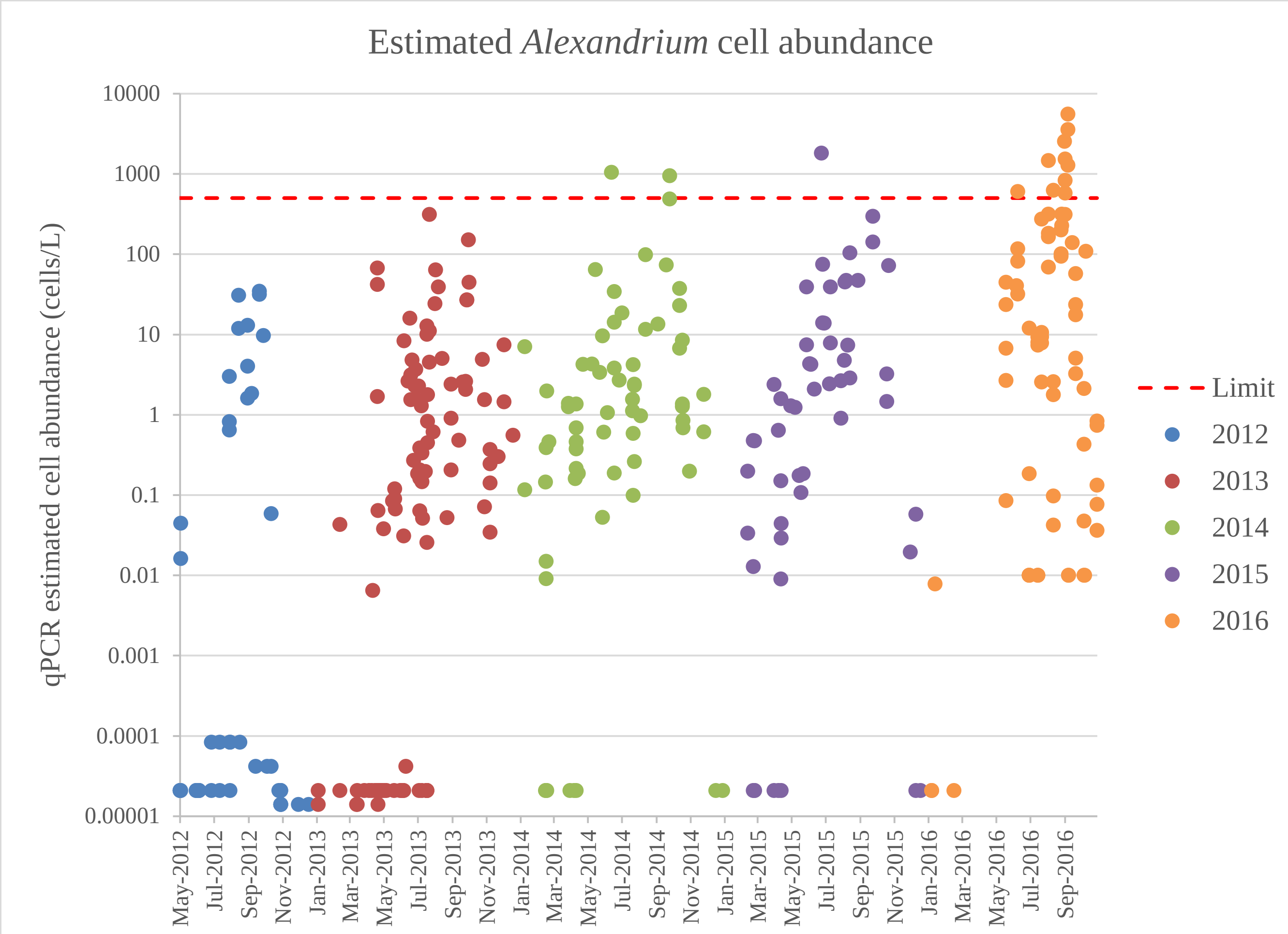


Figure 18. Time series of estimated *Alexandrium* spp. abundances from Kachemak Bay and lower Cook Inlet samples from qPCR analysis for 2012-2016. Results are shown on a logarithmic scale. The level for expecting shellfish toxicity at 500 cells per liter is shown as a dashed red line.

8. Coordination/Collaboration:

A. Projects Within a Trustee Council-funded program

1. Within the Program

Environmental Drivers component: We are collaborating with GWA personnel from the program management team (17120114-A and B), the nearshore ecosystems component (17120114-H), Prince William Sound oceanography (17120114-G), and GAK1 (17120114-I) in a cross-component effort to examine spatial and temporal variability and coherence in water and air temperatures across the GWA study region. As part of this effort we presented collaborative posters at the 2018 Alaska Marine Science Symposium. We collaborate with Rob Campbell and Caitlin McKinstry at the Prince William Sound Science Center (17120114-G) to analyze zooplankton data from the Cook Inlet/Kachemak Bay project. We also continued to coordinate on oceanographic and zooplankton sampling protocols and monitoring results with other Environmental Drivers component investigators (Danielson, Hopcroft, Batten, Campbell) through teleconferences and in breakout discussions at the annual PI meeting.

Pelagic component: We coordinated with Kathy Kuletz of the USFWS Migratory Bird Management office and GWA marine birds (17120114-M) to opportunistically host seabird/marine mammal observers on our shipboard surveys, in order to help the GWA program obtain these observations in lower Cook Inlet. Holderied coordinated with John Moran and Jan Straley (17120114-O) on a NOAA Hollings Scholar student intern humpback whale project in summer 2017.

Nearshore component: We provided information on seasonal and inter-annual patterns in water temperature, stratification, freshwater content and nutrients to the GWA Nearshore component PIs (17120114-H) to assess drivers of intertidal ecosystem changes at their Kachemak Bay sites.

2. **Across Programs**
   a. **Herring Research and Monitoring**
   Holderied co-authored the introduction to the GWA special issue in Deep Sea Research II with Scott Pegau (HRM lead) and other GWA team members. Holderied also coordinated with Scott on long-term, nearshore oceanographic patterns from NOAA tide gauge data, to compare conditions between Prince William Sound and Cook Inlet and assess relationships between marine conditions and plankton, herring and forage fish populations.

   b. **Data Management**
   We are coordinating with the Data Management team to upload data to the Research Workspace and make it available on the Gulf of Alaska data portal, as well as to review metadata and update for accuracy.

   c. **Lingering Oil**
   None

B. Projects not Within a Trustee Council-funded program
None.

C. With Trustee or Management Agencies
1) NOAA/National Ocean Service (NOS)/ NCCOS: We collaborated with researchers at the NOS/NCCOS Beaufort Laboratory (North Carolina) to use the project oceanography and phytoplankton sampling data to identify environmental triggers for increases in the phytoplankton species (*Alexandrium* spp.) that cause paralytic shellfish poisoning events, included drafting a peer-reviewed science journal manuscript for publication in 2018. We partnered with other NCCOS offices and the AOOS to improve the web-based Kachemak Bay HAB Information System (www.aoos.org/k-bay-hab/).
2) NOAA/NOS/Center for Operational Oceanographic Products and Services (CO-OPS): We are using project CTD data to help CO-OPS validate the NOS Cook Inlet ocean circulation model they are testing to implement as the Cook Inlet Operational Forecast System, which is expected to be operational by the end of 2018.
3) NOAA/National Marine Fisheries Service (NMFS): We collaborated with NMFS (Erika Ammann, Restoration Center) on the NOAA Kachemak Bay Habitat Focus Area, under the NOAA Habitat Blueprint program, which includes projects for clam restoration and PSP risk

assessment that use project oceanographic data. Holderied collaborated with Verena Gill in the NMFS Alaska Region Protected Resources office on a student intern humpback whale project in summer 2017, which used project oceanographic data.

4) State of Alaska agencies –ADF&G, Alaska Department of Environmental Conservation (ADEC), Alaska Department of Health and Social Services (ADHSS): We provide real-time and historical trends for water temperature data to shellfish managers with the ADF&G (Commercial and Sportfish Divisions) in Homer, and with the ADEC in Anchorage. We are working with ADEC, ADF&G, ADEC, and other agencies as part of both the Alaska HAB Network and Alaska Ocean Acidification Network. We use project data to help inform management for shellfish harvest, mariculture operations, harmful algal bloom event response and marine invasive species monitoring.
5) USFWS: We collaborate with Kathy Kuletz of the USFWS Migratory Bird Management office to opportunistically host shipboard seabird/marine mammal observers on our shipboard surveys. We coordinate with the USFWS Marine Mammals Office on sea otter stranding and sampling programs and project data was provided to USFWS (Alaska Maritime National Wildlife Refuge) and NOAA (NMFS Protected Resources) to help understand potential ecosystem causes of seabird, sea otter and whale mortality events.
6) North Pacific Research Board (NPRB): Holderied participated in the NPRB-funded FY16-18 synthesis effort for the Gulf of Alaska Integrated Ecosystem Research Program with researchers from NOAA, USFWS, ADF&G and other organizations. Project data is being used to help understand how linkages between nearshore and shelf waters affect forage fish distributions and groundfish recruitment.
7) NOAA Kasitsna Bay Laboratory and Bureau of Ocean Energy Management (BOEM): Holderied is collaborating with BOEM to update information on marine conditions and ecological linkages in Cook Inlet, to support BOEM's environmental analysis needs for potential oil and gas lease sales and development in the region. Project data through 2017 have been incorporated into the final report for BOEM, which will be provided in 2018.

9. Information and Data Transfer:

A. Publications Produced During the Reporting Period

Aderhold, D. R., D. Esler, R. A. Heintz, R. R. Hopcroft, M. R. Lindeberg, W. W. Pegau. Editors. Spatial and Temporal Ecological Variability in the Northern Gulf of Alaska: What have we learned since the Exxon Valdez Oil Spill? Deep Sea Research Part II: Topical Studies in Oceanography, Volume 147, Pages 1-202, ISSN 0967-0645. January 2017. https://www.sciencedirect.com/journal/deep-sea-research-part-ii-topical-studies-in-oceanography/vol/147/suppl/C.

Doroff, A., and K. Holderied. 2018. Long-term monitoring of oceanographic conditions in Cook Inlet/Kachemak Bay to understand recovery and restoration of injured near-shore species. *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 16120114-G). *Exxon Valdez* Oil Spill Trustee Council, Anchorage, Alaska.

Doroff, A., M. Johnson, and G. Gibson. 2017. Ocean Circulation Mapping to Aid Monitoring Programs for Harmful Algal Blooms and Marine Invasive Transport in South-central, Alaska. State Wildlife Grant, Alaska Dept. of Fish and Game. Annual Report. 41pgs.

Walsh, J.R., R. Thoman, U.S. Bhatt, P.A. Bieniek, B. BrettsChneider, M. Brubaker, S. Danielson, R. Lader, F. Fetterer, K. Holderied, K. Iken, A. Mahoney, M. McCammon, and J. Partain. 2018. The high latitude marine heat wave of 2016 and its impacts on Alaska [in "Explaining Extreme Events of 2016 from a Climate Perspective"]. *Bull. Amer. Meteor. Soc*. **99** (1). S39-43. doi:10.1175/BAMS-D-17-0105.1

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

Holderied, K., D. Hondolero, S. Kibler, M. Vandersea, A. Doroff, J. Schloemer, and S. Buckelew. 2017. Using coastal Alaska marine responses to the 2014-2016 Pacific Warm Anomaly to improve risk assessment for climate-driven increases in paralytic shellfish poisoning events. **Oral presentation** at Climate Predictions Applications Science Workshop. Anchorage AK. May 2017.

Holderied, K. and E. Ammann. 2017. Improving shellfish restoration and habitat assessment in coastal Alaska: Kachemak Bay Habitat Focus Area. **Oral presentation** at Coastal and Estuarine Research Federation conference. Providence, RI. Nov 2017.

Holderied, K., K. Powell, S. Baird, and J. Schloemer. 2018. Variability in estuarine salinity and stratification in Kachemak Bay, Alaska from 2012-2017. **Poster presentation** at Alaska Marine Science Symposium, Anchorage AK. Jan 2018.

Powell, K., J. Schloemer, K. Holderied and A. Doroff. 2018. Oceanographic characteristics associated with spring zooplankton community structure in Kachemak Bay, Alaska from 2012 to 2016. **Poster presentation** at Alaska Marine Science Symposium, Anchorage AK. Jan 2018.

Renner, M., K. Holderied, K. Powell, D. Hondolero, J. Schloemer, A. Doroff, and K. Kuletz. 2018. Ecosystem variability in lower Cook Inlet across trophic levels, space, seasons, and climate regimes. **Oral presentation** at Alaska Marine Science Symposium, Anchorage, AK. Jan 2018.

Vandersea, M., P. Tester, K. Holderied, D. Hondolero, S. Kibler, K. Powell, S. Baird, A. Doroff and W. Litaker. 2018. Distribution and abundance of *Alexandrium catenella* in Kachemak Bay and lower Cook Inlet, Alaska. **Poster presentation** at Alaska Marine Science Symposium, Anchorage, AK. Jan 2018.

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

DataONE published data:

Holderied, K. and A. Doroff. 2017. Oceanographic Monitoring in Cook Inlet and Kachemak Bay, Water Quality, Meteorological, and Nutrient Data collected by the National Estuarine Research Reserve System's System-wide Monitoring Program (NERRS SWMP), 2012-

2016, Gulf Watch Alaska Environmental Drivers Component. *Exxon Valdez* Oil Spill Trustee Council Long-Term Monitoring program, Gulf Watch Alaska. Research Workspace. https://doi.org/10.24431/rw1k1c.

Holderied, K. and A. Doroff. 2017. Oceanographic Monitoring in Cook Inlet and Kachemak Bay, CTD Data, 2012-2016, Gulf Watch Alaska Environmental Drivers Component *Exxon Valdez* Oil Spill Trustee Council Long-Term Monitoring program, Gulf Watch Alaska. Research Workspace. https://doi.org/10.24431/rw1k1d.

Holderied, K. and A. Doroff. 2017. Oceanographic Monitoring in Cook Inlet and Kachemak Bay, Zooplankton Data, 2012-2015, Gulf Watch Alaska Environmental Drivers Component. *Exxon Valdez* Oil Spill Trustee Council Long-Term Monitoring program, Gulf Watch Alaska. Research Workspace. https://doi.org/10.24431/rw1k12.

Additional information products: A variety of data and information products have been developed for science presentations listed in 9.2 above, as well as presentations for the general public in Homer Alaska. Data products include graphics of oceanographic time series plots, time series anomalies, comparisons of temperatures between different regions (e.g., GAK1, Seldovia, and Cordova), and along-transect vs depth contour plots. Time series and contour plot data products have been provided to BOEM for shipboard transects (2012-2016). Data and graphic products from this project were used by a NOAA Hollings Undergraduate Scholar student from the University of North Carolina Wilmington working on a humpback whale research project in summer 2017 with Holderied and researchers from NOAA/NMFS, USFWS and the University of Alaska Anchorage (UAA) Kachemak Bay Campus. The student intern provided a public science outreach talk on their results in Homer Alaska and gave a scientific presentation at NOAA offices in Silver Spring, MD.

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

1. CTD data sets and associated metadata from 2012, 2013, 2014, 2015, 2016 and 2017 have been uploaded to the AOOS Research Workspace, and 2012 – 2016 data published to the GWA Data Portal. The 2017 data will be published after final review is completed with the data management team.
2. Zooplankton data and associated metadata through 2016 have been uploaded to the AOOS Ocean Workspace and 2012-2015 data have been published to the GWA Data Portal. The 2016 data will be published after final review is completed with the data management team. 2017 data are being analyzed and will be uploaded to the Research Workspace when the species identifications and data QA/QC are complete.
3. Phytoplankton data and associated metadata through 2016 have been uploaded to the AOOS Research Workspace and will be published to the GWA Data Portal after final review is coordinated with the data management team. 2017 data are being analyzed and will be uploaded to the Research Workspace when the species identifications and data QA/QC are complete.
4. KBNERR SWMP water quality data from Bear Cove, Homer, and Seldovia water quality data sondes and associated metadata through 2016 have been uploaded to the Ocean Workspace and are published on the Gulf of Alaska Data Portal. Data are also publicly

available through 2016 on the NOAA National Estuarine Research Reserve site: http://cdmo.baruch.sc.edu/. The 2017 data will be uploaded to Research Workspace when QA/QC is completed.

10. Response to EVOSTC Review, Recommendations and Comments:

Science Panel Comments and Responses on Revised FY17-21 Proposal, September 2016

In September 2016, the Science Panel commented: The Science Panel appreciated the PI's responses to our comments. The proposal is fundamentally sound. However, our primary concern was not addressed. The proposed research is beyond the core area of interest, and it remains unclear how the study would significantly advance the core mission of EVOSTC and justify a second cycle of $800,000 in funding.

As noted in a follow-up Panel discussion with the Program Team Leads, the results from the original research proposal in Cook Inlet and Kachemak Bay provided data that may be useful to those interested in this project's study area, and, for example, the proposal may serve those with an interest in harmful algal blooms, bivalve mariculture, invasive species and to EVOSTC PIs currently sampling in PWS but who would be pleased to expand activities to the project area. However, the proposal did not demonstrate actual use of these data by other projects in either the Long-Term Monitoring Program or the Herring Program and it still remains to be seen just how relevant these data will be to EVOSTC.

PI Response: In our FY18 work plan we clarified how this project directly links to the Kachemak Bay sampling for the nearshore project, other environmental drivers projects (GAK1, Seward Line, and PWS Oceanography), and pelagic projects with regard to marine mammals and birds.

Science Panel Comments and Responses on FY18 Work Plans, September 2017

In September 2017, the Science Panel commented: The Panel was happy to see that the PIs explained how data from this study tie into the decline in sea stars, marine mammal and seabird mortalities and changes in the presence of zooplankton species. The Panel was pleased to see how the funding is being used and how the PIs found connections as previously requested.

PI Response: Thank you for the comments.

11. Budget:

Please see provided program workbook.

Both organizations experienced obligation delays in 2017 that we expect to resolve in 2018. NOAA Kasitsna Bay Laboratory was delayed in fully obligating FY17 (project year 6) funds by January 2018, primarily due to issues with delays of the award of a NOAA multi-year labor services contract. We prioritized contractor efforts to be able to complete all FY17 oceanographic field sampling efforts and expect to complete additional data analyses and get back on track for project spending within FY18 (project year 7).

KBNERR experienced obligation delays due to the departure of Research Coordinator, Angie Doroff, in July (halfway through the budget year). All field sampling tasks were met by remaining staff on the project and Jessica Shepherd (acting Manager and Education Coordinator) stepped in as the co-PI. A new Research Coordinator is expected to be hired in the coming months and we expect to be able to maintain our sampling schedule, complete additional data analyses and get back on track for spending within FY18.