1. Program Number:

18120114-J

2. Project Title:

Long-term monitoring of oceanographic conditions in Cook Inlet/Kachemak Bay

3. Principal Investigator(s) Names:

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4. Time Period Covered by the Report:

February 1, 2018-January 31, 2019

5. Date of Report:

April 1, 2019

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 variations in nearshore and pelagic food webs. The project is part of Environmental Drivers component of the *Exxon Valdez* Oil Spill Trustee Council (EVOSTC) Gulf Watch Alaska (GWA) program and provides data to help assess the impacts of nearshore oceanographic variability on nearshore and coastal pelagic species injured by the spill. Project data are compared with oceanographic and plankton data from other GWA Environmental Drivers projects in Prince William Sound, the outer Kenai Peninsula, and the Gulf of Alaska. Project data provide a year-round oceanographic context and information on coastal response to climate variability for the GWA Nearshore project in Kachemak Bay, as well as other ongoing state and federal agency programs in the region.

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 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 (ADFG), 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 2018, 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 2017, continued multivariate analysis on plankton data, delivered quality-controlled data to the Research Workspace before program deadlines, and conducted data analyses with project time series data from 2012-2018. Sample collection dates and locations from both 2017 and 2018 are summarized in Table 1. Shipboard sampling completed in 2018 included oceanographic and plankton surveys monthly in Kachemak Bay along mid-bay (Transect 9), outer-bay (Transect 4), and along-bay lines, with additional quarterly surveys in southeast Cook Inlet near Anchor Point (Transect 3), Flat Island (Transect 7) and Point Adam (Transect 6) (see Fig. 1 for station locations). Oceanographic data were collected vertically from surface to near-bottom at stations (shown as dots on Fig. 1), using conductivity-temperature-depth (CTD) profilers. Zooplankton and phytoplankton sampling were also conducted at up to three stations along each Kachemak Bay transect and one station on the Cook Inlet transects (red dots in Fig. 1). In addition to shipboard surveys, continuous, year-round oceanographic data and monthly nutrient and chlorophyll data were obtained from 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 (shown by green stars in Fig. 1). In 2018, oceanographic observations from shipboard CTD and continuous water quality stations in Kachemak Bay showed more average conditions in winter and summer, similar to 2017, with cooler and higher salinities than was observed during the 2014-2016 Pacific marine heat wave. However, in fall months of 2018, bay waters again became warmer and fresher than the average for that time period. From plankton data, a surprising finding in 2018 was significantly lower peak phytoplankton abundances than observed in previous years, with lower abundances found consistently in shipboard surveys, intensive sampling at Kasitsna Bay Laboratory dock, and in daily averaged chlorophyll probe data from the KBNERR water quality stations. Initial analyses of five years (2012-2017) of zooplankton data found that community composition had more spatial variability in spring than fall months, and seven zooplankton species contributed most to both spatial and interannual variability: barnacle nauplii, *Neocalanus plumchrus,* siphonophora, *Oithona similis,* unidentified egg, *Oikopleura* spp., and *Aglantha digitale.*

Field Sampling

Field sampling activities for 2018 were completed in accordance with our proposal and with the detailed sampling protocols available on the Alaska Ocean Observing System (AOOS) Research Workspace. We maintained monthly shipboard oceanographic and plankton sampling in Kachemak Bay and quarterly sampling in outer Kachemak Bay and southeast Cook Inlet, with a few interruptions due to inclement weather (Table 1). The planned April 2018 sampling across the entire Cook Inlet entrance could not be completed due to an extended period of adverse weather conditions, but additional sampling was done in southeast Cook Inlet (to Point Adam) in order to maintain key time series. January 2018 Kachemak Bay sampling was not completed due to the federal government shutdown. We conducted the fall southeast Cook Inlet quarterly sampling in September versus October based on zooplankton and phytoplankton data analyses, and to correlate sampling timing more closely with other GWA Environmental Drivers projects. In addition to meeting GWA project objectives, we leveraged phytoplankton and oceanographic data from shipboard surveys to help support NOAA harmful algal bloom (HAB) research, focusing on environmental factors causing blooms of the phytoplankton species, *Alexandrium spp.,* that produce saxitoxins and cause paralytic shellfish poisoning. Some results from the HAB monitoring efforts are included in this report, as HABs can affect many parts of the marine food web, including EVOS-injured species. Shipboard surveys were also leveraged to collect surface and near-bottom water samples for a KBNERR and NOAA Kasitsna Bay Laboratory ocean acidification monitoring project, conducted in collaboration with the Alutiiq Pride Shellfish Hatchery.

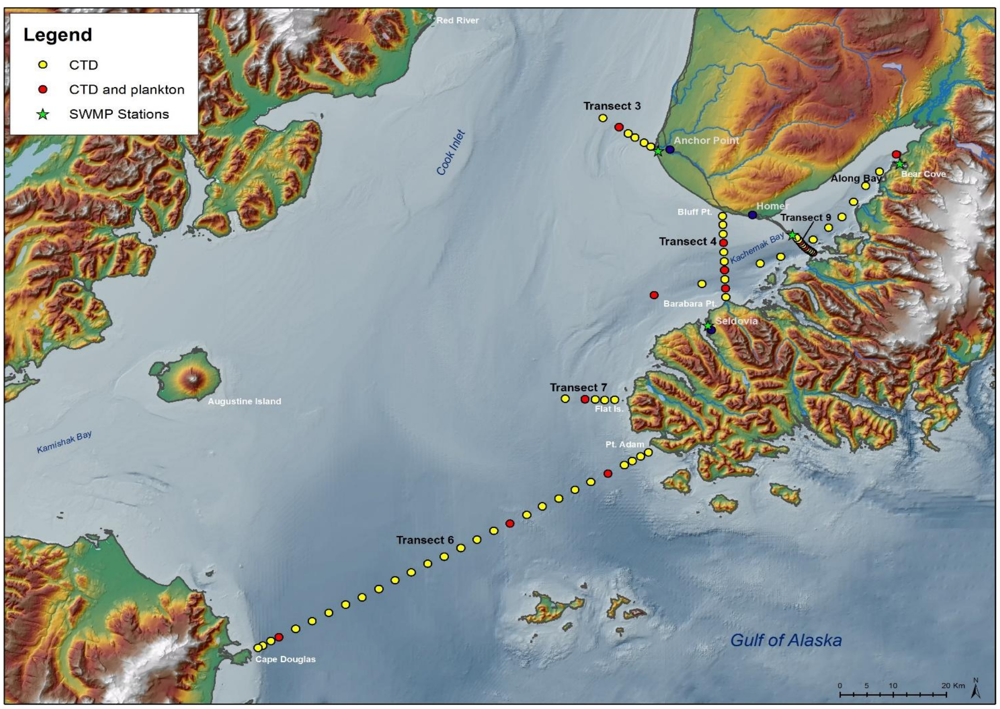

Figure 1. Sampling locations for the lower Cook Inlet and Kachemak Bay project in 2017. Stations shown for shipboard oceanography (all dots) and phytoplankton and zooplankton sampling (red dots). Kachemak Bay NERR continuous sampling stations are marked with green stars.

Table 1. Sampling frequency of Kachemak Bay and lower Cook Inlet transects during second five-year project period (2017-2018). 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.					
Year	**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**
2017	January	■					■						■	■					■						■
2017	February	■					■						■						■						■
2017	March	■					■	■					■	■					■	■					■
2017	April	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■		■	■	■	■	■
2017	May	■					■						■						■	■					■
2017	June	■					■	■					■	■					■	■					■
2017	July	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
2017	August	■					■						■						■						■
2017	September	■					■	■					■	■					■						■
2017	October	■		■			■	■		■			■	■		■			■			■			■
2017	November	■			■	■	■	■			■	■	■	■			■	■	■	■			■		■
2017	December	■					■						■						■						■
2018	January	■					■	■					■	■					■						■
2018	February	■					■	■					■	■					■						■
2018	March	■				■	■	■				■	■	■				■	■	■					■
2018	April	■		■			■	■		■			■	■		■			■	■		■			■
2018	May	■					■	■					■	■					■	■					■
2018	June	■	■	■			■	■	■	■			■	■	■	■			■	■		■			■
2018	July	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					■
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2018	September	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				■		
2018	October	■					■	■					■	■					■	■					■
2018	November	■					■	■					■	■					■	■					■
2018	December	■					■	■					■	■					■	■					

Recent Results and Scientific Findings

Detailed results from 2018 monitoring and analyses of Kachemak Bay/Cook Inlet project data are described below, and address project objectives 1-6. In addition, we have provided oceanographic data to and are collaborating with Rob Suryan (GWA science coordinator, project 18120114-A) and others on a GWA synthesis manuscript (objective 7) and have provided oceanographic data to other NOAA researchers for HAB research, to USGS researchers for seabird mortality event studies and to ADFG Sportfish Division biologists for shellfish population management issues (objective 8).

Oceanography sampling results

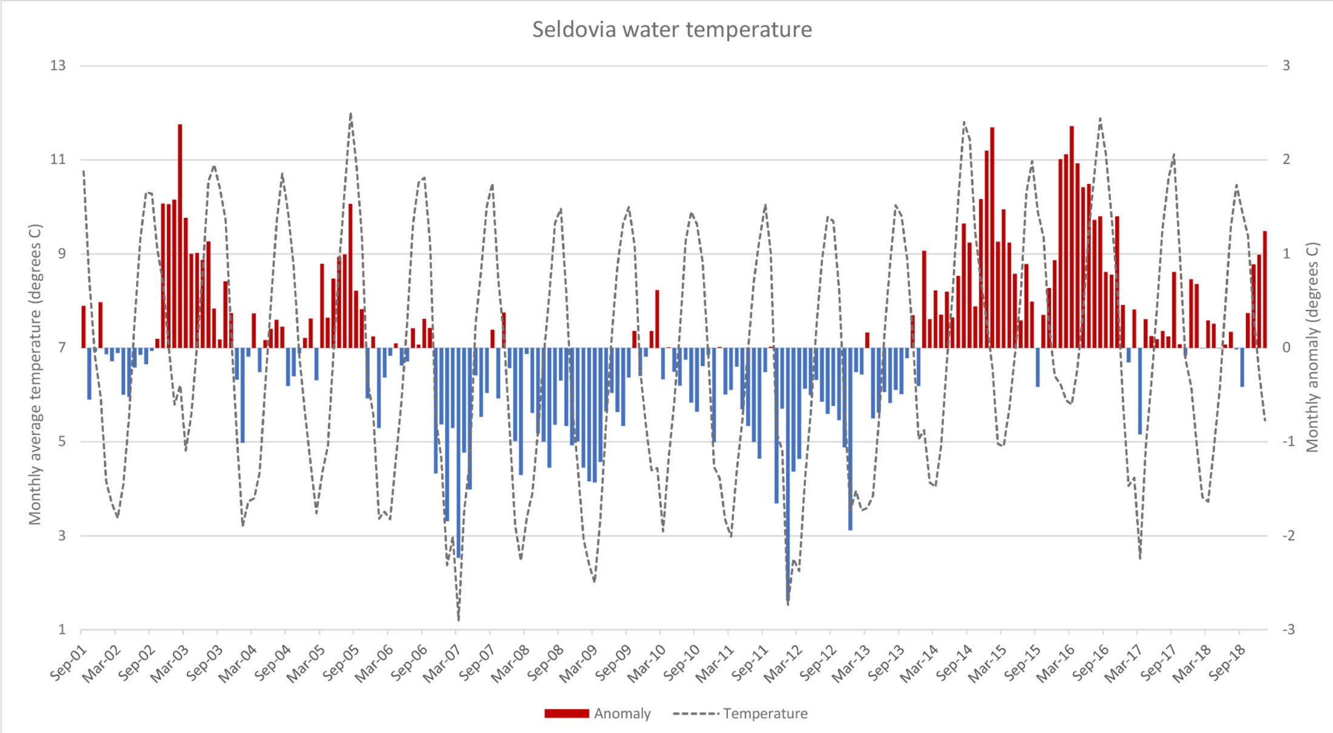
The KBNERR SWMP water quality station data provide a longer-term (2001-2018) context for the GWA study period, as illustrated by temperature and salinity time series from the near-bottom sensor at the Seldovia Harbor station (Fig. 2). Kachemak Bay water temperatures were slightly warmer than average, with near average salinities, for most months in 2018, similar to 2017. These conditions were cooler and more saline than the anomalously warm conditions of more than +2 ˚C and extended period of freshening in 2014-2016 (Fig. 2). However, starting in October 2018, monthly average warm temperature anomalies have averaged +1 ˚C (Fig. 2, top) at Seldovia and salinities also became fresher than normal (Fig. 2, bottom).

A salinity climatology from data at Seldovia and Homer shows the average annual patterns, with higher salinities in winter due to reduced freshwater input as air temperatures drop below freezing and decreasing salinity in spring through late summer with freshwater inputs from precipitation, snowpack melt, and glacier melt. Differences between the two stations reflect variability in freshwater inputs between outer and inner Kachemak Bay. Salinity decreases sharply at both sites from mid-summer into late fall (Fig. 3), which may also reflect intrusion of fresher Alaska Coastal Current waters into the bay at that time of year. The annual salinity pattern was disrupted in 2014-2016, with persistently fresher than normal monthly average salinities the entire time, and much fresher conditions and more variability during the winters of 2014-2015 and 2015-2016 (Fig. 2, bottom). In 2017 and early 2018, salinities were closer to average and the freshening in late 2018 was not as extreme and variable as 2015 and 2016.

Monitoring of near-surface water quality at the Seldovia, Homer, and Bear Cove SWMP stations also provided continuous time series along the estuarine gradient in Kachemak Bay. Daily averaged values are shown for near-surface water temperature (Fig. 4a) and salinity (Fig. 4b) at all three sites from 2012-2018. Surface water temperatures at each site showed close similarities in their seasonal patterns, but 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. 4a). For most of 2018, temperatures were closer to average conditions at all sites, but rose to above monthly averages from October 2018 to January 2019. At Seldovia, surface waters are slightly warmer than deeper waters in spring and summer, and slightly colder in winter (Fig. 4a, bottom), while at the Homer station the seasonal differences are more extreme (Fig. 4a, middle).

Daily averaged salinity data from all three sites show details of seasonal patterns at near-surface and near-bottom locations at each site. Salinities were lowest and most variable near the head of Kachemak Bay at Bear Cove and least variable at the Seldovia site (Fig. 4b), 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 the freshening at the Seldovia station (outer bay) lagging the other two sites. Daily averaged salinities and 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. 4b), which is consistent with mid-bay CTD observations (see below). The surface salinity patterns at these stations did not change consistently during the marine heat wave (Fig. 4b), unlike the persistent freshening observed at the deeper Seldovia station sensor during that period (Fig. 2). 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.

Chlorophyll fluorescence measured at the Seldovia near-surface sonde shows a relatively consistent seasonal pattern between years, with similar high values during spring blooms and low winter values (Fig. 5). However, peak fluorescence values observed in both 2017 and 2018 were considerably lower than those from 2011 to 2016. Although further analysis is needed, we also observed lower peak nitrite-nitrate concentrations from monthly nutrient sampling in 2017 and 2018 relative to earlier years (not shown), and the nutrient draw-down in summer of 2018 was not as much as observed in previous summers.



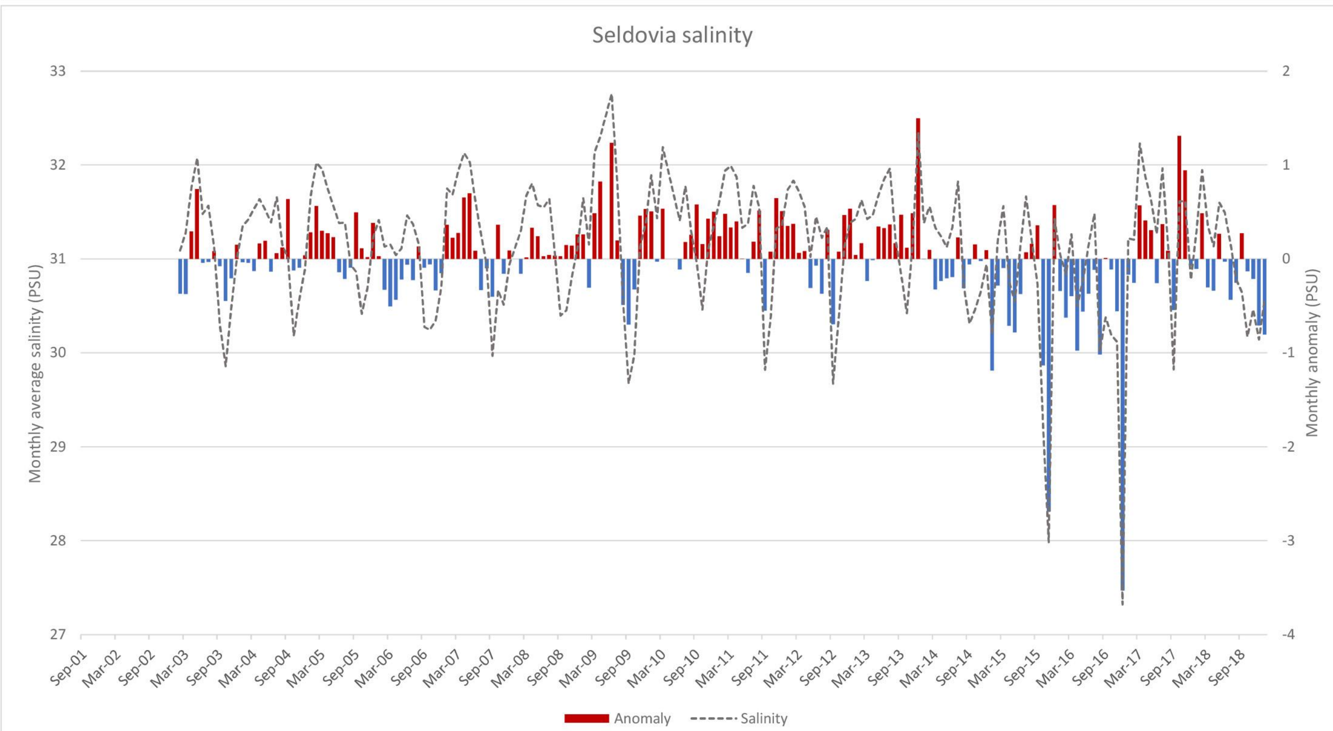


Figure 2. Time series of monthly average (dashed line) and monthly anomaly (bars) water temperatures (top) and salinities (bottom) at KBNERR monitoring station in Seldovia during September 2001 – January 2019 (salinity data starting in 2003). These NERR SWMP station data are collected from a sensor package 1 meter above sea bottom. Red bars indicate positive (warm/salty) anomalies and blue bars indicate negative (cold/fresh) anomalies. Anomalies were based on a comparison to average monthly means for the entire dataset for each parameter.

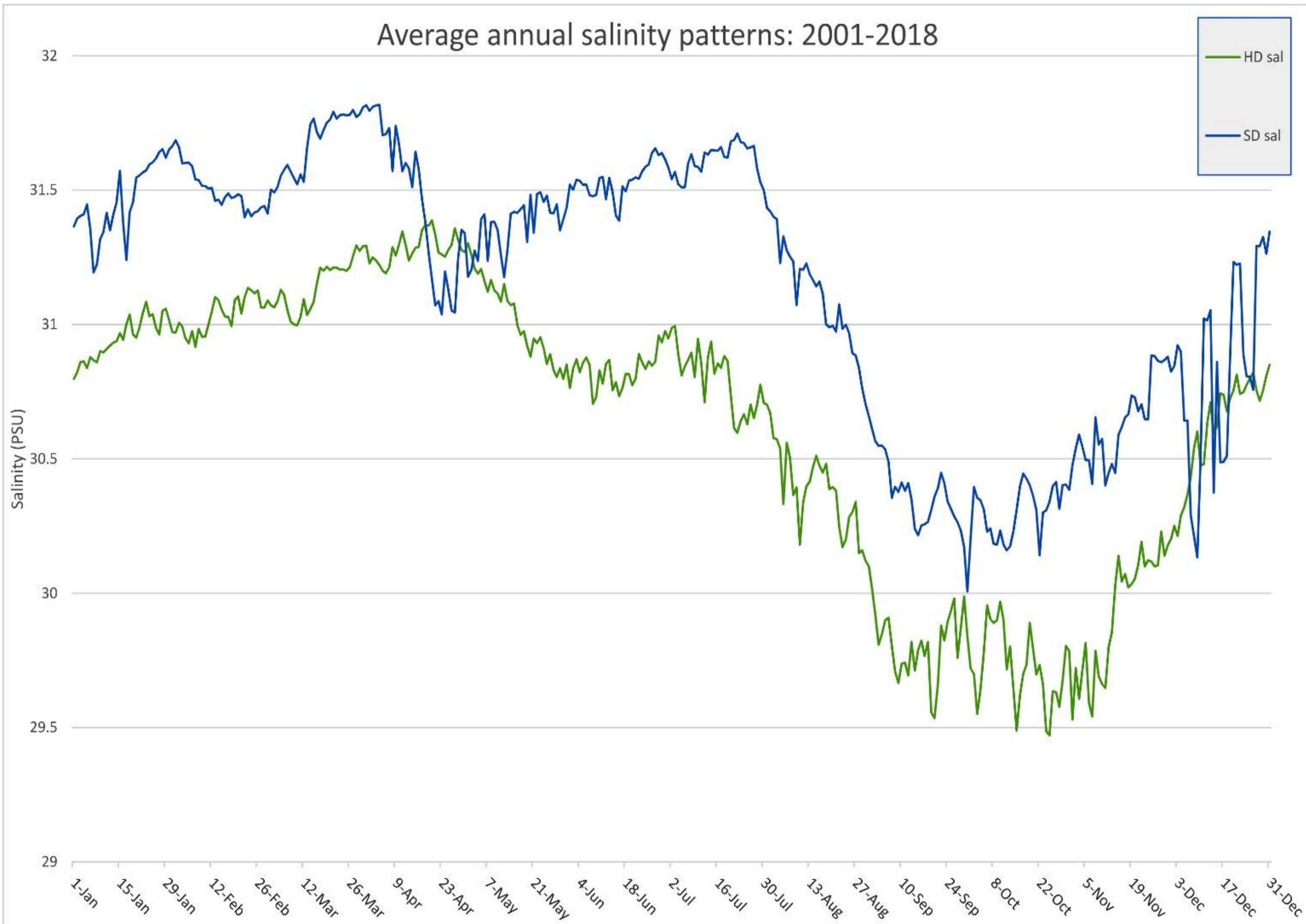


Figure 3. Climatology of seasonal salinity patterns at the Seldovia deep (SD) and Homer deep (HD) SWMP stations, as shown by averages by calendar day using data from 2001-2018.

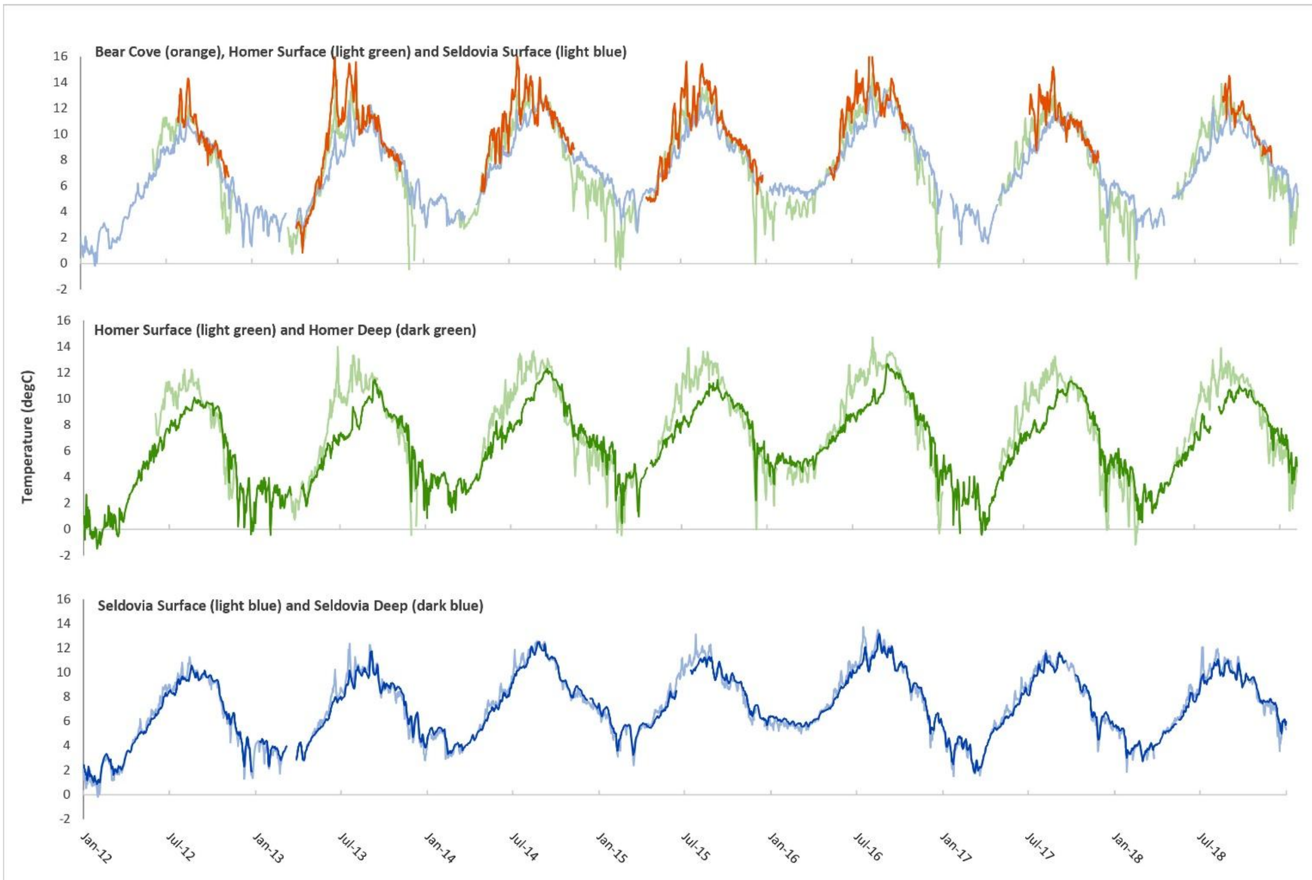


Figure 4a. Daily-averaged temperature data recorded at KBNERR monitoring stations in Seldovia, Homer, and Bear Cove during 2012 – 2018. Top panel compares surface data from all sites and middle/bottom panels compare surface and deep sensor data from Homer and Seldovia. These NERR SWMP station data are collected from a sensor package 1 meter below the sea surface (Bear Cove and surface stations) or 1 meter above the bottom (deep stations). 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.

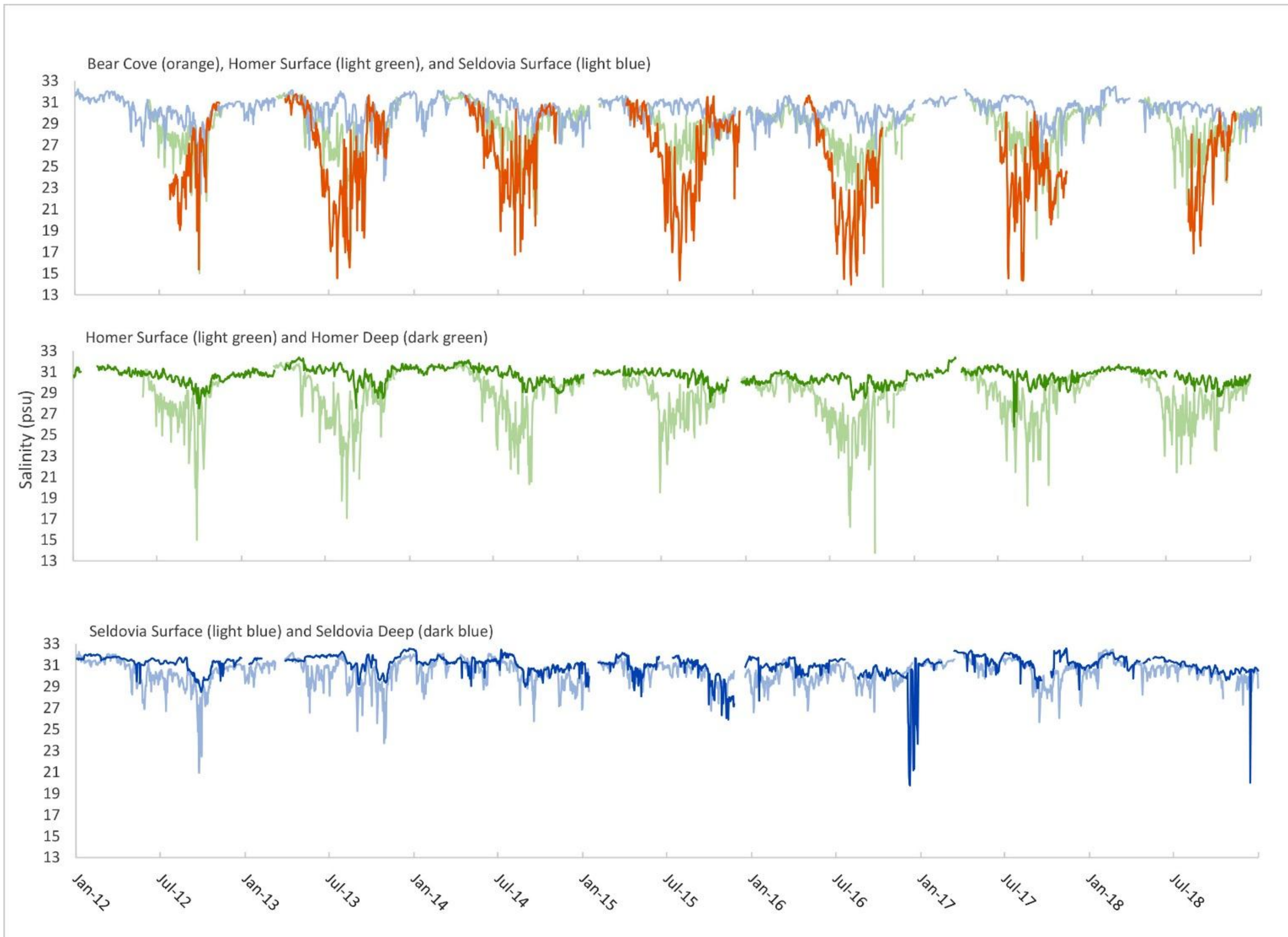


Figure 4b. Daily-averaged salinity data recorded at KBNERR monitoring stations in Seldovia, Homer, and Bear Cove during 2012-2018. Top panel compares surface data from all sites and middle/bottom panels compare surface and deep sensor data from Homer and Seldovia. These NERR SWMP station data are collected from a sensor package 1 meter below the sea surface (Bear Cove and surface stations) or 1 meter above the bottom (deep stations). 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.

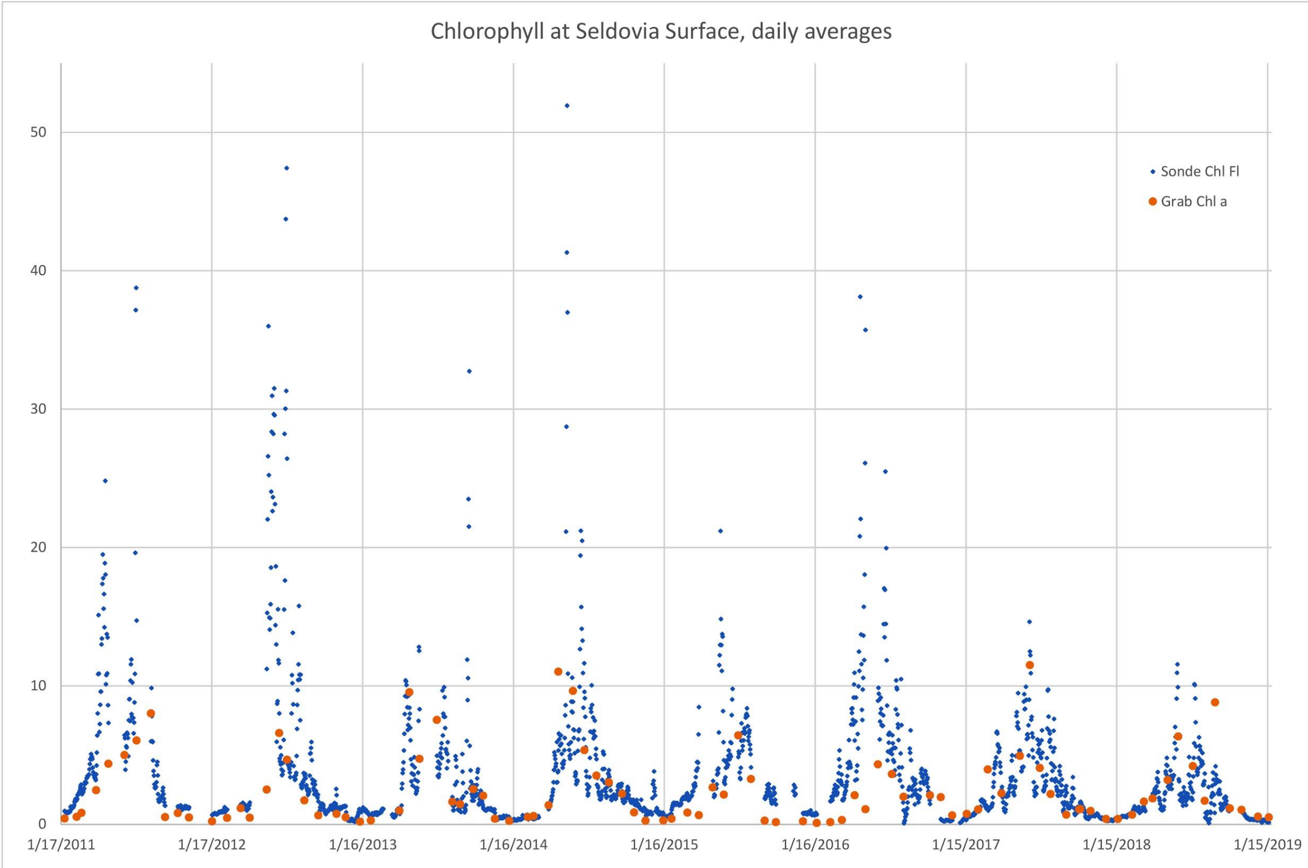


Figure 5. Daily-averaged chlorophyll fluorescence values from the Seldovia surface sonde, and chlorophyll measured from monthly grab samples over the same time period.

To illustrate oceanographic patterns throughout the water column and between years, Fig. 6 shows a time series of vertical temperature (top) and salinity (bottom) profiles from February 2012 to December 2018 from monthly sampling at the middle CTD station along the mid-Kachemak Bay survey line (Transect 9, station 6). The winter of 2017-2018 was similar to that of 2016-2017 and cooler than the anomalously warm winter conditions observed throughout the water column in 2014-2016. In fall 2018, surface waters were slightly warmer than in 2017 and remained fresher into November, and waters below the pycnocline were slightly fresher and warmer in 2018 than in 2017 (Fig. 6). Winter water temperatures in 2018 (<4.5 degrees C) were similar to 2017 (<4 ˚C), as compared to the coldest temperatures observed in 2012 (<2 degrees C) and warmest winter temperatures in 2015-2016 (> 6 degrees C). Similarly, maximum summer near-surface temperatures in 2018 (12 ˚C) were slightly warmer than in 2017 (11 ˚C), but not as warm or as prolonged as during the summers of 2014, 2015 and 2016 (Fig. 6, top). Seasonal variations in water column salinity in 2018 were also similar to 2017, with higher salinities and more mixed conditions in winter than was seen in 2014-2016 (Fig. 6, bottom). The extension of relatively fresh surface water conditions later into fall 2018 is consistent with low salinity anomalies observed at the SWMP stations during October-December 2018.

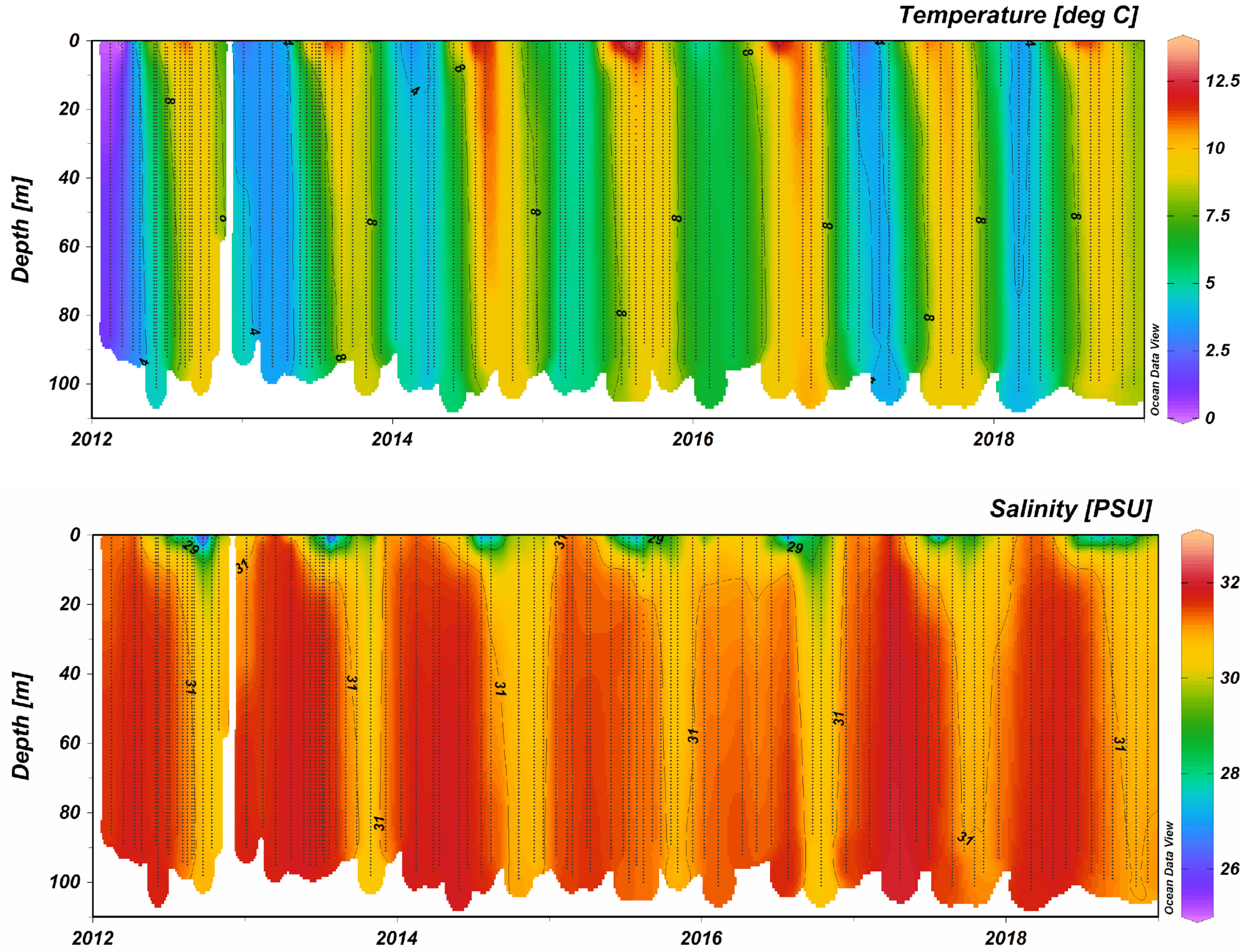


Figure 6. Time series of vertical profiles of water column temperature (top, degrees C) and salinity (bottom, PSU) from 2012-2018 collected from monthly CTD casts at a mid-Kachemak Bay station.

During 2017 and 2018, we conducted monthly along-estuary sampling in Kachemak Bay to improve resolution of spatial and seasonal changes in estuary-shelf oceanographic gradients. To illustrate these patterns, Fig. 7a and 7b provide temperature and salinity time series from some of the along-bay monthly surveys in both 2017 and 2018. Coldest temperatures and mixed conditions were observed during the late March survey, warmest water temperatures were observed throughout the water column in September and freshening was observed consistently in deeper waters from September through November, which may reflect the influence of intrusions of Alaska Coastal Current waters from the shelf. Monthly conditions in 2018 were mostly similar to those in 2017, except that in September 2017 conditions were warmer and fresher throughout the water column, much fresher at the surface, and more stratified than in 2018 (Fig. 7a and 7b).

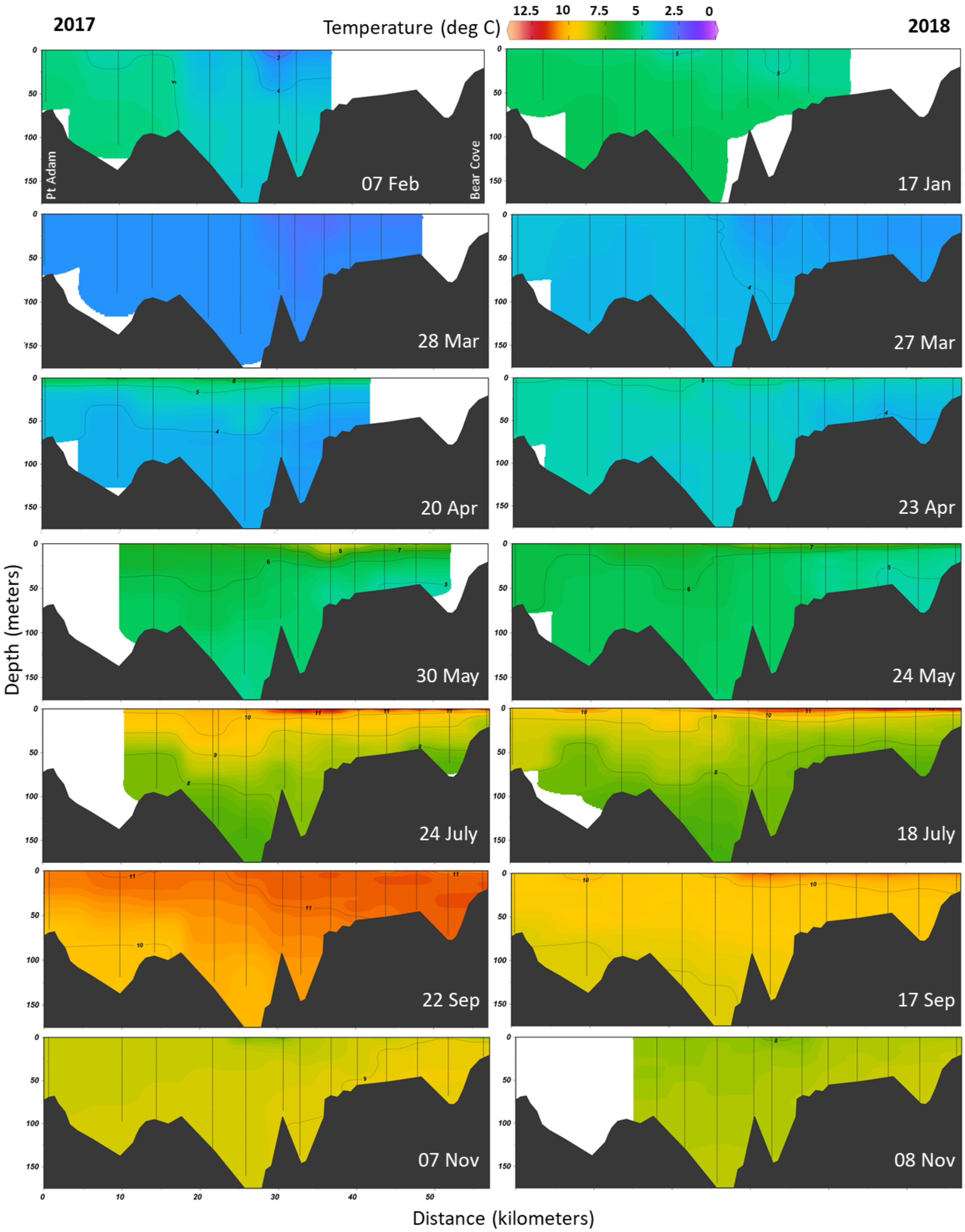


Figure 7a. Comparison of selected 2017 (left column) and 2018 (right column) contours of seasonal variation in temperature from CTD profiler data on the Along-Bay transect. Sections run from Point Adam (left) in southeast Cook Inlet to Bear Cove (right) at the head of Kachemak Bay.

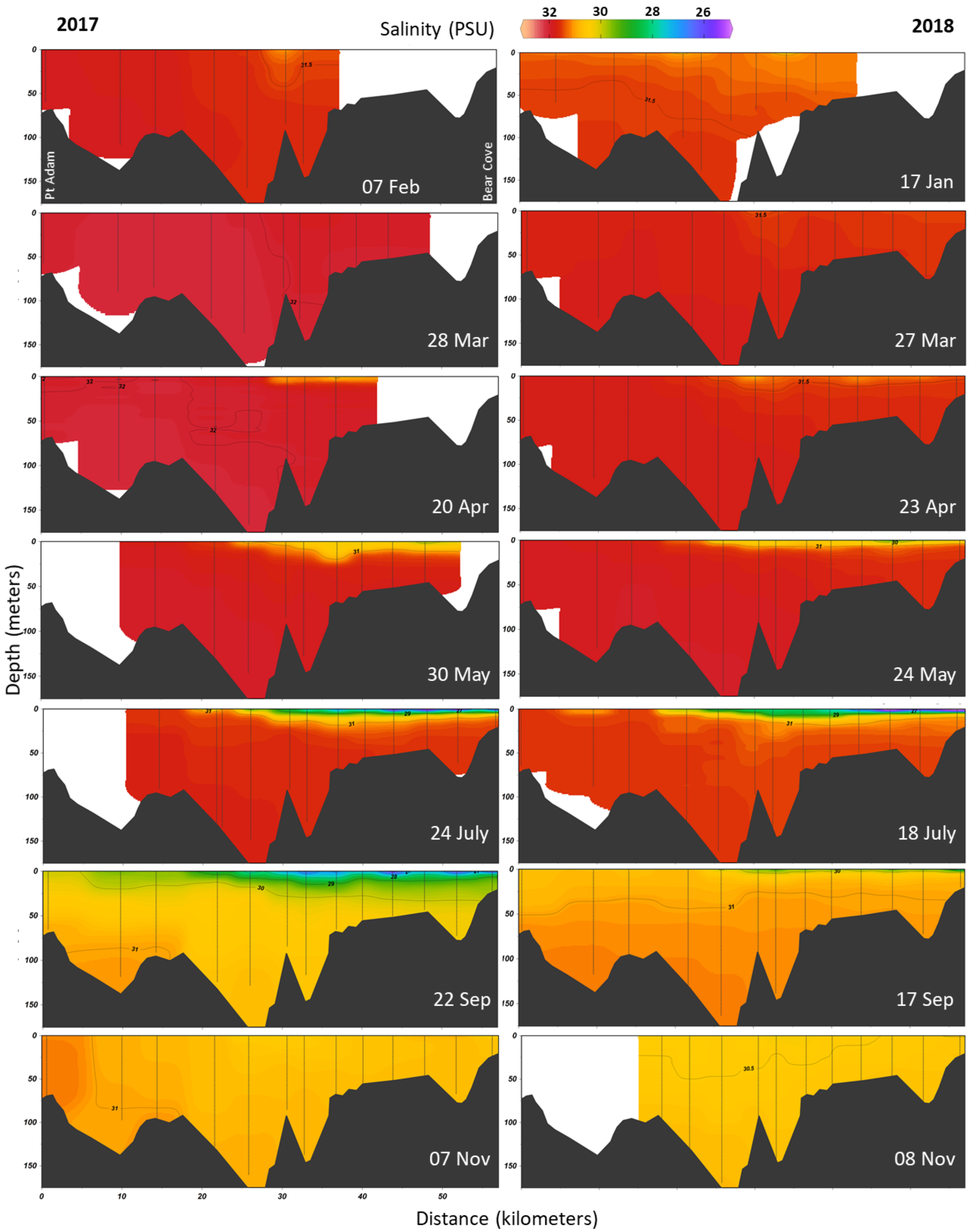


Figure 7b. Same as Figure 7a, but for seasonal contours of salinity from CTD profiler data on the Along-Bay transect in 2017 (left column) and 2018 (right column).

Phytoplankton Results

To see if the observed variability in the water column was reflected in the planktonic community, a multidimensional scaling (MDS) plot, similar percentages (SIMPER), and one-way analysis of similarity (ANOSIM) analyses were performed using the PRIMER-E (v6) statistical package. Data were log(X+1) transformed to stabilize variance. We then used an ANOSIM test to determine if there were differences in phytoplankton assemblages within seasons (spring and fall) using *apriori* factors (year and location (lower Cook Inlet, Anchor Point, Kachemak Bay)). 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. The ANOSIM analyses showed no significant differences in the phytoplankton community structure for the factors year or location for both spring (global R = 0.131 and 0.089 respectively) or fall months (global R = 0.174 and 0.029 respectively). 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 (Fig. 8). Spring and summer samples also showed high abundances of other diatoms, including *Pseudo-nitzschia* spp*.,* *Rhizosolenia* spp., and *Thalassiosira* spp. The intensive phytoplankton sampling data from Kasitsna Bay were used to create more detailed seasonal time series of relative species composition (Fig. 8) and average monthly phytoplankton cell abundance (Fig. 9). The Kasitsna Bay samples were dominated by diatoms, usually *Chaetoceros* spp., with low abundances of dinoflagellates seen throughout the year (Fig. 8). The diversity of samples declined in 2018, likely a result of much lower total cell counts cell counts than previous years (Fig. 9). Average 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. 9). Beginning in 2017, we saw a striking difference relative to 2012-2015. There was a greatly reduced contribution of *Chaetoceros* spp. and increased relative abundance of "other diatoms" (Fig. 8), along with a reduction in total cell abundance in 2017 (Fig. 9). In 2018, there were even lower counts of *Chaetoceros* than 2017, although the peak abundance occurred at approximately the same time as previous years, in mid-June (Fig. 9) the lower total abundances were also noted in the SWMP data which showed reduced chlorophyll levels from the Seldovia surface sonde (Figs. 5 and 9). 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.

Data analyses were conducted in 2018 to examine spatial and temporal variability in *Alexandrium* spp. cell concentrations as part of NOAA National Centers for Coastal Ocean Science supported HAB 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. 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. 10 is logarithmic). In 2017 & 2018, *Alexandrium* abundances declined as we returned to water temperatures that were closer to average (Fig. 10). 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, ADFG, and Alaska Department of Health and Social Services.

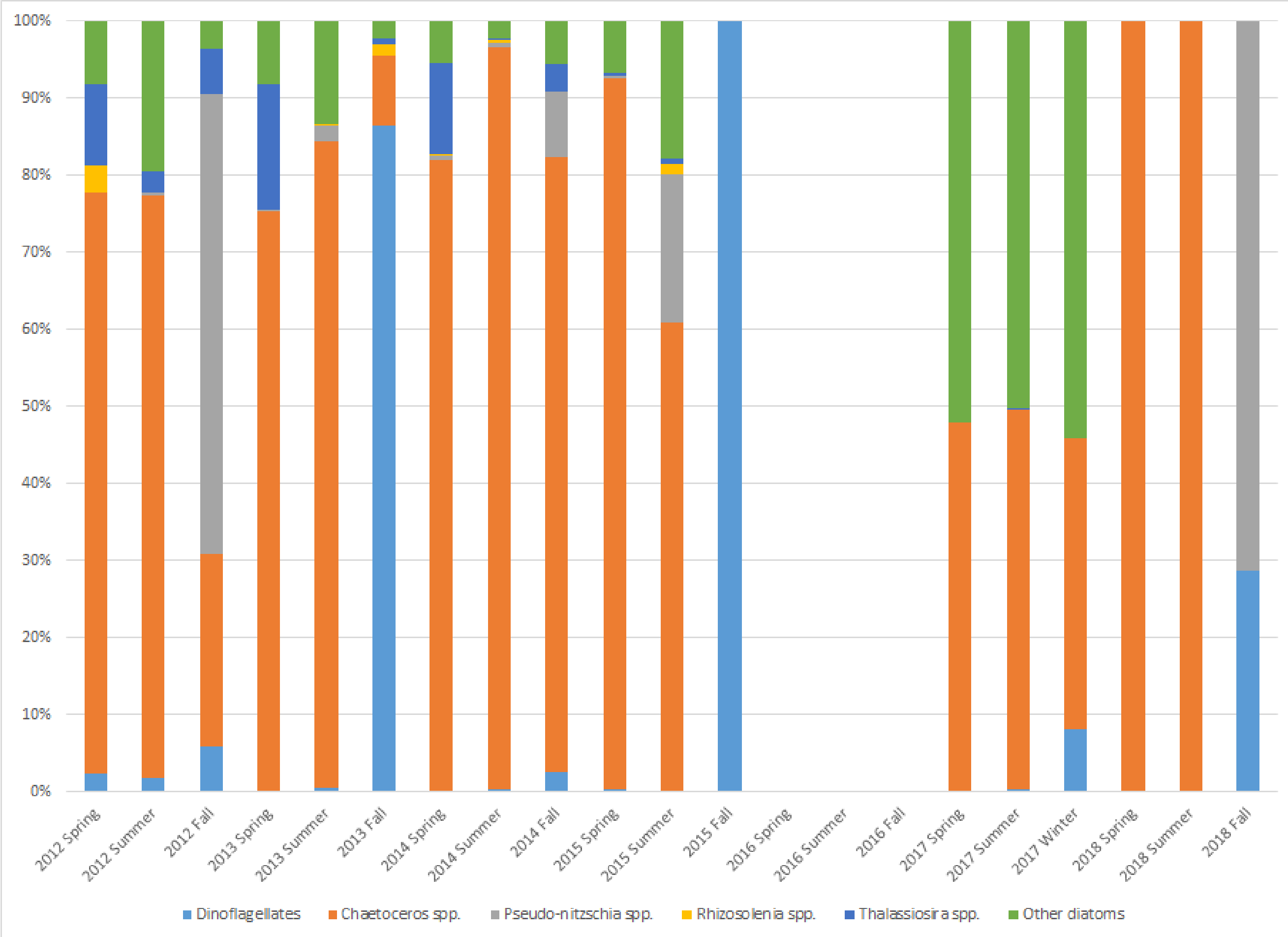


Figure 8. Relative abundance of phytoplankton samples from Kasitsna Bay. Winter samples were excluded because of low abundances of cells and data are not available for 2016. Taxa were grouped into 6 categories: Dinoflagellates, *Chaetoceros* spp. (diatom), *Pseudo-nitzschia* spp. (diatom), *Rhizosolenia* spp. (diatom), *Thalassiosira* spp. (diatom), and "Other diatoms". Compositions for taxa are shown as a percentage of total cell abundance.

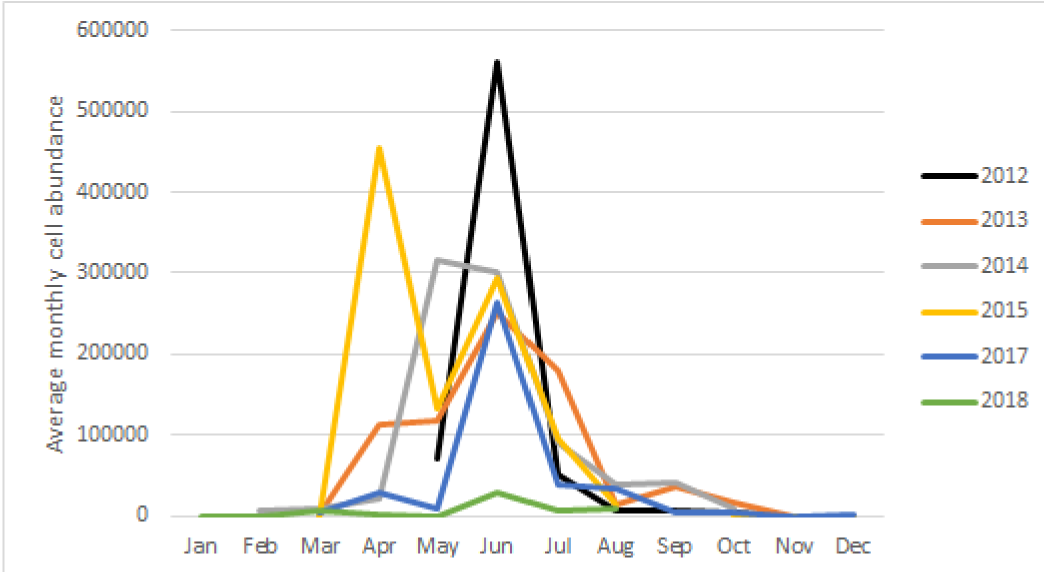


Figure 9. Average phytoplankton cell abundance by month for each year, 2012-2018 from samples collected at the Kasitsna Bay Laboratory dock from May 2012 through October 2018. No sampling data for 2016.

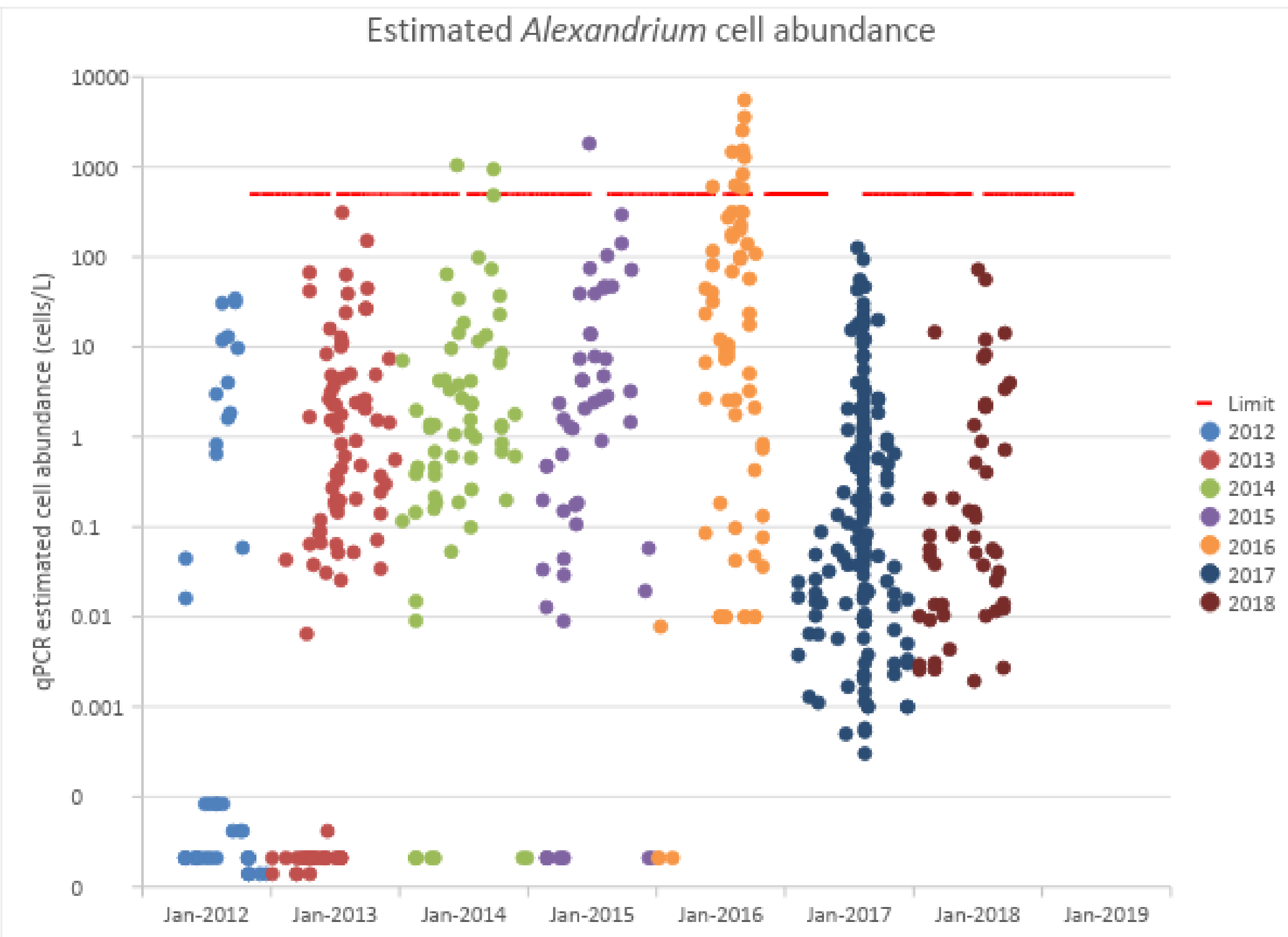


Figure 10. Time series of estimated *Alexandrium* spp. abundances from Kachemak Bay and lower Cook Inlet samples from qPCR analysis for 2012-2016. Results are shown on a logarithmic scale. The level for expecting shellfish toxicity at 500 cells per liter is shown as a dashed red line.

Zooplankton Results

From 2012 to 2017, 462 discrete zooplankton samples from shipboard surveys have been analyzed by researchers (PI R. Campbell, 18120144-G) at the Prince William Sound Science Center, which resulted in the identification of species from 236 taxa. Identification is ongoing for samples collected in 2018. Zooplankton community data were log(X+1) transformed data to stabilize variance, and from this a Bray-Curtis similarity matrix was created in PRIMER. To determine if similar patterns exist in the zooplankton community composition as in the phytoplankton community, an MDS plot was generated to determine how similar or dissimilar samples are to one another, and if a discernable pattern could be found. It was determined that the seasonal signal overwhelmed all other sources of variability in community composition, so analyses were made for each season. An ANOSIM test was performed to determine if there were statistically significant differences in community composition between *apriori* factors (location and year). Spring months had more variability overall than fall months (Fig. 11). For spring, the location of the samples (within Kachemak Bay (KBAY), in lower Cook Inlet (LCI), or north near Anchor Point (Ap)) had a global R statistic of 0.352, with KBay and Ap both being significantly different than LCI (R = 0.542 and 0.500 respectively) (Fig. 11). When looking at the spring samples by year, the global R statistic was also 0.352. The year 2012 was significantly different from 2016 and 2017 (R = 0.563 and 0.516 respectively) (Fig. 11). The zooplankton community composition in 2013 was also significantly different from 2017 (R = 0.552) (Fig. 11). This tracks with the pattern seen in the oceanographic data, with cooler waters in the earlier years of the study, transitioning to warmer waters from 2014 to 2016. In fall months however, there were no significant spatial differences in zooplankton community composition (global R = 0.147) (Fig. 11). However, year was a significant source of variability with a global R statistic of 0.507. The years 2012, 2013 and 2015 were all significantly different from both 2016 (R = 0.753, 0.745, and 0.682 respectively) and 2017 (0.682, 0.662, and 0.667 respectively) (Fig. 11). In addition, 2014 was significantly different than 2015 (R = 0.542) (Fig. 11).

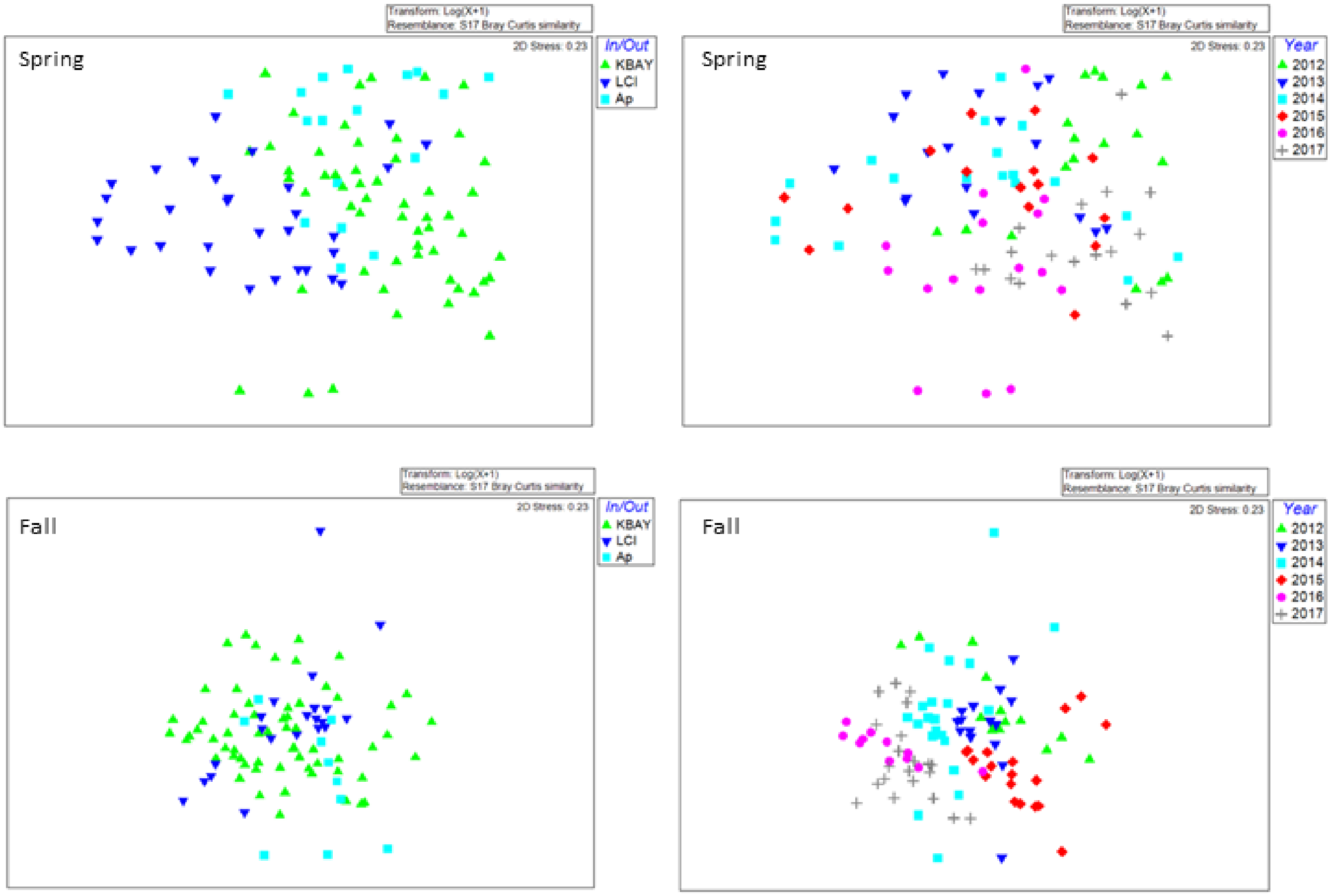


Figure 11. Multidimensional scaling (MDS) plot of spring (top) and fall (bottom) months by location (left) and by year (right).

A SIMPER analysis was performed in PRIMER to determine which species specifically contributed to variability. We identified *Pseudocalanus spp*., *Acartia spp*., *Parasagitta elegans, Calanus marshallae, Limacina helicina, Oikopleura dioica,* barnacle nauplii, and *Aglantha digitale* as the top eight taxa that contributed (60%) to abundance for all years (2012 – 2017) (Fig. 12). Of these taxa, *Pseudocalanus sp., Acartia sp.,* and *Calanus marshallae* were most abundant across sample locations, and showed consistent annual patterns (Fig. 12). Event-driven patterns were seen in abundances of *Parisagitta elegens, Limacina helicina, and Oikopleura dioica,* as abundance decreased during warm water years (Fig. 12). Spatial patterns were generally consistent across sites for *Acartia spp.* and *Pseudocalanus spp.*; unique to Cook Inlet/Kachemak Bay for *Aglantha Digitale*, *Oithona* sp., *Oikopleura dioica,* and *Calanus Marshallae*; and unique to Kachemak Bay/Anchor Point for barnacle nauplii (Figs. 12 and 13). Generally, patterns in abundance were similar between Kachemak Bay and the Cook Inlet entrance, but unique to the Anchor Point location which, with the exception of *Pseudocalanus* spp., *Aglantha Digitale*, and barnacle nauplii, had distinctly lower abundances of all taxa in question. (Figs. 12 and 13). We also determined that seven species contributed most to variability both spatially and temporally: barnacle nauplii, *Neocalanus plumchrus,* siphonophora, *Oithona similis,* unidentified egg, *Oikopleura* spp., and *Aglantha digitale* (Fig. 13). Of these taxa, unidentified egg, barnacle nauplii, and Siphonophora displayed the strongest annual patterns; the latter two taxa also displayed consistent seasonal peaks (Fig. 13). Spatial patterns were consistent across sites for Siphonophora; unique to Cook Inlet/Kachemak Bay for *Aglantha Digitale*, *Oithona* sp., *Oikopleura dioica,* and unidentified egg, and unique to Kachemak Bay/Anchor Point for barnacle nauplii (Figs. 12 and 13). The cold-water copepod *Neocalanus plumcrus* was only abundant at Anchor point, but decreased during warm water years as did *Aglantha digitale,* unidentified egg*, and Limacina helicina* (Fig. 13). Overall, zooplankton density continues to be highest during the spring and summer months, and lowest during winter (Figs. 12 and 13).

Figure 12. Total abundance of zooplankton species contributing most to abundance in Kachemak bay and Cook Inlet. Samples were collected 2012-2017 from combined plankton stations on shipboard surveys at Transect 3 Station 13 (grey series – Anchor Pt to Red River), Transect 9 Station 6(blue series- Homer Spit – China Poot bay), and Transect 6 Station 5 (orange series- Pt. Adam to Cape Douglas). Abundance is determined as the number of individuals in a single sample taken per site on that date.

Figure 13. Total abundance of zooplankton species contributing most to community variability in Kachemak bay and Cook Inlet. Samples were collected 2012-2017 from combined plankton stations on shipboard surveys at Transect 3 Station 13 (grey series – Anchor Pt to Red River), Transect 9 Station 6 (blue series- Homer Spit – China Poot bay), and Transect 6 Station 5 (orange series- Pt. Adam to Cape Douglas). Abundance is determined as the number of individuals in a single sample taken per site on that date.

We summarized temporal variation in zooplankton species contributing most to variability and abundance for each transect in a stacked histogram of the relative proportion of zooplankton species category by sampling date (Figs. 14 and 15); all other zooplankton were combined in the "other" category. Similar to observations made in zooplankton abundance, compositional changes in community occurred between time and space. Of the taxa contributing most to community abundance, calanoid species were most prevalent at all sample locations (Fig. 14) with peak composition occuring during years 2015-2016. Each location had unique seasonal patterns: Anchor Point is characterized large fluxes of barnacle nauplii during the spring season and followed by a shift to summer peaks of *Pseudocalanus* spp. and *Acartia* spp. which diminish progressively through fall and winter (Fig. 14); Kachemak Bay is characterized with summer peaks in calanoid copepods, winter peaks in barnacle nauplii, and greater proportions of *Parasaggita elegans* and *Oikopleura dioica* than other locations (Fig. 14); Cook Inlet is characterized by similar calanoid trends, greater proportions of *Limacina helicina* during summer and fall, and the greatest proportion of "other" species contributing to composition (Fig. 14). Of the taxa contributing most to community variability, barnacle nauplii, *Neocalanus* *plumchrus, Oithona* sp., and Siphonophora were greatest in proportion across sample locations (Fig. 15). Anchor Point is characterized by mixed proportions of barnacle nauplii and *Neocalanus plumchrus* during the spring season with greater contributions of Siphonophora during the summer/fall (Fig. 15). Anchor Point winter was most greatly influenced by "other" species (Fig. 15). Kachemak Bay is characterized by mixed proportions of unidentified egg, barnacle nauplii, and *Oikopleura dioica* during spring; *Oithona* sp. and Siphonophora during summer/fall, and a mix of varying species in winter (Fig. 15). There were also interannual shifts with "other" species comprising most of the community during 2012, 2013, and 2016 (Fig. 15). Cook Inlet is characterized large fluxes of *Neocalanus plumchrus* during spring, and varying proportions of other species throughout the year (Fig. 14).

In order to make our study more comparable to the other zooplankton studies within GWA, analyses used in Mckinstry and Campbell (2018) were reproduced by the GWA partners at the Prince William Sound Science Center (project 18120114-G). 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. Based on the indicator species analysis of 2012-2017 zooplankton, we've separated plankton into groups by season. For all sampling areas combined, it was determined that early spring periods were characterized by *Scolechithricella minor* and cumaceans (Fig. 16). Late spring months were primarily identified by the presence of all *Neocalanus* species and fish eggs. Summer was most characterized by presence of bivalve veliger larvae, the copepod *Ointhona similis,* and nauplii. Four warm-water copepods: *Ointhona* sp., *Pseudocalanus* sp., *Limacina helina,* and *Acartia longiremeis* clustered with each other during this period, similar to analysis in Prince William Sound. A distinct late summer group consisted of megalopae, *Clione limacina,* and hydrozoans. Species that categorized the late fall were dominated by the copepods *Mesocalanus tenuicornis* and *Calanus pacificus*, in addition to Siphonophora, and Pleurobrachia (Fig. 16). Seasonal transitions of these species groups were consistent until summer 2014 where they began showing earlier onset and longer periods of late summer/autumn assemblages (Fig. 16).

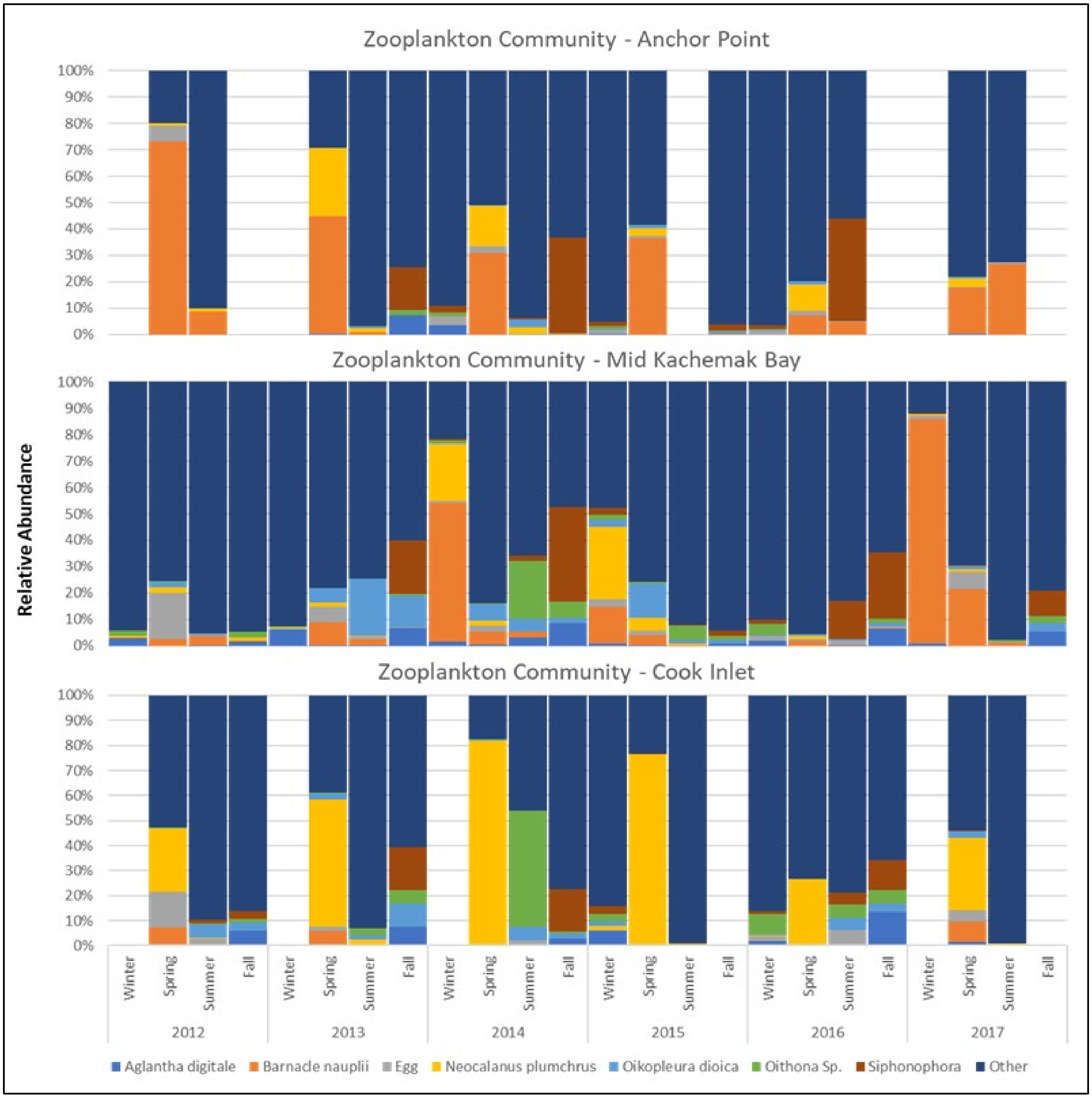


Figure 14. Proportion of zooplankton species contributing most to community variability in Kachemak Bay and lower Cook Inlet. Samples were collected 2012-2017 from combined plankton stations on shipboard surveys (north to south) at Transect 3 Station 13 (top – Anchor Pt to Red River), Transect 9 Station 6 (middle – Homer Spit – China Poot bay), and Transect 6 Station 5 (bottom- Pt. Adam to Cape Douglas). Species not identified as top contributors were combined in the "other" category.

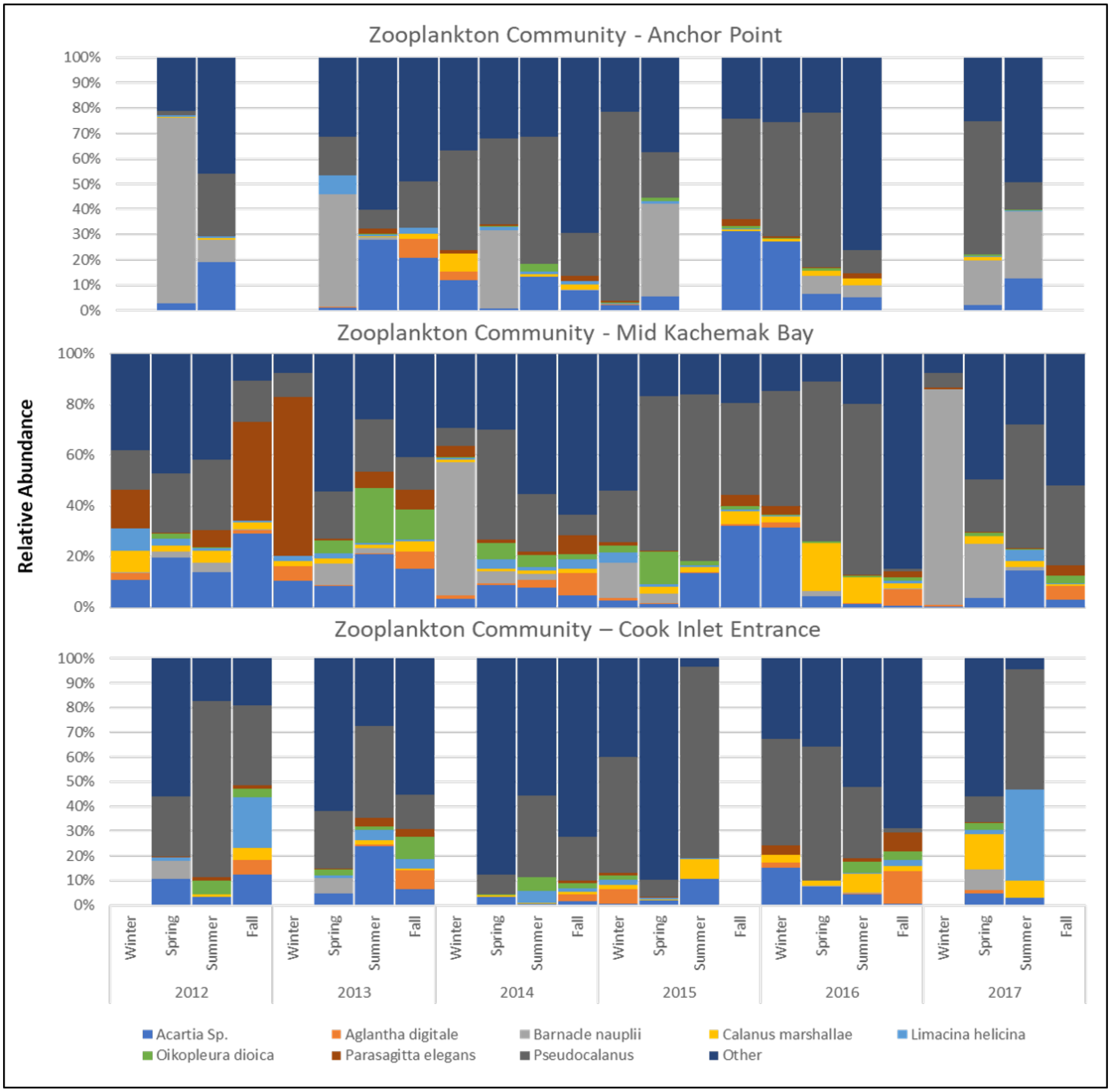


Figure 15. Proportion of zooplankton species contributing most to community abundance in Kachemak Bay and lower Cook Inlet. Samples were collected 2012-2017 from combined plankton stations on shipboard surveys (north to south) at Transect 3 Station 13 (top: Anchor Pt to Red River), Transect 9 Station 6 (middle: Homer Spit to China Poot Bay), and Transect 6 Station 5 (bottom: Pt. Adam to Cape Douglas). Species not identified as top contributors were combined in the "other" category.

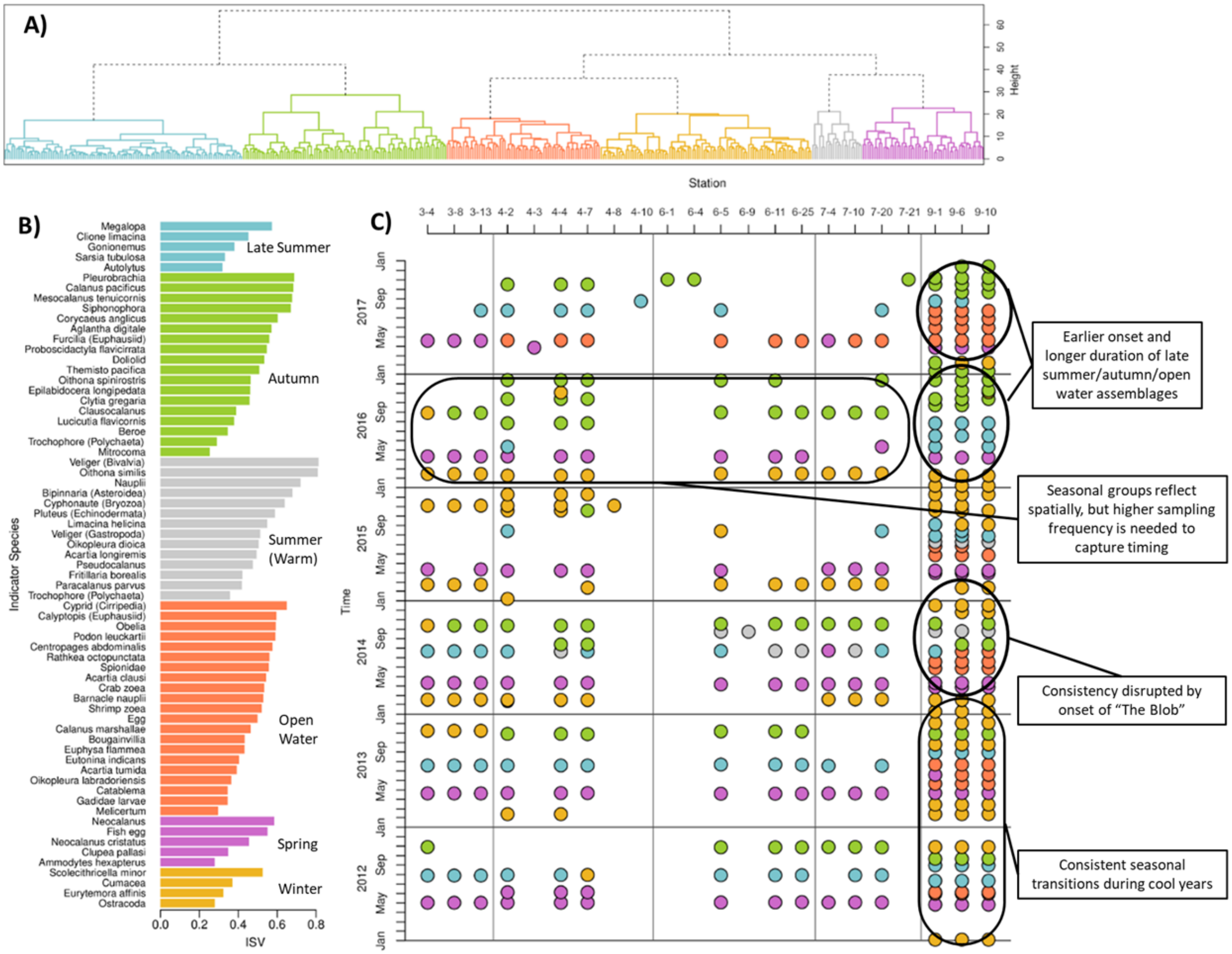


Figure 16. A) Dendrogram of sample groups produced by the hierarchical cluster analysis (HCA) with a B) dot matrix showing HCA cluster assignments by date and location. C) Significant ($p < 0.05$) species were determined as indicative of sample-group clusters and indicator species values. All colors correspond with sample-group clusters. Annotations are included to ease figure interpretation.

8. Coordination/Collaboration:

A. Projects Within a Trustee Council-funded program

1. Within the Program

Environmental Drivers component: We continue to coordinate on oceanographic and zooplankton sampling protocols and synthesis of monitoring results with all GWA Environmental Drivers component investigators through teleconferences, joint field work, and GWA principal investigator (PI) meetings. We are collaborating with PI Rob Campbell (Prince William Sound Environmental Drivers component project 18120114-G) at the Prince William Sound Science Center on zooplankton sample analyses. The project provides year-round, seasonally resolved oceanographic and plankton data and detailed information on along- and across-estuary gradients to the GWA program. We are collaborating with other Environmental Drivers PIs (projects 18120114-D, G, I, and L) and Rob Suryan (GWA Science Coordinator, project 18120114-A) to incorporate project data into synthesis manuscripts in 2019.

Nearshore component: The Cook Inlet/Kachemak Bay project provides information on seasonal and inter-annual patterns in water temperature, stratification, freshwater content and nutrients to the GWA

Nearshore component PIs to assess drivers of intertidal ecosystem changes at their Kachemak Bay sites. We are collaborating with Dan Monson to assess nearshore oceanographic variability across the GWA study area, to develop a synthesis manuscript in 2019. Cook Inlet project scientists (Dominic Hondolero and Kim Powell Schuster) also assisted with Nearshore component sampling in Kachemak Bay in May 2018.

Pelagic component: We provide opportunities to GWA Pelagic component (Kathy Kuletz, USFWS Migratory Bird Management office) to host a seabird/marine mammal observer on our shipboard surveys. However, USFWS was not able to provide observers for most of 2018.

2. Across Programs

a. Herring Research and Monitoring

We coordinate informally with Scott Pegau (Herring Research and Monitoring program lead) to investigate long-term changes in oceanographic patterns at near-shore sites across the northern Gulf of Alaska. We coordinated with Maya Groner from the Herring Research and Monitoring program on an outreach event at Port Graham in spring 2018.

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. We have continued a collaboration with Axiom, AOOS and the Alaska Harmful Algal Bloom Network to develop improved web-based tools for paralytic shellfish poisoning risk assessment that include the real-time water temperature observations from the KBNERR water quality stations.

c. Lingering Oil

None

B. Projects not Within a Trustee Council-funded program

None

C. With Trustee or Management Agencies

NOAA: We collaborate with researchers at the National Ocean Service/ National Centers for Coastal Ocean Science 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. In 2018 we started a study to investigate the potential for forage fish to provide a vector for PSP toxins to seabirds and whales. We collaborate with NOAA National Marine Fisheries Service on the NOAA Kachemak Bay Habitat Focus Area, including clam restoration and paralytic shellfish poisoning risk assessment efforts.

State of Alaska agencies: We provide real-time and historical trends for water temperature data to shellfish managers with the ADFG (Commercial and Sportfish Divisions) in Homer and Kenai, and with the Alaska Department of Environmental Conservation in Anchorage. Project data helps inform management for shellfish harvest, mariculture operations, harmful algal bloom event response and marine invasive species monitoring.

USFWS: We opportunistically host USFWS shipboard seabird/marine mammal observers on our surveys. We coordinate with the USFWS Marine Mammals Office on sea otter stranding and sampling programs and project data is provided to USFWS (Alaska Maritime National Wildlife Refuge) and NOAA (National Marine Fisheries Service Protected Resources Division) to help understand potential causes of seabird, sea otter, and whale mortality events.

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, ADFG and other organizations. Project data are being used to help understand how linkages between nearshore and shelf waters affect capelin distributions.

9. Information and Data Transfer:

A. Publications Produced During the Reporting Period

Publications (project scientists in bold)

Bentz, S., M. Johnson, G. Gibson, **S. Baird**, and **J. Schloemer.** 2018. 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. 45pgs

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 Long-term Monitoring Program (Gulf Watch Alaska) Final Report (Exxon Valdez Oil Spill Trustee Council Project 16120114-G), Exxon Valdez Oil Spill Trustee Council, Anchorage, Alaska.

Holderied, K., and **J. Shepherd**. 2018. Long-term monitoring of oceanographic conditions in Cook Inlet/Kachemak Bay to understand recovery and restoration of injured near-shore species. FY17 annual report to the Exxon Valdez Oil Spill Trustee Council, project 17120114-J.

Vandersea, M.W., S.R. Kibler, P.A. Tester, **K. Holderied**, **D.E. Hondolero**, **K. Powell, S. Baird**, A. Doroff, D. Dugan, R.W. Litaker. 2018. Environmental factors influencing the distribution and abundance of Alexandrium catenella in Kachemak Bay and lower Cook Inlet, Alaska. Harmful Algae, 77:81-92. https://doi.org/10.1016/j.hal.2018.06.008

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. 2018. Alaska Coastal Science and Management Examples. **Oral presentation** at Joint Polar Satellite System Arctic Summit, Anchorage, AK. May 2018.

Holderied, K., K. Powell, J. Schloemer, and D. Hondolero. 2018. Variability in nearshore and estuarine oceanography in the northern Gulf of Alaska: 2004-2017. **Poster presentation** at 2018 Ocean Sciences Meeting, Portland, OR. Feb 2018.

Holderied, K., K. Powell, J. Schloemer, S. Baird, and D. Hondolero. 2018. Heating up and cooling off in Kachemak Bay Alaska – what does it mean for the marine ecosystem? **Oral presentation** at the Kachemak Bay Science Conference, Homer, AK. Mar 2018.

Hondolero, D, Vandersea, M, Holderied, K, Kibler, S, Powell, K, Baird, S, Doroff, A, Litaker, W. 2018. Environmental factors affecting toxic phytoplankton plankton in Kachemak Bay. **Oral presentation** at the Kachemak Bay Science Conference, Homer, AK. Mar 2018.

Holderied, K., J. Schloemer, K. Powell Schuster, S. Baird, and D. Hondolero. 2019. Seasonal and spatial variability in ocean acidification conditions in Kachemak Bay and Cook Inlet Alaska. **Poster presentation** at Alaska Marine Science Symposium, Anchorage AK. Jan 2019.

Powell Schuster, K., K. Holderied, J. Schloemer, and D. Hondolero. 2019. Variability of zooplankton abundance and community structure in Kachemak Bay and lower Cook Inlet Alaska: 2012-2017. **Poster presentation** at Alaska Marine Science Symposium, Anchorage AK. Jan 2019.

Schloemer, J., S. Baird, S. Bentz, M. Johnson, and R. Masui. 2019. Using circulaton mapping and long-term water quality data to aid community monitoring programs in Kachemak Bay, Alaska. **Poster presentation** at Alaska Marine Science Symposium, Anchorage AK. Jan 2019.

Outreach Presentations:

Aderhold, D., S. Buckelew, M. Groner, K. Holderied, K. Iken, B. Konar, H. Coletti, and B. Weitzman. 2018. GWA and HRM information exchange event in Port Graham, AK, May 15 2018.

Shepherd, J. 2018. Reading the landscape. 49 Writers Online Blog. April 2018.

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

DataONE: Published data updated in August 2018 with final 2016 zooplankton data.

Holderied, K., Baird, S., Schloemer, J. 2018. 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., Schuster, K., Baird, S. 2018. 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. Baird, S., Schloemer, J., Schuster, K. 2018. 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.

NOAA. 2018. Science and Stewardship: Keys to Restoring Kachemak Bay (video). NOAA National Marine Fisheries Service. https://coastalscience.noaa.gov/news/kachemak-bay-hfa-video/.

Additional information products: A variety of data and information products have been developed for science and outreach presentations listed above, presentations for the general public in Homer Alaska and for management agency use (NOAA, Bureau of Ocean Energy Management, ADFG, and U.S. Geological Survey). 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. Data and graphic products from this project were used by a NOAA Hollings Undergraduate Scholar student (Adrian Teegarden) for a project with Holderied on visualizing zooplankton, fish and oceanography data in Kachemak Bay. Teegarden provided a public science outreach talk on her results in Homer Alaska and gave a scientific presentation at NOAA offices in Silver Spring, MD in August 2018.

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

Quality-controlled CTD data sets and associated metadata through January 2019 have been uploaded to the AOOS Research Workspace. The 2018 data will be published after final review is completed with the data management team.

Quality-controlled zooplankton data and associated metadata through December 2017 have been uploaded to the AOOS Ocean Workspace and 2012-2016 data have been published to the GWA Data Portal. The 2017 data will be published after final review is completed with the data management team. 2018 data are being analyzed by Rob Campbell at Prince William Sound Science Center and will be uploaded to the Research Workspace when the species identifications and data QA/QC are complete.

Quality-controlled phytoplankton data and associated metadata through September 2018 have been uploaded to the AOOS Research Workspace. The remaining 2018 data are being analyzed and will be uploaded to the Research Workspace when the species identifications and data QA/QC are complete.

KBNERR SWMP water quality data from Bear Cove, Homer, and Seldovia water quality data sondes and associated metadata through 2017 have been uploaded to the Research Workspace. Data are also publicly available on the NOAA National Estuarine Research Reserve site: http://cdmo.baruch.sc.edu/. The 2018 data will be uploaded to Research Workspace when QA/QC is completed.

10. Response to EVOSTC Review, Recommendations and Comments:

Science Panel Comment (EVOSTC FY18 Work Plan)**:** 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 comment.

11. Budget:

Please see the provided program workbook.

PI Holderied (NOAA) was delayed in fully obligating FY18 (project year 7) funds by 31 January 2019, for travel, contracts, and commodities ($22.4K total). Travel issues were due primarily to federal employee travel issues associated with the federal government shutdown. We expect to accomplish additional cross-GWA project field work collaborations with the travel funds. Obligations for contracts are behind schedule primarily due to issues with the vessel charter for spring 2018 Cook Inlet entrance sampling and obligations for commodities are behind schedule primarily due to contract administration delays (including those associated with the shutdown). We expect to be able to catch up on these contractual and commodity obligations by the end of FY19 and we do not expect to need any >10% change of funding between budget categories.

KBNERR was again without a designated research coordinator for FY18, so charges to this project were reduced because staff with a lower pay rate took on most of the research coordinator's duties. Despite being short-handed, all field sampling tasks were met by remaining staff on the project. To rectify the staff shortage, KBNERR's GIS analyst, Steve Baird, has assumed the role of acting research coordinator, and will act as the GWA PI for FY19 and beyond.

Budget Category:	Proposed FY 17	Proposed FY 18	Proposed FY 19	Proposed FY 20	Proposed FY 21	TOTAL PROPOSED	ACTUAL CUMULATIVE
Personnel	$47.2	$49.3	$44.5	$41.4	$40.1	$222.5	$73.1
Travel	$7.9	$7.6	$10.5	$8.6	$9.1	$43.7	$10.6
Contractual	$74.8	$76.8	$88.1	$49.2	$47.9	$336.8	$136.8
Commodities	$11.0	$11.5	$11.5	$12.5	$12.5	$59.0	$7.3
Equipment	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Indirect Costs (*will vary by proposer*)	$14.8	$14.8	$13.6	$12.9	$12.7	$68.7	$20.4
SUBTOTAL	$155.7	$160.0	$168.2	$124.6	$122.3	$730.7	$248.1
General Administration (9% of	$14.0	$14.4	$15.1	$11.2	$11.0	$65.8	N/A
PROJECT TOTAL	$169.7	$174.4	$183.4	$135.8	$133.3	$796.5	
Other Resources (Cost Share Funds)	$205.0	$213.0	$215.0	$217.0	$194.0	$1,044.0	

Literature Cited

McKinstry, C. A. E., and R. W. Campbell. 2018. Seasonal variation of zooplankton abundance and community structure in Prince William Sound, Alaska, 2009–2016. Deep Sea Research Part II: Topical Studies in Oceanography 147:69-78.