Influence of the 2013-2016 marine heatwave on zooplankton community structure in the lower Cook Inlet, Alaska

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Summary

- A marine heatwave (MHW) called "The Blob" affected the Gulf of Alaska from 2013-2016
- Cook Inlet (CI) and Kachemak Bay (KB) zooplankton were collected (2012-2018) to assess ecological patterns in the nearshore marine system & how the MHW influenced the region
- Large calanoid copepod abundance peaked in early spring followed by small bodied copepods in late spring/early summer
- Warm water copepods numbers were highest in fall and remained elevated during 2016
- CI and KB zooplankton community composition displayed a seasonal progression of *Neocalanus* spp. and ichthyoplankton in early spring, switching to a meroplanktonic larval group in late spring, then to a fall gelatinous plankton & warm water copepod community
- In 2016, during the MHW, the timing of community transitions shifted; the late spring group emerged earlier in the year and the fall group persisted into winter
- Sea surface temperature (SST), temperature of the mixed layer depth (MLDT), temperature of the top 50 m of the water column, mixed layer depth (MLD), and integrated chlorophyll *a* drove the observed community patterns

Introduction

In the past 30 years, Cook Inlet, Alaska (CI) and Kachemak Bay (KB) have experienced significant changes in environmental conditions from anthropogenic and atmospheric events including the Exxon Valdez Oil spill, multiple ENSO cycles, and the recent 2014-2016 Pacific marine heatwave known as "the Blob". The latter event coincided with the documented appearance of several marine species (e.g. ocean sunfish, skipjack tuna, and several species of copepods) common along the coasts of California to Washington. As part of the Gulf Watch Alaska long-term monitoring program, CI zooplankton were collected to understand the spatial and temporal characteristics, and community structure of zooplankton in the region. Here we present evidence of how the Gulf of Alaska MHW affected the zooplankton community in the CI and KB before, during, and after this disturbance from 2012-2018.

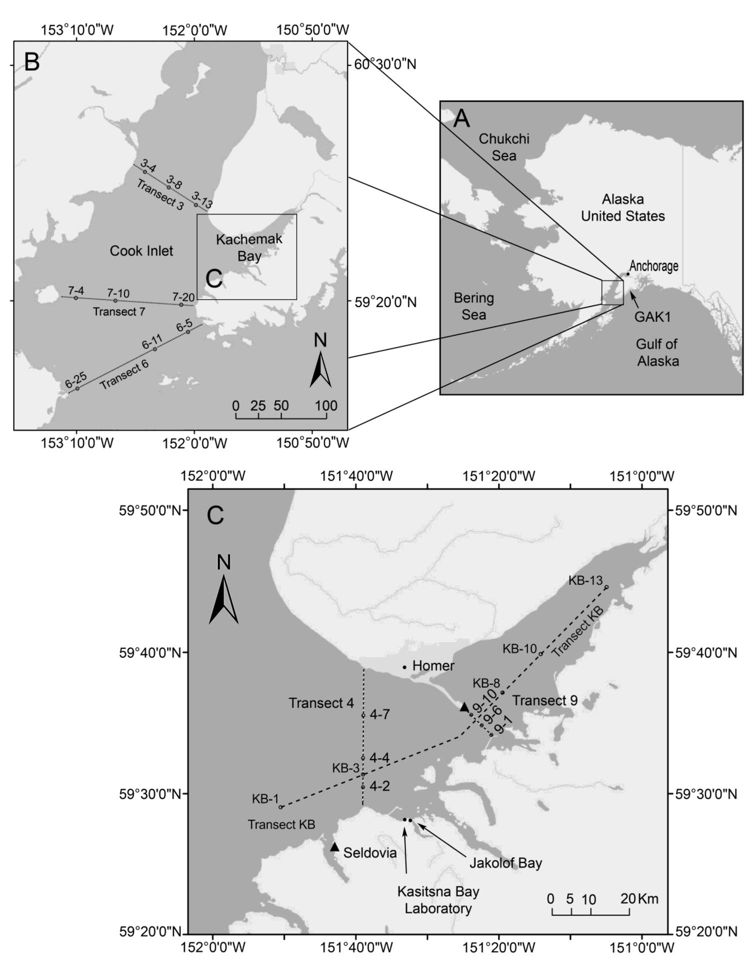

Figure 1. Map of the study region in Cook Inlet and Kachemak Bay, Alaska, USA with transects (dashed lines) and stations (open circles) along each transect.

Methods

- Six transects sampled quarterly and monthly during daylight hours (Fig. 1)
- Vertical plankton hauls (0-50m) with a 0.6 m bongo net (333 µm mesh; n = 489)
- Seasonal patterns of communities and species abundance ($\log_{10}(n+1)$) were analyzed with generalized additive models (GAMs) and multivariate statistic; see figures for details

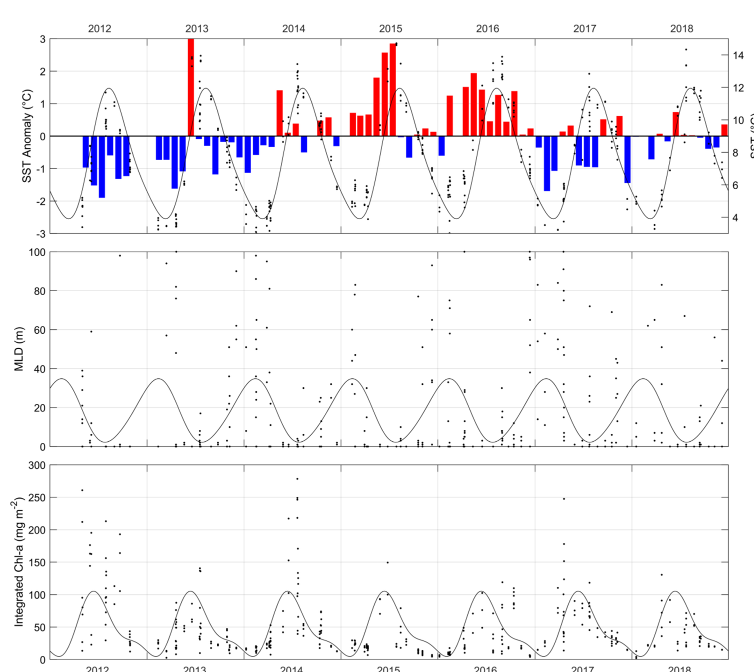

Figure 2. Time series of oceanographic variables found significant by the BIO-ENV "Best" model.

Results – Oceanography

- Sea surface temperature (SST) and temperature of the mixed layer depth (MLDT) were highly correlated ($r^2 = 0.97$); only SST is presented (Fig. 2)
- SST anomalies show the MHW began to manifest in CI and KB in the summer of 2014; highest anomalies were observed in the summer of 2015; the MHW persisted into 2016 and began to dissipate in the late fall

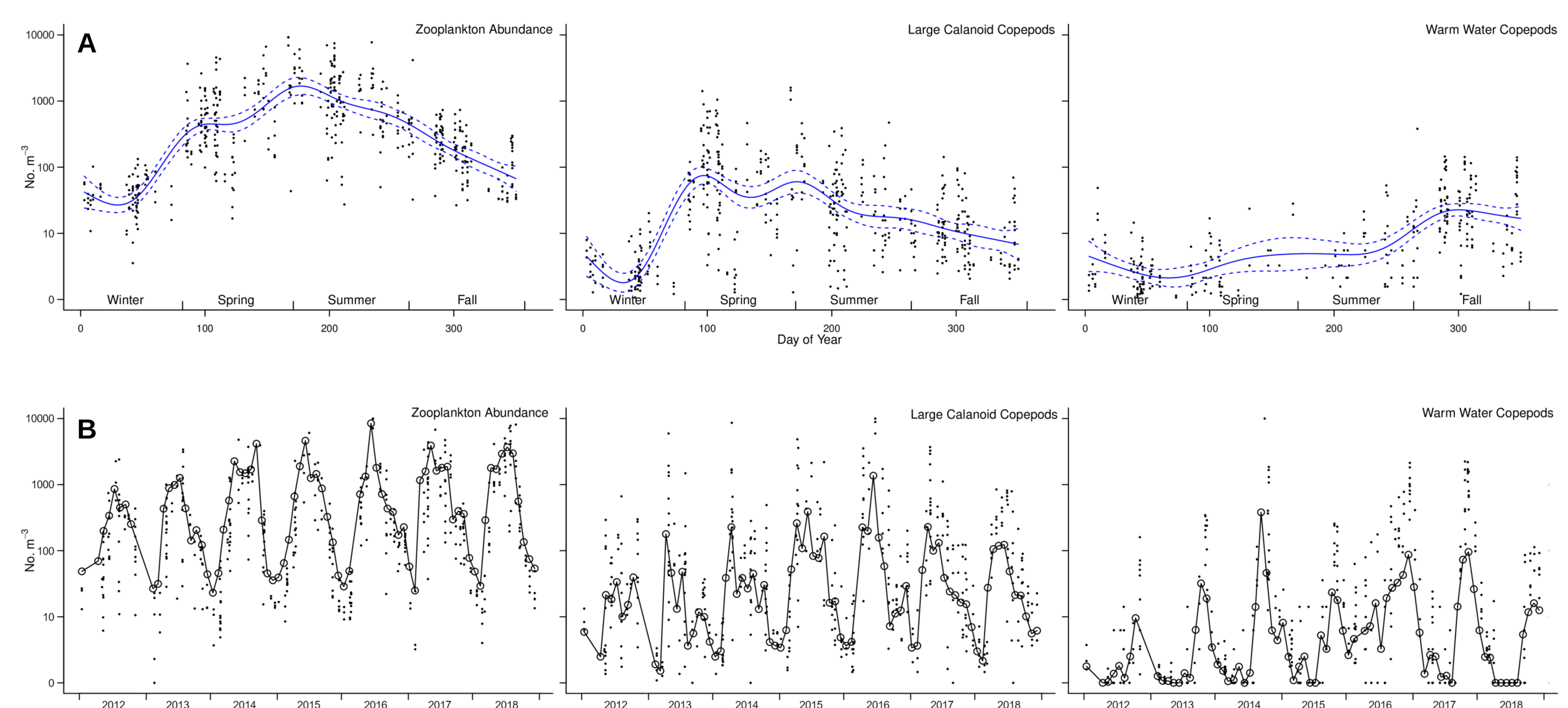

Figure 3. Zooplankton abundance as $\log_{10}(n+1)$; (•) indicate observations (n = 489) for overall zooplankton, large calanoid copepods (>3mm), and warm water copepods (WWC) common along the coast of California to Washington. **A**. Seasonal abundance pattern of zooplankton in Cook Inlet and Kachemak Bay with GAM best-fit models (—) and 95% confidence intervals (- -). **B.** Monthly means time series of zooplankton during the study period. Note that standard deviation is not included and variance should be expected. The (○) represent monthly means (n = 78). WWC include *Calanus pacificus*, *Clausocalanus* spp., *Ctenocalanus* spp., *Corycaeus anglicus*, *Mesocalanus tenuicornis*, and *Paracalanus parvus.* Large calanoid abundance combines *C. marshallae*, *Epilabidocera longipedata*, *Eucalanus bungii*, *Metridia okhotensis*, *M. pacifica*, *Neocalanus cristatus*, *N. plumchrus*, and *N. flemingeri* data.

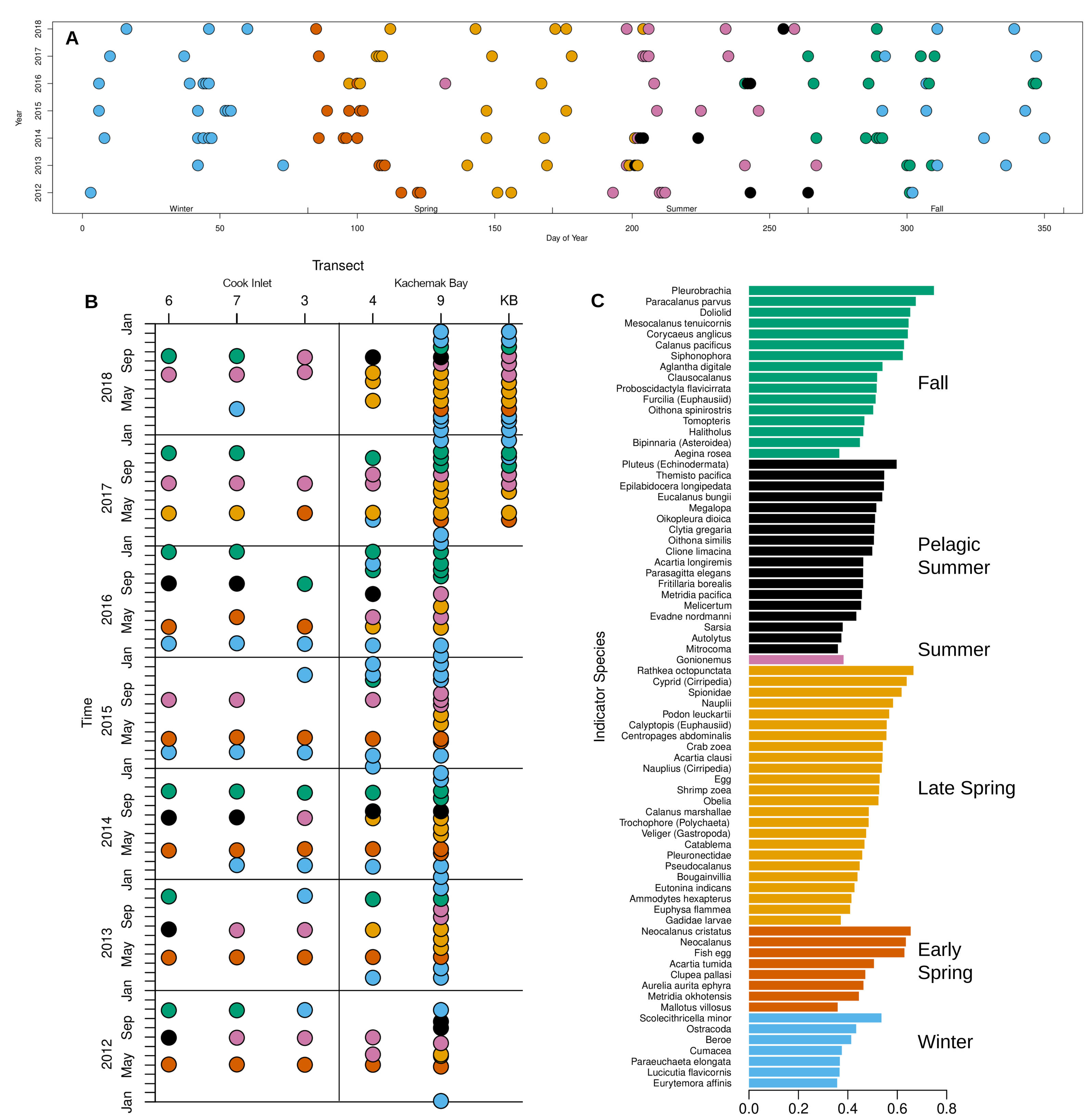

Figure 4. **A.** Indicator species analysis (ISA) groups based on year and day of year to show seasonal transition of communities. Colors correspond to the indicator species group of each tow (Fig 5). **B**. Splat plot of time and ISA groups averaged over each transect (n = 196). **C.** Indicator species values that defined each group produced by hierarchical clustering analysis. Of the 88 species/categories included in the analysis, the 74 most significant (p < 0.05) are presented.

Results – Zooplankton Abundance

- Overall peak abundance (2533.70±189.64 no. m^{-3}; Fig. 3A) in late spring/early summer
- Large copepod abundance peaked in early spring and steadily declined from summer to fall (Fig. 3A)
- Warm water copepod abundance peaked in the fall (Fig. 3A)
- Seasonal cycles of zooplankton and copepod groups generally followed GAM seasonal trend except for warm water copepods (WWC) during MHW (Fig. 3B)
  - Fall 2014: WWC highest abundance (379.92 no. m^{-3}), an order of magnitude increase
  - 2015/2016: overwintering WWC did not decline as in previous years
  - 2016: WWC highest in spring (15.08±3.82 no. m^{-3}); gradual increase through summer into fall unlike previous years

Results – Community Composition

- HCA (cophenetic correlation coefficient = 0.514) produced six clusters of transects based on a clear seasonal progression of species composition
- ISA: 88 species/categories of zooplankton; 74 had a significant ISV (α = 0.05; Fig. 4C)
  - Winter group transitioned to early spring group that reliably emerged by late March and was defined by all three species of *Neocalanus* and forage fish ichthyoplankton
  - The late spring group of meroplankton common to estuarine environments replaced the early spring group consistently in late May until 2016 when this group appeared earlier in the year for the remainder of the study
  - Between late spring and fall, two transition groups emerged; the summer group (defined by a single cnidarian) was the most common. The second summer Pelagic group appeared sporadically mainly in CI and was absent in 2015 and 2017
  - Fall gelatinous zooplankton and WWC appeared late October in years before MHW then emerged earlier during MHW (late August) and persisted into December 2016
  - Transects 4, 9, and KB describe an estuarine environment fertile for meroplankton
- 4D NMDS had the lowest stress (0.088) compared to 2D (0.182) and 3D (0.116) and confirmed the seasonality of groups
- BIO-ENV "Best" model showed that SST, temperature in the top 50m of the water column, MLDT, MLD, and integrated chlorophyll *a* cumulatively correlated with NMDS ordination (ρ = 0.3491, Mantel Test: r = 0.3491, α = 0.001)

Conclusions

- Anomalously elevated SST and MLDT showed similar patterns as elsewhere in the Gulf of Alaska confirming that the MHW was present in CI and KB
- Overall zooplankton abundance may not have exhibited measurable affects of the MHW, but the species composition of zooplankton showed significant changes in abundance and persistence of WWC typically found near CA to WA
- Zooplankton communities of KB were similar to the estuarine bays of Prince William Sound versus the communities found in more pelagic areas of CI
  - Meroplanktonic late spring groups were found more consistently and for a longer period of time in KB compared to CI
  - The early spring group of zooplankton comprised of large bodied pelagic copepods (*Neocalanus* spp.) were more consistently observed in CI
- Timing of transitions may suggest a shift in phenology of communities during the MHW
- Many of these patterns persisted into 2017 after the MHW dissipated suggesting that recovery from a MHW may take years

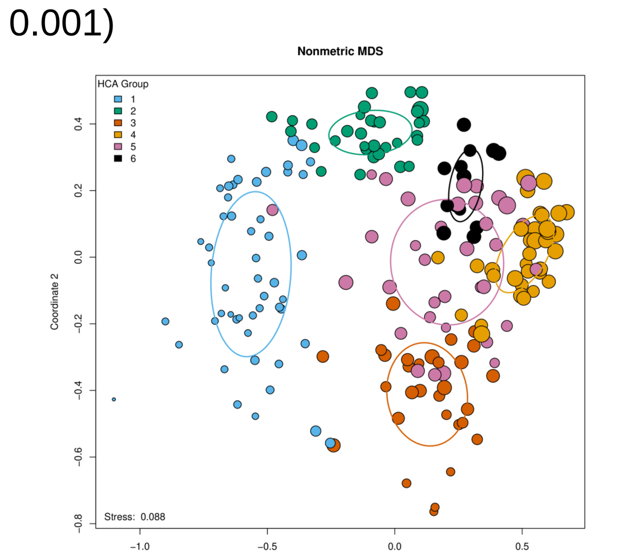

Figure 5. Non-metric multidimensional scaling plot of transects with ellipses to indicated the standard deviation of point scores based on grouping from the ISA.

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Literature Cited

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