Diversity, Distribution, and Dynamics of Larval Cephalopods off of Northern California

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Introduction

- Cephalopods are important members of their ecosystems due to their voracious appetites and manipulation of their surroundings. Too little is known about adult cephalopod distribution and dynamics as it is nearly impossible to monitor adults
- Many cephalopods have a planktonic juvenile stage which can be used to assess not only where adults may be, but how the dynamics of the ocean are affecting them and the planktonic community as a whole
- The Trinidad Head Line (THL- **Fig. 1**) has been sampled for plankton communities since 2008 as a reference for ecosystem health and response of the Northern California Current (NCC). The THL is located in an area of strong seasonal upwelling in spring and summer, and downwelling, storms and freshwater input in the winter
- This study takes advantage of the warm water mass known as "the blob" that hit the THL in mid 2014 and continued through 2016. This event is clearly visible in the Pacific Decadal Oscillation (PDO), and Multivariate Enso Index (MEI) (**Fig. 4**)
- We also see two cases of El Nino events along the THL, one in 2009 and another hitting during the middle of the high PDO event in 2015-2016
- A previous study by NOAA looking at the same plankton samples, but analyzing ichthyoplankton, euphausiid and copepod communities shows distinct shift in structure. Adding cephalopods to this list will add a new level of depth to NOAA research

Oceanic Conditions

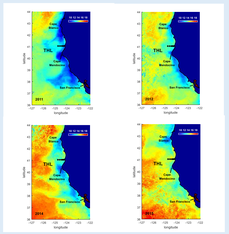


Figure 1: Maps of sea surface temperature during high PDO event (2014, 2016), and standard upwelling conditions along the THL (2011, 2012). July is the chosen month pictured

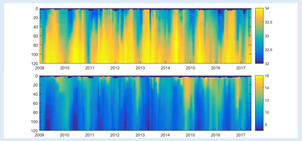


Figure 2: Top graph displays the fluctuations in salinity from 2009 to 2017. Bottom graph displays temperature fluctuations from 2009-2013. The data used for both graphs was taken at Station 3

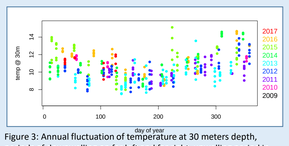


Figure 3: Annual fluctuation of temperature at 30 meters depth, periods of downwelling on far left and far right, upwelling period in center

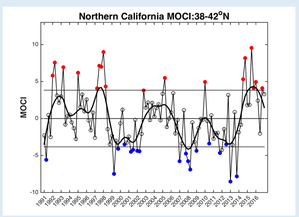


Figure 4: The MOCI incorporates PDO, MEI, North Pacific Gyre Oscillation, Northern Oscillation Index, wind, temperature, pressure and upwelling indices

Methods

Samples were taken on cruises that occurred on a roughly monthly basis. Sampling would typically begin on the shelf stations in the late afternoon and progress to stations on the shelf-break after sunset and into night. For each of the samples taken there was a corresponding CTD deployed to record station temperature, salinity, chlorophyll fluorescence and dissolved oxygen. Samples were taken at each station using a 0.7 meter bongo net fitted with a 505 um mesh and a General Oceanics flowmeter. Nets were deployed to within a few meters of the seafloor or 100 m at maximum. Samples were preserved immediately in 5% formalin in seawater. Later samples were sorted for target organisms (Copepods, Crab Larvae, Cephalopods, Eggs, Ichthyoplankton) and each set of target organisms was analyzed to quantify plankton community and identify individuals to species. Cephalopods that were either too underdeveloped or too mangled for identification were not counted in analysis. Identifications were based on literature references and expert consultation.

Comparison of Distributions

- Distributions of six common species show correlated changes in distributions over time and with oceanographic conditions. *Octopus rubescens*, *Abreleopsis felis,* and *Chiroteuthis* spp were all more common over shelf waters during the marine heatwave, when offshore transport was reduced. In contrast, *Onchoteuthis borealijaponica* and Gonatidae were more abundant during cooler periods, perhaps due to increased transport from the north in the California Current.
- *Gonatidae* and *Octopus rubescens* are seasonally offset. This likely reflects a difference in reproductive timing and how each species balances the tradeoff between productivity and offshore transport due to upwelling (Parrish and Bakun 1981). Both are more common in 2014-2016, when transport offshore was reduced.

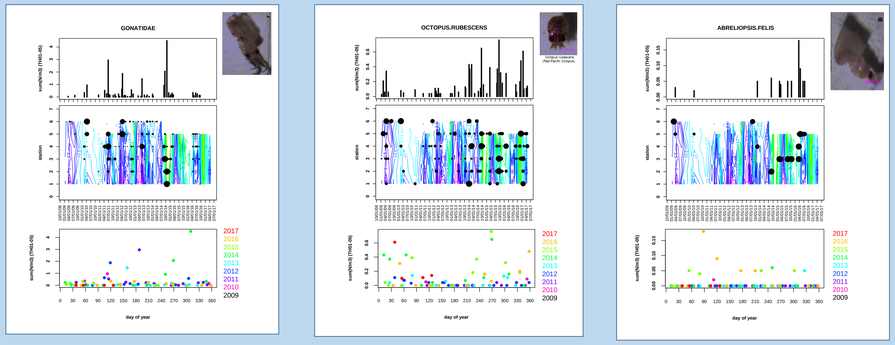
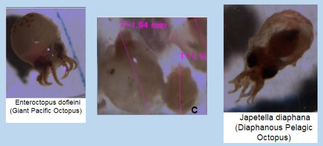


Figure 5: Species distribution plots, plotted with temperature, cruise, and station, as well as abundance values and temporal arrangements of data for day of year rather than cruise. Top row from left to right; Gonatidae, Octopus rubescens, Abreliopsis felis. Bottom row left to right; Doryteuthis opalescens, Onchoteuthis borealijaponica, Chiroteuthis spp.. It should be noted that for six cruises from 10/05-10/10 no Bongo A samples were taken, so that chunk of Cephalopod data is missing on the distribution plots

- Presence of *Doryteuthis opalescens* larvae in 2009 and during the 2014-2016 warming event confirms that adult *Doryteuthis opalescens* migrated to northern California to spawn.
- *Chiroteuthis* is not observed until mid 2011, but becomes abundant in 2014-2017. Chiroteuthis is not observed closer to shore than station 3. The presence of these larvae corroborates the incursion of warmer waters to coastal regions during the marine heatwave.
- Year 2009 is very similar to 2015 in terms of species distribution. 2009 is the beginning of an El Nino event, slight warming. *Doryteuthis opalescens* shows up in both time frames which may explain the similarity between the two years

The Unmentioned



Enteroctopus dofleini, *Japetella diaphana* were found in such small numbers (5 and 1 respectively) that they were not included in distribution and ordination plots. Individuals that were too mangled or too young to be identified were also seen, but not included in results.

Spatial and Temporal Species Ordinations

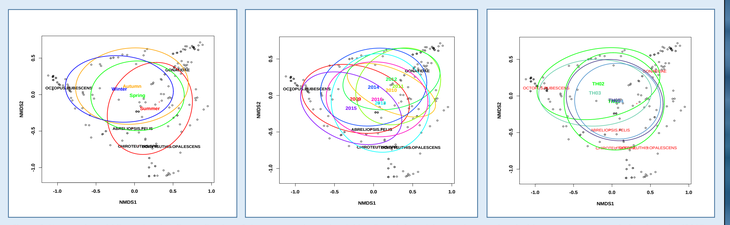


Figure 6: Nonmetric multidimensional scaling ordination of six target species and variables. From left to right; species correlated with season, years sampled and species (2017 taken out of ordination due to limited data), NMDS ordination of stations sampled and species.

- Using a Nonmetric Multidimensional Scaling (NMDS) ordination technique we are able to look at how our six target species are correlated with season, year, and station
- There is strong correlation with some species and season, *Octopus rubescens* is seen almost exclusively in Winter and Autumn. Gonatidae, *Chiroteuthis* and *Doryteuthis opalescens* are mostly in the summer
- In the year-species ordination, 2009 and 2015 are very similar which is most likely due to the El Nino events that took place during these years which brought in a higher abundance of spawning adult *Doryteuthis opalescens* to northern California.

Discussion

The marine heatwave of 2014-2016 provided a natural experiment for examining how the planktonic cephalopod community responds to warm conditions along the Trinidad Head Line off of Northern California. Contrasting the warm water phase of 2014-2016 with the preceding cooler water phase we see shifts in the distribution of off-shelf species coming closer to shore, and species showing up in numbers exceeding their normal abundances. As many cephalopods of the Pacific Northwest have planktonic juveniles, using relating plankton distributions and abundances to oceanographic conditions could inform population assessments, juveniles observed during the PaCOOS cruises can serve as verification of species' spawning. Our data do not address cephalopods in general , especially species that lack extensive larval stages. This is a perfect representation of why cephalopods pose such a problem to biologists and fishermen alike. This study sheds more light into the dynamic world of cephalopods and suggests that plankton research may be useful for addressing hypotheses about the dynamics of species that are otherwise challenging to sample in the field. Though further analysis would benefit these findings, preliminary results show how larval cephalopod distributions are affected by various environmental factors which may help fisheries and biologists understand adult movement of several taxa with planktonic larvae.

Acknowledgements ☺

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