Environmental Factors Influencing Zooplankton Diel Vertical Migration in Monterey Bay, California

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ABSTRACT:

Seasonal upwelling is a primary driver of ecosystem variability within the California Current System (CCS) and is the main process by which nutrients are replenished along the US west coast region. This upwelling result in abundant populations of zooplankton (copepods and krill) that congregate at specific locations along the western coast. These zooplankton 'hotspots' are important food sources for a variety of marine life and comprise an essential component of marine food webs. One factor that influences these hotspots is diel vertical migration (DVM), where zooplankton are at depth during the day to escape predation and journey to the productive surface at night to forage. Here, we characterize DVM patterns from an acoustic doppler current profiler (ADCP) on a long term mooring in ~1000 m water depth near the mouth of Monterey Bay. The ADCP is an instrument used to measure ocean currents but also provides estimates of the concentration of particles (backscatter mostly zooplankton) in the water; DVM patterns are clearly visible in the ADCP records. Algorithms tracking day and night variations in zooplankton abundance and migration depth were developed and applied. We relate variations in DVM patterns to time of year, and measurements of chlorophyll fluorescence, and thermocline/mixed layer depth. The patterns and the primary drivers of DVM in Monterey Bay are presented and discussed. Day time maximum zooplankton concentration depth was significantly correlated with thermocline depth on seasonal (r= 0.72) and daily averages (r= 0.42).

INTRODUCTION:

Zooplankton populations constitute an important link within ocean ecosystems. As primary consumers, zooplankton are heterotrophs that feed mainly on primary producers such as phytoplankton and other smaller zooplankton. Previous research suggests zooplankton are a primary food source for marine organisms ranging from small pelagic fish to top carnivores (Espinoza et al. 2009) and function as a main trophic link between primary producers and organisms higher up on the marine food chain (Inoue et al. 2016). Dense aggregations of zooplankton in epipelagic (euphotic) habitats such as the northern, central, and southern portions of the California Current Upwelling System off the US west coast have been greatly recognized. Research conducted by Santora et al. (2012a) shows there is a strong correlation between the presence of zooplankton (mainly krill) hotspots within the California Current System (CCS) and the occurrence of marine mammals (e.g. whales) at several observed locations during various seasons in the year. Hotspots are described as areas containing high biodiversity and/or concentration of species that persist days to months over time. Consequently, zooplankton hotspots play an important role within their ecosystem as they are an essential food source for many marine organisms in Monterey Bay, such as forage fish and whales, on their migration path. One important behavior exhibited by zooplankton species is their diel vertical migration pattern. Diel vertical migration is a natural phenomenon occurring in the world oceans daily and is a behavioral pattern characterized by zooplankton species (mainly copepods and Krill) ascent to the surface layer at dusk and decent to deep water at dawn (Radenac et al. 2010). At night, when near the surface zooplankton are easily able to escape predators and utilize the dark to feed on plankton. Therefore, it’s been commonly believed that diel vertical migration is a strategy for organisms to escape visual predators by staying at depth during the day and feed in the surface layer during the night, and constitutes the larges marine migration known. This general upward/downward movement of certain species populations is influenced by environmental factors such as sunlight availability, food availability, dissolved oxygen concentration, and temperature. Several theories suggest this behavior is an attempt for zooplankton to decrease predator encounters and increase survival and feeding rates, others have suggested this behavioral pattern is linked to carbon export to deeper waters, however no consensus has yet been reached. In our study, we focus on how certain environmental factors affect this diel vertical migration and so the purpose of this study is to characterize zooplankton diel vertical migration patterns in Monterey Bay, California by means of a set of chosen environmental parameters. We accomplish this by using in-situ data from an Acoustic Doppler Current Profiler (ADCP) combined with shipboard CTD measurements collected at the same location over the period of our study. We propose a hypothesis of the existence of a significant correlation between zooplankton diel vertical migration patterns and our chosen environmental predictors, and for seasonal variations in diel vertical migration patterns to be consistent with sunrise-sunset times. This research project is part of a larger collaboration with UCSC aiming at building a coupled biophysical oceanographic model of zooplankton distribution in the CCS, therefore by characterizing DVM patterns in Monterey Bay, we are able to provide a basic model of zooplankton behavior. Information obtained from this research model can be used to inform future research in the area, as well as a template for use in other ecosystems. This research can be helpful for informing local regulations and policies as well as efforts for conservation and preservations of marine resources in Monterey Bay.

METHODS:

In this study, in order to find the dominant features characterizing diel vertical migration in the Monterey Bay, we use a combination of continuous time-series acoustic backscatter data (a measure of the reflection of sound on suspended particles in the water column, in dB) obtained from moored ADCP instrument at site M1, (36.75 N, -122 W) (fig. 1.1) in Monterey Bay. Our time-series was collected from 1992 to 1998 (fig. 1.2) and CTD surface measurements were obtained via shipboard gathered every three weeks from 1989-present, however we only use data matching our ADCP time series from1992-1998. The ADCP is moored at station M1 approximately 12 nautical miles from MBARI, at the mouth of Monterey Canon and is placed facing down into the water column (~1meter) collecting data every 15-min interval by producing a 'ping' or sound frequency of 150kHz into the water column capturing to a depth of 250m, by using a delayed response between the time the instrument produces the soundwave and the time it takes to scatter off moving particles in the water column and return to the ADCP, we obtain water current measurements and as a byproduct of this lag, we also obtain suspended particle size. Particle size captured during this time period is ≥2mm, consistent with copepod and krill sizes (2mm-10mm). We utilize MATLAB programming software for writing a working algorithm that does two things: 1. it automatically detects zooplankton diel vertical migration patterns within our dataset and 2. generate a dataset of DVM characteristics such as maximum and minimum zooplankton concentration depths, zooplankton concentration at the depths, observing the pattern from sunrise to sunrise, and averaging concentration two hours before and after sunrise and two hours before and after sunset, that are matched, later on to environmental predictors such as chlorophyll (proxy for phytoplankton abundance) and thermocline/mixed layer depths. Here backscatter concentration (dB) is used as a proxy for zooplankton abundance. We manually examined DVM pattern for a significant amount of days to see variations in our data, we use the algorithm to determine seasonal changes in DVM characteristics over time, obtaining an averaged seasonal cycle and averaged day series, as well as day and night maximum concentration depths. Next, we analyzed Conductivity, Temperature, Density (CTD) data for maximum surface chlorophyll-fluorescence depth and thermocline depth, using Matlab. We then calculate seasonal and day averages for our chosen environmental parameters (chlorophyll, thermocline/mixed layer depth) to test for significant correlation alongside the DVM pattern.

RESULTS:

In order to determine if there is a relationship between zooplankton DVM patterns and environmental parameters in Monterey Bay, we examine line and scatter plots of our data that include statistical tests for correlation and significance (correlation coefficient and p-value). We observe a daily cycle (fig. 1.3) as well as a seasonal cycle in zooplankton diel vertical migration patterns. When looking at seasonal changes in our data, there is a close relationship between night time maximum concentration depth and surface chlorophyll maximum depth, however no strong correlation exits and no seasonality is shown. We found a high correlation ($r= 0.72$) and a significant relationship ($p< 0.01$) between thermocline depth and day maximum concentration depths on a seasonal scale however, on a daily scale, the correlation coefficient was weaker ($r= 0.42$) and p-value very small ($p<0.0000$) suggesting a significant relationship.

DISCUSSION:

The data in our study was used to determine several parameter's influence on zooplankton diel vertical migration patterns in Monterey Bay. Thermocline depth and zooplankton day maximum concentration depths show a strong correlation and significant relationship on a seasonal scale. The thermocline depth varies in response to seasonal changes, and zooplankton depth varies in response to shifts in thermocline depth, as we have anticipated. Previous research on zooplankton energetics shows they occupy a layer of water in which they exhibit optimal energetics (Hansen, Visser 2016). This leads us to conclude temperature has an effect on zooplankton diel vertical migration patterns as it varies with seasons. Hereafter, when comparing thermocline depth and day time zooplankton maximum concentration depth on a monthly and daily averages using statistical methods, we found a relatively high correlation and significant relationship in both cases ($r = 0.72$ and $p < 0.01$ for seasonal scale, $r = 0.42$ and $p < 0.00001$ on daily scale). However, correlation coefficient for seasonal variability is found to be much higher ($r = 0.72$) whereas a weaker correlation for the daily averages was found ($r = 0.42$), that is mainly due to daily variations in our data set. As for the relationship between night time zooplankton maximum concentration depth and chlorophyll concentration depth, we saw no significant relationship on a seasonal scale however, it is evident there is a strong relationship between the two concentration depths. Therefore, we conclude zooplankton migrate up near the surface to a depth at which a high concentration of chlorophyll is found. This behavior is possibly a mechanism used for avoidance of visual predators. It's more efficient for zooplankton to graze on phytoplankton in the dark when it's less likely to be visible to predators.

Variability in the seasonal pattern of zooplankton diel vertical migration was apparent in our results. For the purpose of this study, we compare one average day for two months in a given year (1.4a, b) where we found visual differences in zooplankton maximum concentration depths. an average day in the month of April (fig1.4a) shows zooplankton day time depth to be shallower than an average day in the month of November (fig.1.4b). This signifies two important findings: first, it shows a DVM cycle confirming our algorithm works, and second, it shows the difference in depths between the seasons which raises the question of why? We reason that this difference in shallowness is due to other seasonal factors that we have not studied in our research. Although during the month of April the day-time is longer however, there is much more cloud coverage and he presence of fog over the Monterey Bay region in the spring and summer seasons. Whereas, in the fall and winter seasons the sun sets earlier in the day, however there is less cloud coverage and fog at that time of the year therefore, zooplankton migrate to deeper depths.

Other environmental parameters influencing diel vertical migration patterns in Monterey Bay are still to be tested. Parameters such as oxygen concentration, pH, sunlight availability (PAR), lunar cycle, and currents should all be taken into account over a longer time-series available for use in order to better characterize zooplankton diel vertical migration patterns in Monterey Bay.

Finally, this research is important to the advancement of and understanding the role zooplankton occupy within their ecosystem. As primary consumers, zooplankton are an essential food source for predators ranging from small pelagic fish to large marine mammals such as whales; therefore, understanding their dynamics is fundamental to predicting hotspots within the California Current System. Information obtained from this research will help our collaborators at UCSC better parameterize coupled biophysical model of zooplankton distribution. This currently on-going project can be used as a basic model and a template for use in similar ecosystems. Understanding the behavior of foraging species like zooplankton is especially important when considering conservation and preservation efforts of marine resources, as well as inform local policy makers on protection of key ecosystems.

Figures:

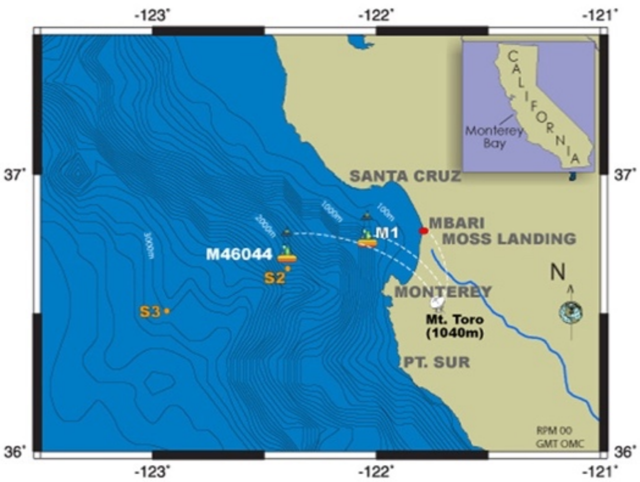

Figure 1.1: M1 ADCP location, approximately 12 nautical miles off the Monterey Bay coast. M1 is located at the center of Monterey Bay, over the mouth of Monterey canon, a hub of physical and biological activity.

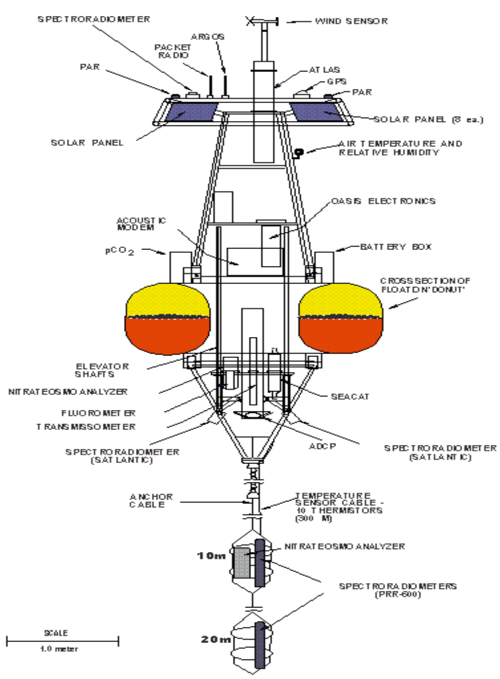

Fig 1.2: ADCP orientation at center within the M1 mooring, placed ~1.5 meters facing down into the water column.

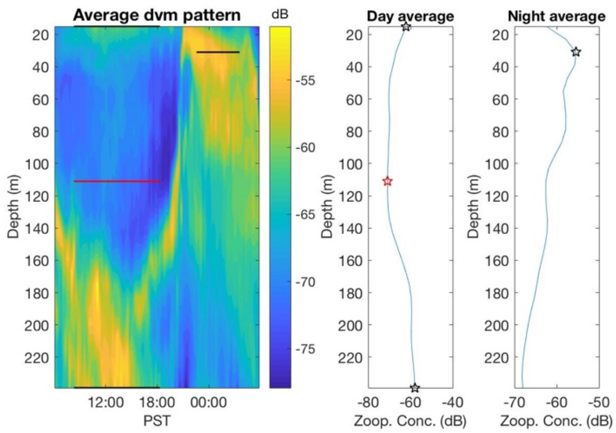

Figure 1.3: a randomly chosen day showing DVM pattern detected by the algorithm. The bright colors show high zooplankton concentration observed at a depth of 250m during the day and near the surface layer during the night. The black stars represent depths where maximum concentration of zooplankton occur- are the depths matched onto the left part of the figure.

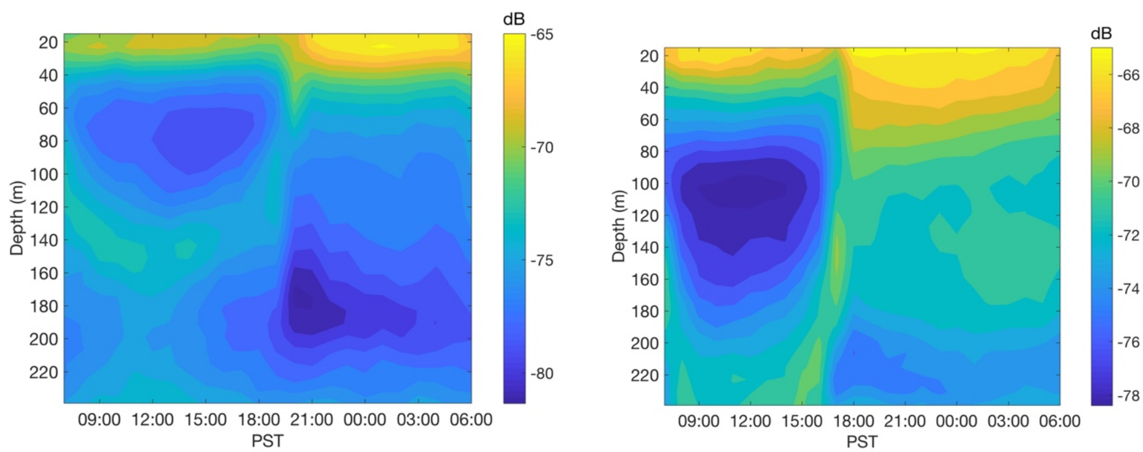

Figure 1.4a and 1.4b: Seasonal Variability in DVM pattern evident here. The image on the left is an average day in the month of April, and the one on the left is an average day in the month of November. In April zooplankton reside at shallower depths, whereas in November they reside at deeper depths consistent with the changes in thermocline depth seasonal changes.

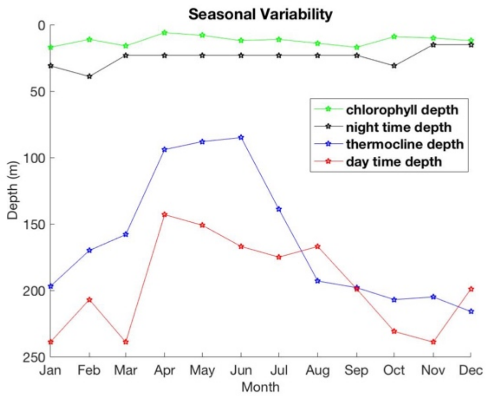

Figure 1.4: shows Seasonal variability in our data set. The dots represent months averaged over the time-series. From top: the green line is chlorophyll max concentration depth; black line is zooplankton night time max concentration depth. Blue line is thermocline depth, and red line is zooplankton day-time maximum concentration depth.

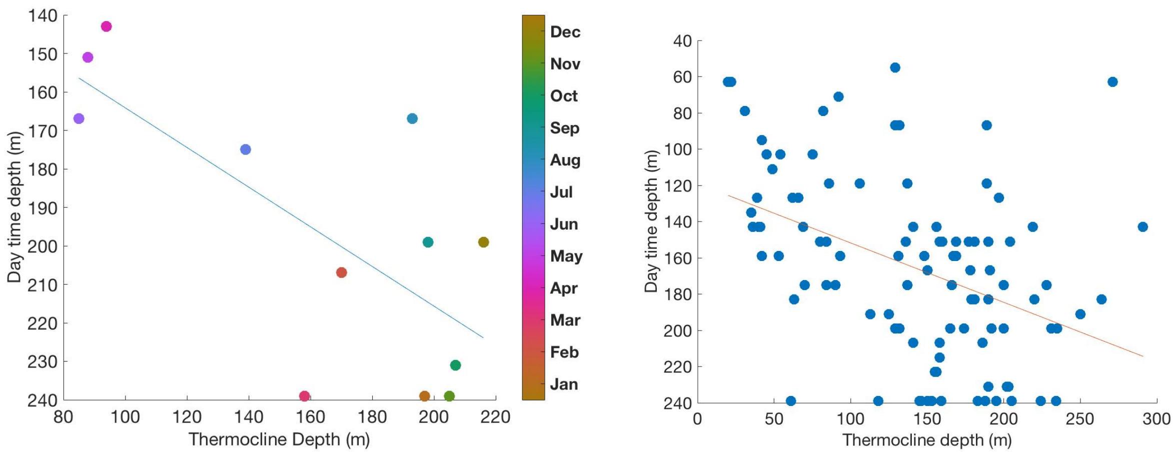

figure 1.5: correlation between thermocline depth and day time zooplankton depth on right are monthly averages, on left are daily averages) $R=0.72$ and $p<0.01$ for the monthly averages and $r=0.42$ and $p<0.00001$ for daily averages.

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