An increase in recruitment and an ENSO transition: CWPA Market Squid Paralarvae Research Program, year-end survey review 2022-2023

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December, 2023

Highlights

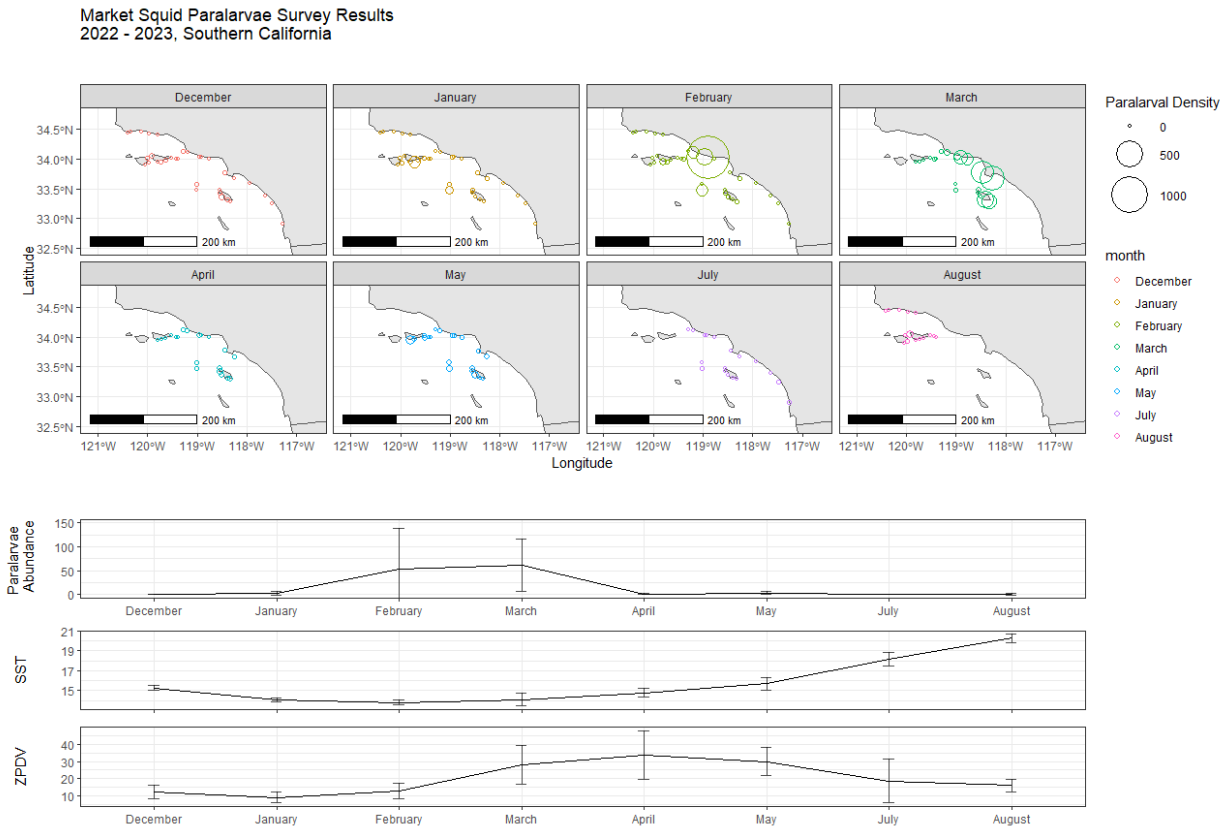
- Monthly paralarval abundance in Southern California during February and March (2023) was the largest seen since 2014
- Peak paralarval abundance appeared later than normal, peaking during February and March
- The ocean state has transitioned from 3 years of La Niña (2020 – 2022) to an El Niño, officially declared in May, 2023
- This El Niño is expected to peak in winter 2023 and subside to neutral conditions by spring, according to NOAA projections
- There was increased survey effort, with six consecutive months of observation in Southern California

Background

The California Wetfish Producers Association (CWPA) has sponsored ocean surveys to collect market squid paralarvae as part of its ongoing Market Squid Paralarval Research Program (MSPRP). This program began in January, 2011 and has surveyed the Southern California Bight (SCB, Fig. 1) at least twice a year since, as well as surveying the Monterey Bay Area (MBA) since 2014. The primary objectives of these surveys are to elucidate the population dynamics of market squid, understand the influence the ocean environment has on these fluctuations, and use paralarval abundance as an indicator of both spawning success and a metric for the strength and timing of the subsequent cohort. Paralarvae are captured among the zooplankton community using "bongo" nets with a 505 µm mesh. The net frames are affixed with "flow-meters" to determine the volume of filtered sea-water, which is used to calculates standardized paralarval density values. Nets are towed obliquely through the water column in shallow waters. The net is slowly descended from the surface to approximately half, to two-thirds, of the ocean depth at that location, typically 40-70 m, towed for 15 minutes, and slowly retrieved. Stations are fixed at traditional spawning grounds in the SCB and MBA. In the laboratory, market squid paralarvae are sorted from the zooplankton samples and quantified to number of individuals per 1,000m^3 of filtered sea-water (see: Van Noord & Dorval 2017; Van Noord 2020 for full methodological details.)

2022 – 2023 Survey Results

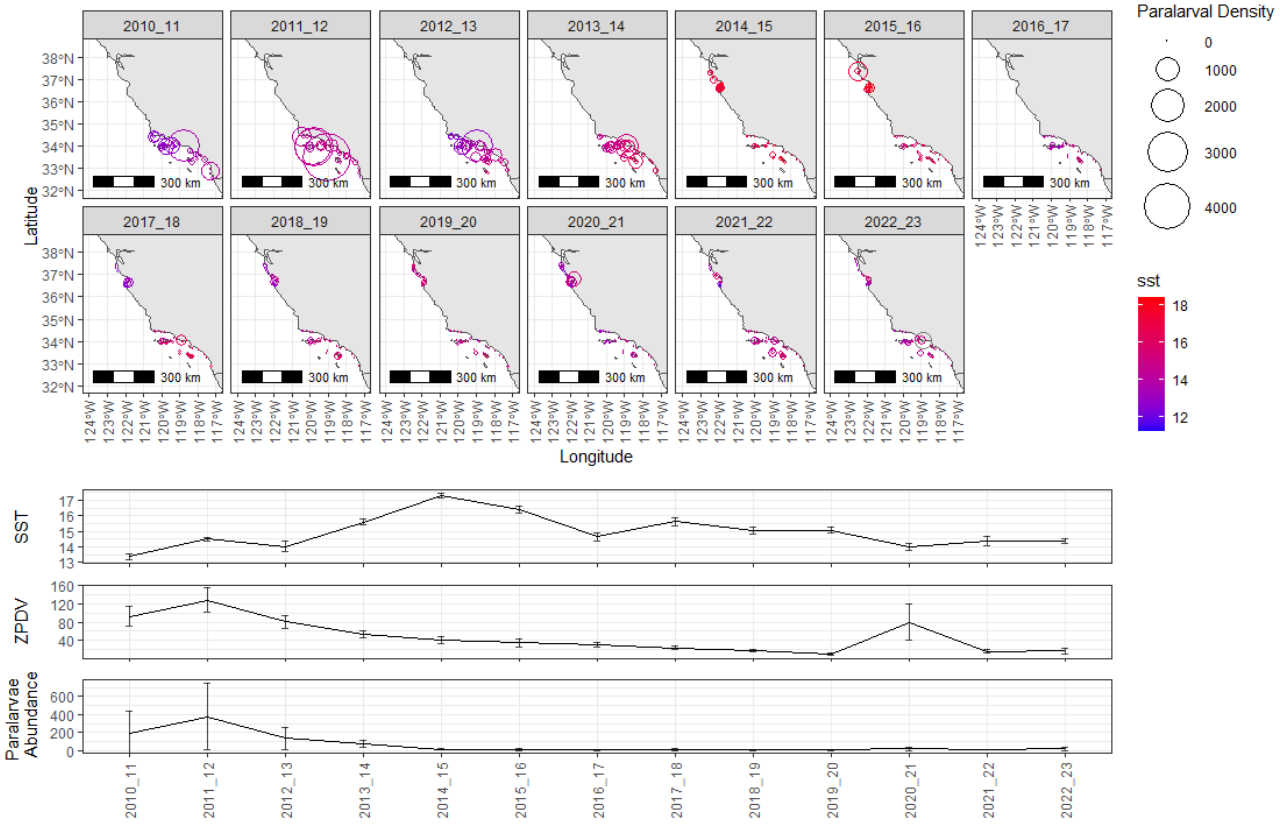
From December, 2022 through August 2023, the CWPA conducted eight surveys (Fig. 1) aboard two chartered fishing vessels, accomplishing 191 net tows. Since 2011, there has been a cumulative total of 69 surveys (52 in the SCB and 17 in the MBA) and 1,752 net tows. Paralarval abundance peaked in February and March, 2023 at 52.5 (± 86.5 CI) and 61.3 (± 54.4 CI). SST was lowest during February, at 13.8 ℃ (± 0.72 SD, 56.8 ℉). ZPDV was low during winter and increased during spring, which is typical of the seasonal upwelling patterns in the California Current, and decreased again in the summer (Fig. 1, bottom panel).



(**Figure 1**. Survey effort from December, 2022 through August, 2023. Top panel shows sampling locations in the Southern California Bight by month. Paralarval densities are measured in number of individuals per 1,000m^3 of filtered sea-water. Note that during December – February, a full SCB survey was accomplished, while March – May, a central 'hybrid' survey was conducted. The three bottom panels show paralarval abundance, sea surface temperature at the sampling locations, measured in degrees Celsius, and Small Zooplankton Displacement Volume, measured in ml displaced per 1,000m^3 of filtered sea water. Months correspond to sampling month and error bars represent a 95% confidence interval.)

While paralarval abundance increased substantially this season, average abundances are still dwarfed by the strong La Niña event of 2011-2012 (Fig. 2). The same can be said for zooplankton volumes, which declined sharply during the 2015-16 El Niño and have remained at low levels since, with the exception of a notable increase during 2020-21, which was the result of

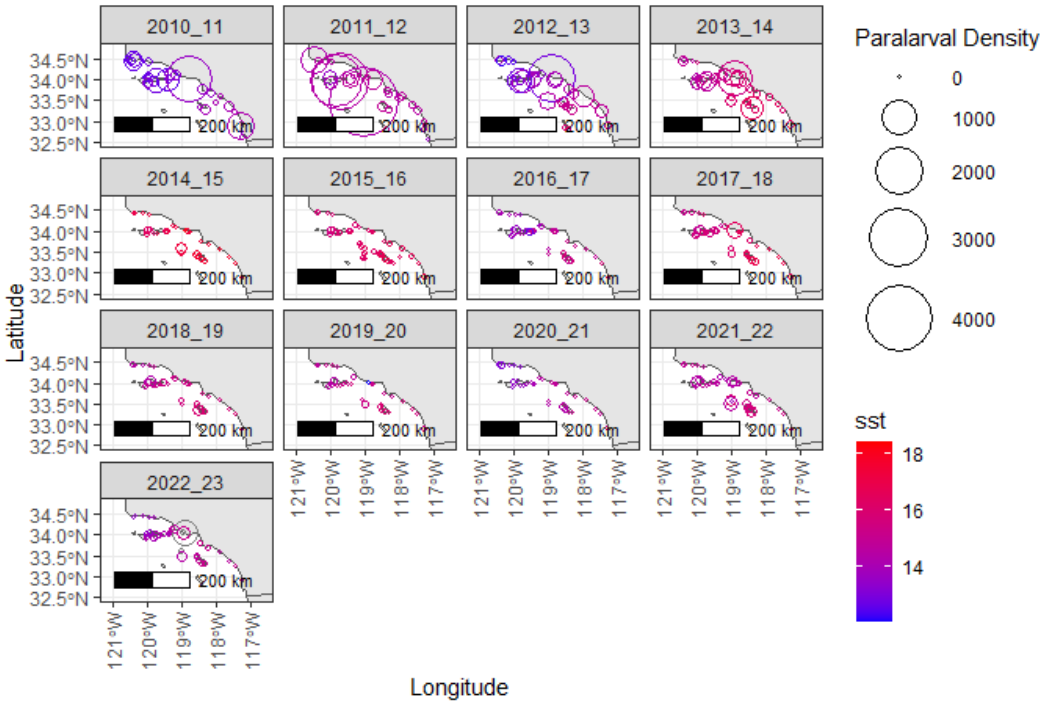
extremely dense and widespread algae encountered in Monterey. While not quantified numerically, there was an improvement in the zooplankton prey field during the last two years, with a notable increase in euphausiids, copepods, and amphipods. From 2018-2020, samples were extremely sparse and often comprised of just several gelatinous organisms (Fig. 2 bottom panel, middle). Mean SST peaked during the historic El Niño in 2015, and incrementally declined the years following.



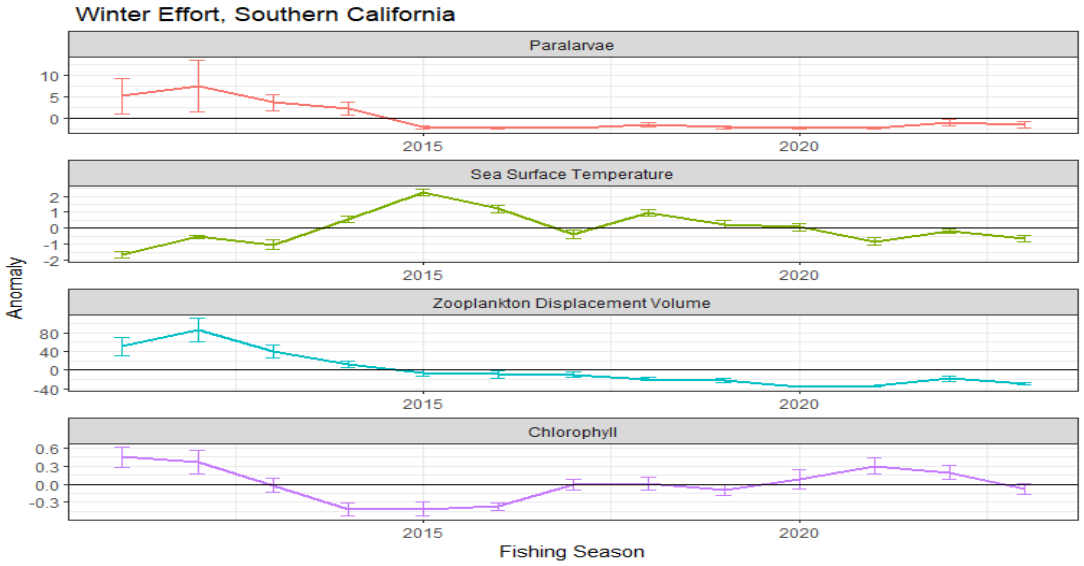
(**Figure 2**. Survey effort displayed from January, 2011 through August, 2023 showing data from only the traditional 'hatching season' for paralarvae; this corresponds to winter (Dec.-Feb) in the Southern California Bight (SCB) and summer (Jun-Aug) for the Monterey Bay Area (MBA). Top panel shows sampling locations in the SCB and MBA. Mean paralarval densities for those locations across all effort during the hatching season for that year are displayed by circles; larger circles indicate greater mean paralarval density at that location as measured in number of individuals per 1,000m^3 of filtered sea-water. Note that survey effort was not always uniform per fishing season and depended on funding. Dates are displayed by fishing season along the x-axis. Market squid fishing season extends from April 1 to March 31 the following year. The three bottom panels below show sea surface temperature (Celsius), Small Zooplankton Displacement Volume (ml displaced per 1,000m^3 of filtered sea water), and paralarval abundance. Error bars represent a 95% confidence interval.)

These overall trends are largely the same when focused in the SCB during the winter (Fig 3 & 4). However, while zooplankton volumes, a measure of secondary productivity, have remained low since the warm 2015 El Niño event and subsequent marine heatwaves,

chlorophyll-*a* concentrations, on the other hand, have risen to near the long-term average seen in our study – an indication of improving primary productivity.

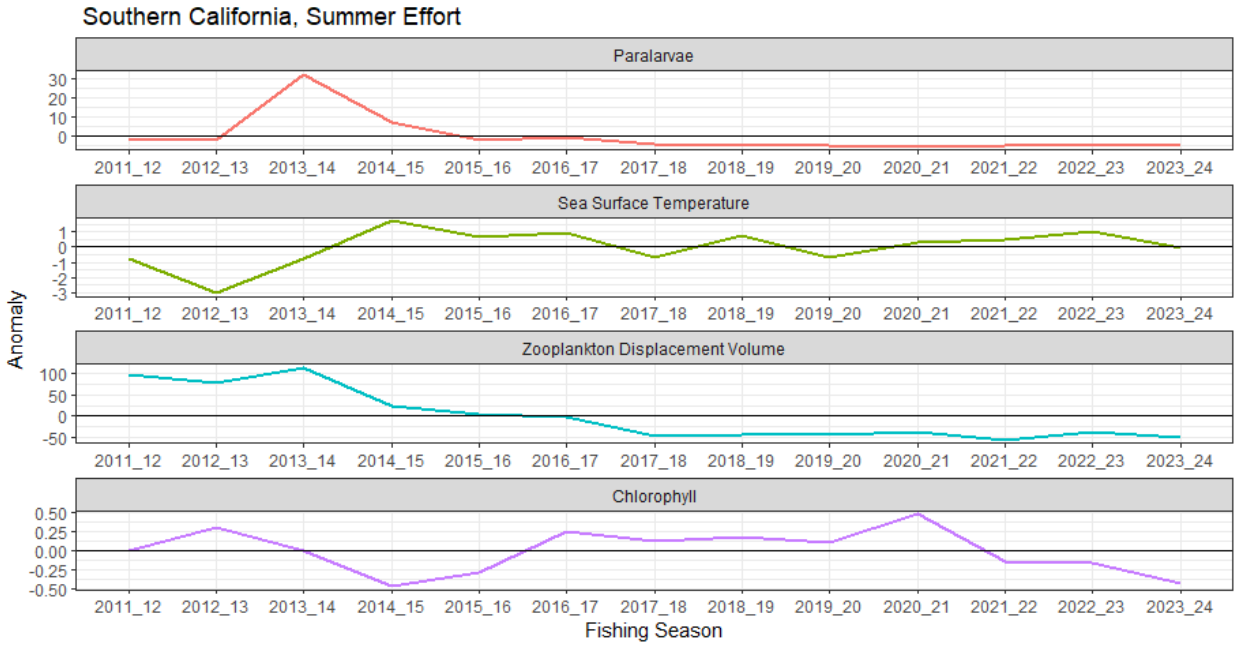


(Figure 3. Survey effort displayed from January, 2011 through August, 2023 showing data from only the traditional 'hatching season' (Dec.-Feb) for paralarvae in the Southern California Bight (SCB). Mean paralarval densities for those locations across all effort during the hatching season for that year are displayed by circles, larger circles indicate greater paralarval density at that location as measured in number of individuals per 1,000m^3 of filtered sea-water.)



(**Figure 4**. Anomaly values shown for paralarval abundance, sea surface temperature, small zooplankton displacement volume, and log of surface chlorophyll-*a* by fishing season for southern California during the winter months).

During the summer of 2023, the SCB was surveyed during July and August. Paralarval abundance was very low (< 0.5 ind. per 1,000 m^3 filtered sea water). Low paralarval recruitment is typical during the summer in the SCB and the only exception to this was in 2014 during the build-up of the strong El Niño that developed the subsequent year, when ocean temperatures gradually rose and caused early maturation in market squid (Van Noord & Dorval 2017) and earlier spawning in the season (Fig. 5). Interestingly, SST during the summer at paralarval sampling locations increased during the 3 years corresponding to the weak La Niña from 2020-2022 (Fig. 5); this trend was not evident when observing winter months only. This indicates some degree of disconnect between the regional equatorial indices (Oceanic Niño Index) and local conditions, as well as differential warming patterns during a given year. Excessively warm summer and autumn temperatures could pose metabolic stress on market squid and lower their fecundity (Pecl & Jackson 2008; Rosa et al 2012), and therefore, the number of paralarvae observed. An anonymously warm summer and autumn in southern California could also deter the recruitment of squid to their spawning beds and delay the timing of spawning. This could have happened during the winter of 2022-23, when the ocean temperature remained warm through the autumn and early winter, and peak paralarval abundance wasn't observed until after SST's declined in the spring of 2023 (Fig 1). Phenology is a term describing the timing of biological events to abiotic forcing. Market squid spawn in southern California during the autumn and paralarvae hatch during the winter, when temperatures are coldest and paralarvae are able to utilize their egg yolks at a slower rate; then, juveniles are timed to match the spring upwelling period, when the greatest amount of food is available. Anonymously warm events can alter the timing of these events and lead to reduced survival.



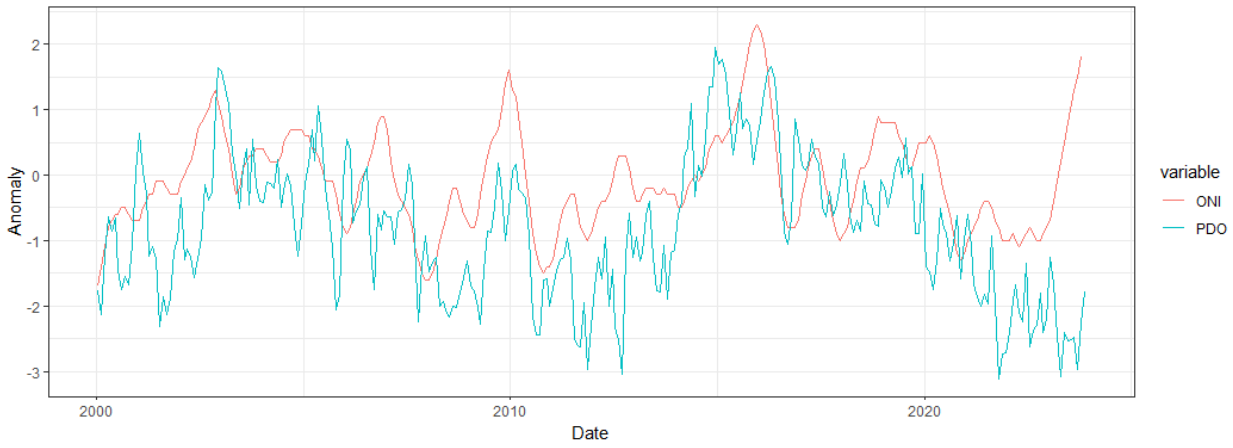
(**Figure 5** Anomaly values shown for paralarval abundance, sea surface temperature, small zooplankton displacement volume, and log of surface chlorophyll-*a* by fishing season during summer months).

Another El Nino…

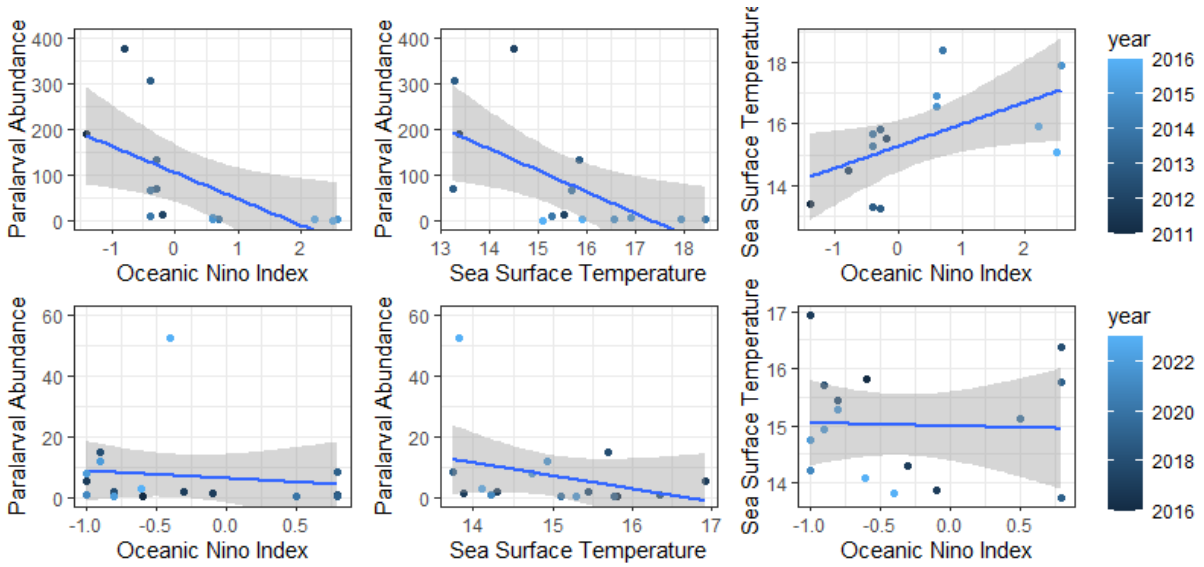
Both market squid and zooplankton biomass showed an agnostic response to the 2020-22 La Niña. Typically, La Niña events bring colder ocean temperatures, increased ocean productivity, and a surge in market squid abundance and an expansion in their range (Reis et al 2004; Koslow and Allen 2011; Van Noord and Dorval 2020). There was not a notable increase in either zooplankton abundance or paralarval abundance as seen during the previous La Niña episode of 2011-12. In fact, the relationship between paralarval abundance and the ONI and SST before and after the El Niño and marine heatwaves of 2015-16 seems to have been abbreviated (Fig. 7). Before these unusual heating events, paralarval abundance significantly increased along with colder SST's and negative ONI values. This relationship has not extended past the marine heatwave, and local SST's do not show a significant relationship with the ONI either (Fig. 7). There is a growing body of literature indicating that the marine heatwaves in the north Pacific were so strong that they altered the typical teleconnections between regional and local ocean conditions in the California Current, notably the Pacific Decadal Oscillation (PDO, Werb & Rudnick 2023). It seems that this latest La Niña did not drive a notable increase in either ZPDV or paralarval abundance as would have been anticipated based on the 2011-12 event (Fig. 2, Fig, 7). In fact, it wasn't until the La Niña officially subsided to neutral conditions in February, 2023[1], that substantial paralarval abundance was observed; during the winter and spring of 2023 there was a series of local storms that drove increased upwelling and colder ocean temperatures in the SCB (Fig. 8). The spring and early summer of 2023 in southern California were characterized by strong local winds and storms that drove upwelling that resulted in cooler ocean conditions, all this while a strong El Niño was developing in the equatorial Pacific (Fig. 8, March and July, 2023). It is uncertain how this current El Niño will affect local conditions and market squid recruitment. It seems likely that market squid response will be dependent on local SST and ocean productivity, so if conditions in the California Current remain mild or neutral, a strong negative response in recruitment might not occur. Furthermore, NOAA forecasts indicate that this El Niño will peak in intensity this winter and begin to subside during the spring of 2024.

Sampling has resumed in December 2023, and surveys are planned for January and February 2024, along with hybrid surveys in March and April 2024, in the SCB. Both winter and spring-summer surveys in Monterey are anticipated as well, and will continue to document market squid response to changing conditions.

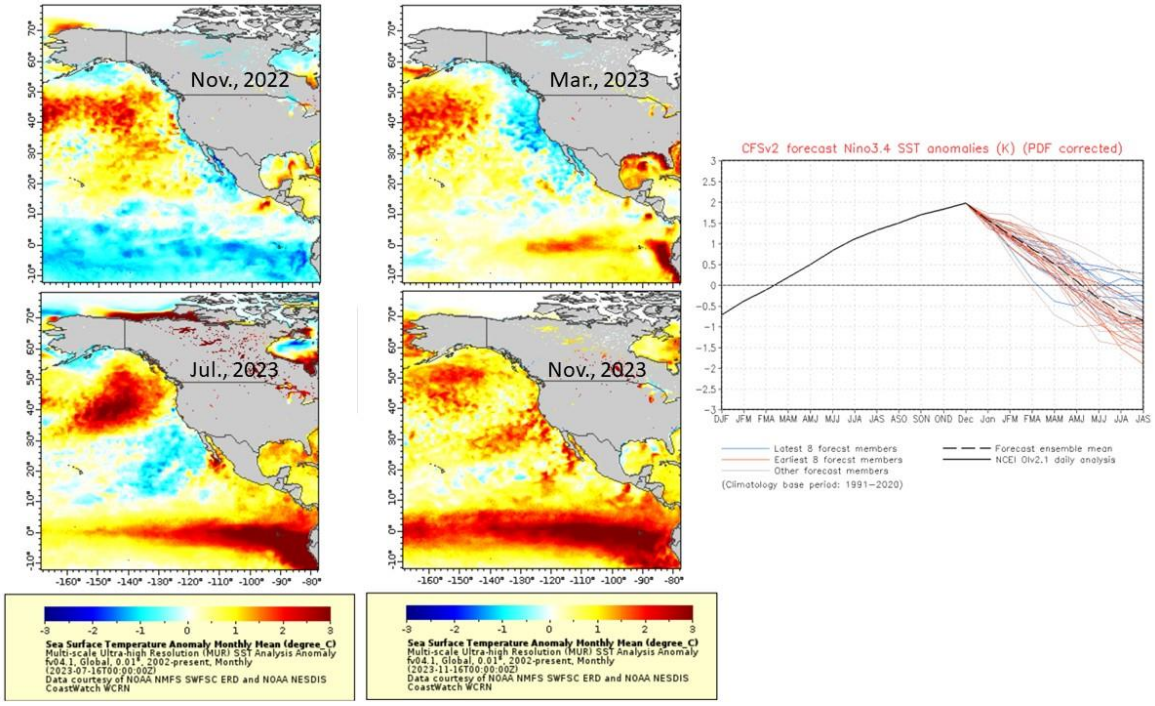
[1] https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php



(Figure 6 Oceanic Niño Index (red) and Pacific Decadal Observation (blue) from January, 2000 through November, 2023. El Niño (La Niña) events are typically defined as 3 consecutive months of anomalous temperatures above (below) + (-) 0.5. Data accessed via NOAA: https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php; https://www.ncei.noaa.gov/access/monitoring/pdo/)



(Figure 7 Before (top panel) and after (bottom panel) the warm El Niño of 2015-16, showing the relationship between, from left to right: the Oceanic Niño Index (ONI) and paralarval abundance (ind. per 1,000m^3), local sea surface temperature (SST, °C) and paralarval abundances, and the ONI and SST. A mild La Niña occurred during each of these periods; however, the predictability of the ONI was abbreviated during the 2016-2023 period. Only data from the winter hatching period in southern California was used. Dates on the top panel range from January, 2011 – February, 2016; dates on the bottom panel range from December, 2016 – February, 2023.)



(Figure 8 Left-side maps show the monthly sea surface temperature anomalies for November, 2022; March, 2023; July, 2023; and November, 2023, which highlight the dissipation of the La Niña and the evolution of the El Niño in the equatorial Pacific. As the La Niña subsided in January, 2023, local storm activity in the California Current drove an increase in upwelling and cooler sea surface temperatures. The right-side graph shows the sea surface temperature anomalies in the "Niño3.4" region of the equatorial region, the geographic area used to determine ENSO state. The solid line indicates the ONI value, and the colored lines are the projected model outputs for future ENSO state. Projections indicate the El Niño should peak in late fall, 2023 or early winter 2024, and return to neutral in the spring. Data accessed through, https://coastwatch.pfeg.noaa.gov/erddap/griddap/jplMURSST41.graph; https://www.cpc.ncep.noaa.gov/products/CDB/Forecast/figf4.shtml)

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