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Short Communication

Zooplankton biomass in the Pacific Ocean off the coast of Mexico and the southern Gulf of California during the strong El Niño event of 2023-2024

Erik Coria-Monter[1], María Adela Monreal-Gómez[1], Ligia Pérez-Cruz[2]
Elizabeth Durán-Campos[3] & David Alberto Salas-de-León[1]
[1]Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México
Ciudad de México, México
[2]Instituto de Geofísica, Universidad Nacional Autónoma de México, Ciudad de México, México
[3]Escuela Nacional de Ciencias de la Tierra, Universidad Nacional Autónoma de México
Ciudad de México, México
Corresponding author: Erik Coria-Monter (coria@cmarl.unam.mx)

ABSTRACT. Over the past five years, significant changes have occurred in Earth's climate system. For example, from mid-2020 to early 2023, a strong La Niña event took place, which quickly transitioned into an intense El Niño that lasted until the first four months of 2024. The consequences of this phenomenon are still being studied. This study reports on zooplankton biomass values in the Pacific Ocean off the coast of Mexico (POM) and the southern Gulf of California (SGC) during the strong El Niño 2023-2024, using both *in situ* and satellite data. Satellite observations revealed a warm water pool in the POM, which was associated with low chlorophyll-*a* (Chl-*a*) concentrations. As a result, zooplankton biomass values in this region were extremely low. In contrast, the SGC experienced slightly elevated sea surface temperatures and higher Chl-*a* concentrations, leading to zooplankton biomass reaching its highest values.

Keywords: zooplankton; biomass; El Niño; Gulf of California; Mexico; Pacific Ocean

The El Niño-Southern Oscillation (ENSO) is one of the most significant climatic processes on Earth, affecting various aspects of daily life (Goddard & Gershunov 2020). Indeed, in the atmosphere, it plays a crucial role in influencing wind patterns and regulating both local and global rainfall (Tang et al. 2025); in the ocean, ENSO events are linked to changes in sea surface temperature (SST) levels, which lead to variability in water column stratification, nutrient concentrations, and, as a result, planktonic production (McPhaden 2020).

ENSO has two phases: La Niña, the colder phase, and El Niño, the warmer phase. La Niña is typically characterized by the advection of cold, nutrient-rich water masses that enhance planktonic production in the ocean (Durán-Campos et al. 2024a). In contrast, El Niño is associated with warm, nutrient-poor water masses, which negatively affect production by reducing the biomass levels of both phytoplankton and zooplankton (Durán-Campos et al. 2024b).

Zooplankton biomass serves as an indirect indicator of secondary production in marine ecosystems (Hernández-León et al. 2019). Measuring this biomass is a crucial first step in estimating the availability of both organic and, in some cases, inorganic matter and energy throughout food webs (Drago et al. 2022). Furthermore, quantifying zooplankton biomass helps estimate the amount of carbon that can be transported

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to the ocean's depths (Burd & Thomson 2022). This process is crucial in relation to the potential and efficiency of the biological carbon pump (Irigoien et al. 2004).

It is now relatively well known that fluctuations in global zooplankton biomass levels are influenced by hydrodynamic processes in the water column, including ENSO events (Aguilera et al. 2025). During El Niño events, the biomass levels of zooplankton can fluctuate significantly. For instance, unusually low zooplankton biomass values were reported off the coast of Peru during the 1982-1983 El Niño event (Carrasco & Santander 1987). Similarly, during the 1992 El Niño event, unusually warm surface water temperatures (>28°C) were observed in the tropical Pacific Ocean. These warm temperatures were associated with low chlorophyll-*a* (Chl-*a*) concentrations (0.05 mg m^{-3}) and reduced zooplankton biomass (White et al. 1995). A similar pattern was observed off the central Oregon coast during the 1997-1998 El Niño event, which was characterized by an extended warming period that also impacted zooplankton populations, particularly by reducing the biomass of copepods (Peterson et al. 2022).

There are reports of zooplankton biomass variability in Mexican waters during El Niño events. In the Mexican Central Pacific, during the El Niño 1997-1998, the SST was high (>25°C), associated with a predominance of small diatoms and lower zooplankton biomass than in regular periods (Franco-Gordo et al. 2004). Similar observations were made for the El Niño 2010, which generated a seasonal shift that induced elevated SST values and low zooplankton biomass (Pelayo-Martínez et al. 2017). Likewise, in the Gulf of California, there are reports of marked decreases in zooplankton biomass associated with strong El Niño events (Lavaniegos-Espejo & Lara-Lara 1990).

Under neutral ENSO conditions, the surface temperature of the southern Gulf of California (SGC) during the summer months is approximately 26ºC. At this temperature, zooplankton biomass can exceed 4 g 100 m^{-3} when expressed as dry weight (Färber-Lorda et al. 2004, 2010). In the Bay of La Paz, wet weight biomass of zooplankton can reach as high as 75 g 100 m^{-3} (Durán-Campos et al. 2015). During La Niña events, some studies indicate that zooplankton biomass in the coastal environments of the SGC can exceed 50 g m^{-3} (Durán-Campos et al. 2019), with the copepod fraction contributing over 6 mg 100 m^{-3} (Rocha-Díaz et al. 2022).

To date, significant efforts have been made to understand the dynamics of ENSO events occurring in the Pacific Ocean off the coast of Mexico (POM) and the SGC, as well as their impacts on zooplankton biomass. However, additional observations are still required, especially in this time of global change, where, in particular, El Niño events are becoming longer and more intense, and the transitions between different phases (such as neutral, El Niño, and La Niña) are becoming more rapid and unpredictable (L'Heureux et al. 2020). Under this scenario, this study presents zooplankton biomass values estimated from *in situ* observations conducted during an oceanographic research cruise in January and February 2024 in the POM and the SGC onboard the R/V El Puma operated by the National Autonomous University of Mexico (UNAM, by its Spanish acronym). Additionally, the data were supplemented with satellite observations of SST and Chl-*a* levels during the cruise. It is worth noting that the Oceanic Niño Index (ONI) recorded numerical values of 1.8 in January 2024 and 1.5 in February 2024, indicating that a strong El Niño event occurred during our sampling period.

The zooplankton samples used in this study were collected at 33 stations (Fig. 1). We conducted oblique hauls using bongo nets (60 cm mouth diameter and a mesh size of 333 µm) equipped with mechanical flowmeters (General Oceanics 2030R).

Each haul lasted 15 min at 2 kn, starting from a depth of 200 m to the surface. Once on board, the nets were thoroughly inspected, and all collected material was removed and immediately preserved in a 4% formalin solution buffered with sodium borate. After 24 h in this solution, the organisms were transferred to 70% ethanol for transport and final preservation. Once in the laboratory, zooplankton biomass was calculated immediately after the research cruise.

We used three different approaches for this study. Initially, we calculated biomass based on wet weight (WW), following the procedures outlined in Durán-Campos et al. (2015, 2019). This method has been successfully applied in various environments in Mexico, including the Gulf of California (Durán-Campos et al. 2019) and the Gulf of Mexico (Fuentes-Martínez et al. 2023), yielding reliable data. Multiple comparisons of the data generated using this method with other reported methodologies have demonstrated that the results obtained yield valuable and high-quality scientific information (e.g. Durán-Campos et al. 2015, 2019, Coria-Monter et al. 2020, Rocha-Díaz et al. 2022, 2024, Fuentes-Martínez et al. 2023, and the references cited therein).

To obtain the biomass, we weighed the entire zooplankton sample collected from each sampling site

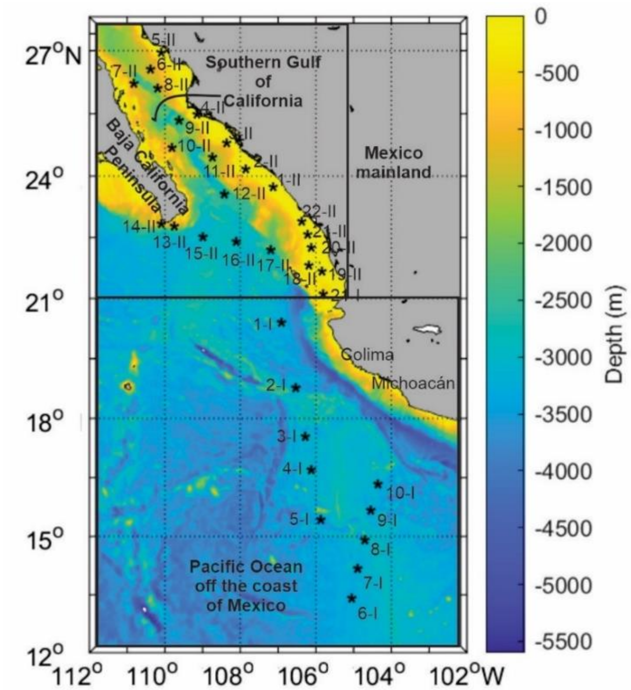

Figure 1. Study area. The black asterisks indicate the stations where zooplankton samples were collected. Bathymetry is represented in meters. The rectangles represent the domains of interest in this study, specifically the Pacific Ocean off the coast of Mexico and the southern Gulf of California.

using a plastic sieve with a 200 μm mesh. We removed all excess ethanol using blotting paper, a process that took between 1 and 3 h to complete. While we recognize that the use of ethanol can lead to the extraction of water from the organisms, to the best of our knowledge, no significant loss of water within the organisms has been documented due to ethanol usage. In fact, ethanol is considered one of the standard procedures for fixing zooplankton organisms (Kramer et al. 1972, Harris et al. 2000, Santhanam et al. 2019). The zooplankton biomass for each station (expressed in g 100 m^{-3}) was calculated using the formula $ZB = \frac{Nw}{Fw} \times 100$, where Nw is the net weight of the sample (after ethanol removal) expressed in grams. Fw is the volume of water filtered during each haul (obtained from the flowmeter on the nets), expressed in cubic meters.

After calculating the zooplankton biomass in terms of WW, we determined the zooplankton biomass in terms of dry weight (DW; mg m^{-3}) and the zooplankton carbon biomass using the protocols outlined in Wiebe (1988). These calculations follow the expressions LOG (WW) = -2.002 + 0.950 × LOG(DW), and LOG (WW) = -1.537 + 0.852 × LOG(C), respectively, where the latter equation relates WW to carbon content (mg C m^{-3}).

It is essential to note that large organisms, which could bias the calculations, such as large gelatinous zooplankton (e.g. jellyfish) and juvenile fish, were removed before weighing the samples. Additionally, unrelated items such as marine debris, leaf litter, and small mangrove branches were excluded.

In addition to the laboratory procedures, satellite data on SST and Chl-*a* (from February 5, 2024) were obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS-AQUA) at a resolution of 1 km per pixel. Following the protocols outlined by Coria-Monter et al. (2018) and Durán-Campos et al. (2023), several filters and masks were applied to ensure the generation of high-quality data. Finally, maps for both variables were created using standard MATLAB routines.

Although there were some gaps due to cloud cover, which is common in satellite oceanography when working with large domains, clear differences were observed between the studied regions. In the POM, the sea surface temperature image revealed the highest temperatures, with a warm water pool exceeding 30°C located between 15°N and 105°W (Fig. 2a). In contrast, the SGC exhibited lower temperature values, ranging from 22 to 25°C. This temperature gradient decreased from the connection with the Pacific Ocean towards the northern part of the Gulf. Consequently, the distribution of Chl-*a* displayed distinct patterns. Extremely low

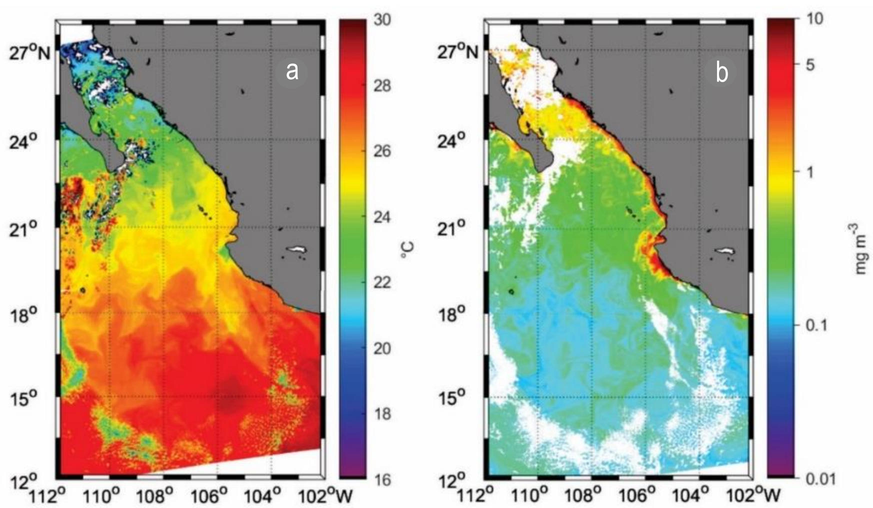

Figure 2. a) Satellite images taken on February 5, 2024: a) sea surface temperature (°C), and b) chlorophyll-*a* concentration (mg m^{-3}).

Chl-*a* values (<0.15 mg m^{-3}) were found in the POM, associated with the warm water pool, while higher concentrations (>2.0 mg m^{-3}) were recorded in the SGC. The highest Chl-*a* readings (>8 mg m^{-3}) were found along the eastern coast of the Gulf (Fig. 2b). Recently published hydrographic data during the strong El Niño event of 2023-2024 (Monreal-Gómez et al. 2025, their Figure 2) indicated that the first 50 m of the water column in the SGC consist of water masses with temperatures around 20°C, salinities exceeding 34.9, and Chl-*a* concentrations of 1.20 mg m^{-3}. In contrast, towards the POM, the surface temperature rises above 29°C, Chl-*a* levels decrease to 0.10 mg m^{-3}, and the thermocline deepens, a typical occurrence during El Niño events.

Zooplankton biomass values, measured as WW, ranged from 1.02 to 28.8 g 100 m^{-3}, with the lowest values observed in the POM and increasing towards the SGC (Fig. 3a). In terms of carbon units (Fig. 3b), zooplankton biomass varied from 0.29 to 14.8 mg C m^{-3}, with the POM region showing lower values compared to the SGC, which had the highest values. When expressed as DW (Fig. 3c), the biomass ranged from 1.02 to 34.6 mg m^{-3}. This trend mirrored the previous observations, with low values in the POM region and an increase towards the SGC.

Several interesting differences emerged when comparing zooplankton biomass in the two regions considered in this study. First, the extremely low levels in the POM region are noteworthy; these values are consistent throughout this area. In contrast, the values in the SGC region increase considerably. Notably, the higher biomass levels are found near the eastern coast of the Gulf, which coincides with the highest Chl-*a* values shown (Fig. 2b). The northernmost area of the study area exhibited the highest zooplankton biomass values, aligning with elevated Chl-*a* concentrations. Additionally, it is essential to highlight that along the connection between the Gulf of California and the Pacific Ocean, relatively high secondary levels of zooplankton biomass were recorded in an area characterized by relatively low temperatures (23°C) and higher Chl-*a* concentrations (~2 mg m^{-3}).

During our research cruise conducted just before the conclusion of the strong El Niño event of 2023-2024, we observed notable differences in the variables we analyzed. These included satellite-derived measurements of SST and Chl-*a*, as well as *in situ* data on wet zooplankton biomass. We found that SST was exceptionally high in the POM region, indicating the presence of a warm pool that led to extremely low levels of both phytoplankton and zooplankton biomass. In contrast, values for all three variables tended to increase northward into the SGC region.

Our observations align with those noted in other El Niño events. For instance, during the moderate El Niño of 2010, the central Pacific region of Mexico experienced unusually warm temperatures, exceeding 28°C in January. These temperatures gradually decreased throughout the year, ultimately leading to a transition to a La Niña event. This change in temperature resulted in a seasonal shift in biomass values, likely due to the top-down control of zooplankton grazing on phytoplankton and the acclimatization

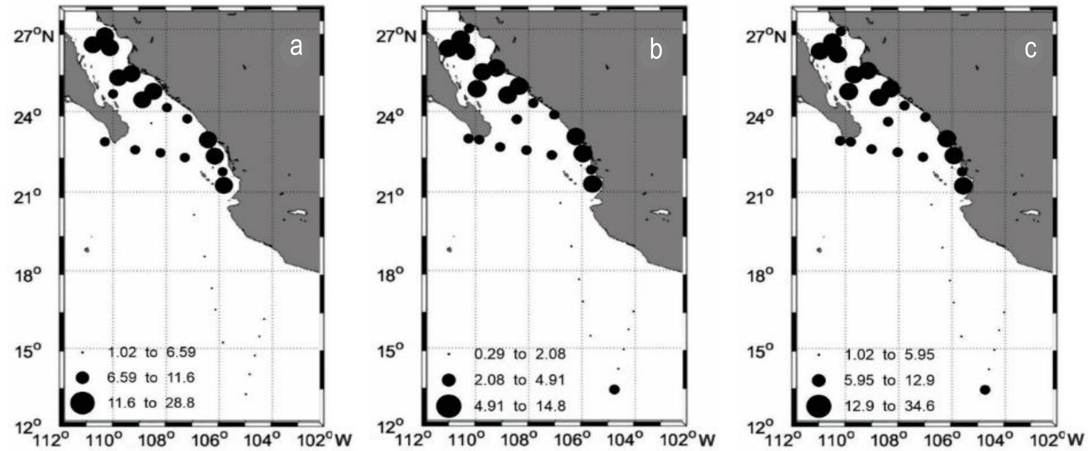

Figure 3. Zooplankton biomass in the Pacific Ocean off the coast of Mexico and the southern Gulf of California during the strong El Niño event of 2023-2024: a) zooplankton biomass expressed as wet wight (g 100 m^{-3}), b) zooplankton biomass expressed as carbon units (mg C m^{-3}), and c) zooplankton biomass expressed as dry weight (mg m^{-3}).

of both plankton groups to the environmental variability caused by the transition from a warm to a cold ENSO phase (Pelayo-Martínez et al. 2017).

Our findings suggest that the SGC region is highly dynamic, characterized by a confluence of various physical processes that promote mixing in the water column. This mixing enhances the supply of nutrients to the euphotic layer, benefiting planktonic populations. It has been proposed that these physical processes may mitigate some of the adverse effects of El Niño (e.g. Santamaría-del-Ángel et al. 1994, Sánchez-Velasco et al. 2017, Coria-Monter et al. 2018), which could explain why SST levels in the SGC region did not increase significantly and why Chl-*a* levels and zooplankton biomass remained relatively stable. This pattern may account for our contrasting observations between the POM and SGC regions.

In the SGC, surface temperatures of ~26ºC and zooplankton biomass values exceeding 4 g 100 m^{-3} have been reported under ENSO neutral conditions (Färber-Lorda et al. 2004, 2010). In coastal areas of the Gulf of California, these biomass values can reach as high as 54 g 100 m³ (Durán-Campos et al. 2019). This latter value is significantly higher than those documented in our study, suggesting that the El Niño 2023-2024 has impacted zooplanktonic communities. The negative effects of El Niño events on the Mexican Pacific are well established. Our observations align with scientific evidence indicating that zooplankton biomass typically decreases during El Niño events compared to neutral years. Such decreases have been observed in various locations, including the western part of the Baja California Peninsula (Castro-Longoria & Hammann 1989), the central Pacific coast of Mexico (Franco-Gordo et al. 2001, 2004), and off the coasts of Colima and Michoacán (Pelayo-Martínez et al. 2017). However, further *in situ* observations are necessary to fully comprehend the effects of El Niño on zooplankton populations, particularly in the Pacific Ocean basin off the coast of Mexico.

Credit author contribution

E. Coria-Monter: conceptualization, validation, methodology, formal analysis, writing-original draft; M.A. Monreal-Gómez: conceptualization, validation, methodology, formal analysis, funding acquisition, writing-original draft, review, and editing; L. Pérez-Cruz: validation, formal analysis, funding acquisition, writing-original draft, review, and editing; E. Durán-Campos: conceptualization, validation, methodology, formal analysis, writing-original draft; D.A. Salas-de-León: validation, formal analysis, funding acquisition, writing-original draft, review, and editing.

Conflict of interest

The authors declare no potential conflict of interest in this manuscript.

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