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Short Communication

Vertical distribution patterns of chlorophyll-*a* during autumn in a coastal environment inside the Gulf of California

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ABSTRACT. An evaluation of the vertical distribution of chlorophyll-*a* (Chl-*a*) levels, as an indicator of phytoplankton biomass, has strong repercussions in any marine ecosystem since it allows evaluating its productive potential and the amount of matter that is available for the higher trophic levels of the pelagic food web. This short communication aims to report the vertical distribution patterns of Chl-*a* levels and some selected hydrographic parameters during autumn in the Bay of La Paz, the biggest and deepest coastal environment inside the Gulf of California, a site also recognized for its high biodiversity. Two oceanographic research cruises were carried out during November 2014 and 2016. A CTD probe configured with dissolved oxygen and active fluorescence sensors, all pre-calibrated by the manufacturer, was used to acquire high-resolution data along the water column. The results showed two distribution patterns of Chl-*a*: 1) deep peaks (>60 m depth, with concentrations >6 mg m^{-3}) associated with the bottom at nearshore stations, and 2) maximum concentration peaks associated with the thermocline/pycnocline with concentrations up to 7.40 mg m^{-3} observed at deep stations. A multivariate statistical analysis confirmed the role played by some physical variables in the distribution patterns described. The results shown in this study complement the previous research and fill in the existing gaps for the transition periods between the warm and the cold.

Keywords: chlorophyll-*a*; phytoplankton biomass; seasonal variability; hydrography; Bay of La Paz; Mexico

Phytoplankton comprises an extremely heterogeneous group of microorganisms distributed in the oceans' euphotic layer, responsible for producing half of the oxygen in the atmosphere and for more than 45% of the planet's net primary production (Simon et al. 2009). They represent the base of the food chain, supporting fisheries of high commercial value in the world. They play a fundamental role in mitigating climate change and global warming by reducing global CO_2 levels by photosynthesis (Vajravelu et al. 2017).

As one of the photosynthetic pigments present in all photoautotrophic phytoplankton species, chlorophyll-*a* (Chl-*a*) is still recognized as one of the main proxies of phytoplankton biomass in the marine environment (Cullen 2015) and the measurement of its fluorescence emission has become a standard method to evaluate photosynthetic performance since it represents a sensitive and non-invasive technique (Davies et al. 2018). To date, the evolution of submersible fluorometers has made them increasingly accessible to the

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scientific community, which has led to the implementation of long-term monitoring programs; therefore, studies on the Chl-*a* vertical distribution patterns are currently recognized as being essential to assess the productive potential of the oceans and to evaluate the role that phytoplankton may play in climate change (Durán-Campos et al. 2019).

A growing body of scientific evidence presented in many marine ecosystems around the world suggests that the variations of the Chl-*a* vertical distribution patterns are closely related to the presence of multiple physical factors, including modulations in the thermocline/pycnocline depth, processes of mixing/ stratification of the water column, the propagation of internal waves, among others, which modify the availability of nutrients for phytoplankton (Behrenfeld et al. 2021). Therefore, evaluating the Chl-*a* vertical distribution patterns becomes complex but a necessary endeavor that requires multidisciplinary research to understand the physical and biological mechanisms of aggregation in which these organisms are involved.

Multidisciplinary investigations on this topic have appeared in the last decades in contrasting environments worldwide. Indeed, by using a submersible fluorescence probe along with conductivity, temperature, and pressure, Ríos et al. (2016) evaluated the vertical distribution patterns of Chl-*a* in the Magellan fjord system (Chile), showing that the stratification of the water column induced the formation of thin layers which were detected in 50% of their profiles. Ediger et al. (2005) identified a deep Chl-*a* maximum established near the base of the euphotic zone in a strong relationship with the nutricline depth in the eastern Mediterranean Sea. In the southeast Beaufort Sea, Tremblay et al. (2008) reported that the mixing along the water column induced the generation of a subsurface Chl-*a* maximum developed in relationship with the nitracline. In particular, for Mexican waters, the Chl-*a* vertical distribution patterns have been addressed in different environments, including the Caribbean Sea (Signoret et al. 1998), regions under the influence of river discharges in the southern Gulf of Mexico (Signoret et al. 2006), in the California Current System (Millán-Núnez et al. 1997), in the upper Gulf of California (Hidalgo-González & Álvarez-Borrego 2000) and the Bay of La Paz, southern Gulf of California (Durán-Campos et al. 2019).

The Bay of La Paz is the largest and deepest coastal environment inside the Gulf of California, located in the southeastern Baja California Peninsula, Mexico, approximately 200 km from the free connection with the open Pacific Ocean (Fig. 1). The bay represents a place of refuge, growth and feeding for numerous species, some of them threatened or endangered, and as a whole, the region is recognized for its high biological diversity as a result of their hydrodynamic, which includes the presence of a quasi-permanent cyclonic eddy that induces an Ekman pumping that positively impacts the phytoplankton communities (Coria-Monter et al. 2017), and thus triggers a bottom-up mechanism that influences the organisms positioned in the highest trophic levels of the food chain (Coria-Monter et al. 2020). Besides, the presence of additional physical processes at different scales has been related to the high biological diversity that the bay supports, including hydraulic jumps (Rocha-Díaz et al. 2021) and the propagation of internal waves (Coria-Monter et al. 2019), which raise nutrients towards the euphotic zone, which benefits phytoplankton communities.

The bay is recognized for its high phytoplankton species richness, whose abundances fluctuate throughout the year. One of the pioneering studies showed that diatoms, particularly of the genus *Chaetoceros*, *Rhizosolenia*, and *Nitzschia*, are dominant species throughout the year, followed by dinoflagellates (Signoret & Santoyo 1980). Subsequent studies in the southern portion of the bay confirmed the predominance of diatoms throughout the year, with a total of 16 species, followed by dinoflagellates (7 species) and silicoflagellates (2 species) (Lavaniegos & López-Cortés 1997); the authors noted that during autumn the dominant diatoms were of the genus *Chaetoceros*, while during the spring and summer the dominant species were of the genus *Nitzchia*, possibly related to the influx of nutrients into the bay. More recently, Verdugo-Díaz & Gárate-Lizárraga (2018) analyzed the phytoplankton community structure in the central portion of the bay through an annual cycle reporting 62 taxa (45 species of diatoms, 11 species of dinoflagellates, 3 species of silicoflagellates, 1 ciliate, 1 cyanophyte and 1 coccolithophore); along the annual cycle, the diatoms were the dominant species, followed by dinoflagellates.

To date, due to a monitoring program implemented by the National Autonomous University of Mexico (UNAM, by its Spanish acronym), it has been identified that the region is highly dynamic and that the vertical distribution of phytoplankton is closely related to the hydrographic properties of the water column and with the presence of hydrodynamic processes that occur at different scales of space and time, as mentioned above. Indeed, Durán-Campos et al. (2019) presented a first approximation of the vertical distribution patterns of the phytoplankton biomass (expressed as Chl-*a* concen-

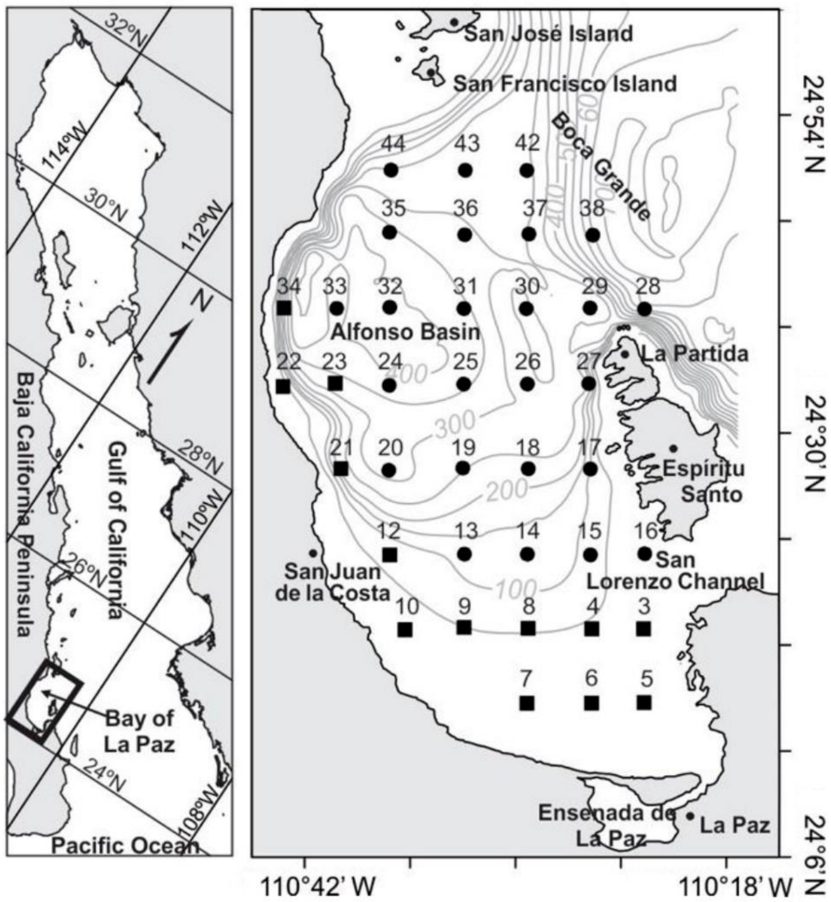

Figure 1. The left panel shows the Gulf of California, and the right panel shows the location of the Bay of La Paz. Symbols represent the hydrographic stations considered in this study: ● deep stations (those with a depth greater than 100 m), ■ shallow stations (those with a depth less than 100 m). Bathymetry is shown in meters.

tration) within the Bay of La Paz during summer, identifying that there is a marked regionalization, with two vertical distribution patterns: 1) maximum peaks located near the bottom in the regions close to the coast, and 2) maximum peaks associated with the thermocline/pycnocline in the central region of the bay. The authors emphasized the ecological importance that these vertical distribution patterns have inside the bay because the herbivorous and filter-feeding zooplankton (e.g. some copepods) have to couple to these vertical distributions to obtain the required food. Thus, there can be a correct transfer of carbon and energy throughout the water column. Also, the authors emphasized the need to analyze the evolution of these vertical distribution patterns at different seasons to establish a complete picture of how the phytoplankton changes vertically throughout the year, considering that the investigations in this regard inside the Bay of La Paz are still scarce and fragmented, therefore gaining scientific relevance in a time in which a growing deterioration in marine ecosystems (including those inside the Gulf of California) due to anthropogenic activities has been identified, then, evaluating the vertical distribution patterns of phytoplankton becomes necessary to identify, among other things, the specific depths at which organisms are distributed and then to be able to assess its capacity to absorb carbon.

Under this scenario, this short communication aims to report the vertical distribution patterns of Chl-*a* levels and some selected hydrographic parameters acquired in two research cruises that were carried out in autumn seasons (November) in the Bay of La Paz and their connection with the Gulf of California onboard the R/V El Puma, operated by UNAM, intending to contribute to the knowledge of the ecological aspects of the phytoplankton of the region and thus continue advancing in the scientific understanding of this ecosystem recognized for its high biodiversity.

The first research cruise (from now on referred to as Paleomar 1) took place between November 22 and 27 of 2014, while the second research cruise (from now on referred to as Paleomar 2) took place between November 15 and 21 of 2016. In each one, a total of 38 hydrographic stations that covered the entire bay, including its connection to the Gulf of California, were executed with high-resolution data acquired with a CTD probe (SeaBird 19 plus) configured with dissolved oxygen (SeaBird 43) and active fluorescence (ECO Wet Labs) sensors calibrated by the manufacturer prior each research cruise. Each CTD cast was as close to the bottom (5 m), acquiring data at 24 Hz.

The stored data at each station were subjected to different levels of processing. First, they were converted using the nominal calibration files with the software provided by the manufacturer (SBE Data Processing 7.26.7) following the standard processing routines that consisted of applying filters to eliminate spurious or poor-quality data and then averaging them every 1 dB. Finally, the conservative temperature and absolute salinity were obtained following the routines of the Thermodynamic Equation of the Sea Water - 2010 (IOC et al. 2010).

Based on previous research and to have elements of comparison, we used the regionalization of the Bay of La Paz proposed by Durán-Campos et al. (2019) (their Fig. 4) that divides the bay into two large regions: 1) the shallow zone, close to the coast (<100 m depth), and 2) the stations with greater depth (>100 m depth), including the stations located on Alfonso Basin, and the stations in the connection between the bay and the Gulf of California. In this sense, for each cruise, we selected 13 stations close to the coast (■ symbols Fig. 1) and 25 deeper stations (● symbols Fig. 1). Vertical profiles were drawn for conservative temperature (ºC), the absolute salinity, density (kg m^{-3}) and Chl-*a* (mg m^{-3}). Finally, to identify those physical variables with the highest relationship with the observed patterns, a principal component analysis (PCA) was applied to the dataset, which was carried out following the standard routines of the PRIMER v6 software.

The results showed interesting variations in each research cruise. Based on the regionalization proposed by Durán-Campos et al. (2019), in the shallow stations for the Paleomar 1 cruise, it was observed that the conservative temperature at the surface presented values of ~26ºC with a thermocline located at 50 m depth (Fig. 2a). The absolute salinity values were relatively uniform along the water column (Fig. 2b). The density showed a pycnocline at 50 m depth (Fig. 2c) in agreement with the thermocline, as expected. The Chl-*a* values were observed in range from 0.20 to 3.08 mg m^{-3} with a relatively homogeneous vertical distribution pattern throughout the water column, without marked maximum concentration peaks; however, in some stations it was observed that the Chl-*a* concentration increased close to the bottom (Fig. 2d). In the Palomar 2 cruise, in the shallow stations, interesting differences were observed about the Paleomar 1 cruise, particularly in the values of Chl-*a* and their vertical distribution. The conservative temperature showed surface values of ~27ºC with a thermocline located at 50 m depth (Fig. 2e), the absolute salinity was observed to be homogeneous throughout the water column (Fig. 2f), and the density showed that pycnocline was located at a depth of 50 m (Fig. 2g). Chl-*a* values rose into a range from 0.26 to 6.53 mg m^{-3} with a vertical distribution whose maximum concentration was observed close to the bottom (Fig. 2h).

In the deepest stations, interesting changes were also observed between both cruises. In the Paleomar 1 cruise, the conservative temperature at the surface was observed with a value of ~26ºC, with a thermocline located at an average depth of 50 m (Fig. 3a). The absolute salinity values at the surface ranged from 34.6 to 34.9 (Fig. 3b). The vertical distribution of density showed a pycnocline located at 50 m depth (Fig. 3c), while the Chl-*a* levels rose into a range from 0.01 to 2.37 mg m^{-3} with maximum peaks that were observed above the thermocline and pycnocline (Fig. 3d). In the case of the Paleomar 2 cruise, very marked changes were observed, particularly in the vertical distribution of Chl-*a* and their concentration. The conservative temperature at the surface showed values of ~27ºC with a thermocline located at 50 m depth (Fig. 3e). The absolute salinity showed homogeneous values of ~35.2 with the halocline located at a depth of 50 m (Fig. 3f). The vertical distribution of the density showed that the pycnocline was located at 50 m depth (Fig. 3g). In contrast, the Chl-*a* concentration showed maximum values of 7.40 mg m^{-3}, with peaks located at 50 m depth, coinciding with the thermocline and the pycnocline (Fig 3h).

A multivariate statistical analysis was applied to the data set to identify those physical variables that could determine the distribution patterns observed. A principal component analysis (PCA) (Fig. 4) showed that the two first axes explained 74.5% of the accumulated variance and that the conservative temperature and the total depth of each station were the variables that had the greatest relationship with the observed patterns.

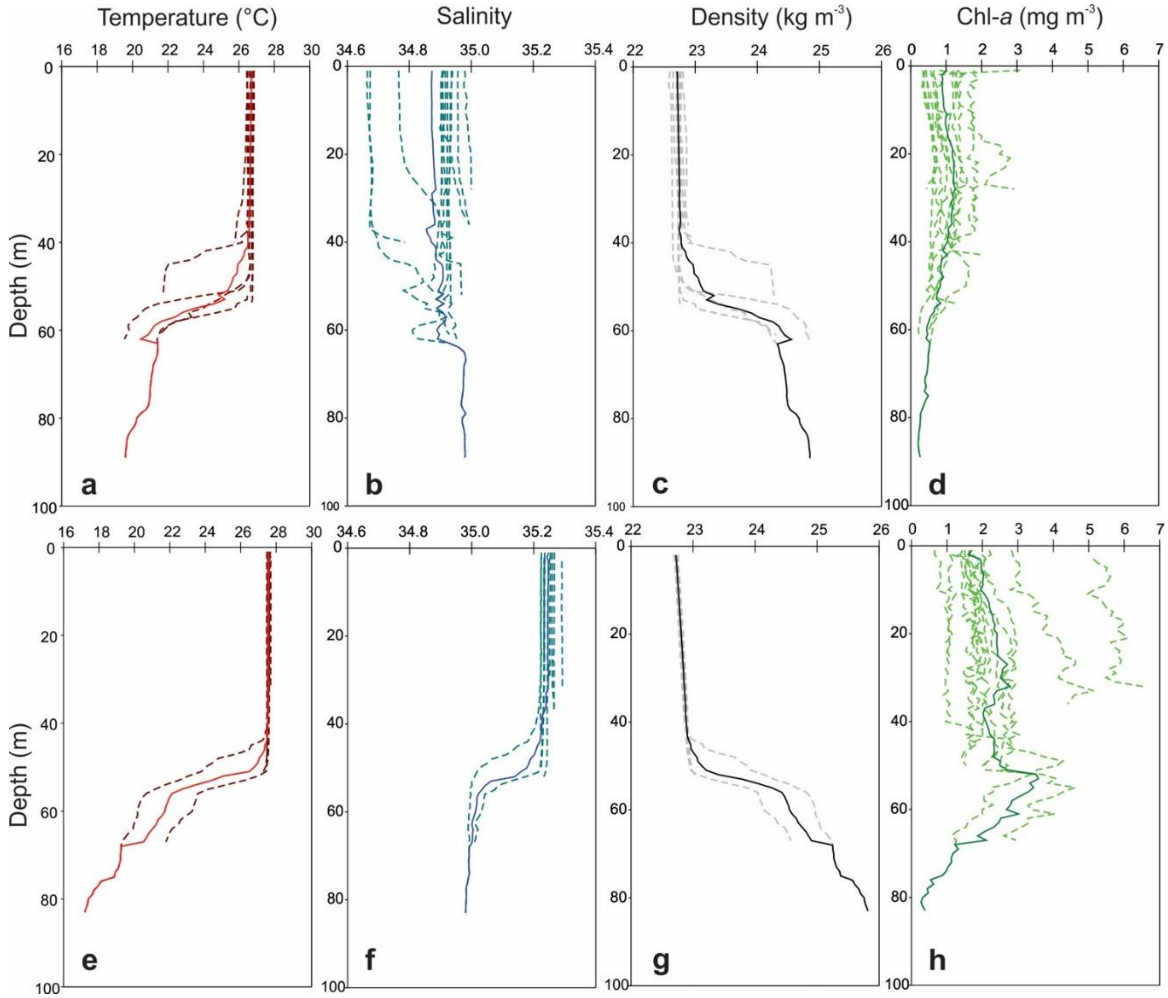

Figure 2. Cumulative vertical profiles in the shallow stations. In the top panel: a) conservative temperature (ºC, red dashed line), b) absolute salinity (blue dashed line), c) density (kg m^{-3}, gray dashed line), and d) chlorophyll-*a* (mg m^{-3}, green dashed line) during the Paleomar 1 research cruise. In the bottom panel: e) conservative temperature (ºC, red dashed line), f) absolute salinity (blue dashed line), g) density (kg m^{-3}, gray dashed line), and h) chlorophyll-*a* (mg m^{-3}, green dashed line) during the Paleomar 2 research cruise. The solid lines represent the average profile.

The multiple CTD casts along a fluorescence probe presented in this study allowed us to identify different distribution patterns during autumn, which showed clear differences depending on the total depth of each station and the conservative temperature. It was observed that there were two patterns of vertical distribution of Chl-*a*, the first with a maximum peak that was located near the bottom, which occurred in the shallow stations close to the coast; the second pattern consisted of the presence of a maximum peak that was in association with the thermocline and pycnocline, documented in the deepest stations. Both patterns coincided with what was previously reported by Durán-Campos et al. (2019) for the summer season, which suggests that these patterns are a typical structure inside the Bay of La Paz with which it would be possible to establish that these patterns of vertical distribution are persistent throughout the year which could also be confirmed by considering the physical configuration of the water column inside the bay, which is characterized by the presence of a cyclonic eddy that has been documented throughout the year, which contributes nutrients from the bottom to the euphotic zone, impacting positively to the phytoplankton communities, which could maintain throughout the year the vertical distribution patterns described in this study.

These distribution patterns also coincided with those reported in different regions, both coastal and oceanic regions. Indeed, in the Mediterranean Sea,

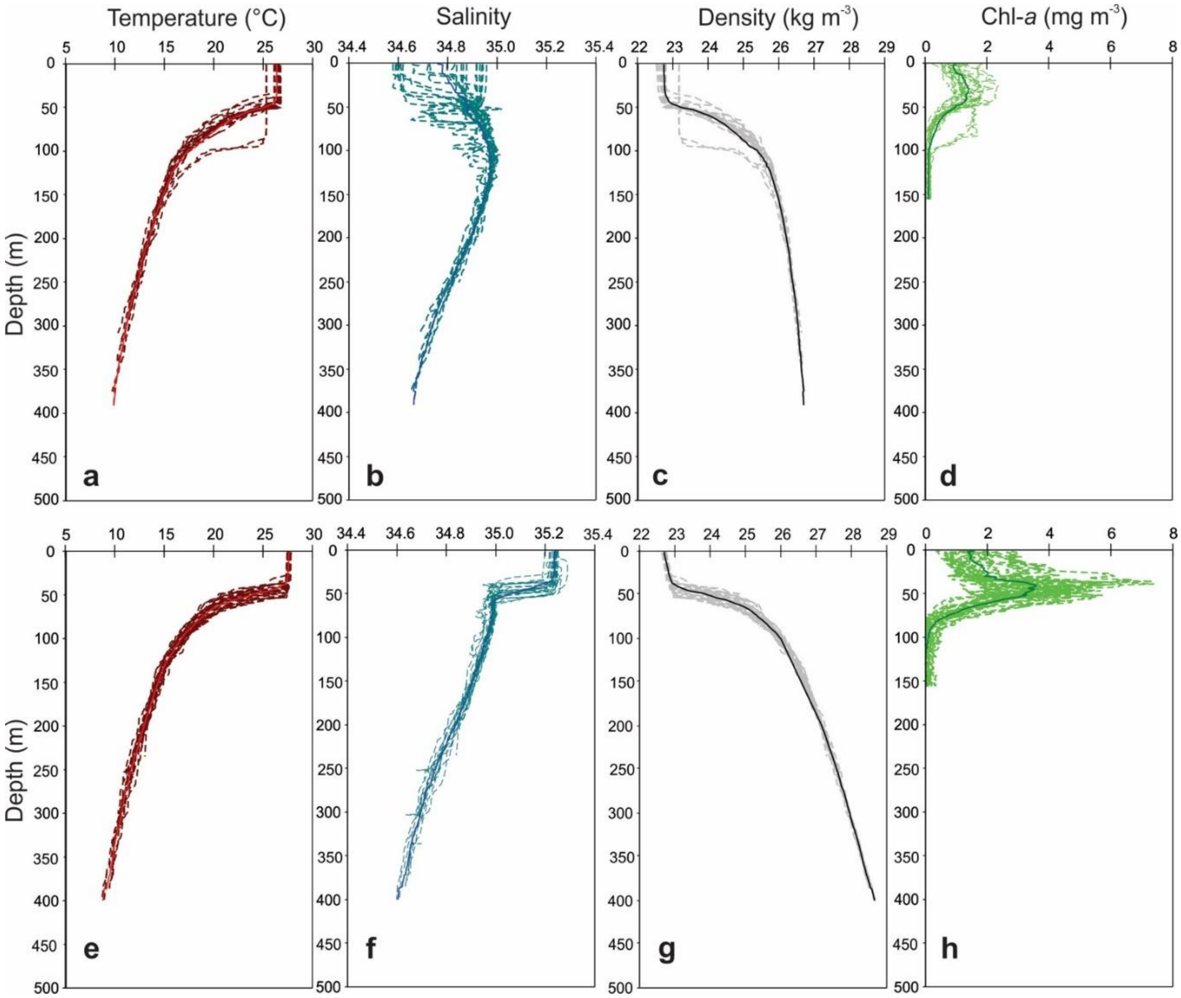

Figure 3. Cumulative vertical profiles in each deep station. In the top panel: a) conservative temperature (ºC, red dashed line), b) absolute salinity (blue dashed line), c) density (kg m^{-3}, gray dashed line), and d) chlorophyll-*a* (mg m^{-3}, green dashed line) during the Paleomar 1 research cruise. In the bottom panel: e) conservative temperature (ºC, red dashed line), f) absolute salinity (blue dashed line), g) density (kg m^{-3}, gray dashed line), and h) chlorophyll-*a* (mg m^{-3}, green dashed line) during the Paleomar 2 research cruise. The solid lines represent the average profile.

Estrada & Salat (1989) documented maximum concentration peaks close to the bottom. Signoret et al. (2006) reported maximum peaks near the bottom, representing an important food source for benthic communities in the inner-shelf region of the Gulf of Mexico.

In the case of the Bay of La Paz, the peaks of maximum concentration near the bottom, in the stations close to the coast, can be explained by the fact that, since they are located in shallow regions, there is adequate availability of nutrients for the phytoplankton populations. Hence, they tend to aggregate near the bottom. Although we do not have measurements of photosynthetically active radiation throughout the water column for this study, we assume that since they are shallow stations, the availability of light was not limiting and, therefore, may also have been a factor in the formation of the peaks near the bottom.

In the case of the deeper stations, the maximum peaks associated with the thermocline/pycnocline can be explained because this physical structure retains nutrients and, therefore, phytoplankton around the depth at which it occurs. To date, there is considerable evidence about the role played by the thermocline/ pycnocline in the aggregation of phytoplanktonic organisms, which agrees with our observations. Since the development of continuous Chl-*a* fluorescence measurement techniques, the thermocline has been documented to be an enhanced layer because it coincides with the nutricline, and particularly in tropics

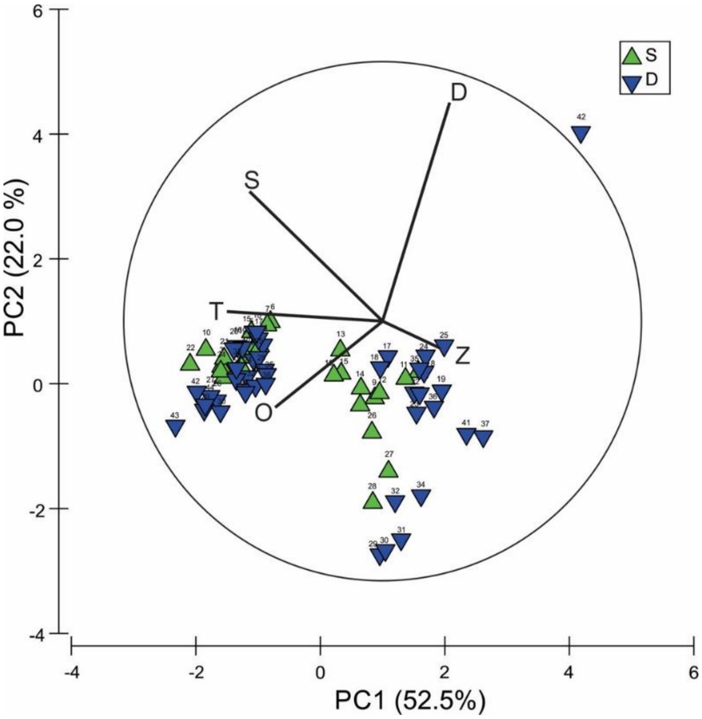

Figure 4. Principal component analysis applied to the dataset. T: conservative temperature, S: salinity, Z: total depth of each station, and O: dissolved oxygen. The triangles in blue and green represent the two regions considered in this study; S: shallow stations, and D: deep stations.

and subtropics environments, the coincidence between the thermocline and the nutricline has been documented as a typical structure that separates nutrient-rich deep waters from oligotrophic surface layers which tend to aggregate phytoplanktonic organisms (Wilson & Adamec 2002). For example, in the Cariaco Basin (Venezuela), it has been documented that annual changes in the depth of the thermocline strongly affect the vertical distribution of phytoplankton and, therefore, the Chl-*a* levels (Alvera-Azcárate et al. 2011).

On the other hand, the Chl-*a* values reported in this study (up to 7.40 mg m^{-3}) were considerably higher compared to those reported for other seasons of the year inside the Bay of La Paz. For example, during the late spring season (June), Coria-Monter et al. (2017) reported maximum values of 2.1 mg m^{-3}. During the summer season (August), Durán-Campos et al. (2019) reported maximum values of 3.03 mg m^{-3}. However, values up to 9.87 mg m^{-3} have been reported during the winter season (December) by Durán-Campos et al. (2020). This marked seasonal variability in the Chl-*a* values reported inside the bay could be attributed to multiple factors, including natural warming/cooling changes between summer/winter and the regional wind pattern, which present a very marked seasonal trend as autumn and winter approaches, intense and persistent winds from the northwest occur, which mix the water column, resuspending nutrients from the bottom towards the base of the pycnocline, which favors the increase in phytoplankton biomass; contrary, during the summer season there is a marked stratification of the water column which inhibits the vertical flow of nutrients towards the euphotic layer and, therefore, low values of phytoplankton biomass are presented.

Unfortunately, in this study, we do not have water samples at different depths that would allow us to identify the phytoplankton community structure associated with the vertical distribution patterns described here; however, as mentioned above, it is known that the bay supports a high phytoplankton species richness with diatoms as the dominant group throughout the year, which have been observed in high abundances particularly in autumn (e.g. Lavaniegos & López-Cortés 1997, Verdugo-Díaz & Gárate-Lizárraga 2018). Then, we could assume that the species that induced the patterns described here and those described in Durán-Campos et al. (2019) could be diatoms, also considering the broad pigment spectrum that this group hosts, which makes them more efficient in the photosynthetic process, even more than other phytoplankton groups (Kuczynska et al. 2015).

As final remarks, it is important to note that the vertical distribution patterns of phytoplankton biomass, expressed as Chl-*a*, have strong implications for pelagic food webs, particularly for herbivorous zooplankton because the availability of food for this group is quite different when the phytoplankton is concentrated in a thin layer, but in high densities, than when it is dispersed in a wide thickness and low densities. In addition, it is different if the highest concentration of Chl-*a* is in a single maximum or if the vertical distribution shows several peaks or is homogeneous (Durán-Campos et al. 2019). Due to the above, the herbivorous and filtering zooplankton must couple to these patterns to have, in each case, the required food, which allows the proper functioning of the "biological or carbon pump" (Richardson 2008). On the other hand, the analysis of the vertical distribution of phytoplankton biomass makes it possible to identify specific regions and productive seasons and, therefore, to propose strategies for adequate management of the regional marine resources. The preceding becomes more relevant in coastal environments because these sites represent refuge, feeding, and breeding areas for numerous species of high value, both ecologically and economically, such as the Bay of La Paz. Additionally, having more vertical Chl-*a* profiles at different times of the year would allow for predicting changes in phytoplankton biomass due to global warming and focus on designing strategies to avoid the decline of primary production and the consequent decline in fisheries.

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REFERENCES

Alvera-Azcárate, A., Barth, A., Weisberg, R.H., Castañeda, J.J., Vandenbulcke, L. & Beckers, J.-M. 2011. Thermocline characterization in the Cariaco basin: a modelling study of the thermocline annual variation and its relation with winds and chlorophyll-a concentration. Continental Shelf Research, 31: 73-84. doi: 10.1016/j.csr.010.11.006

Behrenfeld, M.J., Brooks, S.D., Gaube, P. & Mojica, K.D.A. 2021. Editorial: Unraveling mechanisms underlying annual plankton blooms in the North Atlantic and their implications for biogenic aerosol properties and cloud formation. Frontiers in Marine Sciences, 8: 764035. doi: 10.3389/fmars.2021.764035

Coria-Monter, E., Monreal-Gómez, M.A., Salas-de-León, D.A. & Durán-Campos, E. 2020. Zooplankton abundance during summer in the Bay of La Paz (southwestern Gulf of California, Mexico). Latin American Journal of Aquatic Research, 48: 794-805. doi: 10.3856/vol48-issue5-fulltext-2515

Coria-Monter, E., Salas-de-León, D.A., Monreal-Gómez, M.A. & Durán-Campos, E. 2019. Internal waves in the Bay of La Paz, southern Gulf of California, Mexico. Vie et Milieu-Life and Environment, 69: 115-122.

Coria-Monter, E., Monreal-Gómez, M.A., Salas de León, D.A., Merino-Ibarra, M. & Durán-Campos, E. 2017. Wind driven nutrient and subsurface chlorophyll-*a* enhancement in the Bay of La Paz, Gulf of California. Estuarine Coastal and Shelf Sciences, 196: 290-300. doi: 10.1016/j.ecss.2017.07.010

Cullen, J.J. 2015. Subsurface chlorophyll maximum layers: enduring enigma or mystery solved? Annual Review of Marine Science, 7: 207-239. doi: 10.1146/annurev-marine-010213-135111

Davies, C., Ajani, P., Armbrecht, L., Atkins, N., Baird, M.E., Beard, J., et al. 2018. A database of chlorophyll-*a* in Australian waters. Scientific Data, 5: 180018. doi: 10.1038/sdata.2018.18

Durán-Campos, E., Monreal-Gómez, M.A., Salas de León, D.A. & Coria-Monter, E. 2019. Chlorophyll-*a* vertical distribution patterns during summer in the Bay of La Paz, Gulf of California, Mexico. Egyptian Journal of Aquatic Research, 45: 109-115. doi: 10.1016/j.ejar.2019.04.003

Durán-Campos, E., Monreal-Gómez, M.A., Salas de León, D.A. & Coria-Monter, E. 2020. Field and satellite observations on the seasonal variability of the surface chlorophyll-*a* in the Bay of La Paz, Gulf of California, Mexico. International Journal of Oceans and Oceanography, 14: 157-167. doi: 10.37622/IJOO/14.1.2020.157-167

Ediger, D., Tugrul, S. & Yilmaz, A. 2005. Vertical profiles of particulate organic matter and its relationship with chlorophyll-*a* in the upper layer of the NE Mediterranean Sea. Journal of Marine Systems, 55: 311-326. doi: 10.1016/j. jmarsys.2004.09.003

Estrada, M. & Salat, J. 1989. Phytoplankton assemblages of deep and surface water layers in a Mediterranean frontal zone. Scientia Marina, 52: 203-214.

Hidalgo-González, R.M. & Álvarez-Borrego, S. 2000. Chlorophyll profiles and water column structure in the Gulf of California. Oceanologica Acta, 24: 19-28.

Intergovernmental Oceanographic Commission (IOC), Scientific Committee on Oceanic Research (SCOR) & International Association for the Physical Sciences of the Oceans (IAPSO). 2010. The international thermodynamic equation of seawater - 2010. Calculation and use of thermodynamic properties. Intergovernmental Oceanographic Commission, Manual and Guides N°56. UNESCO, Paris.

Kuczynska, P., Jemiola-Rzeminska, M. & Strzalka, K. 2015. Photosynthetic pigments in diatoms. Marine Drugs, 13: 5847-5881. doi: 10.3390/md13095847

Lavaniegos, B.E. & López-Cortés, D. 1997. Fatty acid composition and community structure of plankton from the San Lorenzo Channel, Gulf of California. Estuarine, Coast and Shelf Science, 45: 845-854. doi: 10.1006/ecss.1997.0245

Millán-Núñez, R., Álvarez-Borrego, S. & Trees, C.C. 1997. Modeling the vertical distribution of chlorophyll in the California Current System. Journal of Geophysical Research, 102: 8587-8595. doi: 10.1029/97JC00079

Richardson, A.J. 2008. In hot water: zooplankton and climate change. ICES Journal of Marine Science, 65: 279-295. doi: 10.1093/icesjms/fsn028

Ríos, F., Kilian, R. & Mutschke, E. 2016. Chlorophyll-*a* thin layers in the Magellan fjord system: the role of the water column stratification. Continental Shelf Research, 124: 1-12. doi: 10.1016/j.csr.2016.04.011

Rocha-Díaz, F.A., Monreal-Gómez, M.A., Coria-Monter, E., Salas-de-León, D.A., Durán-Campos, E. & Merino-Ibarra, M. 2021. Copepod abundance distribution in relation to a cyclonic eddy in a coastal environment in the southern Gulf of California. Continental Shelf Research, 222: 104436. doi: 10.1016/j.csr.2021.104436

Signoret, M. & Santoyo, H. 1980. Aspectos ecológicos del plancton de la Bahía de La Paz, Baja California Sur. Anales del Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, 7: 217-248.

Signoret, M., Bulit, C. & Pérez, R. 1998. Patrones de distribución de clorofila a y producción primaria en aguas del Golfo de México y del Mar Caribe. Hidrobiologica, 8: 81-88.

Signoret, M., Monreal-Gómez, M.A., Aldeco, J. & Salas-de-León, D.A. 2006. Hydrography, oxygen saturation, suspended particulate matter, and chlorophyll-*a* fluorescence in an oceanic region under freshwater influence. Estuarine Coastal and Shelf Science, 69: 153-164. doi: 10.1016/j.ecss.2006.04.011

Simon, N., Cras, A.-L., Foulon, E. & Lemée, R. 2009. Diversity and evolution of marine phytoplankton. Comptes Rendus Biologies, 332: 159-170. doi: 10.1016/j.crvi.2008.09.009

Tremblay, J.E., Simpson, K., Martin, J., Miller, L., Gratton, Y., Barber, D., et al. 2008. Vertical stability and the annual dynamics of nutrients and chlorophyll fluorescence in the coastal, southeast Beaufort Sea. Journal of Geophysical Research, 113: C07S90. doi: 10.1029/2007JC004547

Vajravelu, M., Martin, Y., Ayyappan, S. & Mayakrishnan, M. 2017. Seasonal influence of physicochemical parameters on phytoplankton diversity, community structure and abundance at Parangipettai coastal waters, Bay of Bengal, southeast coast of India. Oceanologia, 60: 114-127. doi: 10.1016/j.Oceano.2017.08.003

Verdugo-Díaz, G. & Gárate-Lizarraga, I. 2018. Distribución de grupos funcionales de fitoplancton en la zona eufótica durante un ciclo anual en Bahía de La Paz, Golfo de California. CICIMAR Océanides, 33: 47-61. doi: 10.37543/oceanides.v33i1.227

Wilson, C. & Adamec, D. 2002. A global view of bio-physical coupling from SeaWiFS and TOPEX satellite data, 1997-2001. Geophysical Research Letters, 29: 981-984. doi: 10.1029/2001GL014063

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