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Distribution pattern of picoplankton carbon biomass linked to mesoscale dynamics in the southern gulf of Mexico during winter conditions

Lorena Linacre [a,*], Rubén Lara-Lara [a], Víctor Camacho-Ibar [b], Juan Carlos Herguera [c], Carmen Bazán-Guzmán [a], Vicente Ferreira-Bartrina [a]

[a] *Departamento de Oceanografía Biológica del Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), Baja California, Carretera Ensenada-Tijuana No. 3918, Zona Playitas, 22860 Ensenada, Baja California, Mexico*

[b] *Instituto de Investigaciones Oceanológicas, Universidad Autónoma de Baja California (IIO-UABC), Carretera Transpeninsular Ensenada-Tijuana No. 3917, Frac. Playitas, Ensenada, Baja California 22860, Mexico*

[c] *Departamento de Ecología Marina del Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), Baja California, Carretera Ensenada-Tijuana No. 3918, Zona Playitas, 22860 Ensenada, Baja California, Mexico*

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ABSTRACT

In order to characterize the carbon biomass spatial distribution of autotrophic and heterotrophic picoplankton populations linked to mesoscale dynamics, an investigation over an extensive open-ocean region of the southern Gulf of Mexico (GM) was conducted. Seawater samples from the mixed layer were collected during wintertime (February–March 2013). Picoplankton populations were counted and sorted using flow cytometry analyses. Carbon biomass was assessed based on *in situ* cell abundances and conversion factors from the literature. Approximately 46% of the total picoplankton biomass was composed of three autotrophic populations (*Prochlorococcus*, *Synechococcus*, and pico-eukaryotes), while 54% consisted of heterotrophic bacteria populations. *Prochlorococcus spp.* was the most abundant pico-primary producer (> 80%), and accounted for more than 60% of the total pico-autotrophic biomass. The distribution patterns of picoplankton biomass were strongly associated with the mesoscale dynamics that modulated the hydrographic conditions of the surface mixed layer. The main features of the carbon distribution pattern were: (1) the deepening of picoplankton biomass to layers closer to the nitracline base in anticyclonic eddies; (2) the shoaling of picoplankton biomass in cyclonic eddies, constraining the autoprokaryote biomasses to the upper layers, as well as accumulating the pico-eukaryote biomass in the cold core of the eddies; and (3) the increase of heterotrophic bacteria biomass in frontal regions between counter-paired anticyclonic and cyclonic eddies. Factors related to nutrient preferences and light conditions may as well have contributed to the distribution pattern of the microbial populations. The findings reveal the great influence of the mesoscale dynamics on the distribution of picoplankton populations within the mixed layer. Moreover, the significance of microbial components (especially *Prochlorococcus*) in the southern GM during winter conditions was revealed, indicating that they may play an important role in the pelagic food web, and that they may have a substantial impact on the carbon cycle in oligotrophic regions.

1. Introduction

Picoplankton populations are microbial components of plankton communities. They contribute to the structure and function of marine ecosystems and play a significant role in the global carbon cycle (Azam and Malfatti, 2007). The smallest known picoplanktonic oxyphototrophs, *Prochlorococcus,* and the closely related marine *Synechococcus* account for as much as two thirds of the CO_2 fixation in the oceans, and are responsible for nearly one third of the global primary biomass production (Bryant, 2003). A large fraction of primary production turns into dissolved organic matter (DOM), which is almost exclusively accessible to heterotrophic bacteria as the major carbon-flow pathway in the oceans. Most of the DOM is respired to carbon dioxide and exchanged to the atmosphere, while another portion is assimilated and re-introduced to the classical food chain (large phytoplankton, suspension-feeding zooplankton, and fish) through microbial trophic components. Thus, the picoplankton community is an integral part of the

* Corresponding author.
E-mail address: llinacre@cicese.mx (L. Linacre).

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pelagic food web (Azam and Malfatti, 2007).

Picoplankton populations are composed of single-celled autotrophic and heterotrophic organisms ranging from 0.2 to 2.0 μm. They are characterized by high growth and mortality rates, controlled by microzooplankton grazing. Autotrophic picoplankton consists of prokaryote (*Prochlorococcus*, *Synechococcus*) and pico-eukaryote populations (Chisholm et al., 1992; Raven, 1998; Urbach et al., 1998). The numerically most dominant photoautotroph and most significant contributor to primary production in oligotrophic waters is the marine cyanobacterium *Prochlorococcus*. Ubiquitous from 40°S to beyond 40°N, its abundances in surface waters (upper 200 m) usually exceed other pico-sized phytoplankton groups by 1 to 2 orders of magnitude (Chisholm et al., 1988; Olson et al., 1990; Campbell et al., 1994; Partensky et al., 1999; Bryant, 2003). Besides *Prochlorococcus*, there are two other populations of autotrophic picoplankton that are important primary producers in tropical and subtropical environments: *Synechococcus,* often most abundant in the upper, nutrient-rich layers of either upwelling or frontal systems, and pico-eukaryotes, which belong to diverse taxa (prymnesiophytes, pelagophytes, prasinophytes), and usually represent a large fraction of the picophytoplankton at the deep chlorophyll maximum. Both *Prochlorococcus* and pico-eukaryote abundances generally exceed those of *Synechococcus* at low light intensities. In addition to the autotrophs, heterotrophic bacteria can be as important as *Prochlorococcus* in terms of abundance and biomass (e.g., in oligotrophic regions of the Northern Hemisphere: Olson et al., 1990; Campbell and Vaulot, 1993; Partensky et al., 1996; Zubkov et al., 1998, 2000). In the oligotrophic open ocean waters of the Gulf of Mexico (GM), autotrophic prokaryotes represent a numerically even more significant portion of the phytoplankton community than any micro-sized autotrophic group (Wawrik et al., 2003; Liu et al., 2004; Wawrik and Paul, 2004; Hernández-Becerril et al., 2012; Aquino-Cruz, 2013).

The GM, one of the 64 Large Marine Ecosystems (LME) of the world (Sherman and Hempel, 2009), is a semi-enclosed, topographically very variable coastal sea, partially isolated from the Atlantic Ocean (Fig. 1). The eutrophic coastal and oligotrophic open ocean waters provide a moderate productivity (150–300 gC m^{-2} yr^{-1}), which supports a diverse marine community and high biomass of fish, sea birds, and marine mammals (Heileman and Rabalais, 2009). The open ocean waters of the southern GM region (i.e. southward from 26 °N, Fig. 1) are little influenced by continental river run-off, and they are fed by two water masses of subtropical origin from the North Atlantic Ocean: the Caribbean or Loop Current Water Mass and the Gulf Common Waters. Moreover, this region is strongly influenced by mesoscale circulation patterns characterized by: (1) the presence of counter-paired anticyclonic and cyclonic eddies in the western GM waters and their interaction with the continental slopes influencing the circulation over the shelves; (2) a cyclonic eddy in the southernmost region, topographically confined to the deep western basin in the Bay of Campeche; (3) the seasonal reversal of surface circulation on the western shelves (Tamaulipas and Veracruz) with a southward flow during autumn and winter, driven by the passage of atmospheric cold fronts proceeding from the North American continent during winter (the "nortes" season), and a northward flow during summer, driven by southerly upwelling favorable winds; (4) the upcoast and favorable circulation inducing upwelling events throughout the year over the western Campeche Bank; and (5) the local circulation features over the Campeche Canyon escarpment,

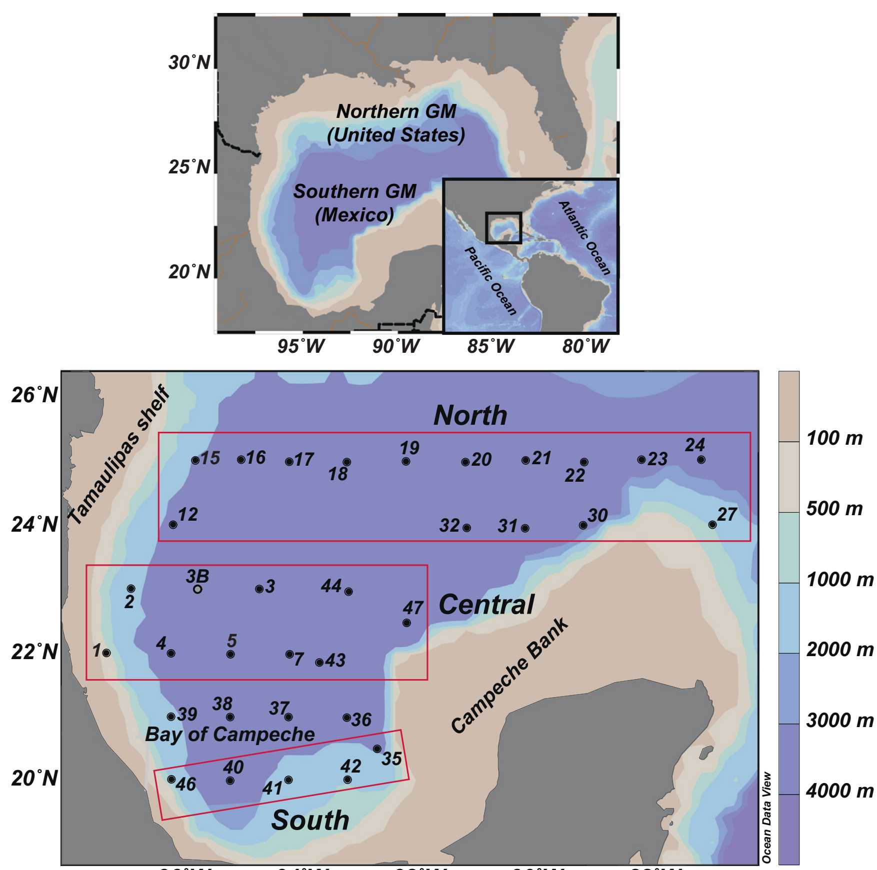

Fig. 1. Map of the study site in the Gulf of Mexico (GM), showing the grid stations of picoplankton sampling conducted in the deep-water region of the southern GM (i.e. southward from 26°N) during February 19 to March 11, 2013. Red rectangles indicate the three transects "north" (24–25°N), "central" (22–23°N) and "south" (20–20.5°N). At station 3B (grey dot) only hydrographic parameters, but no picoplankton, were sampled.