CICIMAR OCEÁNIDES
ISSN 2448-9123
https://cicimaroceanides.mx
Centro Interdisciplinario de Ciencias Marinas
https://doi.org/10.37543/oceanides.v39i1.304

Vol.39 No. 1
Enero - Junio
2024

EFFECTS OF A *Myrionecta rubra* PROLIFERATION ON PRIMARY PRODUCTIVITY AND CHLOROPHYLL-*a* CONCENTRATIONS IN LORETO BAY NATIONAL PARK, BAJA CALIFORNIA SUR, MÉXICO

Efectos de una de una proliferación de *Myrionecta rubra* sobre la productividad primaria y concentración de clorofila-*a* en el Parque Nacional de Loreto, B.C.S.

RESUMEN. Las llamadas "mareas rojas" o florecimientos algales nocivos (FAN) se caracterizan por un aumento exponencial de la abundancia de una o varias especies. Se ha reportado que su ocurrencia puede estar asociada a eventos naturales y antropogénicos, por lo que se ha observado un incremento global en las últimas décadas. De acuerdo con su impacto en el ecosistema, estos fenómenos han sido clasificados como tóxicos o nocivos. El presente trabajo es resultado de una investigación sustentada en los análisis de muestras recolectadas el 12 de abril de 2018, en la región sur del Parque Nacional Bahía de Loreto, BCS. En cuanto a la composición específica de las muestras, se determinaron nueve taxa pertenecientes a la fracción microfitoplanctónica (siete diatomeas, un dinoflagelado y un ciliado) con una abundancia total de 264,600 céls L^{-1}, concentración de 40.79 mg m^{-3} de clorofila-*a*, y productividad primaria equivalente a 80.5 mg C m^{-3} h^{-1}. Las abundancias registradas para las diferentes especies dan evidencia clara de una proliferación monoespecífica del ciliado *Myronecta rubra* el cual presentó una abundancia máxima de 256,600 céls L^{-1} la cual representa más de 96% de la abundancia total del microfitoplancton.

Palabras clave: Florecimiento, productividad primaria, clorofila-*a*.

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Verdugo Díaz, G., Martínez López, A., Rocio, Lara Rosales, C. (2024). Effects of a *Myrionecta rubra* proliferation on primary productivity and chlorophyll-*a* concentrations in Loreto Bay National Park, Baja California Sur, México. *CICIMAR Oceánides*, 39(1), 46-52.

The so-called "red tides" or Harmful algal blooms (HABs), refer to events of natural or anthropogenic origin characterized by an exponential increase of autotrophic microorganisms that may be toxic or non-toxic (Weir *et al*., 2022). Interest in these phenomena has increased worldwide in recent decades due to concern about the eventual damage they may cause to ecosystems and/or human health (Kourantidou *et al*., 2022). Events of this kind have been recorded frequently along México's western and eastern coasts, where the main species responsible are not restricted to one taxonomic group but, rather, present high biodiversity, as they include dinoflagellates, diatoms, ciliates, and cyanophytes (Gárate-Lizárraga *et al*., 2001; Cortés-Altamirano, *et al*., 2019). Regarding the ciliates, the earliest reports of non-toxic proliferations of *Myrionecta rubra* on México's coasts date to the 19th (Streets, 1872) and 20th centuries (Pakkard *et al*., 1978), but have become more common in recent times (Gárate-Lizárraga *et al*., 2001; López-Cortés *at al*., 2008).

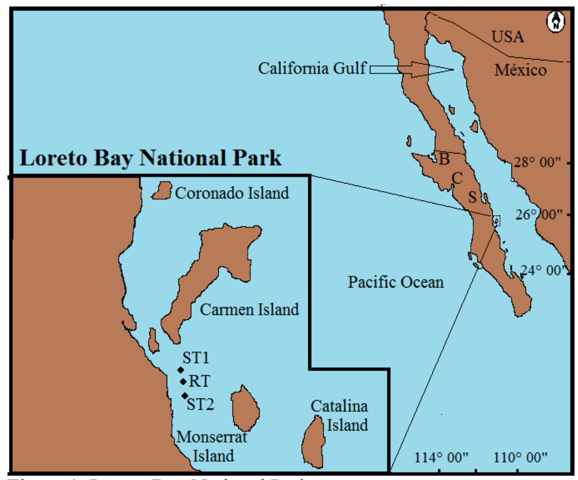

Figure 1. Loreto Bay National Park

The Loreto Bay National Park in the state of Baja California Sur (BCS, Fig. 1), México, has an approximate area of 206,580 hectares, with 88% consisting of marine environments, and the remaining 12% terrestrial, made up of islands and islets (Arnaud & Popoca, 2022). The study region harbors several types of marine and terrestrial habitats with the capacity to maintain high biodiversity (Huerta-Hernández, 2020). In addition to the area's regional and national importance, its characteristics project it at the international level. In fact, in 2004 it was included as a RAMSAR site and is now in the category of protected islands in the Gulf of California and, in 2005, was named a UNESCO World Heritage of Humanity site.

Sampling was conducted at three sites on April 12, 2018: one in the red tide (RT) and two outside it, at an approximate distance of 500 m from the slick, toward the south (ST1) and north (ST2). At each sampling station, a CTD haul was conducted at a depth of 100 m. Samples of surface water were collected using a Nansen bottle. Sub-samples were then drawn from the original samples to

Fecha de recepción: 19 de octubre de 2023
Fecha de aceptación: 13 de febrero de 2024

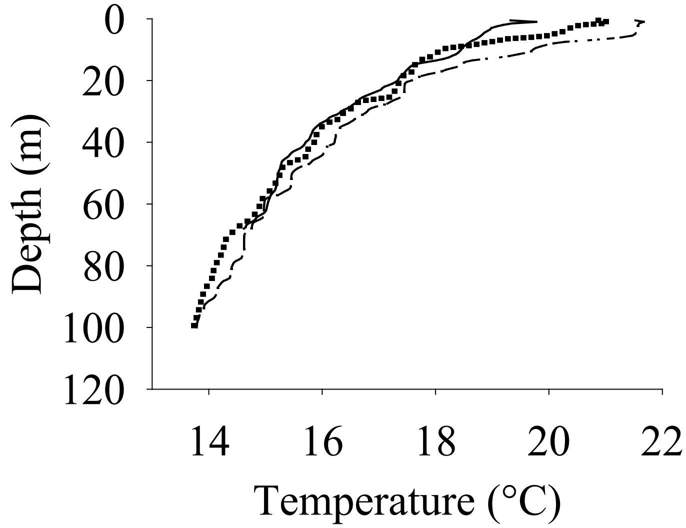

Figure 2. Temperature profiles from ST1 (dotted line), RT (solid line), and ST2 (dashed line)

determine chlorophyll-*a* (Chl-*a*) concentrations as proposed in Strickland & Parsons (1972). The final calculations of concentrations were made following Jeffrey & Humphrey (1975). An additional sample was taken to estimate primary productivity using the radioactive carbon assimilation technique (Nielsen, 1952).

Regarding the structure of the water column, we observed a gradual decrease in temperature at greater depth, but no indications of a surface mixing layer. All three sampling stations presented the same vertical pattern. Maximum temperatures ranged from 19.7 (RT) to 21.6°C (ST2), while the minimum value recorded was identical at all three sites (13.7°C) at a depth of 100 m (Fig. 2). In terms of point values and the general pattern of the temperature profiles, results concur with previous reports in surrounding areas, especially those referring to months of the cold period or cold-warm transition (Verdugo-Díaz *et al*., 2012; Verdugo-Díaz *et al*., 2014; Verdugo-Díaz & Gárate-Lizárraga, 2018).

Proliferations of *M. rubra* have been objects of research by the scientific community. Though not considered toxic, their importance lies in their potential to harm the environment and health (Cortés-Altamirano *et al*., 2019). However, these proliferations can, paradoxically, be beneficial by increasing the primary productivity of an area, since this planktonic ciliate has endosymbiont cryptophytes that give it the ability to photosynthesize and act a fundamental element of primary productivity when abundance and biomass increase significantly (Montagnes *et al*., 2008). Similarly, it has been reported that *M. rubra* can extract chloroplasts from the symbiont, thus acquiring the ability to divide and regulate them to function as true photoautotrophs (Gustafson *et al*., 2000; Johnson *et al*., 2007).

Proliferations of *M. rubra* have been reported frequently in the Gulf of California in recent decades but are not associated exclusively with this period. Historically, Streets (1872) made one of the first recordings of this kind of event. In the present study, the season corresponding to the RT presented fewer species. While a total of 9 taxa (7 diatoms, 1 dinoflagellate and 1 ciliate) were determined at sampling from the three stations, and 21 taxa, respectively, were recorded at stations ST1 and ST2. It is noteworthy that the dinoflagellate group presented only one species during the RT, while in the surrounding stations the specific richness registered was 11. The ciliate group was homogeneously represented by only one species at all three sites (Fig. 3).

Regarding the abundance of microphytoplankton, it was evident that the species responsible for the proliferation was the ciliate *M. rubra*, since at stations ST1 and ST2 abundances of 100 and 2.3e+3 cells L^{-1} were determined, while at station RT this species reached 256.6e+3 cells L^{-1}. In this regard, recent antecedents include Gárate-Lizárraga *et al*. (2001), who reported proliferations of this species on the order of 174.0e+3 to 23.0e+6 cells L^{-1} along the western coast of the Gulf of California, mainly in spring. The latter, extraordinarily high value, was registered in the Bay of La Paz in April 1994. Gárate-Lizárraga *et al*. (2002) reported a proliferation of this same ciliate in the Gulf of California, with maximum abundances close to 2.0e+6 cells L^{-1}. Those authors noted that their findings coincided with observations of dead jellyfish and fish. Similarly, López-Cortés *et al*. (2008) reported a RT of *M. rubra* (214.0e+3 cells L^{-1}) in the Bay of La Paz, in the southern area of the Gulf of California. The abundance values reported for that area can be considered intermediate values since RTs of this species have shown levels around 6.0e+5 cells L^{-1} (Herfort *et al.*, 2011).

In our study, the proliferation of *M. rubra* caused a marked decrease in the specific richness of dinoflagellates,

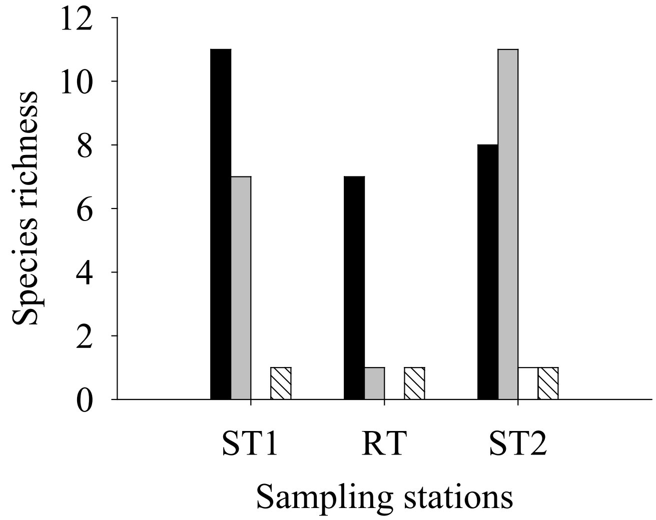

Figure 3. Specific richness of the four groups determined: diatoms (black bar), dinoflagellates (gray bar), flagellates (empty bar), and ciliates (bar with diagonals).

though this effect was not observed for diatoms. Total microphytoplankton abundance at RT was 96.9% *M. rubra*, while at sites ST1 and ST2 it was 0.2 and 7.1%, respectively. Leackey *et al*. (1992) observed similar proliferations but did not report catastrophic effects. In fact, their results showed an association with beneficial ecosystemic effects, such as higher chlorophyll-*a* concentrations and primary productivity.

The chlorophyll-*a* concentrations recorded were relatively low (0.31 and 0.42 mg Chl-*a* m^{-3}) at stations ST2 and ST1, but during the RT event this value increased to 40.79 mg Chl-*a* m^{-3}, a change of approximately two orders of magnitude. Observations like this, or of even greater magnitude changes, have been reported by various researchers in the Gulf of California (López-Cortés *et al*., 2008) and other environments (Yunus *et al*., 2015; Kim *et al*., 2023).

The primary productivity values at stations ST1 and ST2 were 1.59 and 1.62 mg C m^{-3} h^{-1}, respectively, while at station RT it was 80.5 mg C m^{-3} h^{-1}. This significant increase represents approximately 50 times the primary productivi-

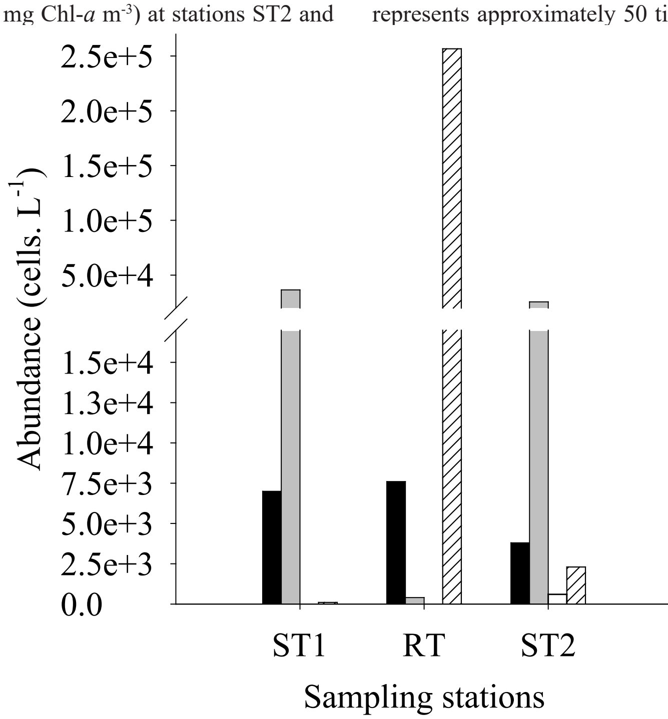

Figure 4. Abundance of the four groups determined: diatoms (black bar), dinoflagellates (gray bar), flagellates (empty bar), and ciliates (bar with diagonals).

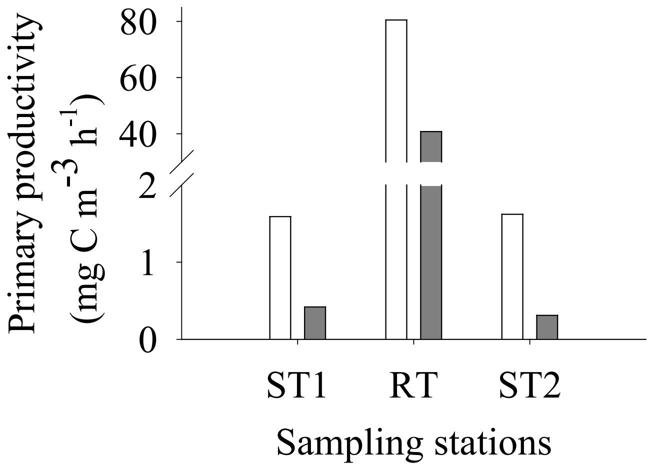

Figure 5. Primary productivity (empty bar) and chlorophyll-*a* concentrations (black bar) at the three sampling stations.

ty recorded outside the RT. A similar case, though one of lesser magnitude, was reported for a dinoflagellate RT by Vargo *et al.* (1987), who stated that events of this nature can increase primary productivity by up to 5 times. This same effect was observed in the concentration of chlorophyll-*a*, where the stations outside the RT presented values of 0.42 and 0.31 mg Chl-*a* m^{-3}, respectively, in contrast to the figure of 40.79 mg Chl-*a* m^{-3} recorded in the RT (Fig. 5).

In this regard, Jimenez and Gulancañay (2005) and Johnson *et al*. (2013) found that increases in chlorophyll concentrations in these orders of magnitude are common when events like *M. rubra* proliferations occur, so it is clear that a proliferation of this ciliate can positively influence chlorophyll-*a* concentrations and primary productivity, though it is important to consider that these effects are localized and short-lived, so it is difficult to estimate ecosystemic benefits on a larger spatial scale. In this regard, Herfort *et al*. (2012) mentioned that *M. rubra* proliferations can have an important biogeochemical impact in areas like estuaries, where they act as conditioning factors for the presence of hotspots.

Using the data described above, assimilation ratios were calculated to evaluate possible changes in photosynthetic efficiency. Results showed that during the RT this ratio presented a considerable decrease. While the value at station was 3.7 mg C (mg Chl-*a*)$^{-1}$ h^{-1} and at ST2 5.2 mg C (mg Chl-*a*)$^{-1}$ h^{-1}, at RT the site of the proliferation– the value was 1.9 mg C (mg Chl-*a*)$^{-1}$ h^{-1}, indicating a decrease of approximately 40-50%.

These values are similar to those observed in Bahía de La Paz, although that zone reached values above 20 mg C (mg Chl-*a*)$^{-1}$ h^{-1} (Verdugo-Díaz *et al*., 2014). Similarly, the assimilation ratios recorded in Loreto Bay National Park are similar to those reported by Valdez-Holguín *et al*. (1999) for the central area of the Gulf of California, where maximum values reached 10 mg C (mg Chl-*a*)$^{-1}$ h^{-1}. Note, however, that these two cases were not associated with phytoplankton blooms.

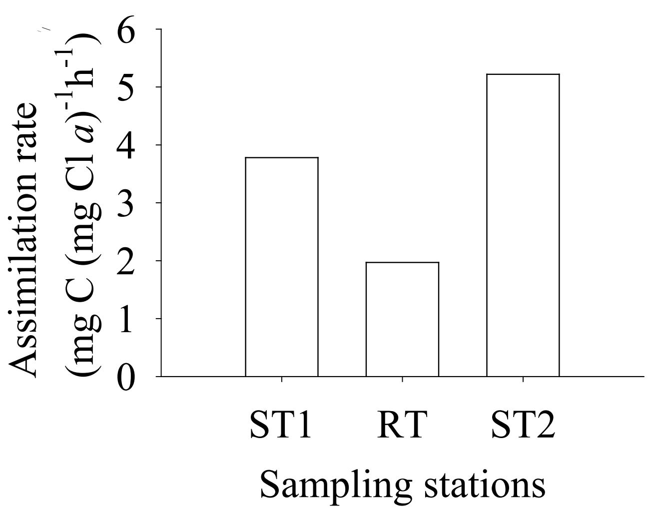

Figure 6.- Assimilation ratio at the three sampling stations.

We thank the Instituto Politécnico Nacional and the Secretaría de Investigación y Posgrado for the funding provided for the research project CLAVE SIP 20242204. We also thank COFAA-IPN and EDI for their support through Fellowships granted to GVD, AML. RCLR intern CONAHCYT and BEIFI authors of this publication.

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