

BLOOMS OF *Myrionecta rubra* IN BAHÍA DE LA PAZ, GULF OF CALIFORNIA, DURING EARLY SUMMER OF 2005

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ABSTRACT. Blooms of the ciliate *Myrionecta rubra* are quite common in Bahía de La Paz. In June and July 2005 two blooms of this species were sampled to determine abundance, plankton biomass, nutrients, dissolved oxygen, and temperature. During the bloom in June, surface temperature ranged from 19.0 °C to 19.6 °C and dissolved oxygen from 4.2 mg l⁻¹ to 4.7 mg l⁻¹. During the second bloom, surface temperature was 24.2 °C and dissolved oxygen was 6.7 mg l⁻¹. At 25 m depth, conditions were 20.0 °C and 3.5 mg l⁻¹, respectively. At the surface, nutrients were low, except for ammonium (1.14 µM – 2.27 µM). High densities of *M. rubra* (2.14 × 10⁶ cells l⁻¹), chlorophyll a (55.6 µg l⁻¹), chlorophyll c (6.0 µg l⁻¹), and alloxanthin (8.1 µg l⁻¹) were recorded. This last pigment is characteristic of the cryptophyte group, suggesting an association of the ciliate with this algal group. Winds from the southeast varied from 3 to 4.5 m s⁻¹ in June and 1.7 to 4.8 m s⁻¹ in July. The presence of this bloom under low thermal stratification and with the highest density of the ciliates at the surface during the onset of the bloom suggest that southeastern winds mixed the shallow water column, brought up nutrients from the bottom sediments, and induced high concentrations of the cryptophytes.

Keywords: Ciliates, photosynthetic pigments, nutrients, mixing processes.

Proliferaciones de *Myrionecta rubra* en Bahía de La Paz, Golfo de California, al inicio del verano de 2005

RESUMEN. Las proliferaciones del ciliado *Myrionecta rubra* son frecuentes en Bahía de la Paz. Durante junio y julio de 2005 se registraron dos proliferaciones de esta especie en tres sitios de esta bahía. Durante estos eventos se tomaron muestras para determinar abundancia, biomasa planctónica, nutrientes, oxígeno disuelto y temperatura. En junio, la temperatura osciló entre 19.0 °C y 19.6 °C y el oxígeno entre 4.7 mg l⁻¹ y 4.2 mg l⁻¹. En julio fue de 24.2 °C y 6.7 mg l⁻¹ y disminuyó a 20.0 °C y 3.5 mg l⁻¹ a 25 m de profundidad. Los nutrientes fueron bajos, siendo únicamente altos los de amonio en superficie (1.14-2.27 µM). Se presentaron valores altos de biomasa, expresada como clorofila a (55.6 µg l⁻¹), clorofila c (6.0 µg l⁻¹) y de aloxantina (8.1 µg l⁻¹); este último, es característico de criptofitas asociadas con el ciliado *M. rubra*, el cual alcanzó densidades máximas de 2.14 × 10⁶ células l⁻¹. Los vientos dominantes de junio fueron del sureste (3.0 m s⁻¹- 4.5 m s⁻¹) y de 1.7 m s⁻¹- 4.8 m s⁻¹ en julio. La débil estratificación y la presencia en superficie de *M. rubra* durante la tarde, sugieren que los vientos del sureste promueven la mezcla de la columna de agua. Esto propicia la remoción de nutrientes de los sedimentos hacia la superficie, promoviendo el incremento de la abundancia de la criptofita.

Palabras clave: ciliados, pigmentos fotosintéticos, nutrientes, procesos de mezcla

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INTRODUCTION

The protozoan *Myrionecta rubra* (Lohmann, 1908) Jankowski, 1976 is a cosmopolitan planktonic ciliate (Cloern *et al.*, 1994), and whose swimming capacity under experimental conditions of up to 8 mm s⁻¹ (Lindholm, 1985; Crawford & Purdie, 1992; Fenchel & Hansen,

2006) allows it to make extensive vertical migrations (Rychert, 2004). Although *M. rubra* is a mixotrophic species that feeds on phytoplankton and bacteria (Myung *et al.*, 2006), it also has the capacity to retain ingested chloroplasts (Gustafson *et al.*, 2000) that enhance growth rates. Recently, Johnson *et al.* (2007) observed that the cryptophyte nucleus is retained

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ned in *M. rubra* for up to 30 days and remains transcriptionally active, permitting the temporary access to the genetic information and the biochemical potential of other species. These successfully 'feeding' strategies permit formation of dense red tides in many coastal and upwelling zones (Hayes *et al.*, 1989). Blooms of this species are more frequent in cold and temperate coastal waters, but they are also present in upwelling zones, estuaries, and bays (Packard *et al.*, 1978; Wilkerson & Grunseich, 1990; Daneri *et al.*, 1992; Cloern *et al.*, 1994; Gárate-Lizárraga *et al.*, 2002; Proença, 2004; Bulit *et al.*, 2004). Several mechanisms of bloom formation have been proposed. For instance, in upwelling zones the combination of movements of convection and convergence of waters, daily migratory patterns, and nutrient enrichment have been proposed (Packard *et al.*, 1978). In estuaries, vertical migrations are considered very important to avoid the turbulence generated at the surface layer during tidal reflux, thereby enabling them to stay in the estuaries (Crawford & Purdie, 1992; Daneri *et al.*, 1992). Other mechanisms include weak mixing conditions that permit fast biomass production in the photic zone and biomass retention on the surface by phototaxis (Cloern *et al.*, 1994; Proença, 2004).

Several authors have reported blooms of this species in the Gulf of California, particularly in the central part of the Northern Gulf, and from Espíritu Santo and Cerralvo Islands in Bahía de La Paz, during winter-spring (Hernández-Becerril, 1987; Cortés-Altamirano, 1984; Manríque & Molina, 1997; Gárate-Lizárraga *et al.*, 2001, 2002, 2006). Although hydrographic conditions were not reported, high instability of the water column was linked to northwestern winds and upwelling conditions during this period (Soto-Mardones *et al.*, 1999). These data suggest that *M. rubra* blooms occur under unstable water column conditions. In this study, we describe bloom conditions of *M. rubra* in Bahía de La Paz and a mechanism to explain their formation.

STUDY AREA

Bahía de La Paz is located on the southeastern coast of the Baja California Peninsula, approximately 180 km north of the mouth of the Gulf of California between 24° 06' N and 24° 47' N, 110° 16' W and 110° 45' W (Fig. 1). The bay has a water exchange with the southwestern part of the Gulf of California. In this zone the presence of a cyclonic gyre introduces water into Bahía de La Paz and probably regulates primary production in the bay (Monreal-Gómez *et al.*, 2001). Mixing is under the seasonal influence of winter winds from the northwest from November through April. Stratification occurs in spring and summer from May through October, but it can be interrupted by south-southeast winds that, in shallow areas not far from shore, generate convection or upwelling movements in the southern end of the bay that re-suspend nutrients and enrich the water column (Reyes-Salinas, 1999). The tidal regime is mixed semi-diurnal (Obeso-Nieblas *et al.*, 1993). Freshwater runoff is scarce (Jiménez-Illescas *et al.*, 1997; Robles Gil-Metre, 1998). During the summer, salinity increases from evaporation, high surface water temperatures prevail, and stratified layers occur when winds do not mix the water column.

MATERIALS AND METHODS

On June 17 and July 12 of 2005, red tides occurred in Bahía de La Paz (Fig. 1). These were sampled at 0 m and 3 m at sampling stations 1 and 2 during the June event and in station 3 at 0 m, 3 m, 5 m, 10 m, 15 m, and 25 m during the July event. Temperature, dissolved oxygen (Winkler method), and nutrients (nitrates, nitrites, ammonium, reactive phosphorus, and reactive silica) were measured, using methods described in Strickland & Parson (1972). Temperature was measured directly with a bucket thermometer. For nutrients, a continuous-flow auto-analyzer (Quik Chem, Series 8000, Milwaukee, WI, USA) was used. Photosynthetic pigments were identified and quantified with HPLC (high-performance liquid chromatography), according to Vidussi *et al.* (1996). Taxonomic identification followed the work of Lassus (1988) and Taylor *et al.* (1971). Phytoplankton counts were made with an inverted microscope (Zeiss,

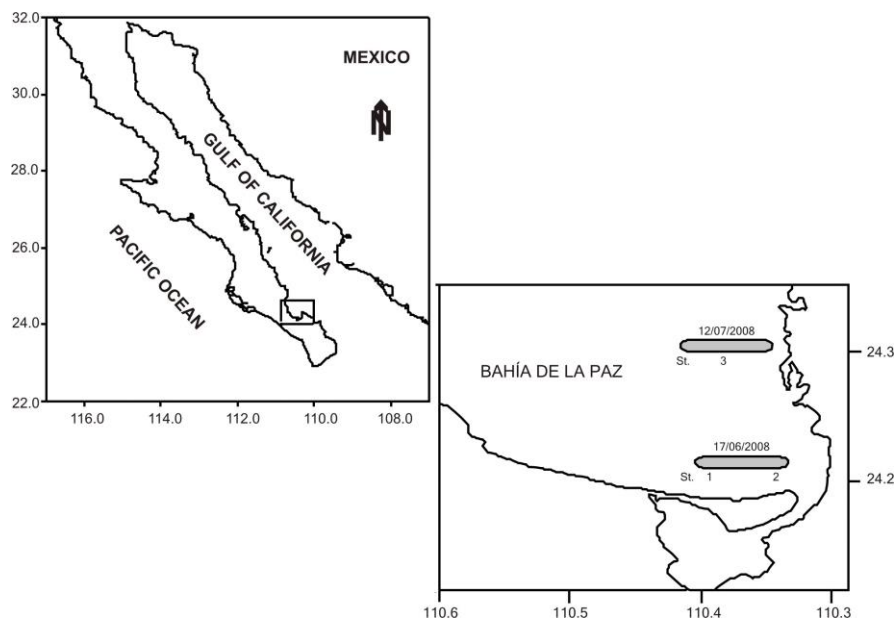


Figure 1. Study area and sampling stations (st.) of *Myrionecta rubra* blooms.

Germany), using 10-ml sedimentation chambers (Hasle, 1978). Wind data (speed and direction) were obtained from the automated meteorological station at CIBNOR, ~25 km west of the bloom area (<http://www.cibnor.mx/meteo>).

To characterize water column stability (July event) a stratification index was calculated as the difference of temperature/m at each sampling depth (Bustillos-Guzmán *et al.*, 1995). The values of this index ($^{\circ}\text{C m}^{-1}$) permitted the definition of hydrographic conditions as follow: index value < 0.05 indicates mixing, >0.05 and <0.2 indicates transition and >0.2 indicates stratification (López-Cortés *et al.*, 2003).

RESULTS

In June surface temperature at Stations E1 and E2 were 19.0°C and 19.6°C ; dissolved oxygen was 4.7 mg l^{-1} and 4.2 mg l^{-1} , respectively. During July, both variables increased at both stations to $\sim 24.2^{\circ}\text{C}$ and 6.7 mg l^{-1} at the surface. Temperature gradually decreased to 20.0°C at 25 m (Fig. 2 A). Oxygen concentrations varied little at the surface and 15 m (5.9 mg l^{-1}) and decreased to 3.5 mg l^{-1} at 25 m (Fig. 2 B). Low temperatures appear to be a general feature of deep bay water, as sugges-

ted by satellite images (Figs. 3 A, B). The thermal stratification index was $0.18^{\circ}\text{C m}^{-1}$, which indicated one transitional mixing-stratification state. Nutrient concentrations were relatively low at the surface during both events. Nitrate ranged from $0.16\text{ }\mu\text{M}$ to $0.82\text{ }\mu\text{M}$ and ammonium from $1.14\text{ }\mu\text{M}$ to $2.27\text{ }\mu\text{M}$; both decreased with depth (Figs. 4 A, B). Phosphates ranged from $1.12\text{ }\mu\text{M}$ to $1.64\text{ }\mu\text{M}$ at the surface to 25 m, and silicates from $8.90\text{ }\mu\text{M}$ to $16.30\text{ }\mu\text{M}$ from the surface to 25 m (Figs. 4 C, D).

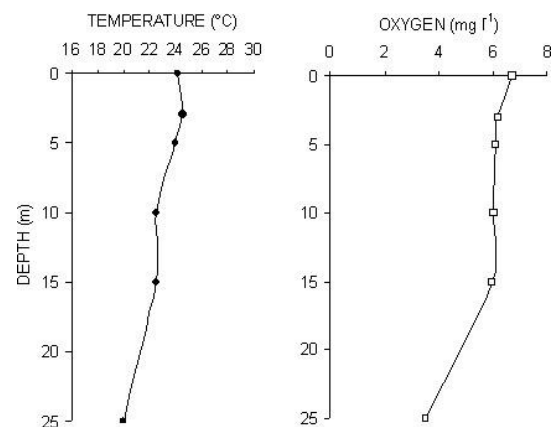


Figure 2. Vertical profile of temperature and dissolved oxygen during the *Myrionecta rubra* bloom of 12 July 2005 in Bahía de La Paz.

Southern winds dominated during both sampling periods at 3.0 m s^{-1} – 4.5 m s^{-1} in June and 1.7 m s^{-1} – 4.8 m s^{-1} in July (Figs. 5 A, B). Abundance of *M. rubra* was 8.62×10^4 cells l^{-1} in June and 2.14×10^6 cells in July. Pigment

signatures suggested the presence of other phytoplankton groups (dinoflagellates and diatoms), however they were not confirmed under the microscope. Density of cryptophytes was of 4.0×10^4 in June and 6.0×10^4 cells l^{-1} in

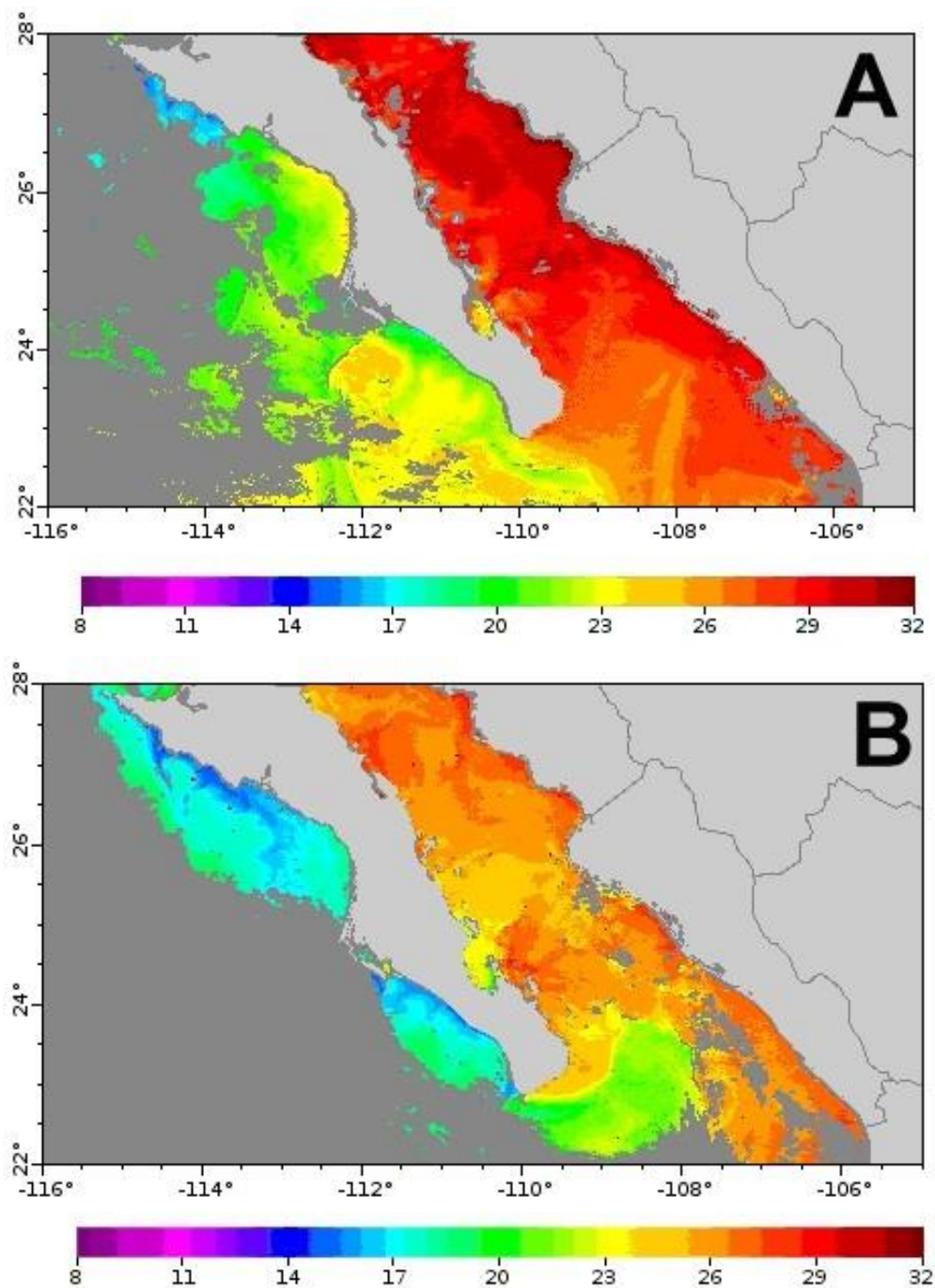


Figure 3. Sea WiFS images showing temperature variations in Bahía de La Paz (A) 17 June 2005 composite image. (B) 12 July 2005 composite image. Seasurface temperature maps were obtained from the CoastWatch Program, National Oceanic and Atmospheric Administration.

July. Both ciliates and cryptophytes decreased sharply with depth (Fig. 6). Pigment analyses showed mainly chlorophyll *a* and alloxanthin. This carotenoid is a characteristic pigment for cryptophytes (Jeffrey & Veski, 1997). At the surface of Station E1, chlorophyll *a* was $38.6 \mu\text{g l}^{-1}$, $22.2 \mu\text{g l}^{-1}$ at E2, and $55.6 \mu\text{g l}^{-1}$ at E3. Alloxanthin concentrations were 5.7, 3.1, and $8.1 \mu\text{g l}^{-1}$ at Stations E1, E2, and E3, respectively. The pigment profile at Station E3 was highest at the surface ($55.6 \mu\text{g-Chl } a \text{ l}^{-1}$), noticeably decreased at 3 m ($2.9 \mu\text{g Chl } a \text{ l}^{-1}$), and declined further at 25 m ($1.1 \mu\text{g-Chl } a \text{ l}^{-1}$) (Fig. 7 A). A similar profile pattern occurred for alloxanthin (Fig. 7 B). Values of other pigments, such as peridinin and fucoxanthin, were very low ($<0.08 \mu\text{g l}^{-1}$), suggesting that dinoflagellates and diatoms were uncommon.

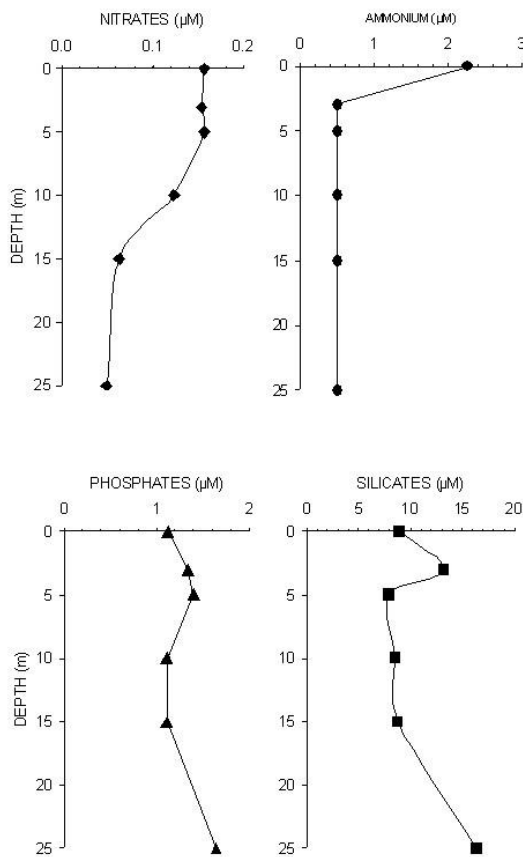


Figure 4. Vertical profile of nutrients (N-NO_3^- , N-NH_4^+ , P-PO_4^{3-} , S-SiO_2^-) during the *Myrionecta rubra* bloom in Bahía de La Paz.

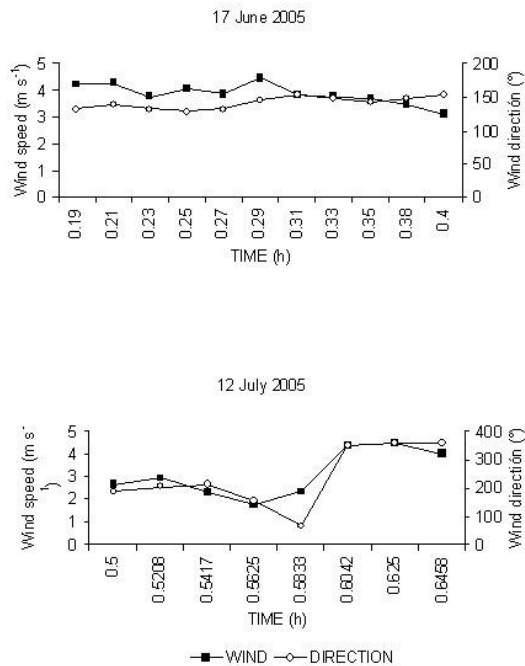


Figure 5. Speed and direction of wind during the *Myrionecta rubra* bloom in Bahía de La Paz.

DISCUSSION

The ciliate *Myrionecta rubra* inhabits waters with temperatures ranging from 2.0°C to 32.0°C and salinities ranging from 4.0 psu to 35.0 psu (Taylor *et al.*, 1971; Bulit *et al.*, 2004) and has a mixotrophic diet (Gustafson *et al.*, 2000; Johnson & Stoecker, 2005). In our area, blooms occur from the beginning of winter (December-January), coinciding with coastal upwelling (Gárate-Lizárraga *et al.*, 2001, 2006) to the end of June. In other regions of the Gulf of California, blooms have also been recorded during upwelling events (Gárate-Lizárraga *et al.*, 2001, 2002) in waters where temperature and salinity ranged from 20.3°C to 23.2°C and 34.7 psu to 35.2 psu. Our records of surface temperature are similar to events in other places. However, blooms occur during the early-summer when the water column is at least partially mixed (stratification index = $0.18^\circ\text{C m}^{-1}$) and temperatures are relatively low. For instance, Reyes-Salinas (1999) recorded SST of 27°C to 28°C decreasing to 25°C at 25 m - 30 m for the same area and months. At our stations, the water column was relatively cold, probably caused by upwe-

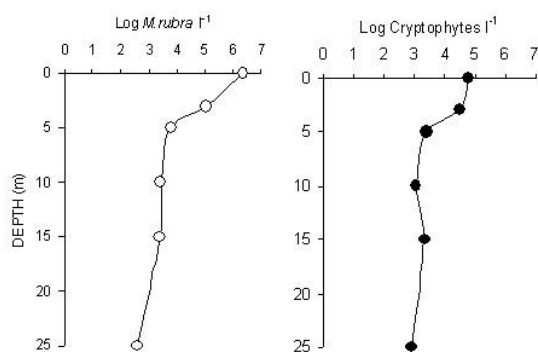


Figure 6. Vertical profile of concentrations of *Myrionecta rubra* (A) and cryptophytes (B) during the *M. rubra* bloom in Bahía de La Paz. Note cell concentration is in logarithm scale.

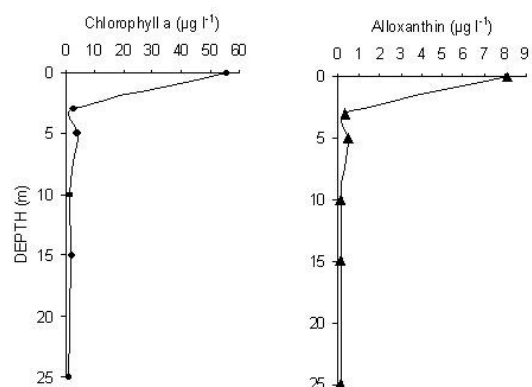


Figure 7. Vertical profile of concentrations of: chlorophyll a (A) and alloxanthine (B) during the *Myrionecta rubra* bloom in Bahía de La Paz.

ling in the bay. These short-term events have been recorded during summer (Grana-dos-Guzmán & Álvarez-Borrego, 1984; López-Cortés *et al.*, 2006; Gárate-Lizárraga *et al.*, 2007), generated by steady southeastern winds (Roden, 1964; Lavin *et al.*, 1997). Satellite images show areas of the southeastern bay with low temperatures (Figs. 3A, B), which is supportive evidence of upwelling.

Some studies have demonstrated that when cryptophyte populations increase, *M. rubra* sequesters more cryptophyte chloroplasts, which increases population growth of the ciliate (Gustafson *et al.*, 2000; Yih *et al.*, 2004; Johnson & Stoecker, 2005). Alloxanthin carotenoid is dominant in both kinds of organisms and their concentration varies with the density of *M. rubra*, which strongly suggests that cryptophytes are the main food source.

Our findings show high concentrations of cryptophytes, mainly in shallow waters at concentrations of 6.0×10^4 cells l^{-1} , so it is plausible that the cryptophytes stimulate blooms of *M. rubra*. Low values of alloxanthine ($<0.5 \mu g l^{-1}$) have been reported during the phytoplankton spring blooms in the central North Sea (Gieskes & Kraay, 1983). Similar values have also been recorded in an oligotrophic eastern Adriatic estuary (Vilicic *et al.*, 2008). We found similar values of alloxanthine (0.11 – $0.48 \mu g l^{-1}$). The highest value ($8.12 \mu g l^{-1}$) was due to the contribution of cryptophyta, as well as the chloroplast of cryptophyta inside *M. rubra*.

High wind speeds (up to $4.8 m s^{-1}$) probably provoked the mixing of the water column, but apparently the winds were not sufficiently strong to reduce the movement of *M. rubra* towards the surface. This seems to be a common condition. For example, in the Gulf of Naples, Italy, high concentrations of *M. rubra* (16.4×10^4 cells l^{-1}) in June, immediately after a major mixing event from a storm in May, the seasonal thermocline of the water column was partially eroded (Modigh, 2001).

Nutrients seem to have an important role in the formation and maintenance of *M. rubra* blooms. Packard *et al.* (1978) showed that after relaxation of upwelling in the Baja California, there was enrichment by phosphate ($1.5 \mu M \pm 0.3 \mu M$), silicate ($15.9 \mu M \pm 0.6 \mu M$), and nitrate ($9.9 \mu M \pm 3.4 \mu M$), which coincided with blooms of *M. rubra*. Interestingly, ammonium remained constant with or without the presence of *M. rubra*. In an area of upwelling in Peru, nitrate levels were low, but ammonium, phosphate, and silicate remained unchanged, with or without the presence of *M. rubra* (Wilkerson & Grunseich, 1990). In that area, nitrate contents were low in shallow waters inhabited by the ciliate because of its capacity to take up nitrates during the day and ammonium at night. These physiological characteristics support massive blooms. Conditions during our study included a relatively mixed water column, low concentrations of nitrate to depths of 25 m, and high concentrations of ammonium near the surface, which coincided with the highest concentration of *M. rubra* at the surface. This suggested upward migration of the ciliates during the day, a feeding activity that depleted nitrate

from the top of the water column, by the activity of cryptophytes, and sequestered chloroplast by ciliates.

In summary, *M. rubra* blooms during the summer are the result of southeastern winds mixing the water column, re-suspension of nutrients into the euphotic zone, decreasing of these winds and migration of *M. rubra* to the surface, uptake of the re-suspended nutrients, and rapid growth that generates large populations and biomass over relatively short periods (Cortés-Altamirano *et al.*, 2004).

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