Bio-optical characteristics of a phytoplankton bloom event off Baja California Peninsula (30–31°N)

Óscar A. Barocio-León, Roberto Millán-Núñez, Eduardo Santamaría-del-Ángel, Adriana Gonzalez-Silva, Charles C. Trees, Elizabeth Orellana-Cepeda

Facultad de Ciencias Marinas, Universidad Autónoma de Baja California, Km. 103 Carretera Tijuana-Ensenada, Ensenada, Baja California, C.P. 22830, Mexico

NATO Undersea Research Centre, Viale San Bartolomeo 400, 19138 La Spezia, Italy

Received 8 July 2007; received in revised form 27 November 2007; accepted 13 December 2007

Abstract

A phytoplankton bloom was detected in the Southern California Current System, off the Baja California Peninsula (Mexico) on June 2003 with chlorophyll-a concentration (TChl) of 10.13 mg m⁻³. Two stations (D1 and D2) were sampled on June 24, and D2 was resampled 6 days later; chlorophyll-a concentration had decreased by about one half. LAC MODIS-Chl images were obtained and showed the spread of the bloom on the day after sampling. The phytoplankton community consisted primarily of dinoflagellate temporary cysts, mainly at the surface and at 5 m in station D1. Two Pseudo-nitzschia species (P. australis, P. seriata) were also very abundant. Samples from the bloom had a specific phytoplankton absorption coefficient (a(ph)(λ)) lower than the rest of the samples. Values varied from 0.0186 to 0.0455 m² mg⁻¹ for a(ph)(440) and from 0.0092 to 0.0294 m² mg⁻¹ for a(ph)(675), with ratios a(ph)(440):a(ph)(675) ranging from 0.99 to 2.20. These low ratios were associated with the combined effect of packaging, and with the relatively high ratios of fucoxanthin, peridinin, diadinoxanthin and chlorophyll-c to TChl. Samples from the surface and 5 m depth at station D1 had higher ratios of Perid:TChl (0.12–0.32) than the rest of the samples, suggesting that cysts have similar Perid:TChl as free-living dinoflagellates. An unusual absorption spectrum with a broad maximum around 480–500 nm was associated with the high proportion of cysts and diatoms. The slope of the spectra between 443 and 488 nm was a good index to differentiate bloom samples containing high proportions of dinoflagellate temporary cysts. Further investigation of the absorption properties of dinoflagellate cysts is needed in order to detect these waters by remote sensing. Although much work is still necessary to understand and explain the bio-optical properties of a bloom, the present study is the first assessment off the Baja California coast to simultaneously consider aspects such as absorption properties, pigment composition and to include a spatial evaluation of the extension of a bloom with satellite images.

Keywords: Phytoplankton; Absorption coefficient; Pigments; HPLC; Dinoflagellate cyst; Pseudo-nitzschia; Mexico; California Current (30–31°N)

1. Introduction

Phytoplankton blooms are events of proliferation of microalgal organisms in an aquatic environment. They can be quick events that begin and end within a few days or they may stay for several weeks; they can occur on a relatively small scale or cover hundreds of square kilometers of the ocean’s surface. The excessive growth of algae during a bloom usually causes water discoloration, turning it red to brown or green, depending on the predominant species and it may disrupt higher links of the local food web. Cells that die and sink to the bottom stimulate bacterial growth and deplete oxygen near the bottom layers that can kill fish and other organisms, leading to the eutrophication of the system (Quilliam, 2003).

Blooms may also be of concern as some microalgal species produce toxins. Among the thousands of

0278-4343/S - see front matter © 2007 Elsevier Ltd. All rights reserved.
Among the most common species causing blooms are dinoflagellates and diatom species, about 300 can at times produce blooms, while only 80 or so species have the capacity to produce potent toxins that can find their way through fish and shellfish to humans (Hallegraeff, 2003). The frequency of occurrence, abundance and geographical range of many harmful algal blooms (HABs) appears to be increasing worldwide. Several hypotheses have been proposed to explain this apparent increase in algal blooms; four major ones are: increased scientific awareness of toxic species; increased utilization of coastal waters for aquaculture; stimulation of plankton blooms by cultural eutrophication and/or unusual climatological conditions; and transportation of dinoflagellate resting cysts either in ballast water of ships or associated with translocation of shellfish stocks from one area to another (Hallegraeff, 2003).

Eastern boundary upwelling coasts, such as the California Current System (CCS), are characterized by highly productive upwelling regimes, which account for a large fraction of global fisheries production, but are increasingly susceptible to the proliferation and negative effects of HABs (Kudela et al., 2005). These blooms in upwelling systems have been closely linked to wind events, which is the main driving force in these systems (Pitcher et al., 1998).

Paralytic shellfish poisoning (PSP), resulting from a number of saxitoxin derivatives produced by dinoflagellates of the genus Alexandrium, and Domoic acid poisoning (DAP) caused by diatoms of the genus Pseudo-nitzschia, are the primary HAB problems (Horner et al., 1997) in the CCS. Off the northern Baja California area (31°35′N, 116°45′W), the most important potential harmful diatoms are Pseudo-nitzschia australis, Pseudo-nitzschia multiseries and Pseudo-nitzschia pseudodelicatissima (Orellana-Cepeda et al., 2004a). These diatoms are known to bloom regularly during spring-summer, a few days after the beginning of upwelling (Orellana-Cepeda et al., 2004b). Dinoflagellate blooms have also been recurrent during spring and the beginning of summer in the Southern California area (Kahru and Mitchell, 1998; Peña-Manjarrez et al., 2005). Among the most common species causing blooms are Lingulodinium polyedra and Prorocentrum micans.

This study reports our observations and findings of an algal bloom dominated by dinoflagellate temporary cysts and two species of Pseudo-nitzschia observed during June of 2003 off the northern Baja California coast with analysis of in situ water column measurements supplemented by satellite images. This examination of the algal bloom with physical and bio-optical water column measurements contributes to our knowledge of water conditions and especially of the optical characteristics of the phytoplankton community involved. In addition, the use of satellite images (MODIS) allowed us the opportunity to estimate the spatial distribution of the bloom.

2. Materials and methods

Between June 20 and 30, 2003, an oceanographic cruise along the Baja California coast was conducted on board R/V Río Suchiate, from the Mexican Navy; 49 stations were visited in the southern region of the California Current from the USA–Mexico borderline to Punta Eugenia. At two of the stations we found a phytoplankton bloom close to the shore, off San Quintin Bay (stations D1 and D2) (Fig. 1). These stations were sampled on June 24, with station D2 resampled again on June 30 during transit back to Ensenada.

For each station, two CTD casts were performed; the first one with a SeaBird CTD measuring physical parameters (temperature and conductivity) just above the sea floor or to 200 m where the bottom was deeper. The other CTD (Ocean Sensors 200), equipped with a fluorimeter (Chelsea Aquatrak III) and an underwater irradiance sensor (Li-Cor spherical SPQA), was deployed to select the four sampling depths (surface, above the DCM, at the DCM and below it). Water samples were collected from four pre-selected depths using 5-L Niskin bottles and subsamples taken for phytoplankton counts, phytoplankton absorption coefficient $\alpha_{ph}(\lambda)$ and pigment concentration measurements. These depths were 1, 5, 10 and 15 m for stations D1 and D2 on June 24, and 1, 10, 15 and 20 m for station D2 on June 30.

Samples for phytoplankton counts were stored in amber high-density polyethylene 250 mL Nalgene bottles and preserved with 2.5 mL of acid Lugol’s solution (Andersen and Throndsen, 2003). To estimate phytoplankton abundance, we used the Utermöhl (1958) technique with an inverted phase contrast Zeiss microscope. Aliquots of 2, 5 and 10 mL were settled and counts were done after 24 h.
Identification of the most important diatoms was performed by Scanning Electron Microscope (SEM) (Hasle and Syvertsen, 1997).

Two liters of seawater were filtered through Whatman GF/F filters with positive pressure and immediately frozen and stored in liquid nitrogen until analysis in the laboratory at the Center of Hydro-Optics and Remote Sensing (CHORS) in San Diego, California. Chlorophylls and carotenoids were separated using HPLC (Wright et al., 1991) with an ODS-2 C18 column using a three solvent gradient system at a flow rate of 1 mL min⁻¹. The separation of the various pigments required 25 min with the pigment peaks being detected by an absorption detector (ThermoQuest UV6000 scanning diode array detector, from 190 to 800 nm at 1 nm resolution). In addition, a ThermoQuest FL 3000 scanning fluorescence detector was used to detect and quantify the various Chl degradation products, which occur at lower concentrations. Canthaxanthin was used as an internal standard for correcting changes in volume during the extraction process.

Two liters of seawater were filtered through Whatman GF/F filters (25 mm) with positive pressure, and preserved in liquid nitrogen. In the laboratory, blank filters were saturated with filtered seawater, which had been irradiated with UV lamps (25 W). Absorption of the blank filters was measured on a Perkin-Elmer Lambda 10 spectrophotometer with integrating sphere, following the procedure in Mitchell et al. (2003). The absorption was measured from 400 to 750 nm with a resolution of 1 nm before and after rinsing the filters with hot methanol (Kishino et al., 1985) for 15 min twice. Particulate (aₚ(λ)) and detritus absorptions (aₒ(λ)) were determined using the equation:

\[
a(\lambda) = \left( \frac{2.303 \cdot S}{V} \right) (0.4068\text{OD} + 0.368\text{OD}^2)
\]

where S is the filter clearance area, V is the filtered volume, 0.4068 and 0.368 are the coefficients to correct the increase in pathlength caused by multiple scattering in the glassfiber filter, which were previously determined for this spectrophotometer.

Phytoplankton absorption aₒ(λ) was determined by the difference between total particulate matter absorption aₚ(λ) and non-pigmented detritus material aₒ(λ). The specific absorption coefficient by phytoplankton (aₒₚ(λ)), with units m⁻² (mg Chl:a)⁻¹ was obtained by standardizing aₒₚ(λ) (m⁻¹) by the concentration of TChl [mg m⁻³] measured by HPLC, where TChl [mg m⁻³] is the summation of chlorophyllide a, allomer and epimer Chl a, and monvinyl and divinyl Chl a (Trees et al., 2000). Wavelengths 440 and 675 nm (aₒₚ(440) and aₒₚ(675)) were used as indices of pigment absorption peaks. To compare curve shapes, normalized absorption (A, adimensional) was plotted, which was calculated by normalizing the spectrum aₒₚ(λ) to the absorption maxima in the blue (around 440 nm).

3. Results

3.1. Oceanographic conditions

During the survey, high concentrations of TChl were observed at stations D1 (8.60 mg m⁻³ at surface and 8.65 mg m⁻³ at DCM) and station D2 (8.88 mg m⁻³ at surface and 10.13 mg m⁻³ at DCM) on June 24, 2003. We also sampled station D2 on June 30 (6 days later), and found that TChl concentration had diminished to 2.56 mg m⁻³ at the surface and to 4.08 mg m⁻³ at the DCM. LAC MODIS/Aqua images show a relatively high Chl concentration along the Baja California west coast on June 24 with a considerable increase in concentration and extension on June 25 (not sampled in situ) (Fig. 2).

An upwelling condition prevailed along the Baja California coast during the survey (Fig. 1). It was stronger in front of San Quintin and in front of Point Canoas. Fig. 3 shows the temperature profile of transect D, with a “dome” of cooler water at station D2 (14.4°C at surface), even colder than at station D1 (14.6°C at surface).

3.2. Phytoplankton community structure

Phytoplankton community structure was dominated by a combination of dinoflagellate round to ovoid temporary cysts (10–15 μm in diameter) and diatoms. The dominant diatom species were *Pseudo-nitzschia australis* and *Pseudo-nitzschia seriata*, but other species were also present, as *Thalassiosira* spp., *Leptocylindrus* spp., *Cylindrotheca closterium* and *Nitzschia longissima*. Dinoflagellate temporary cysts were very abundant, exceeding the number of diatom cells. Some dinoflagellates were also present (*P. micans* and *gracile, Protoperidinium* spp., *Amphidinium* spp., *Akashiwo sanguinea* and *Gymnodinium* spp.), but with
a relative small abundance compared to dinoflagellate temporary cysts and diatoms (Fig. 4, Table 1). Station D2 had a relatively higher abundance of dinoflagellates and lower number of cysts on June 30 than on June 24 but with an overall lower pigment concentration (maximum TCha of 4.08 mg m$^{-3}$).

3.3. Phytoplankton pigment composition

From the HPLC analysis, the accessory pigments with elevated concentrations were chlorophyll $c_2$ (Chl$c_2$), fucoxanthin (Fuco), peridinin (Perid) and diadinoxanthin (Diad) (Fig. 5). At station D1, Perid was the main accessory pigment at the surface and at 5 m, while samples from 10 and 15 m were dominated by Fuco. Station D2 was dominated by Fuco at all depths on both days (June 24 and 30), but Perid diminished considerably and chlorophyll $b$ (Chlb) increased in the samples of June 30, compared to those of June 24. Chl$c_2$ was present in similar proportions in samples from the bloom and outside of it, with a tendency to increase with depth. Both stations from the bloom presented similar proportion of Diad, being higher at surface, with the tendency to decrease with depth. The presence of these accessory pigments coincide with phytoplankton groups observed from microscopic enumeration.

3.4. Phytoplankton absorption

Absorption spectra curves from the bloom (stations D1 and D2 on June 24) were notably different from the rest of
Table 1
Phytoplankton counts by group (cells L\(^{-1}\) x 10\(^3\)) at stations D1 (June 24) and D2 (June 24 and 30)

<table>
<thead>
<tr>
<th>Station D1 (June 24)</th>
<th>Station D2 (June 24)</th>
<th>Station D2 (June 30)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 m</td>
<td>5 m</td>
</tr>
<tr>
<td>Total diatoms (%)</td>
<td>548.2</td>
<td>618.4</td>
</tr>
<tr>
<td>(54%) (72%) (39%) (22%)</td>
<td>618.4 (72%) (39%) (22%)</td>
<td>690.2 (39%) (22%) (10%) (5%)</td>
</tr>
<tr>
<td>Total dinoflagellates %(50 (\mu m))</td>
<td>7.2</td>
<td>16.4</td>
</tr>
<tr>
<td>(79%) (19%) (47%) (46%)</td>
<td>6.8 (20.7) (6.8) (3.2)</td>
<td>5.5 (3.2) (5.5) (2.8)</td>
</tr>
<tr>
<td>Dinoflagellate cysts (100%)</td>
<td>38.8</td>
<td>402.5</td>
</tr>
<tr>
<td>Silicoflagellates (100%)</td>
<td>0.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Total (100%)</td>
<td>4979.9</td>
<td>5296.3</td>
</tr>
<tr>
<td>(a_{440}^c) (440)</td>
<td>0.0220</td>
<td>0.0284</td>
</tr>
<tr>
<td>(a_{675}^c) (675)</td>
<td>0.0221</td>
<td>0.0221</td>
</tr>
<tr>
<td>(a_{440}^c/a_{675}^c)</td>
<td>0.99</td>
<td>1.28</td>
</tr>
<tr>
<td>Chl(a)</td>
<td>8.59</td>
<td>8.08</td>
</tr>
<tr>
<td>Chl(c2)</td>
<td>1.88</td>
<td>1.80</td>
</tr>
<tr>
<td>Fuco</td>
<td>1.77</td>
<td>1.64</td>
</tr>
<tr>
<td>Perid</td>
<td>2.49</td>
<td>2.59</td>
</tr>
<tr>
<td>Chl(c2)/TChl(a)</td>
<td>0.22</td>
<td>0.22</td>
</tr>
<tr>
<td>Fuco/TChl(a)</td>
<td>0.21</td>
<td>0.20</td>
</tr>
<tr>
<td>Perid/TChl(a)</td>
<td>0.29</td>
<td>0.32</td>
</tr>
</tbody>
</table>

In parenthesis is indicated the percentage of cells smaller than 50 \(\mu m\) within the group. Specific absorption coefficients of phytoplankton at 440 nm \(a_{440}^c\) and 675 nm \(a_{675}^c\) in \(m^2 mg TChl^a_1\). Ratio \(a_{440}^c/a_{675}^c\). Total chlorophyll \(a\) (TChl\(a\)), chlorophyll \(c2\) (Chl\(c2\)), fucoxanthin (Fuco) and peridinin (Perid) concentrations in \(mg m^3\). Pigment ratios Chl\(c2\)/TChl\(a\), Fuco/TChl\(a\) and Perid/TChl\(a\).
The absorption curves for surface and 5 m samples at station D1 showed a shift in their maximum absorption peak from 440 to around 480–500 nm (Fig. 6). Another peculiarity of these spectra is that they present a notably lower ratio $a_{ph}(440):a_{ph}(675)$ (Table 1). The absorption spectrum of the following depth (10 m) changes its shape and shows its maximum absorption peak at 465 nm, while that of 15 m depth has two maximum (465 and 440 nm).

The absorption spectra from station D2 are very similar to the deep samples (10 and 15 m) of station D1. They have their absorption maximum at 465 nm and shoulders at 440 nm and around 490 nm. Their ratio $a_{ph}(440):a_{ph}(675)$ is also low (Table 1).

When this same station (D2) was revisited on June 30 the absorption spectral curves changed and their shape (Fig. 6) is similar to those observed on the rest of the stations of the same cruise (data not shown). Here, the ratio $a_{ph}(440):a_{ph}(675)$ increased (Table 1).
On June 30, the bloom had diminished considerably or migrated (Table 1). No MODIS images were obtained in the next 5 days after June 25 due to cloud cover, so it is unclear how the bloom evolved between June 25 and 30, except that dinoflagellates increased 1 order of magnitude, temporary cysts decreased 2 orders of magnitude and diatoms decreased 1 order of magnitude in those 5 days for station D2. Diatoms were the dominant group as confirmed by the high proportion of Chl c2 and Fuco (Fig. 5), but the dominant species was not from the genus *Pseudo-nitzschia*, as on June 24. In fact, the community structure changed notably from June 24 to 30 and could be considered as ‘non-bloom samples’, similar to the ‘average’ phytoplankton community and pigment composition found within the same cruise.

4.1. Phytoplankton pigments

Dinoflagellates characteristically contain Perid as their signature pigment. In contrast, diatoms contain Fuco and Chl c2, but these pigments can also be found in prymnesiophytes, chrysophytes and raphidophytes, and Chl c2 is also found in cryptophyta and several dinoflagellates (Jeffrey et al., 1997). However, microscopic counts confirmed that the high ratios of Perid, Fuco and Chl c2 to TChl a from the bloom samples were mainly due to the abundance of dinoflagellate temporary cysts and diatoms (Table 1).

Perid:TChl a ratios from the bloom samples (0.12–0.32) were higher than the rest of the samples from the cruise. These ratios are similar to those found by Valenzuela et al. (2005) in monospecific dinoflagellate cultures (*Amphidinium carteri*) with different light and nutrient regimes. This implies that temporary cysts have similar Perid content as free-living dinoflagellates. Perid:TChl a was particularly high in samples from the surface and 5 m at station D1, which were the only two stations of the whole cruise where Perid:TChl a was higher than Fuco:TChl a. The high Perid:TChl a concentration coincided with the largest proportion of temporary cysts, which was more than sixfold the number of diatoms (Table 1).

Diatoms are widely distributed in the whole region from the USA–Mexico borderline to Punta Eugenia (Barocio-León, 2006; Barocio-León et al., 2006). Samples from the Vizcaino Bay had higher ratios of Fuco:TChl a than those from the bloom. Ratios from the complete cruise ranged from 0.04 to 0.40, while samples from the bloom ranged from 0.20 to 0.32. Bloom samples contained the highest proportions of Chl c2 (stations D1 and D2 on June 24), with ratios of Chl c2:TChl a from 0.17 to 0.23, while these ranged from 0.01 to 0.23 in the rest of the samples. We attribute the high relative concentration of Fuco and Chl c2 to the widely spread distribution of diatoms in the area, specially *P. australis* and *P. seriata* in the samples from the bloom.

It should be considered that even for pure assemblages of phytoplankton, the relative concentration of the...
primary biomarker pigment can be highly variable (Mackey et al., 1996; Alvain et al., 2005), depending on the physiological state of the organisms (Jeffrey et al., 1997).

4.2. Effect of pigments on phytoplankton absorption

Pigments are widely used to characterize phytoplankton physiological state, species identity and biomass in marine and freshwater environments (Falkowski and Raven, 1997). Variations in the relative proportions of accessory pigments also alter the shape of the absorption spectrum of phytoplankton ($a_{ph}(\lambda)$) (Bricaud et al., 2004). Such $a_{ph}(\lambda)$ variations are due to physiological changes in cellular pigment ratios and pigment packaging (Sathyendranath et al., 1987; Moisan and Mitchell, 1999; Fujiki and Taguchi, 2002; Bricaud et al., 2004) and can also reflect variations in taxonomic composition (Johnsen and Sakshaug, 1996).

In our study, the most peculiar absorption spectrum curves were found in surface and 5 m samples of station D1 (Fig. 6), corresponding to those with high dinoflagellate temporary cyst dominance and an important presence of *P. australis* and *P. seriata*. Temporary cysts are known to be covered with a cellulose pellicle and to be in a “latent” physiological state, which allows them to bloom in a short period of time (Matsuoka and Fukuyo, 2000), so they may contain the photosynthetic pigments needed for an efficient light absorption and rapid growth. Evidence from our data indicates that their presence could explain the high Perid:TChl$a$ ratios of samples from the bloom. Additionally, in these spectra, the blue maximum absorption peak of Chl$a$ was shifted to higher wavelengths (480–500 nm) (Fig. 6), where, among other accessory pigments, Fuco and Perid have their maximum *in vivo* absorption peak (Bricaud et al., 2004).

The rest of the samples from the bloom [D1 (10 and 15 m) and D2 (all depths)] also presented their maximum absorption peaks mostly at wavelengths higher than 440 nm (Fig. 6). However, they did not have a broad peak (480–500 nm) as in surface and 5 m samples from station D1. The only difference between the D1 samples and the others was the high proportion of dinoflagellate temporary cysts. There are no previous works focused on absorption properties of dinoflagellate temporary cysts that could explain these peculiar absorption spectra. Indeed, we cannot rule out some particular effect of the cellulose wall on it although it was observed as very thin and pigments could be considered as “visible”. Further research is needed in this respect.

In comparison, community structure of the samples from June 30, considered as a “non-bloom sample”, was dominated by diatoms, as could be confirmed by the higher Fuco:TChl$a$ and Chl$c$:TChl$a$ than Perid:TChl$a$ ratios and microscopy counts (Table 1). These samples had very similar absorption spectra compared to the average of the rest of the stations from the same cruise, and are in
good agreement with those reported by Millán-Núñez et al. (2004) and Aguirre-Hernández et al. (2004) for this area. Additionally, in these spectra, the blue absorption peak of Chla was very depressed or flattened (Fig. 7). This also led to lower ratios \( a_{\text{ph}}^c(440)/a_{\text{ph}}^c(675) \) for stations D1 and D2 on June 24 than for the rest of the stations (Table 1). The package effect (also known as flattening effect) describes the decreased absorption of pigments in cells compared with the absorption potential for the same amount of pigment in solution (Duysens, 1956; Morel and Bricaud, 1981). An increase in pigment packaging occurs either as cell size increases or as the internal concentration of pigments increases (Morel and Bricaud, 1981; Sosik and Mitchell, 1995). Hence, it is expected to have a relative higher package effect in waters with high concentrations of large micro-phytoplankton (>20 \( \mu \)m) and lower in waters with predominance of pico-phytoplankton (<2 \( \mu \)m). In our data, we noted that the peak depression at 440 nm relative to that at 675 nm was higher when the shift to higher wavelengths was stronger. This observation agrees with Bricaud et al. (1995) who modeled a progressive shift to higher wavelengths of the blue maximum absorption peak with increasing Chla. They explained this pattern as a result of the combined effect of accessory pigments (in our case Perid, Fuco, Chl c2 and Diad) and packaging effect due to the dominance of relatively large cells (micro- and nanophytoplankton).

Taking into account a possible application of these results for remote sensing purposes, we plotted the ratios Perid:TChla, Fuco:TChla and Chl c2:TChla vs. the slope between \( a_{\text{ph}}^c(443) \) and \( a_{\text{ph}}^c(488) \), considering that these wavelengths correspond to MODIS channels. Samples with dominance of cysts showed a tendency to a positive slope, while most of the other stations had slopes between −0.004 and −0.008 (Fig. 8). The remote detection of phytoplankton biomass is based on remote sensing reflectance, where the effect of phytoplankton absorption may be masked by other factors (e.g. other components absorbing and scattering light in the water and atmosphere) (Carder et al., 1999; Morel and Maritorena, 2001). For this reason, the use of the absorption peculiarities observed here in order to be able to detect waters dominated by dinoflagellate temporary cysts with remote sensing data requires more investigation We believe that the measurement of water reflectance in situ and coinciding with measurements of the absorption properties of these organisms is necessary in order to better understand the bio-optical relationship between these variables.

5. Conclusions

The data analyzed in this work gave us some insights into the bio-optical properties of a bloom produced by a combination of dinoflagellates temporary cysts and diatoms. In general, data from the bloom showed a combination of high Chla concentration, large cells and high ratios Perid:TChla or Fuco:TChla (Table 1). This implies that both the unusual shape of the absorption spectra and the flattening effect observed were a result of the combined effect of accessory pigments (mainly Perid and Fuco) and the packaging effect due to the dominance of relatively large cells (micro- and nanophytoplankton). In addition, we cannot rule out the particular effect of the cellulose wall of the cysts on the shape of the absorption spectra. However, the relative importance of each factor (pigments, cell size or cellulose wall) could not be separately evaluated. We must emphasize the peculiar absorption properties of the samples dominated by dinoflagellate temporary cysts, which calls for further studies in this respect, especially on the application of absorption properties to the remote detection of phytoplankton blooms. Although much work is still necessary to understand and explain bio-optical properties of dinoflagellate temporary cysts, the present study is the first assessment off the Baja California Peninsula to simultaneously consider aspects such as absorption properties, pigment composition and to include a spatial evaluation of the extension of a bloom with satellite images.

Acknowledgments

This work was funded by projects 1361, 1374, 310 and 322 of the UABC. Cruises were supported by the Mexican Navy (Secretaría de Marina); physical data were generated by their CTD. The first author wishes to thank CO NAcYt for the scholarship granted during his Ph.D. studies. The authors wish to thank Jorge López-Calderón for his invaluable help during cruises and Israel Gradilla-Martínez for technical assistance with SEM. We gratefully acknowledge comments, suggestions and English revision of the editor and two anonymous reviewers.

References


Barocio-León, O., 2006. Variabilidad Espacial y Temporal del coeficiente de absorción y pigmentos del fitoplancton en la Corriente de Baja California. Ph.D. Thesis. Faculty of Marine Sciences, University of Baja California, Mexico, October 2006, 196pp.

