Journal of Marine Systems 160 (2016) 17–25

Contents lists available at ScienceDirect

Journal of Marine Systems

journal homepage: www.elsevier.com/locate/jmarsys

Bio-optical characteristics of a red tide induced by *Mesodinium rubrum* in the Cariaco Basin, Venezuela

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ARTICLE INFO

Article history:
Received 1 December 2015
Received in revised form 24 March 2016
Accepted 27 March 2016
Available online 10 April 2016

Keywords:
Mesodinium
Cryptophyceae
Algal bloom
Bio-optical properties
Southeastern Caribbean Sea

ABSTRACT

The bio-optical changes of the water induced by red tides depend on the type of organism present, and the spectral characterization of such changes can provide useful information on the organism, abundance and distribution. Here we present results from the bio-optical characterization of a non-toxic red tide induced by the autotrophic ciliate *Mesodinium rubrum*. Particle absorption was high [$a_p(440) = 1.78\ m^{-1}$], as compared to measurements done in the same region [$a_p(440) = 0.09 \pm 0.06\ m^{-1}$], with detrital components contributing roughly 11% [$a_d(440) = 0.19\ m^{-1}$]. The remainder was attributed to absorption by phytoplankton pigments [$a_{ph}(440) = 1.60\ m^{-1}$]. These a_{ph} values were ~15 times higher than typical values for these waters. High chlorophyll *a* concentrations were also measured (52.73 μg L^{-1}), together with alloxanthin (9.52 μg L^{-1}) and chlorophyll *c* (6.25 μg L^{-1}). This suite of pigment is typical of the algal class *Cryptophyceae*, from which *Mesodinium* obtains its chloroplasts. Remote sensing reflectance showed relatively low values [$R_{rs}(440) = 0.0007\ sr^{-1}$], as compared to other R_{rs} values for the region under high bloom conditions [$R_{rs}(440) = 0.0028\ sr^{-1}$], with maxima at 388, 484, 520, 596 and 688 nm. Based on the low reflection in the green-yellow, as compared to other red tides, we propose a new band ratio [$R_{rs}(688)/R_{rs}(564)$] to identify blooms of this particular group of organisms.

1. Introduction

Red tides have received increased attention during the last decades due to their apparent increase throughout the world, and in particular because of their harmful effects on fisheries, aquaculture and human health. Red tides have also been used as an indicator of water quality (Hallegraeff, 1993, 2010; Hallegraeff et al., 1995; Anderson, 2004; Azanza et al., 2005; Gilbert et al., 2005; Larkin and Adams, 2007; Alvarez-Salgado et al., 2009; Landsberg et al., 2009; Morgan et al., 2009; Pitcher and Probyn, 2011). The most visible manifestation of red tides is the change in water color, induced by the pigment contained within the organisms that comprise the bloom (Dierssen et al., 2006; Roesler and Boss, 2008). There can also be increased scattering which reduces the transparency of the water column (Cannizzaro et al., 2008). Indeed, in Eastern Venezuela red tide events are known as 'turbios' (or 'turbid' in English), due to the aforementioned water characteristics.

Red tides are generally noticed when the bloom is in an advanced stage and the numbers of dinoflagellates, diatoms, cyanophytes and ciliates are well within the thousands of cells per L (Cannizzaro et al., 2008; Soto, 2013). The color of the bloom can vary, depending on the species present, on the concentration of organisms and their distribution throughout the water column (Dierssen et al., 2006; Roesler and Boss, 2008). In economically important locations, early detection networks have been put in place (e.g.; Cannizzaro et al., 2008; Alvarez-Salgado et al., 2009; Heil and Steidinger, 2009; Soto, 2013), where waters are consistently monitored through in situ sampling for the presence of harmful algae. Many of these monitoring techniques take advantage of the changes in the bio-optical properties of the water induced by the red tide (Millie et al., 1997; Kyewalyanga et al., 2002; Cannizzaro et al., 2008; Sasaki et al., 2008; Anderson, 2009; Shen et al., 2012). One of the advantages of using bio-optical techniques, in particular remote sensing, is that they can cover large surfaces synoptically, providing information on the extent and distribution of the bloom (Kahru and Mitchell, 1998; Stumpf et al., 2003; Cannizzaro et al., 2008, 2009).

Because of their important impact on resources and human health, most of the research on red tides has focused on those species which are toxic. However, there are other species of red tides which do not produce toxins, but still induce significant changes in the water quality and can thus have adverse effects in the regions where they occur, and are thus classified as Harmful Algal Blooms, or HABs. One such species is *Mesodinium rubrum*, a phototrophic ciliate that it is kleptochloroplastidic and robs the pigmented organelles from their cryptophyte algal prey (Gustafson et al., 2000). Due to its ample geographic distribution (e.g. Crawford, 1989; Kyewalyanga et al., 2002), *M. rubrum* has been considered a group of species, more than a

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http://dx.doi.org/10.1016/j.jmarsys.2016.03.015
0924-7963/

single one (García-Cuetos et al., 2012). *M. rubrum* can have adverse effects on water quality if in sufficient numbers (e.g. oxygen depletion, change or disrupt food-web dynamics; Hornerl et al., 1997; Johnson et al., 2013), and has been identified as prey for *Dinophysis* spp., a dinoflagellate responsible for the diarrheic shellfish poisoning (DSP) (Park et al., 2006, Nishitani et al., 2008; Riisgaard and Hansen, 2009). Most research about this species has been done in cultures (Gustafson et al., 2000; Hansen and Fenchel, 2006; Park et al., 2007; García-Cuetos et al., 2012; Hansen et al., 2012); booms of *M. rubrum* are difficult to quantify in the field because of the speed in which this ciliate aggregates and disaggregates (Crawford, 1989). It is distributed worldwide, and has also been reported in Eastern Venezuela (La Barbera-Sánchez et al., 2004; Mutshinda et al., 2013). To the best of our knowledge, there has not been a characterization of the bio-optical properties of red tides induced by this organism (or others) in this region. Optical characterization of *M. rubrum* has been carried out in temperate areas such as the Bedford Basin (Nova Scotia, Canada; Kyewalyanga et al., 2002), Long Island Sound (USA; Dierssen et al., 2015), the southern Benguela Upwelling System (Roesler et al., 2004a, 2004b; Babin et al., 2005), and Southampton Water (UK; Garcia et al., 1993).

Here we present bio-optical properties of a red tide of *Mesodinium rubrum* in the Cariaco Basin which occurred in April 2008. We investigate the changes in the water color through particle absorption (a_p, a_d, a_{ph}), high performance liquid chromatography (HPLC) and in situ remote sensing reflectance (R_{rs}). These results are further compared with characteristics of this region, which has been studied under the framework of the CARIACO Ocean Time-Series project since 1995 (Muller-Karger et al., 2010).

2. Methods

2.1. Study area

The Cariaco Basin is an ~1400 m deep tectonic pull-apart basin located on the continental margin of northeastern Venezuela (Fig. 1). A shallow sill with two channels (~140 m) isolates the deeper waters of this basin, and exchange with the Caribbean Sea occurs only in surface waters. The basin experiences an upwelling season as Trade Winds intensify between December and May. The rainy season extends from June to November, and surface waters are thermally stratified during this time. Due to the strong coastal upwelling and restricted circulation, the basin is anoxic below ~250 m. The basin has been the site of the CARIACO Ocean Time-Series project since 1995, which seeks to understand the biogeochemistry, sedimentology and the bio-optics of the Basin (e.g. Thunell et al., 2007; Muller-Karger et al., 2010; Muller-Karger et al., 2013; Scranton et al., 2014). During one of the CARIACO core cruises on April 8, 2008, a red tide was observed at 14:20 h, 10.65° N, 64.44° W, roughly 30.4 km NE from the CARIACO site and 16 km W from the Araya Peninsula (Fig. 1).

2.2. Hydrographic measurements

So as to be able to understand the bloom conditions, hydrographic data from the CARIACO time-series station corresponding to the same day was utilized. Specifically, salinity, temperature and mixed layer depth were looked at, together with a 7-day mean (1–8 April 2008) of satellite wind data obtained from http://ood.cbm.usb.ve/historial/viento/ for 11° N 65° W. The methods for collection and processing of the hydrographic data are described in Astor et al. (2013).

2.3. Pigment analysis

All samples for this study were collected from surface waters. For chlorophyll *a* (Chl*a*), four samples of different volumes (125; 180; 50 and 50 mL) were vacuum filtered through 25 mm GF/F filters, stored inside plastic centrifuge tubes and frozen immediately (−20 °C) until analysis. Two samples for pigment analysis through high performance liquid chromatography (HPLC) were also collected by filtering 100 and 50 mL of water through 47 mm GF/F filters. HPLC samples were stored folded in half inside aluminum foil and frozen to −40 °C until analysis.

Fluorometric estimations of Chl*a* concentrations were done using a Turner Design 10-AU-005 Fluorometer (Turner Designs, San Jose, CA, USA), using methanol instead of acetone as the extracting solvent, and sonicating the sample prior to analysis in order to break up the cells (Wright et al., 1997; Astor et al., 2013). HPLC Samples were analyzed at Horn Point Laboratory (HPL; Maryland, USA) following Hooker et al. (2005). Pigment-based size classes were calculated following Uitz et al., 2006. Briefly, seven major diagnostic pigments were used to calculate the proportions of micro-, nano-, and picophytoplankton present in each sample. Pigment ratios, such as alloxanthin:Chl*a*, were calculating by dividing the HPLC-derived alloxanthin by total Chl*a*.

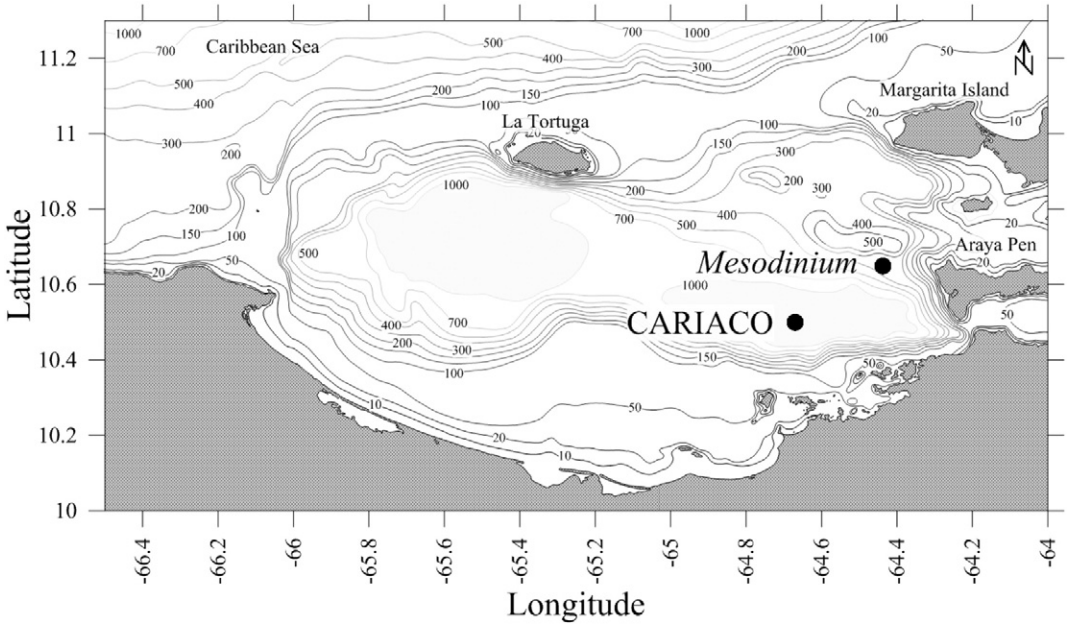

Fig. 1. The Cariaco Basin showing the locations of the CARIACO Ocean Time Series station and the *Mesodinium rubrum* red tide.