Science of the Total Environment 612 (2018) 894–902

Contents lists available at ScienceDirect

Science of the Total Environment

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

Abiotic control of phytoplankton blooms in temperate coastal marine ecosystems: A case study in the South Atlantic Ocean

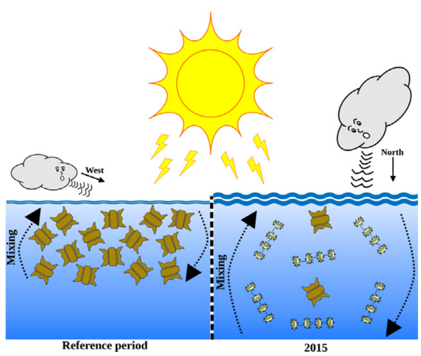
Paula Bermejo [a,b], E. Walter Helbling [a,b], Cristina Durán-Romero [a], Marco J. Cabrerizo [a,c], Virginia E. Villafañe [a,b,*]

[a] *Estación de Fotobiología Playa Unión, Casilla de Correos 15, 9103 Rawson, Chubut, Argentina*
[b] *Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina*
[c] *Departamento de Ecología, Facultad de Ciencias, Universidad de Granada, 18071 Granada, Spain*

HIGHLIGHTS

- The high productivity of coastal SAO is maintained by winter phytoplankton blooms.
- These blooms peaked during June and were dominated by microplanktonic diatoms.
- In 2015 the bloom occurred in August and had a higher proportion of nanoplankton.
- Changes in wind patterns caused the shifts in the 2015 phytoplankton bloom.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 23 June 2017
Received in revised form 16 August 2017
Accepted 16 August 2017
Available online xxxx

Editor: Jay Gan

Keywords:
Anthropogenic influence
Diatoms
Patagonia
Solar radiation
Upper mixed layer
Wind stress

ABSTRACT

Coastal waters of the South Atlantic Ocean (SAO) sustain one of the highest levels of production of the World's ocean, maintained by dense phytoplankton winter blooms that are dominated by large diatoms. These blooms have been associated to calm weather conditions that allow the formation of a shallow and well illuminated upper mixed layer. In Bahía Engaño, a coastal site in Patagonia, Argentina (chosen as a model coastal ecosystem) winter blooms recurrently peaked on June and they were dominated almost entirely by the microplanktonic diatom *Odontella aurita*. However, during the year 2015, a new wind pattern was observed - with many days of northerly high-speed winds, deviating from the calm winter days observed during a reference period (2001–2014) used for comparison. We determined that this new wind pattern was the most important factor that affected the phytoplankton dynamics, precluding the initiation of a June bloom during 2015 that instead occurred during late winter (August). Furthermore, the 2015 bloom had a higher proportion of nanoplanktonic cells (as compared to the reference period) and it was co-dominated by *O. aurita* and *Thalassiossira* spp. Other variables such as nutrient supply and incident solar radiation did not have an important role in limiting and/or initiating the June 2015 bloom, but temperature might have benefited the growth of small cells during August 2015. If these changes in the timing and/or the taxonomic composition of the bloom persist, they may have important consequences for the secondary production and economic services of the coastal SAO.

* Corresponding author at: Estación de Fotobiología Playa Unión, Casilla de Correos 15, 9103 Rawson, Chubut, Argentina.
E-mail addresses: bermejopaula@efpu.org.ar (P. Bermejo), whelbling@efpu.org.ar (E.W. Helbling), mjc@ugr.es (M.J. Cabrerizo), virginia@efpu.org.ar (V.E. Villafañe).

http://dx.doi.org/10.1016/j.scitotenv.2017.08.176
0048-9697/

1. Introduction

Coastal ecosystems worldwide are characterized by their high biodiversity and strong gradients in solar radiation, temperature and nutrients (among others) making them sites of special ecological interest (Cloern et al., 2014). Coastal areas represent a small fraction of the total oceanic area i.e., ~5%, however, they are one of the most productive ecosystems on the Earth (Uitz et al., 2010; Rousseaux and Gregg, 2014), providing also highly valuable services (UNEP, 2006). Among these services, food (in the form of fisheries catch) is one of the most important, accounting for ~80 million tons yr^{-1} over the globe, with a big share of captures in temperate coastal areas (FAO, 2012). In particular, the coastal waters of the South Atlantic Ocean (SAO) sustain one of the highest production levels of the World's ocean (Longhurst, 1998; Skewgar et al., 2007). They are also important for nursery and recruitment of several species of commercial interest (e.g., hake, Argentine red and Patagonian shrimp; Boschi, 1997), and breeding of several flagship species (e.g., the austral right whale, orca and the Magellan penguin; IWC, 2013).

The high production, richness and biodiversity of species in the SAO is maintained by dense phytoplankton blooms occurring all over the continental shelf (Villafañe et al., 2004; Romero et al., 2006; Guinder et al., 2015) or at the shelf break (Saraceno et al., 2005; Painter et al., 2010; Balch et al., 2014). These blooms may be directly or indirectly affected by diverse drivers (e.g., vertical mixing, solar radiation, temperature and nutrients; Behrenfeld and Boss, 2014), including those of anthropogenic origin. In particular, there is much concern about the impact of excessive inputs of organic and inorganic nutrients via rivers (which in turn is associated to human activities; Cloern et al., 2014) or in the form of atmospheric dust (Jickells and Moore, 2015). These inputs may result in an increase in the biomass and shifts in the phytoplankton structure towards taxa that may be of low nutritional quality, inedible or even toxic for consumers (Smith et al., 1999; Fauchot et al., 2005; Carstensen et al., 2007). All these drivers can affect, in different degree, the dynamics of coastal ecosystems, as well as the functioning and timing of the annual phytoplankton succession, and particularly of the blooms. Since the early work of Sverdrup (1953) on the potential causes that trigger blooms, great efforts have been put to develop a general theory; however, as today, there are many uncertainties respect to: 1) the specific requirements that trigger these massive growth events, 2) when and how are they triggered and, 3) what factors (biotic or abiotic) influence their duration and intensity.

It is already known that blooms usually respond to changes in physical forcing originating in the coastal ocean (e.g., tides), the atmosphere (wind), or on the land surface (precipitation and river runoff) (Paerl et al., 1996; Carstensen et al., 2015). Some abiotic factors are known to directly affect the initiation and the development of phytoplankton blooms, such as light, nutrients (as essential requirements for photosynthesis) and temperature (as catalyst of several enzymatic reactions involved in the CO_2 uptake reactions; Toseland et al., 2013). Wind (speed and direction) may also influence the strength and duration of phytoplankton blooms, as it conditions the stratification and the depth of the upper mixed layer (UML) that in turn, will control the light availability for photosynthesis (Yin et al., 2004; Fitch and Moore, 2007). For the particular case of coastal areas of the SAO it was proposed (Villafañe et al., 2004) that the phytoplankton blooms are triggered by the calm weather conditions characteristic of the winter time. On the other hand, during spring and summer, strong winds predominate, keeping the cells circulating within a relatively deep and poor-illuminated layer and thus the growth of phytoplankton is low (i.e., pre- and post-bloom conditions; Villafañe et al., 2004; Helbling et al., 2005).

During the year 2015 we determined a change in the wind pattern (as compared to previous years) for the area of Bahía Engaño – a coastal site in the Chubut Province (Patagonia, Argentina). This change gave us the opportunity to study the influence of this new wind pattern on the onset and development of the phytoplankton bloom, using Bahía Engaño as a model coastal ecosystem for coastal SAO. To this purpose, we compared not only the patterns of wind but also of other abiotic variables (solar radiation, temperature, nutrients, etc.) for the year 2015 against a reference period (2001–2014) to evaluate their impact on the local phytoplankton dynamics. Our work has an evident usefulness, as the understanding of the link between changes in abiotic factors and the dynamics of phytoplankton blooms will allow for a prediction of future impacts on the secondary production and, ultimately, on the regional economy.

2. Materials and methods

2.1. Study area

Bahía Engaño is located at the mouth of the Chubut River (Patagonia, Argentina) (Fig. 1). The flow of the Chubut River is regulated by the Florentino Ameghino Dam, 150 km upstream of the river's mouth (Fig. 1). The largest cities of the area (Trelew, Rawson, Gaiman, Dolavon, ~150.000 inhabitants in total, www.indec.gov.ar) are located in the fertile Chubut River valley - between the dam and the river's mouth. In this valley the river is diverted into several irrigation channels that supply water for agricultural and animal breeding activities. About 80% of the horticultural production of the Chubut Province is found along the margin of the Chubut River, in the last 100 km before it reaches the sea. In the past decade, the land use for agricultural activities has doubled and therefore, the use of fertilizers (mainly organochlorine and organophosphate compounds) - without adequate control - had increased (Antolini, 2012; Kopprio et al., 2015). Fishing industries also release their wastes near the mouth of the river reaching, ultimately, Bahía Engaño (Chiarandini Fiore et al., 2013). Thus the study area, as a whole, can be considered as highly impacted by anthropogenic activities.

2.2. Data

2.2.1. Meteorological data

Data for the reference period (2001–2014) and for the year 2015 for the different meteorological variables (Table 1) were obtained as follows: Temperature, humidity, wind speed, and direction were continuously obtained (one datum per minute) with a meteorological station (Tecmes, model TS, Argentina) permanently installed (since 2001) on the roof of the Estación de Fotobiología Playa Unión (EFPU; Fig. 1). Precipitation data were obtained from the database SIPAS (Sistema de Información Patagonia Sur, www.sipas.inta.gob.ar) of the Instituto Nacional de Tecnología Agropecuaria (INTA, Trelew; ~15 km upstream from the Rawson Bridge, Fig. 1).

Incident solar radiation is continuously measured (since 1999) using an European Light Dosimeter Network (ELDONET, Real Time Computers, Germany) broadband filter radiometer that measures photosynthetically active radiation (PAR, 400–700 nm), ultraviolet A radiation (UV-A, 315–400 nm) and ultraviolet B radiation (UV-B, 280–315 nm) every second, with the data being averaged and stored every minute. The instrument is permanently located on the roof of the EFPU and is routinely calibrated (once a year) using a solar calibration procedure (Ruggaber et al., 1994; Björn and Murphy, 1985). In this work we only used data corresponding to the reference period (2001–2014) and for the year 2015.

Area-averaged daily aerosol indexes (AI) for the Bahía Engaño area were downloaded from the Earth's database of the National Aeronautics and Space Administration (NASA) (Acker and Leptoukh, 2007). The data were obtained by the Total Ozone Mapping Spectrometer – Earth Probe (TOMS-EP; 2001–2004) with a global grid resolution of 1×1.25 degrees, and by the Ozone Monitoring Instrument (OMI; 2005–2015) with a global grid resolution of 1×1 degrees. We only considered the positive values of AI as they represent absorbing aerosols (i.e., atmospheric dust).