Estuarine, Coastal and Shelf Science 167 (2015) 549–559

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

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

Investigating the impact of land use and the potential for harmful algal blooms in a tropical lagoon of the Gulf of Mexico

Audrey Limoges [a,*], Anne de Vernal [a], Ana-Carolina Ruiz-Fernández [b]

[a] Geotop, Université du Québec à Montréal, C.P. 8888, Succ. Centre-ville, Montréal, Québec, Canada H3C 3P8
[b] Instituto de Ciencias del Mar y Limnología, Unidad Académica Mazatlán, Universidad Nacional Autónoma de México, A.P. 811, Mazatlán 82000, Mexico

ARTICLE INFO

Article history:
Received 15 July 2015
Received in revised form
31 October 2015
Accepted 2 November 2015
Available online 6 November 2015

Keywords:
Sediment samples
Dinocysts
Algal bloom
Deforestation
Southwestern Gulf of Mexico
Lagoon

ABSTRACT

Palynological and geochemical analyses were carried out on a sediment core collected in the shallow Alvarado lagoon (Veracruz, Southwestern Gulf of Mexico) in order to evaluate the impact of the significant decline in the surrounding native coastal vegetation on phytoplankton assemblages. The sedimentary sequence encompasses the last millennium and provides information on pre-industrial phytoplankton assemblages. Results highlight a recent increase of freshwater-sourced organic matter relative to marine organic matter in line with reduced total concentrations of cyst-producing dinoflagellates. These changes appear to be synchronous to the extensive conversion of wetlands into agricultural areas, with consequences on the stability and water retention capacity of the soils bordering the lagoon system. The data also show that *Polysphaeridium zoharyi*, a cyst produced by the potentially toxic dinoflagellate *Pyrodinium bahamense*, is present in high abundance in the dinoflagellate population of the lagoon. Consequently, the modern cyst bank of *P. bahamense* in sediment has the potential to initiate harmful blooms since surface sediments are prone to resuspension events related to strong seasonal winds and human activities.

1. Introduction

Coastal lagoon systems are very productive areas that support diverse habitats with various environmental gradients. In addition to nutrient inputs from watersheds and exchanges with the open ocean, rapid nutrient cycling that generally characterizes such shallow environments stimulates primary production. This, in turn, exerts a strong influence on the higher trophic levels, and these systems frequently offer exceptional fishery resources with nursery areas for commercial fish and shellfish. Coastal lagoons also provide numerous ecosystem services (Costanza et al., 1997; Basset et al., 2006) that serve to promote urban development along the coasts. These systems therefore are under increasing anthropogenic stress (Lotze et al., 2006) and susceptible to pollution and/or cultural eutrophication.

Phytoplankton communities are very sensitive to environmental changes and anthropogenic pressures (Revilla et al., 2010). On one hand, modifications in hydrographical conditions (temperature, salinity, turbidity, water depth) may cause shifts in the composition of phytoplankton communities. On the other hand, exogenous inputs of nutrients may change nutrient ratios and concentrations, and lead to development of harmful algal blooms (HAB) (Anderson, 1989; Hallegraeff, 1993; Burkholder, 1998; Glibert et al., 2005; Glibert and Burkholder, 2006; Smayda, 2002; Anderson et al., 2008). In coastal and estuarine environments, major HABs are caused by opportunistic dinoflagellates that can ultimately replace the most sensitive species, impact the aquatic biota and cause human illness by producing potent toxins. Thus, dinoflagellate blooms may represent a major concern for local economy and society.

Among the nearly 2000 dinoflagellates species described, approximately 15% are known to produce resting cysts as part of their sexual reproduction cycle (e.g. Dale, 1976; Taylor and Pollingher, 1987; Head, 1996). These cysts represent a dormant stage during the normal planktonic life-cycle and can remain viable in the sediment for decades and even centuries before germination (Lundholm et al., 2011; Ribeiro et al., 2011). This capability of forming seedbeds in sediment and surviving under unfavorable conditions is important as it plays a key role in the dynamics of blooms (Dale, 1983; Nehring, 1993; Anderson et al., 1983, 2002;

* Corresponding author.
E-mail addresses: limoges.audrey@courrier.uqam.ca (A. Limoges), devernal.anne@uqam.ca (A. de Vernal), caro@ola.icmyl.unam.mx (A.-C. Ruiz-Fernández).

http://dx.doi.org/10.1016/j.ecss.2015.11.005
0272-7714/

Cembella et al., 1988; Ishikawa and Taniguchi, 1996). Composed of a complex carbohydrate-based polymer (Versteegh et al., 2012) or more rarely of calcareous material (Matsuoka and Fukuyo, 2000), these cysts also are generally well fossilized and may provide sedimentary archives of past primary productivity based on micropaleontological analyses. It is thereby possible to obtain retrospective information on the evolution of dinoflagellate communities in a given environment and evaluate the influence of climatic or anthropogenic stressors on their cyst diversity and abundance, as well as the formation of harmful blooms.

In this study, we report on palynological and geochemical analyses from a sediment core collected in Alvarado Lagoon, Veracruz (Southwestern Gulf of Mexico). Sugarcane cultivation activities have taken place in this region since at least the mid-16th century (SEGOB, 2010). Over the last 50 years, intensification of urban and agricultural activities was accompanied by enhanced rates of deforestation and a deterioration of the lagoon's water quality (Rivera-Guzmán et al., 2014). The main objective of this work is to characterize the evolution of dinoflagellate cyst (hereafter dinocyst) assemblages in relation with increasing anthropogenic disturbance of the natural habitat. Owing to the potential of *Pyrodinium bahamense* to form toxic blooms in similar warm coastal lagoons (Landsberg et al., 2006), special attention was given to its cyst stage, *Polysphaeridium zoharyi*.

2. Regional setting

The Alvarado Lagoon system is located in the southwestern Gulf of Mexico, in the Mexican state of Veracruz. Formed at the confluence of three important rivers (Papaloapan, Blanco and Acula) that bring large volumes of freshwater (~50×10^9 m^3 yr^{-1}; Cruz-Escalona et al., 2007), the lagoon system actually comprises several interconnected lagoons (Alvarado, Camaronera, Buen País and Tlalixcoyan) and numerous smaller aquatic bodies (Fig. 1). The main connection to the Gulf of Mexico is situated in the northeastern part of Alvarado Lagoon (inlet), but an artificial opening was also constructed in 1982 in Camaronera Lagoon (outlet) (see Fig. 1) (Morán-Silva et al., 2005). The water residence time is about 0.5 days, leading to rapid nutrient exchanges with the adjacent environments (Morán-Silva et al., 2005; Cruz-Escalona et al., 2007). Oriented parallel to the coastline, the lagoon has an average depth of approximately 2 m. The tidal range for the region is ~0.75 m.

Primary production is enhanced during the rainy season (June to October) in relation with the high organic- and nutrient-rich river discharges (Abarca-Arenas et al., 2002; Morán-Silva et al., 2005), but also from November to February, when strong northern winds, the *Nortes*, blow off the Gulf of Mexico and drive resuspension of sediments and nutrients into the water column (Contreras et al., 1994). Conversely, the dry season (March–June) is generally characterized by lower and more stable primary production. The tropical precipitation-drought regime and the hydrography of the lagoon system therefore induce significant seasonal variations in productivity (chlorophyll-: ~4.3–92.6 μg/L; Morán-Silva et al., 2005) in addition to temperature and salinity changes, which respectively range from ~18 to 32 °C and ~0 to 17 psu in the area of the study site (Garcia, 1973; Castañeda Chávez et al., 2005; Morán-Silva et al., 2005). Salinity can reach 33.5 psu in June near the Alvarado lagoon inlet (Calva Benítez and Torres Alvarado, 2011). Ecological indicators including physico-chemical properties of the water column and seagrass beds suggest that eutrophic conditions have prevailed for at least the last 30 years in Alvarado lagoon (Rivera-Guzmán et al., 2014).

3. Material and methods

Two sediment cores were collected in October 2011 at 18.7979 °N; 95.8579 °W in the Alvarado lagoon with a gravity corer UWITEC. The complete sequences were sub-sampled continuously at 1-cm intervals. One core was used for palynological analyses and samples were kept refrigerated at 4 °C until analysis. The other core was used for elemental and grain size distribution analyses, and ^{210}Pb dating.

3.1. Age vs. depth determination

In each 1 cm-thick sample, the total ^{210}Pb activity was determined by measuring its daughter product ^{210}Po by alpha spectrometry, assuming secular equilibrium between the two isotopes (for analytical details, see Ruiz-Fernández and Hillaire-Marcel, 2009). Additionally, six accelerator mass spectrometry (AMS)

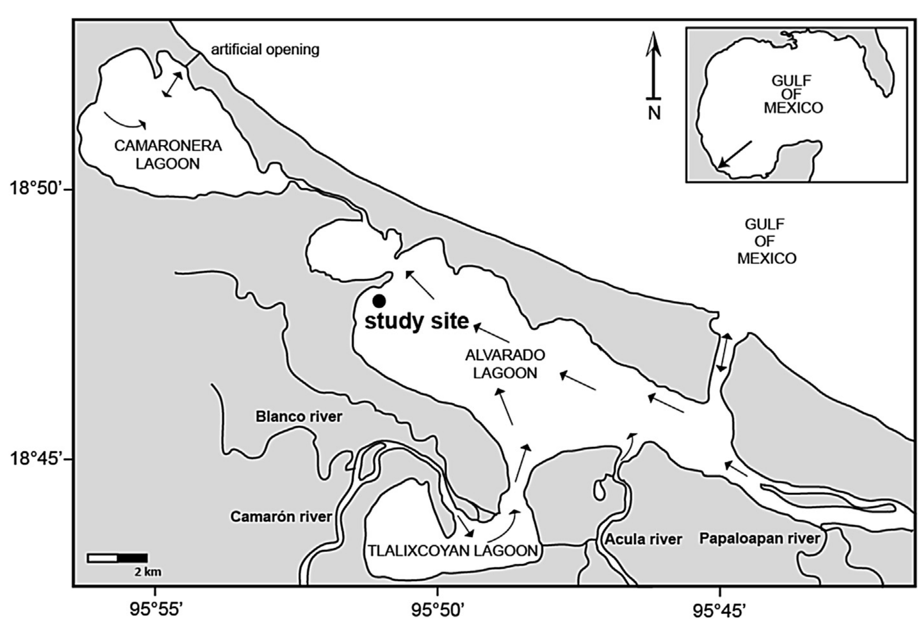

Fig. 1. Study area with position of core site and the main path of surface circulation. Modified from Castañeda Chávez et al. (2005).