Estuarine, Coastal and Shelf Science 120 (2013) 54–63

Contents lists available at SciVerse ScienceDirect

Estuarine, Coastal and Shelf Science

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

Annual patterns of nutrients and chlorophyll in a subtropical coastal lagoon under the upwelling influence (SW of Baja-California Peninsula)

Rafael Cervantes-Duarte [a,b], Ricardo Prego [b,*], Silverio López-López [a], Fernando Aguirre-Bahena [a], Natalia Ospina-Alvarez [b]

[a] Centro Interdisciplinario de Ciencias Marinas (CICIMAR), Av. Instituto Politécnico Nacional s/n, 592 La Paz BCS, Mexico
[b] Marine Biogeochemistry Group, Marine Research Institute (CSIC), Eduardo Cabello 6, 36208 Vigo, Spain

ARTICLE INFO

Article history:
Received 11 October 2012
Accepted 21 January 2013
Available online 14 February 2013

Keywords:
inter-annual
intra-annual
biogeochemistry
California Current
chocked lagoon
Bahía-Magdalena
Pacific coast
Mexico

ABSTRACT

The coastal lagoon of Bahía-Magdalena, located on the west coast of the Peninsula of Baja-California, is a subtropical ecosystem with an arid climate and very little freshwater input. During the 2005–2011 period the thermohaline properties varied between cold and warm half-yearly periods. They were influenced by the Transitional Water mass transported by the South California Current from February to July and by the Subtropical Surface Water from August to January. The nutrient concentrations increased (viz up to 16 μM of nitrate) from March to June, when the upwelling index was the highest. Similarly, the inter-annual variation of chlorophyll-*a* showed a six-monthly pattern with the highest average monthly concentrations being found in June (5 mg m^{-3} *in situ* or 8 mg m^{-3} based on satellite information) and the lowest in December–January. A spatial zoning was also observed in the lagoon with a shallow inner zone that is warmer and richer in chlorophyll-*a* than the deeper closed mouth area. In the Bahía-Magdalena lagoon a spatial-temporal division into two zones and two seasons was repeated year after year with only minor differences. During the first semester in the outer zone, years 2006 and 2007 were colder and nutrient rich while 2010 was warmer, according to the upwelling conditions in the Southern California Region. Hence, among the coastal lagoons that present a prevailing marine influence, the coastal system of Bahía-Magdalena corresponds to an unusual type of subtropical coastal lagoon where the nutrient input is mainly due to upwelling phenomena.

1. Introduction

Continental shelf waters represent 8% of the Earth's oceanic surface but it is where nearly 25% of the primary sea production occurs (Walsh, 1989) and where a variety of types of coastal systems, which determine the exchange between land and sea, are found. In these systems, coastal lagoons, making up 13% of the coastal areas worldwide, are predominant (Kjerfve, 1994). Coastal lagoons are inland water bodies, usually oriented parallel to the coast, separated from the sea by a barrier and connected to the ocean by one or more restricted inlets (Kjerfve and Magill, 1989). In the subtropical climate region bordering, as delimited by Perillo et al. (1999), the Tropics of Cancer and Capricorn (23.5° latitude) and the temperate region (40° latitude), coastal lagoons are subject to a wide climatic diversity ranging from monsoons to desert-like conditions. In all of these climate types the availability of nutrients restricts biological richness (Salomons et al., 2005). Despite this fact, subtropical coastal lagoons have not been studied extensively from a biogeochemical viewpoint, rather it is the ecological aspects that have undergone a more in-depth examination (Kjerfve, 1994).

The wide variety of subtropical coastal lagoons have been classified according to the type of entrance channel into choked, restricted or leaky lagoons (Perillo et al., 1999), distinguished by the freshwater or marine prevailing influence (Abreu et al., 2010) or by the depth and substratum characteristics (Nichols and Boon, 1994). All the same, biological productivity in subtropical coastal lagoons is influenced by hydrodynamic processes such as water residence time (Badylak and Phlips, 2004; Phlips et al., 2012), tidal mixing (Abreu et al., 2010) and water column turbidity (Caffrey et al., 2007). In addition to hydrographical factors, the type of littoral vegetation, i.e. salt marsh, mangle, seagrass and seaweed, is also relevant (Badylak and Phlips, 2004; Phlips et al., 2012) as is the presence of populations of filtering macro-invertebrates, crustaceans and fishes, which may regulate phytoplankton dynamics (Badylak and Phlips, 2004; Jiang et al., 2012).

* Corresponding author.
E-mail address: prego@iim.csic.es (R. Prego).

0272-7714/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ecss.2013.01.020

A key factor in the primary production of subtropical coastal lagoons is nutrient input where the fluvial contributions may be essential (Coutinho and Mello, 2011; Phlips et al., 2012). Upwelling events, rather than continental sources, are the main origin of nutrients transported to the photic layer (Hutchings et al., 1995). So, in the choked, restricted, and leaky lagoons of the arid regions found along the Pacific coast of Mexico (Gilmartin and Relevante, 1978) and southwestern Australia (Hodgkin and Lenanton, 1981), the new nutrients are principally supplied from the sea.

In Mexico there are 124 coastal lagoons (Lankford, 1977) 60% of which are situated in the subtropical region and 50% on the California Peninsula and its Gulf. The lagoons located on the western shore of Baja-California Peninsula (32–23°N) from the San-Quintín lagoon (40 km^2) to the north to the Bahía-Magdalena lagoon (565 km^2) to the south are under the sea influence of the California Current. In this coastal zone the climate is dry and arid with northerly winds prevailing throughout the year. However, to the south of southern parallel 28°N south-westernly and westernly winds are common in summer and autumn (Zaitsev et al., 2010), which modifies the coastal hydrodynamic (Durazo et al., 2005, 2011). The largest, deepest and southernmost lagoon of the Baja-California Peninsula, Bahia-Magdalena, is located in this area.

Due to its wealth of marine resources, the ecological aspects of the aforementioned lagoon were studied extensively, as summarized in the review of Funes-Rodríguez et al. (2007). The nutrient cycle, however, received very little attention. Although the Bahía-Magdalena is the most well known system in the western Californian region, the inter- and intra-annual patterns of nutrient dynamics and, consequently chlorophyll-*a* concentrations, still need to be examined in depth. The research carried out, as little as it is, points to the local importance of coastal upwelling (Álvarez-Borrego et al., 1975) and tidal currents (Acosta-Ruiz and Lara-Lara, 1978; Guerrero-Godínez et al., 1988) in the fertilization of the lagoon. On a large scale, the seasonally high biological production in the western lagoons of the Baja-California Peninsula might be connected with the conditions in the southern boundary of the California Current System (Durazo and Baumgartner, 2002; Durazo et al., 2005).

Therefore, in relation to nutrient input and phytoplankton activity (from chlorophyll levels), in the coastal lagoon of Bahía-Magdalena it is hypothesized that, as result of a prevailing marine influence, the fertilization process inside this lagoon is mainly due to coastal upwelling. In this way, the objectives are as follows: (i) to identify and characterize the main intra-annual periods highlighting the influence of the water masses that yearly are present in Bahia-Magdalena, in particular, Sub-Arctic Water, Equatorial Subsurface Water and the mixing of both of them, the Transitional Water; and (ii) to describe the inter-annual changes in the lagoon and to explore their relationship with the California Current System. These objectives are based on forty-three sampling cruises with a bimonthly frequency and 8-day composite satellite information for Surface Sea Temperature and chlorophyll-*a*. Data were used to analyse the seasonal and inter-annual variations for a period of seven years: from 2005 to 2011.

2. Material and methods

2.1. Study area

The Bahía-Magdalena is a subtropical lagoon located on the southwestern coast of the peninsula of Baja-California (Fig. 1). Following the classification system for Mexican lagoons (Lankford, 1977), Bahía-Magdalena has a tectonic structural origin and is a choked short inlet type of coastal lagoon (Perillo et al., 1999). The lagoon area covers 565 km^2 with a total water volume (low-high tide) of 6.8–8.1 km^3 (Sánchez-Montante et al., 2007). The lagoon is separated from the Pacific Ocean by Margarita and Magdalena islands and sand bars that are protected from ocean swells. The inner zone occupies half of the lagoon surface and is characterized by shallow channels (<10 m in depth) surrounded by extensive mangrove areas. The deeper outer zone is connected to the ocean through a mouth 5.6 km wide and 38 m in depth. The sediment of

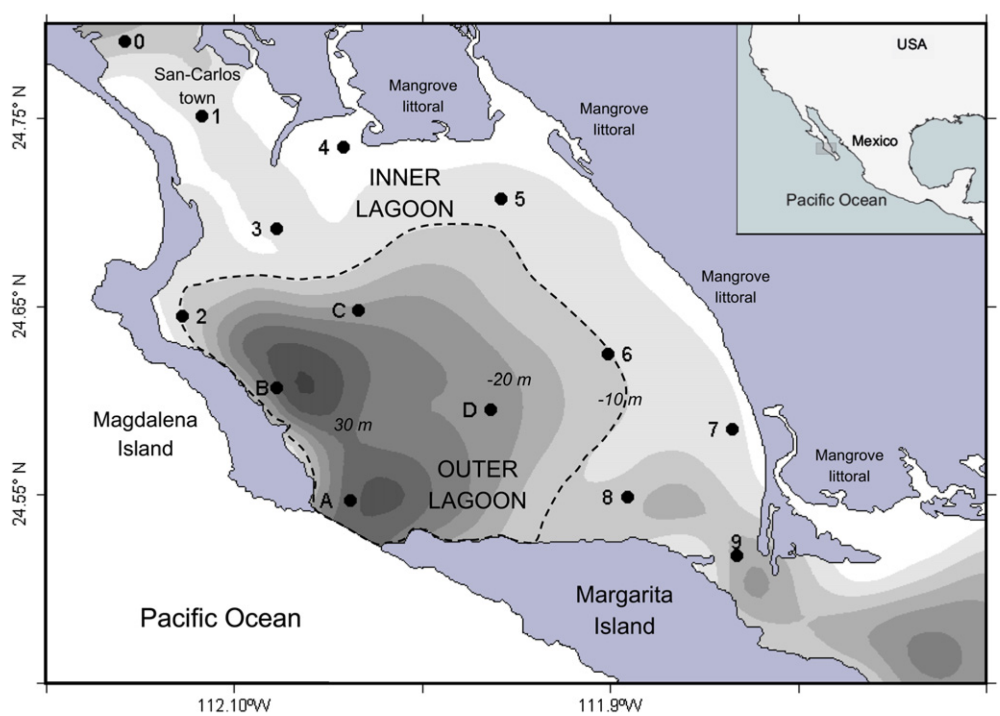

Fig. 1. Location, bathymetry and sampling stations in the subtropical coastal lagoon of Bahía-Magdalena. Letters A–D correspond to the four stations located in the outer lagoon zone while the ten stations numbered 0–9 are within the inner lagoon zone.