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Dominance patterns in macroalgal and phytoplankton biomass under different nutrient loads in subtropical coastal lagoons of the SE Gulf of California

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ABSTRACT

Nine macroalgal blooms were studied in five coastal lagoons of the SE Gulf of California. The nutrient loads from point and diffuse sources were estimated in the proximity of the macroalgal blooms. Chlorophyll *a* and macroalgal biomass were measured during the dry, rainy and cold seasons. Shrimp farms were the main point source of nitrogen and phosphorus loads for the lagoons. High biomasses were found during the dry season for phytoplankton at site 6 (791.7 ± 34.6 mg m^{-2}) and during the rainy season for macroalgae at site 4 (296.0 ± 82.4 g m^{-2}). Depending on the season, the phytoplankton biomass ranged between 40.0 and 791.7 mg m^{-2} and the macroalgal biomass between 1 and 296.0 g m^{-2}. The bulk biomass (phytoplankton + macroalgal) displayed the same tendency as the nutrient loads entering the coastal lagoons. Phytoplankton and macroalgal biomass presented a significant correlation with the atomic N:P ratio.

1. Introduction

Nutrient loads to coastal waters (marginal seas, bays, estuaries and lagoons) have increased in coastal environments worldwide as a direct consequence of the growing human population and the increased settlement and use of coastal areas (Valiela, 2006). These changes in nutrient availability have led to increased eutrophication, representing a growing threat facing coastal ecosystems (Bricker et al., 2008; Teichberg et al., 2010). These changes have caused a variety of impacts, such as high levels of chlorophyll *a* (Boynton et al. 1982), overgrowth of seaweed and epiphytes, anoxia and hypoxia events (Gerlach, 1990; CENR, 2000) and, nuisance and toxic algal blooms (Rabalais et al., 1996; Bricker et al., 2003; Devlin et al., 2011).

The dominance of diverse communities of planktonic and periphytic microalgae, ephemeral and perennial macroalgae and seagrasses is controlled by an array of factors, such as morphometry, exposure to waves and currents, the substratum composition, grazing and, light and nutrient availability either alone or through complex interactions (Sand-Jensen and Borum, 1991). Sources of dissolved inorganic nitrogen (DIN, as ammonia, nitrate, or nitrite) typically limit the distribution, productivity, and abundance of primary producers, including single-celled phytoplankton and larger macroalgae (Ryther and Dunstan, 1971; Nelson et al., 2003; Thornber et al., 2008). Inputs of N through sewage and fertilizer runoff frequently increase the rate of primary production in coastal systems (Doering et al., 1995; Taylor et al., 1999; Thornber et al., 2008) leading to large blooms of phytoplankton and/or macroalgae (Fletcher, 1996; Nixon and Buckley, 2002), altering the natural balance of these ecosystems (Scanlan et al., 2007). Essentially, the increases in anthropogenic sources of inorganic nutrients interfere with natural annual nutrient cycles and can artificially enhance primary production during periods when activity is normally low (Fletcher, 1996).

The Gulf of California is a semi-enclosed sea on the Pacific coast of Mexico and represents one of the most biologically diverse marine areas in the world (Páez-Osuna et al., 2003). The coastal lagoons of the SE Gulf of California, particularly those in Sinaloa, are strongly influenced by anthropogenic activities, including intensive agriculture, shrimp farming and domestic sewage, which discharge significant amounts of nutrients into the coastal lagoons

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(Páez-Osuna et al., 1999; 2003). These activities and the presence of approximately 5.5 million inhabitants constitute a serious threat to the rich and complex biodiversity of the Gulf ecoregion and the Gulf itself because nutrient additions can cause a progression of eutrophic symptoms most often beginning with recurrent high concentrations of chlorophyll *a* (phytoplankton) and/or macroalgal blooms.

Despite the importance of these ecosystems, surprisingly little is known about their ecology and the interaction of nutrients and algal communities in subtropical coastal lagoons as a limited number of studies have focused on the impact of nutrient enrichment on algal communities in these areas (Ochoa-Izaguirre et al., 2002; Piñón-Gimate et al., 2008; 2012; Teichberg et al., 2010). In the particular case of the SE Gulf of California region, Piñón-Gimate et al. (2009) found that depending on the site, macroalgae show different $\delta^{15}N$ values because some sites are more or less influenced by a given source in the associated watershed, which is reflected in the different $\delta^{15}N$ values found in macroalgae in the same system and in the relative contributions of the sources.

The aim of this work was to describe how nutrient loads are related to chlorophyll *a* (phytoplankton biomass) and macroalgal blooms considering the three seasons in the region during a one-year study. Here we examined the relationship of macroalgal and phytoplankton biomass with nutrient loads from nine sites corresponding to five coastal lagoons that receive different nutrient loads from the associated watershed. We estimated the biomass of both phytoplankton and macroalgae at each site during the three periods with contrasting climatic conditions in the region (the dry, rainy and cold seasons), in which the nutrient supplies from different activities differ. We compared biomass between seasons and algal communities, and we examined the relationships between algal biomass and nutrient loads through classical analysis and principal component analysis (PCA).

Table 1
Summary of the characteristics of the coastal lagoons of the southeastern region of the Gulf of California and the associated watersheds.

Lagoon	Lagoon area (ha)	Watershed area (ha)	Average depth (m)	Area of shrimp farming (ha)	Population
Navachiste	28,075	249,975	2.5 ± 0.5	6621	91,156
SAMARE	51,172	782,674	2.5 ± 1.1	7724	169,232
AEP	30,949	925,138	4.0 ± 1.0	7750	896,207
Ceuta	6737	402,916	4.0 ± 0.5	4212	73,406
Teacapán	5506	300,692	4.0 ± 1.0	2089	96,758

Data from Páez-Osuna et al. (2007); SAMARE, Santa María-La Reforma; AEP, Altata Ensenada El Pabellón.

2. Materials and methods

2.1. Study site and sampling

This study was conducted in five lagoons on the Sinaloa coast of the southeastern Gulf of California (Fig. 1). A summary of the main characteristics of each lagoon and their watersheds, including human activity, is shown in Table 1. Each lagoon along the coast was surveyed where access permitted, to select sampling sites based on the presence of macroalgal blooms during the first sampling season (dry season). Macroalgal blooms were defined here as an area with a length greater than 50 m parallel to the shore, conspicuously covered with beds of benthic macroalgae. Nine sampling locations were selected. The species compositions and seasonal changes in macroalgal blooms in these sites were described previously (Piñón-Gimate et al., 2008). In the present work, we describe changes in biomass related to nutrient loads from point sources, such as shrimp farms and municipal sewage from the region.

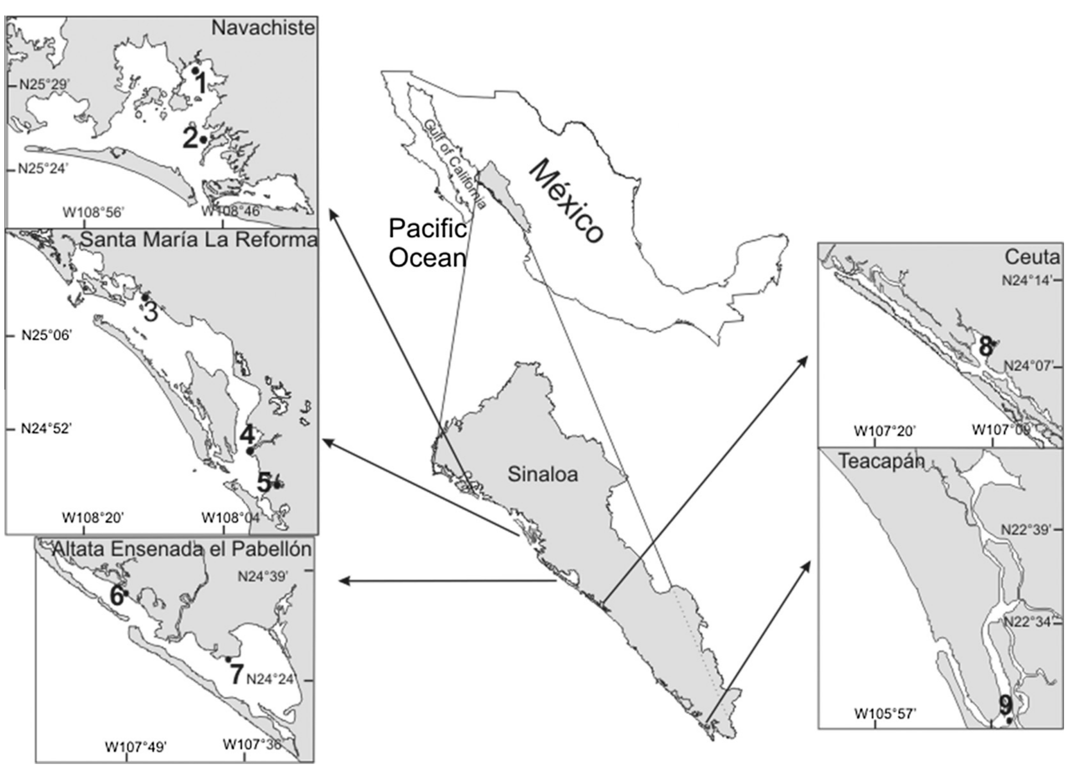

Fig. 1. Sampling sites where macroalgal blooms were found.