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Macroalgae blooms and $\delta^{15}N$ in subtropical coastal lagoons from the Southeastern Gulf of California: Discrimination among agricultural, shrimp farm and sewage effluents

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ABSTRACT

Macroalgae blooms of *Gracilaria vermiculophylla*, *Hypnea spinella* and *Spyridia filamentosa* have been found in coastal lagoons in the SE Gulf of California. Agriculture, livestock, shrimp and poultry farms and sewage contribute anthropogenic nitrogen to the systems. The $\delta^{15}N$ of these sources, water column and macroalgae were studied in order to identify the N supply for macroalgae blooms. $\delta^{15}N$ of three species of macroalgae (4.3–13.6‰) were enriched compared to the water column ($\delta^{15}N$–NO_3^- 3.7–6.8‰), probably because of fractioning from the macroalgae. $\delta^{15}N$ of POM (1.4–10.3‰) was similar to the water column but the relationship was unclear. Depending on the site, macroalgae showed different $\delta^{15}N$ values since some sites receive more or less influence from one given source of the associated watershed, which is reflected in the different $\delta^{15}N$ values of the macroalgae of the same system and in the relative contributions of the sources.

1. Introduction

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) which can lead to large blooms of phytoplankton and/or macroalgae (Harlin, 1995; Fletcher, 1996; Nixon and Buckley, 2002; Berman et al., 2005). As a result of anthropogenic nutrient enrichment, dense mats of macroalgae are increasing in abundance and frequency in coastal waters around the world (Valiela et al., 1997; Bricker et al., 2003; Lapointe et al., 2005). A patchy distribution of macroalgae can be associated with localized pulses of nutrients, like the mats of *Caulerpa*, *Gracilaria*, *Hypnea* and *Spyridia* (biomass >40 g m^{-2}) found in the coastal lagoons of Sinaloa, Mexico (Piñón-Gimate et al., 2008). Understanding how nitrogen enters a water body, and the way it is subsequently used by primary producers, is of great importance in assessing the impacts of anthropogenic vs. "natural" sources of nutrient to marine systems (Rogers, 2003; Kamer et al., 2004; Savage and Elmgren, 2004). The measurement of stable nitrogen isotope ratios ($\delta^{15}N$) in macroalgae can be used to assess the spatial extent and degree of land-based nutrient enrichment in coastal waters by "fingerprinting" the source of N when the various $\delta^{15}N$ signatures are known (Heaton, 1986; Lapointe and Bedford, 2007).

Globally, many studies have used $\delta^{15}N$ as a tool to discriminate between natural and anthropogenic N sources that could in turn support excessive macroalgal growth (e.g., Lapointe, 1997; McClelland and Valiela, 1998; Costanzo et al., 2001; Umezawa et al., 2002; Gartner et al., 2002; Savage and Elmgren, 2004). However, in subtropical ecosystems these types of studies are still scarce (e.g. Barile, 2004; Lapointe et al., 2004; Lapointe et al., 2005).

In this study, we investigated the nitrogen contents and the $\delta^{15}N$ signatures of three important species of macroalgae that frequently grow excessively and form blooms in three coastal lagoons along the southeast Gulf of California coastline. The region supports fisheries, tourism, mining, intensive agriculture, and shrimp aquaculture. These activities and the presence of around 5 million inhabitants constitute a serious threat to the rich and complex biodiversity of the Gulf ecoregion (Páez-Osuna et al., 2003). In order to determine the primary source of DIN for bloom forming macroalgae we compared the $\delta^{15}N$ signatures of three macroalgae species

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with the DIN and $\delta^{15}N$ values of the water column directly influenced by land-based anthropogenic N derived from sewage, shrimp farming and agriculture as the primary nitrogen source supporting macroalgal growth.

2. Study area

This study included three coastal lagoons of the Sinaloa littoral on the southeastern Gulf of California (Fig. 1). The area covered by the main activities and the population of the associated watershed of each lagoon is shown in the same figure. Sample locations were selected according to accessibility of macroalgal blooms (Piñón-Gimate et al., 2008). No macroalgal blooms were found far from shore or in deep water. Macroalgal blooms were defined as an area longer than 50 m, parallel to the shore, conspicuously covered with beds of benthic macroalgae with a biomass higher than 1 g m^{-2}. All stations were located downstream of major anthropogenic influences (Fig. 1).

Additionally, water samples of known effluents from the Culiacán River watershed (CRW) were collected. The CRW has mixed land uses and its major activities include intensive agriculture, livestock, poultry, and urbanism. The Altata-Ensenada El Pabellón (AE) system is associated with the CRW and receives the discharge from the Culiacán River and numerous streams in the watershed.

3. Material and methods

During the dry and rainy seasons of 2004 and 2005, approximately 4 thalli of 3 important species: *Gracilaria vermiculophylla*, *Hypnea spinella* and *Spyridia filamentosa* (red algae specimens) were collected at each of the 7 selected stations when they were present. The nominal dry season was considered from May to June 2004 and the nominal rainy season from August to October 2004, which are defined by monthly average air temperatures between 27 and 30 °C (CNA, 2005) and rainy season is based on well-defined periods of rainfall (Flores-Verdugo et al., 1993). A total of 33

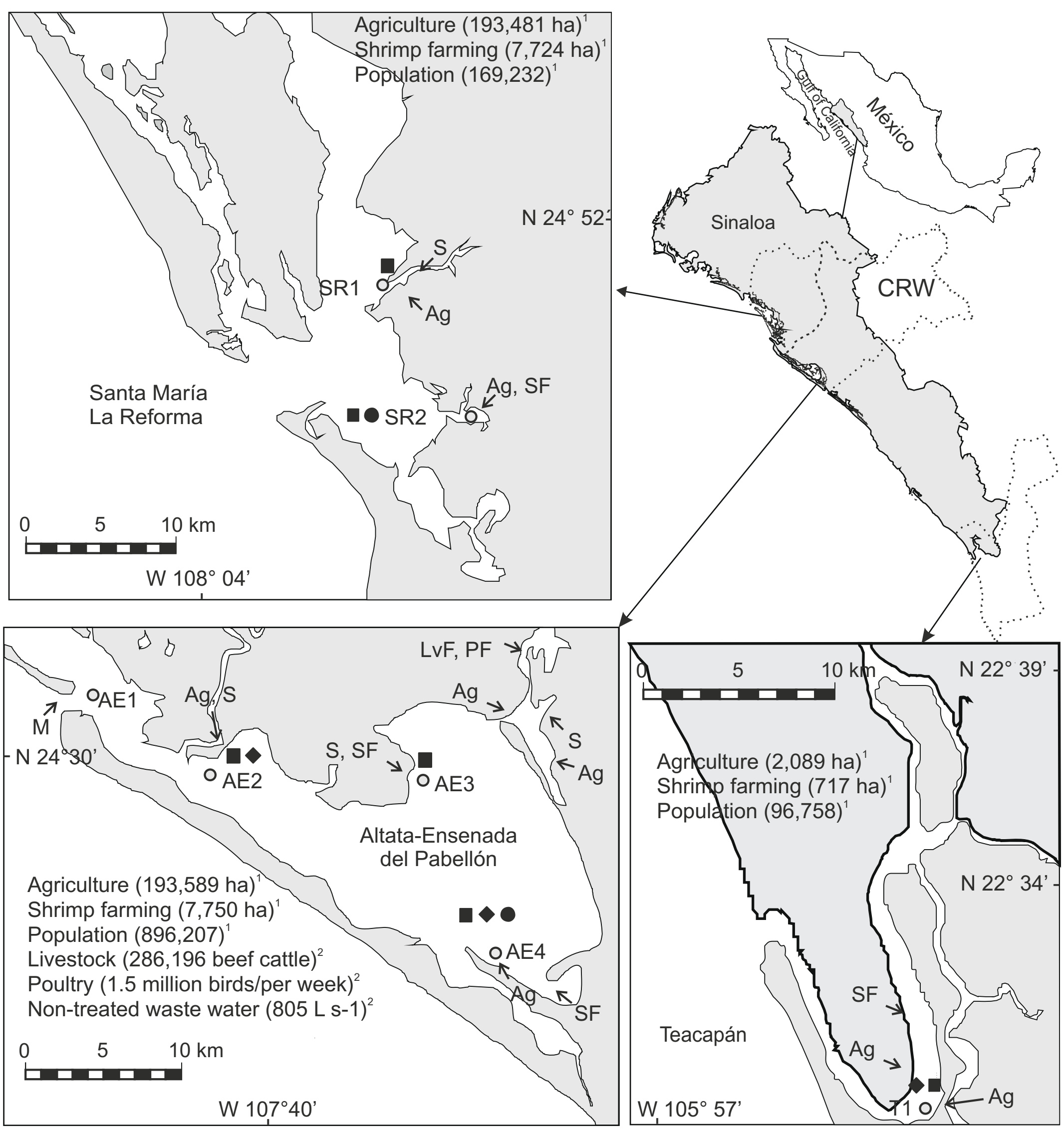

Fig. 1. Sampling stations in three coastal lagoons of Sinaloa where macroalgal blooms were found in 2004 (except for sampling station AE1 which was sampled for marine water). Sampling stations are numbered from north to south and were labeled accordingly: CWR = Culiacán River watershed, SR = Santa María-La Reforma, AE = Altata-Ensenada El Pabellón and T = Teacapán. Ag = Agriculture influence, LvF = Livestock farming loads, PF = Poultry farming loads, S = Sewage influence, SF = Shrimp farm influence, and M = Marine influence (■: *Gracilaria vermiculophylla*, ♦: *Hypnea spinella* and ●: *Spyridia filamentosa)*. Activities (number of ha used) and population (number of inhabitants) of the associated watershed are described ([1]Páez-Osuna et al., 2007; [2]INEGI, 2005a,b).