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Benthic ecology of tropical coastal lagoons: Environmental changes over the last decades in the Términos Lagoon, Mexico

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ABSTRACT

The Términos Lagoon is a 2000-km^2 wide coastal lagoon linked to the largest river catchment in Mesoamerica. Economic development, together with its ecological importance, led the Mexican government to pronounce the Términos Lagoon and its surrounding wetlands as a Federal protected area for flora and fauna in 1994. It is characterized by small temperature fluctuations, but with two distinct seasons (wet and dry) that control the biological, geochemical, and physical processes and components. This paper presents a review of the available information about the Términos Lagoon. The review shows that the diversity of benthic communities is structured by the balance between marine and riverine inputs and that this structuration strongly influences the benthic metabolism and its coupling with the biogeochemistry of the water column. The paper also presents many specific drivers and recommendations for a long-term environmental survey strategy in the context of the expected Global Change in the Central American region.

1. Introduction

In recent years, global concern has arisen concerning the risks of decline in the health of marine ecosystems and the associated functions and services they provide. This has brought about many innovative studies and much path-breaking research, and has led to the development of guidance and policies worldwide. Most of this information underlines the need for observing and managing the state of marine ecosystems as a whole (Tett et al., 2013, Grand Challenge 4 in Borja, 2014). Moreover, scientific literature about marine ecosystems has increased exponentially

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during the last 15 years (Borja, 2014). Coastal ecosystems are likely to have been altered substantially by human activities and probably also by climate drivers of change (climate change related key drivers) (Parry et al., 2007). As stated by Halpern et al. (2008), no marine system remains unaffected by human influence and a large fraction (41%) is strongly affected by multiple drivers.

Marine ecosystems are highly diverse given their biogeographical characteristics on a global scale. Their morphology controls internal hydrodynamics and exchanges with the adjacent sea, regulating in this way the level of anthropogenic pressures and sensitivity to eutrophication (Kennish, 2002). Semi-enclosed coastal systems (SECS), which usually include open, leaky, and choked lagoons and transitional waters (EU, 2000), are sentinel systems and hotspots of coastal vulnerability at a global scale (Newton and Weichselgartner, 2014; Newton et al., 2014 and references therein). Because of the physical connection between the benthic layer and the whole water column, the geochemical and biological dynamics extensively depend on benthic–pelagic interactions.

The Términos Lagoon in the southern Gulf of Mexico is one of the largest lagoons situated in the intertropical zone. Considering the extension and shallowness of the Términos Lagoon as well as its potential sensitivity to environmental change, the objective of this paper is to review and combine existing information on what has been identified as a model tropical coastal lagoon in the Gulf of Mexico (García-Ríos et al., 2013), where seasonal signals are distinct from those in temperate regions. The following sections present an overview of the general features of the Términos Lagoon, as well as its hydrodynamic characteristics and its benthic habitats, with special attention paid to trophic status and benthic communities, as they strongly contribute, together with external loadings, to the biogeochemistry of the water column. In the context of the expected Global Change in the Central American region, the present review also presents many specific drivers of change and pressures, including land use, watershed management, river inputs, coastal erosion processes, and contaminant levels, to assess what major changes can be expected and what effect they might have on the current environmental status, finally issuing recommendations for a long-term environmental survey strategy.

2. General features

The Términos Lagoon borders the southern Gulf of Mexico in Campeche and is, by area and volume, Mexico's second largest estuarine system. The lagoon borders two geologic provinces: to the east the Yucatan Peninsula (low rainfall, calcareous soils, and very low surface drainage) and to the west and south the lowlands of Tabasco and the highlands of Chiapas and Guatemala, an area of high rainfall and fluvial soils (Fig. 1). Three main rivers discharge directly into the lagoon: the Candelaria, the Chumpan, and the Palizada (a tributary of the Grijalva-Usumacinta), with a catchment area totaling 49,700 km^2.

The average freshwater flow rate is approximately 12.5×10^9 $m^3 \cdot yr^{-1}$, with the Palizada River catchment area on the western coast of the lagoon accounting for most of the fresh water inputs. The tidal regime is mixed, mostly diurnal with a mean range of 0.3 m (Contreras Ruiz Esparza et al., 2014).

The continental shelf (Campeche Sound) is one of the most important fishery areas in the western central Atlantic region. Campeche Sound (Tabasco/Campeche) contributes 34% of the total Mexican fishery yield in the Gulf and Caribbean coasts, including penaeid shrimps, mollusks, demersal, and pelagic fishes (CONAPESCA, 2008).

Parallel to fisheries, crude oil extraction in the Gulf of Mexico represents a large economic activity, with Petroleros Mexicanos (PEMEX), a major non-OPEC oil producer (top 10) operating here since 1938. PEMEX is a state-owned company extracting around 2 million barrels per day in Bahia de Campeche (Cantarell oil field). More significantly, revenues from the oil industry (including taxes and direct payments from PEMEX) accounted for about 32% of total Mexican government revenues in 2013. This activity has generated the urban development of Ciudad del Carmen, the largest town (located on the western tip of the island) and, in 1994, it contributed to a great extent to the declaration of the Términos Lagoon as a Protected Area of Flora and Fauna (APFFLT). Ten years later, the lagoon was designated as a wetland of international importance (RAMSAR), and today it represents the largest such zone in Mexico, with 705,016 ha (www.ramsar.org). Unfortunately, PEMEX's activity continues to grow within the protected area, potentially threatening the whole ecosystem through accidental oil spills and pipeline leaks (e.g., Ixtoc-1 in 1979–1980).

The vast wetlands surrounding the Términos Lagoon provide ideal conditions for the migration and breeding of numerous species such as sea bass, shellfish, shrimp, and manatees, amongst others. This area also harbors the highest concentration of dolphins in the Gulf. This protected area is also one of the most important bird wintering areas in the Gulf of Mexico, and its level of marine and terrestrial flora and fauna diversity is considered as very high (Yáñez-Arancibia and Day, 1988). The coastal fringe is occupied by vast areas of mangroves, and the lagoon comprises various habitats, including important oyster and sea grass beds (Moore and Wetzel, 1988).

The area presents two climatic seasons (Yáñez-Arancibia et al., 1983): the rainy season (June–September) and the dry period, which splits into a period with dominant north winds and winter storms (November–March), and a second with lower wind forcing (February–May). The average evaporation is 1512 $mm \cdot a^{-1}$ and the average rainfall is 1805 $mm \cdot a^{-1}$ (Yáñez-Arancibia and Day, 1988). Nevertheless, a strong variability in rainfall and subsequent freshwater discharge to the lagoon has recently been linked to climate variability and to the ENSO regime (Fichez et al., 2017).

The Términos Lagoon stretches over more than 2000 km^2 (Fig. 1). The lagoon is connected to the sea through two inlets: the 'Carmen Inlet' on the western side (4 km in width) and the 'Puerto Real Inlet' on the eastern side (3.3 km in width). These are separated by a carbonate-rich barrier (Carmen Island, 30 km long and 2.5 km wide). The Términos Lagoon is shallow, with an average depth of