Marine Pollution Bulletin 59 (2009) 72–86

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Evaluation of the health status of a coastal ecosystem in southeast Mexico: Assessment of water quality, phytoplankton and submerged aquatic vegetation

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ARTICLE INFO

Keywords:
Coastal ecosystem condition
Eutrophication
Indicators
Phytoplankton
Seagrasses
Submerged aquatic vegetation
Water quality
Yucatan

ABSTRACT

The coastal environment of the Yucatan Peninsula (SE, Mexico) includes a wide variety of ecosystems ranging from mangroves to coral reefs, resulting in a heterogeneous landscape. Specifically, the marine system is characterized by environmental differences which respond to regional and local forcing functions such as marine currents and groundwater discharges (GD). Such functional characteristics were used here to define four subregions across the Yucatan coast and diagnose the health status of this coastal marine ecosystem. To achieve this goal, we conducted an analysis and integration of water quality variables, an eutrophic assessment, evaluated changes in submerged aquatic vegetation (SAV), and analyzed the community structure and distribution of harmful phytoplankton. The first step was to determine the reference values for each subregion based on data previously collected from 2002 to 2006 along the coast of Yucatan, 200 m offshore. The trophic index (TRIX) and Canadian index for aquatic life (CCMEWQI) were used to diagnose each subregion and then the ASSETS approach was conducted for Dzilam and Progreso, sampling localities on each end of the health status continuum (those with the best and worst conditions). Overall, results indicated that the marine coastal ecosystem of Yucatan is in good condition; however, differences were observed between subregions that can be attributed to local forcing functions and human impacts. Specifically, the central region (zone HZII, Progreso-Telchac) showed symptoms of initial eutrophication due to nutrient inputs from human activities. The eastern region (zone HZ III, Dzilam-Las Bocas) showed a meso-eutrophic condition linked to natural groundwater discharges, while the other two subregions western (zone HZI Celestun-Palmar) and caribbean (zone HZ IV Ria Lagartos-El Cuyo) exhibited symptoms of oligo-mesotrophic condition. These findings may be considered baseline information for coastal ecosystem monitoring programs in Yucatan, and the approach used could be replicated for other coastal areas.

1. Introduction

The biological richness of coastal ecosystems is recognized world-wide, and this is one of the main reasons they are attractive for the establishment and development of human communities; approximately 60% of the planet's population is found in coastal areas (Constanza et al., 1997). This situation has generated great pressure on these ecosystems resulting in a decrease of water quality and biodiversity, loss of critical habitats, and an overall decrease in the life-quality of local inhabitants. Such impacts are an urgent call for studies that characterize and diagnose the present condition of coastal environments. This task can be performed based on an ecosystem approach which analyzes the distribution, structure and dynamics of different components of the ecosystem in order to establish management policies for the sustainable use of coastal resources and environmental services.

The first step required to achieve sustainable use of coastal ecosystems is to assess the system's condition, which is a complex process due to natural gradients and variability intrinsic to coastal areas, as well as ongoing structural and functional changes occurring due to human impacts. In response to such complexity, scientists have sought to identify and select the most adequate parameters to define the ecological quality or health status of coastal waters. Previous studies have explored the use of a number of metrics, indices, and analytical frameworks to increase the credibility and robustness of coastal ecosystem health status determinations (Borja, 2005; Borja et al., 2004, 2000; Orfanidis et al., 2003; Dennison et al., 1993; Buchanan et al., 2005).

In the case of Mexico, the environmental protection law known as "Ley General del Equilibrio Ecológico y la Protección al Ambiente" or LGEEPA, suggests the use of a zoning approach as a tool to regulate human activities and to guide the sustainable use of coastal environments. Such zoning of coastal ecosystems must, at

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doi:10.1016/j.marpolbul.2008.11.017

least, include an ecological characterization of the area and a diagnosis of its environmental conditions in order to develop adequate criteria for the regulation of human activities within each area. The desired result is the preservation, protection, and restoration of coastal ecosystem natural resources.

The state of Yucatan is located in the SE portion of the Gulf of Mexico, and includes 365 km of coast which support 1,200,000 people with a population growth rate of 2% per year (greater than the state or national average; INEGI, 2000). In addition, this population doubles during the holiday season, when people from inland move to the coasts where they spend their vacation. As a result, coastal ecosystems of Yucatan, as in other parts of the world, are being heavily impacted by human activities such as: fishing, marine transportation, mining (salt and petreous extraction), cattle-raising, aquaculture and tourism, the last of which has exhibited its most rapid growth during the last five years. These activities require the construction and maintenance of infrastructure, which causes changes in coastal ecosystem structure and dynamics (Pare and Fraga, 1994). As a response to this situation, federal and state governments together with academic institutions designed the Yucatan Coastal Zoning Program (SEMARNAT-SECOL, 2007), legislation designed to achieve sustainable use of coastal ecosystem resources in the region. However, this document lacks a baseline diagnosis of health condition of such areas to be used to measure the success of regulatory performance. Thus, the main objective of the present work was to diagnose the condition of coastal marine waters of the state of Yucatan based on water quality and trophic indices, as well as submerged aquatic vegetation (SAV) and phytoplankton metrics. Given that the Yucatan Peninsula receives considerable freshwater inputs via groundwater discharges, inland human activities which pollute the aquifer will most likely play an important role in this diagnosis. Such diagnosis must also take into account the spatial distribution of human impact by type and intensity.

1.1. Study area

The study was carried out at the coast of the state of Yucatan (SE, Mexico), which is bordered by the Gulf of Mexico on the northwest side and by the Caribbean Sea on the southeast side (Fig. 1). The coastal system extends approximately 365 km which represents 3.3% of the total extent of Mexican coasts. Climate in the study area is dry and arid with a rainy season in summer and little rainfall during the rest of the year. Three well-defined seasons can be identified: dry (March–May), rainy (June–October) and a season of cold fronts referred to as "nortes" (November–February). The tide is mixed and semidiurnal with a range of approximately 0.6 m (Capurro, 2002).

Due to the karstic nature of the substrate in the region, the coastal marine system in Yucatan is highly influenced by submerged groundwater discharges (SGD), which are estimated to be around 8.6×10^6 m^3 km^{-1} $year^{-1}$ (Hanshaw and Back, 1980). The aquifer recharge occurs during the rainy season (Herrera-Silveira et al., 1998; Herrera-Silveira and Comin, 2000). The SGD are characterized by low salinity, high nitrate and silicate concentrations, and may be classified based on the type of discharge as point (direct) or non-point (diffuse). In the first case, discharges occur mostly in the form of springs in the marine zone. In the second case, seepage input is produced by water infiltrations through fractures of the calcareous substrate (Troccoli et al., 2004; Back and Lesser, 1981; Perry, 1990). Other freshwater inputs are through surface runoff due to laminar flux from mangrove fringe areas, coastal lagoons and harbors. Finally, a coastal upwelling from Cabo Catoche (east of the Yucatan Peninsula) also results in nutrient supply to the study system, and its influence becomes more intense during spring (March to May) (Cochrane, 1969; Logan, 1969; Ruiz, 1979; Merino, 1997). Cold fronts ("nortes") and hurricanes are also common in this area and intensify coastal currents and tides, favouring sediment resuspension, changes in water turbidity, and movement of organic and inorganic matter from coastal lagoons and swamps to the marine system resulting in a natural fertilization process of marine waters (Odum, 1972; Morales-Ojeda, 2004).

With respect to the differences along the coast, some are man induced and others are the result of morphology and edaphology of the area. The major human uses of this system include tourism, fisheries, salt extraction, port development, seasonal local tourism and cattleraising. The natural influencing characteristics include

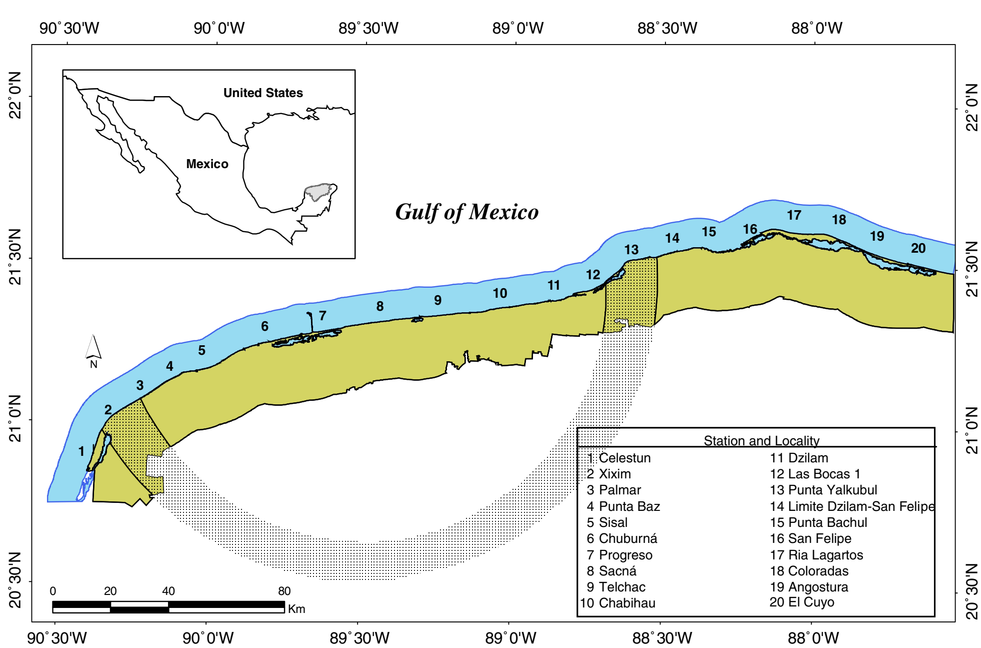

Fig. 1. Study area and location of sampling sites.