Ecological Engineering 65 (2014) 88–100

Contents lists available at ScienceDirect

Ecological Engineering

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

Ecosystem functioning: The basis for restoration and management of a tropical coastal lagoon, Pacific coast of Mexico

Alejandro Yáñez-Arancibia[a,*], John W. Day[b,d], Patricia Sánchez-Gil[c], Jason N. Day[d], Robert R. Lane[b,d], David Zárate-Lomelí[c], Héctor Alafita Vásquez[c], José L. Rojas-Galaviz[c], José Ramírez-Gordillo[e]

[a] Unidad Ecosistemas Costeros, Red Ambiente y Sustentabilidad, Instituto de Ecología A. C., Km 2.5 Carretera Antigua a Coatepec 351 Xalapa, Ver 91070, México
[b] Department of Oceanography and Coastal Sciences, School of the Coast & Environment, Louisiana State University, Baton Rouge, LA 70803, USA
[c] GPPA Consultores, Diomeda, 401 & 409. Zona Hotelera, M27, Lt 1-02, Condominal 54, Cancún, QRoo 77500, México
[d] Comite Resources Inc. 11643 Port Hudson Pride Road. Zachary, LA 70790, USA
[e] Instituto de Protección Civil para Manejo Integral de Riesgos y Desastres del Estado de Chiapas.Km 1.9 Carretera Emiliano Zapata, Aeropuerto Francisco Sarabia. Tuxtla Gutiérrez, Chis 29050, México

ARTICLE INFO

Article history:
Received 1 December 2012
Received in revised form 29 March 2013
Accepted 29 March 2013
Available online 18 May 2013

Keywords:
Ecologic characterization
Water budget
Conceptual model
Sustainable restoration

ABSTRACT

Tropical coastal lagoons (TCL) are among the most productive coastal ecosystems, and they provide a wide range of ecosystem goods and services that support productive economic activities. The objective of this paper is to present a comprehensive review of the ecosystem dynamics in Paraman Lagoon, a wave-dominated, meso-tidal coastal lagoon with an ephemeral inlet on the Pacific coast of Mexico. A conceptual model is used to describe the seasonal environmental cycle for the lagoon, which is characterized by three periods: Period 1 - disconnected from the sea, evaporation is much higher than freshwater input and salinity can exceed 75 *psu*; Period 2 - disconnected from the sea, freshwater input is much higher than evaporation and salinity drops to as low as 5 *psu*; and Period 3 - the inlet is open connecting the lagoon with the ocean resulting in optimal estuarine conditions and moderate salinities between 15 to 25 *psu*. Hydrology and salinity regime in the lagoon are largely controlled by the amount of freshwater discharge that changes the spatial and temporal distribution of environmental parameters. This information is used to develop a conceptual model of the functioning of the lagoon that can be used to aid in decision-making about the restoration and management of the lagoon

1. Introduction

Seasonal closure of tidal inlets to coastal lagoons usually occurs in micro to meso-tidal, wave-dominated coastal environments where there is strong seasonal variability in environmental parameters such as rainfall, river flow, groundwater input, and the near shore wave regime. These ephemeral inlets close annually for a number of months due to the formation of sandbars across the inlet entrance and the lack of sufficient lagoon discharge to keep the inlet open (Yáñez-Arancibia, 1978, 1987; Kjerfve, 1994; Ranasinghe and Pattiaratchi, 2003). Lagoons with ephemeral inlets are common worldwide including the Pacific coast of Mexico and southern California (Lankford, 1977; Yáñez-Arancibia, 1978; Liu et al., 1993; Kjerfve, 1986, 1994; Kjerfve and Magill, 1989; Schwartz, 2005; Kennish and Paerl, 2010). But there is relatively little known about the ecological responses of these coastal lagoon systems to extreme conditions (Yáñez-Arancibia, 1978, 1987; Flores-Verdugo et al., 1987, 1988). During the wet season, increased water levels from seasonal runoff allow waves and swash processes to erode into the sandbar from the ocean side and from the interior of the lagoon due to hydrostatic-head pressure causing filtration through the sandbar, softening it (Liu et al., 1993). Thus, tropical and subtropical lagoon-estuarine systems display great seasonal variation in salinity regimes as a function of geomorphological processes that maintain inlets, and there is a need to better understand elements of environmental physiology, patterns of ecogeomorphology, and responses to stress conditions in these types of ecosystems (Kjerfve, 1986, 1994; Day et al., 2008, 2013; Kennish and Paerl, 2010).

Coastal lagoons with ephemeral inlets such as Paraman Lagoon also play a vital role in artisanal fisheries, production of salt, tourism and other socioeconomic activities (Yáñez-Arancibia et al., 2007; Fanning et al., 2011). The closure of a tidal inlet, either naturally or

* Corresponding author.
E-mail address: alejandro.yanez@inecol.edu.mx (A. Yáñez-Arancibia).

0925-8574/$ – see front matter
http://dx.doi.org/10.1016/j.ecoleng.2013.03.007

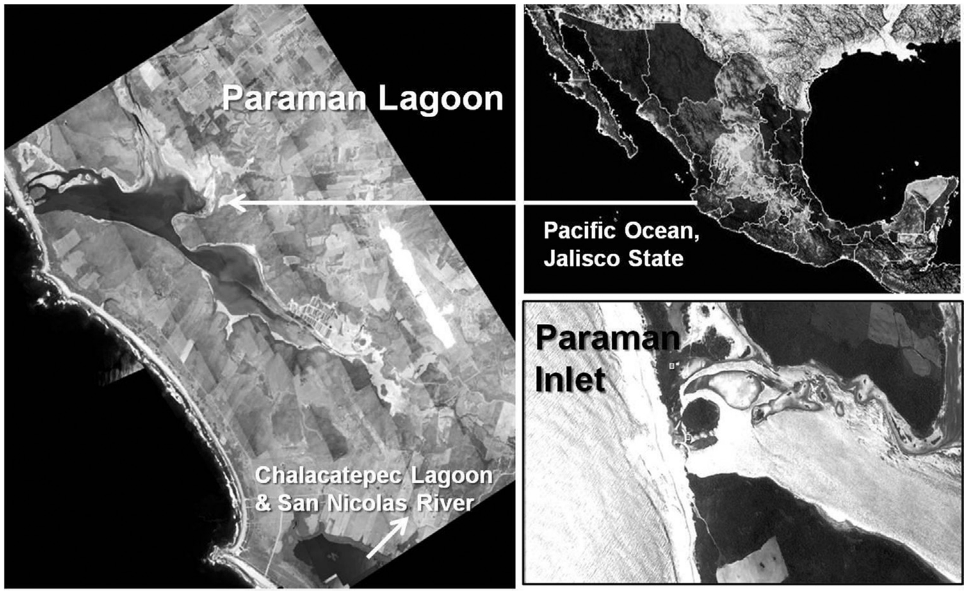

Fig. 1. Map of the study area. Satellite image of the Pacific coast of Mexico. Lidar image of Paraman Lagoon located in Jalisco state, and Lidar image of Paraman inlet. See details in Fig. 2 and Box 2. Chalacatepec Lagoon and the San Nicolas River are located southwest of Paraman Lagoon. Inlet is clearly located in the North West end of the lagoon.

artificially, can result in significant negative economic impacts in the region, as on the Pacific coast of Mexico (Yáñez-Arancibia, 1978; Flores-Verdugo et al., 1987, 1988). Although community interest in finding ways to keep these inlets permanently open has always been high, sustainable engineering solutions to keep inlets open will require more insight into the morphological/hydrologic processes governing seasonal opening and closure of the inlets (e.g., Copper, 1990; Ranasinghe and Pattiaratchi, 2003; Schwartz, 2005; Day et al., 2009a; Yáñez-Arancibia et al., 2009a).

1.1. Background for restoration and ecosystem management: geomorphology and functional structure

Two main aspects must be considered to understand the functional structure in coastal lagoons with ephemeral inlets, e.g., morphology as related to species structure, and coupling among different areas.

1.1.1. Morphology and ecological affinities

Coastal lagoons are dynamic and complex ecosystems that are highly productive. The explanation for this high productivity rests in the balance among morphodynamics, physical features, freshwater input, and the adaptations of the biological communities in these lagoons (Day et al., 2008, 2013; Yáñez-Arancibia et al., 2011, 2013, and Rivera-Monroy et al., 2011). We develop this case study for Paraman Lagoon (Figs. 1 and 2) by characterizing typical seasonal changes in morphological and hydrodynamic processes (e.g., Kjerfve, 1994; Souza et al., 2003). Many tropical and subtropical lagoons have seasonally open inlets that lead to rapid salinity shifts, wave influences, and tidal variability. In turn, these factors influence and regulate levels of primary and secondary production, trophic status, and biogeochemistry (e.g., Mee, 1979; Mandelli, 1981; Flores-Verdugo et al., 1987, 1988, 1990; Rojas-Galavíz et al., 1992; Knoppers, 1994, and Rivera-Monroy et al., 2011) and the seasonal succession of primary producers that regulate secondary production (Yáñez-Arancibia et al., 1982, 1985, 1991, 1993, 1998). Over the last twenty five years, considerable information has become available on the ecology of tropical coastal lagoons (Madden et al., 1988; Kjerfve, 1994; Schwartz, 2005; Kennish and Paerl, 2010; Rivera-Monroy et al., 2011).

1.1.2. Form and function

Several terms of reference can be used to describe lagoons with ephemeral inlets on the Pacific coast of Mexico (Yáñez-Arancibia, 1978, 1981, 1987). The annual salinity cycle in these systems is a function of lagoon depth, seasonal evaporation and precipitation, and runoff volumes. The *rainy season* lasts from June through October with maximum rainfall occurring in September with occasional tropical storms and hurricanes, high temperatures and evaporation rates; the *cold season* lasts from November through January with minor rainfall events associated with the passage of frontal systems; and the *dry season* occurs from February through May with the lowest rainfall and highest evaporation and temperatures (Fig. 3).

The inlets of these lagoons close at the end of the rainy season due to low net outflow of freshwater without sufficient force to erode sediments that have accumulated in the sandbar. During the dry season salinity may rise to 140 *psu* in the shallowest parts of the lagoon (e.g., Mee, 1979; Mandelli, 1981). Salinity drops with the onset of the rainy season and there is extensive accumulation of freshwater in the lagoon basin. When the inlet is first opened, a short period of high volume discharge of water and dissolved and suspended materials to the sea occurs, followed by periods when tidal exchange results in a wide range of salinities controlled by mixing processes.

More than four decades of research in lagoon-estuarine systems have clarified the relationship between geomorphology and other factors such as climate, size of drainage basin, and tide range in the exchange of materials between the lagoon and the sea. In order to determine whether import or export predominates in a particular system, one must take measurements over long periods to compensate for the irregular and infrequent effects of climatic-meteorological forcing (i.e., Nixon, 1979; Yáñez-Arancibia, 1987; Day et al., 2013; Kennish and Paerl, 2010; Rivera-Monroy et al., 2011). We suggest that the geomorphology of tropical lagoon systems, tidal amplitude and the magnitude of freshwater input are the three key factors that determine whether there will be import