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An ecohydrology model of the Guadiana Estuary (South Portugal)

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Abstract

A 1-D ecohydrology model is proposed that integrates physical, chemical and biological processes in the Guadiana Estuary during low flow conditions and that predicts the ecosystem health as determined by the following variables: river discharge, nutrients, suspended particulate matter, phytoplankton, zooplankton, bivalves, zooplanktivorous fish and carnivorous/omnivorous fish. Low flow conditions prevail now that the Alqueva dam has been constructed. The ecological sub-model is based on the non-linear Lotka–Volterra equation. The model is successful in capturing the observations of along-river changes in these variables. It suggests that both bottom-up and top-down ecological processes control the Guadiana Estuary ecosystem health. A number of sensitivity tests show that the model is robust and can be used to predict – within likely error bounds provided by the sensitivity tests – the consequences on the estuary ecosystem health of human activities throughout the river catchment, such as the irrigation farming downstream of the Alqueva dam, reclamation of the salt marshes by urban developments, and flow regulation by the Alqueva dam. The model suggests that the estuarine ecosystem health requires transient river floods and is compromised by flow regulation by the Alqueva dam. Remedial measures are thus necessary.

Keywords: ecohydrology; marine ecology; flushing; modelling; dam; flow regulation; Portugal; Alqueva dam; Guadiana Estuary

1. Introduction

1.1. The need for an ecohydrology estuarine model

Throughout human history, the coastal plains and lowland river valleys have usually been the most populated areas over the world (Wolanski et al., 2004). At present, about 60% of the world's population lives along the estuaries and the coast (Lindeboom, 2002). This is degrading estuarine and coastal waters through pollution, eutrophication, increased turbidity, overfishing, and habitat destruction. The pollutant supply does not just include nutrients; it also includes mud from eroded soil, heavy metals, radionuclides, hydrocarbons, and a number of chemicals including new synthetic products.

The impact on estuaries is commonly still ignored when dams and irrigation farming are proposed on rivers. In addition, estuaries are often regarded as sites for future development and expansion, and have been increasingly canalized and dyked for flood protection, and their wetlands infilled for residential areas.

All these factors impact on the biodiversity and productivity and, hence, the overall health of estuaries and the ecosystem services they provide to humans (Nixon, 2003; Erzini, 2005). They increasingly lead humans away from the possibility of ecologically sustainable development of the coastal zone. Integrated coastal zone management plans are drawn up worldwide (e.g., Haward, 1996; Billé and Mermet, 2002; Tagliani et al., 2003; Pickaver et al., 2004; Lau, 2005). However, in the presence of significant river input, most are bound to fail because they commonly deal only with local, coastal issues, and do not consider the whole river catchment as the fundamental planning unit. It is as if the land, the river, the estuary, and the sea were not part of the same system. When

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dealing with estuaries and coastal waters, in most countries land-use managers, water-resources managers, and coastal and fisheries managers do not cooperate effectively due to administrative, economic and political constraints, and the absence of a forum where their ideas and approaches are shared and discussed (Wolanski et al., 2004). To help alleviate this problem, UNESCO – IHP has launched the ecohydrology program. In this program, the concept of ecohydrology is introduced as a holistic approach to the management of rivers, estuaries and coastal zones within entire river catchments, by adopting science-based solutions to management issues that restore or enhance natural processes as well as the use of technological solutions (Zalewski, 2002).

This science-based management requires the use of a holistic model to quantify the human impact on the ecosystem health of estuaries and to enable the exchange of information between oceanographers, biologists, ecologists, engineers, sociologists, economists and water-resources managers at local and national governmental levels, and the community.

1.2. The science behind the model

The model is process-based. The dominant physical, chemical, biological and human-related processes in an estuary are assumed to follow those described by Wolanski et al. (2004) and are sketched in Fig. 1. These processes are briefly summarised below.

The ecological health of estuaries is determined by the interaction between organisms and variations in salinity, currents, waves, suspended particulate matter (SPM), bed sediments, temperature, air exposure, hypoxia, wetland contaminants and biodiversity. Like the health of a living organism, the health of an estuary or a coastal water body, cannot be measured by one single variable, indeed a number of variables are important (Balls, 1994). Well-flushed estuaries are intrinsically more robust than poorly flushed systems. As a result, environmental degradation is most often apparent during periods of reduced freshwater inflows, e.g. during drought or when human activities reduce the freshwater flow. Therefore, this ecohydrology model focuses on low flow conditions when vertically well-mixed conditions often prevail.

Once riverine-derived suspended particulate matter enters the estuary, it can be trapped within an estuarine turbidity maximum (ETM) zone (Fig. 1). The ETM is commonly located in the very low salinity reaches of an estuary. The maximum, depth-averaged, suspended solid concentration (SSC) at high water within an estuary can be predicted semi-empirically as a function of the tidal intrusion and the tidal range (Uncles et al., 2002).

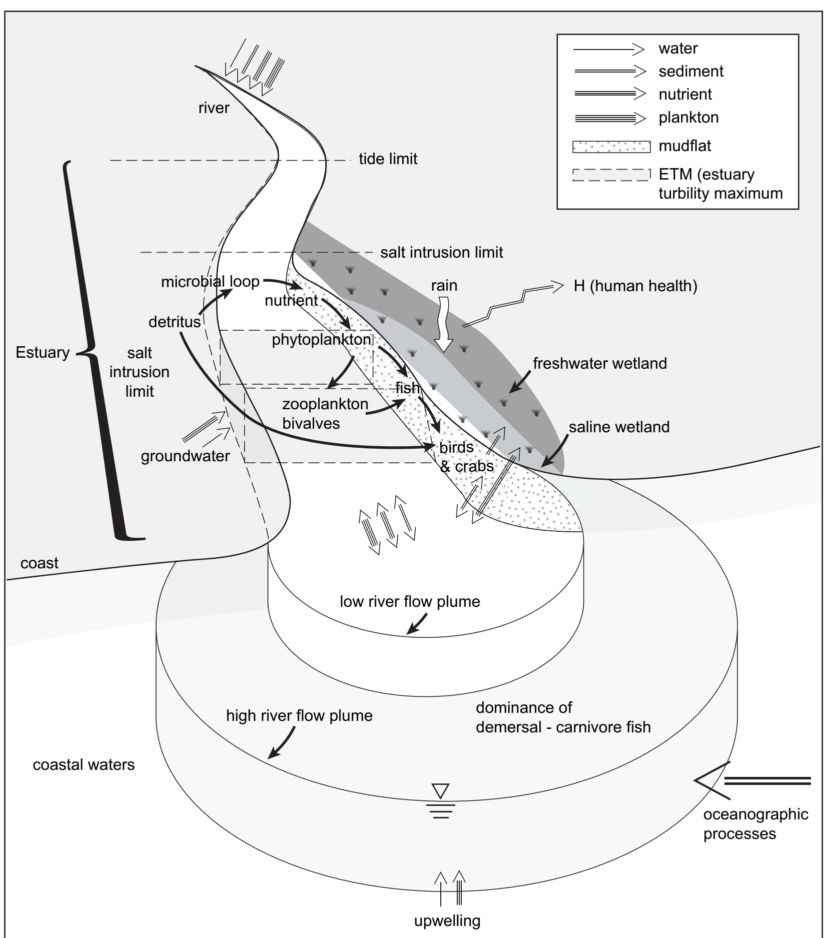

Fig. 1. Sketch of the dominant processes operating in an estuary. Adapted from Wolanski et al. (2004).