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Ecological Indicators 6 (2006) 394–408

ECOLOGICAL INDICATORS

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A Stochastic Dynamic Methodology (SDM) to the modelling of trophic interactions, with a focus on estuarine eutrophication scenarios

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Received 6 January 2005; received in revised form 5 May 2005; accepted 24 May 2005

Abstract

In the face of global change, declines in environmental quality are of increasing concern, especially in shallow coastal areas, densely populated and commonly affected by nutrient enrichment. The warm temperate Mondego estuary (Western Portugal), in common with many other shallow estuarine areas, is exhibiting increased macroalgal growth due to nutrient enrichment. The increase of macroalgal biomass and possible shift of other primary producers resulting from eutrophication, may have profound effects on estuarine trophic chain. The present paper examined the performance of a holistic Stochastic Dynamic Methodology (SDM) in predicting the tendencies of three representative trophic levels as a response to the increase of nutrient concentrations. Therefore, the proposed methodology has been developed by focusing on the interactions between conceptually isolated key-components, such as primary producers (macroalgae and seagrass), some relevant benthic macroinvertebrates, wading birds and changes in local physicochemical conditions. The dynamic model developed was preceded by a conventional multivariate statistical procedure (stepwise multiple regression analysis) performed to discriminate the significant relationships between prevailing biological and environmental variables. Since this statistical analysis is static, the dataset recorded from the field included true gradients of habitat changes. The data used in the model construction was sampled between January 1993 and September 1995 in three areas of the estuary mudflats for benthic macroinvertebrates, macroalgae, environmental and physicochemical factors and from October 1993 to October 1994 for wading birds. The model validation was based on independent data collected in two different periods, from January 1996 to January 1997 and from February 1999 to April 2000 for all the variables selected. Overall, the simulation results are encouraging since they seem to demonstrate the model reliability in capturing the trophic dynamics of the studied estuary by predicting the behavioural pattern for the most part of the components selected under a very complex and variable environmental scenario.

Keywords: Stochastic dynamic modelling; Ecological integrity; Eutrophication; Mondego estuary; Trophic interactions

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1470-160X/$ – see front matter © 2005 Published by Elsevier Ltd.
doi:10.1016/j.ecolind.2005.05.001

1. Introduction

Eutrophication of coastal systems is increasing worldwide in response to increased nutrient loading from urban areas and cultivated land areas (Kinney and Roman, 1998; Flindt et al., 1999; Cloern, 2001). Nutrient enrichment has stimulated opportunistic algal growth leading to the occurrence of macroalgal blooms and extinction of seagrass in shallow areas (Kinney and Roman, 1998; Flindt et al., 1999; Pardal et al., 2000, 2004; Kamer et al., 2001). The green macroalgae often responsible for these blooms, such as *Enteromorpha* spp., have high surface area:volume ratios that allow them to rapidly take up nutrients from the water column (Rosenberg and Ramus, 1984). Following the bloom, decomposing algae contribute significant quantities of dead organic material to the sediments. This may result in the development of anoxic conditions and high hydrogen sulphide concentrations, which are lethal to rooted macrophytes (Pardal, 1998; Terrados et al., 1999).

In the Mondego estuary, blooms of green macroalgae, primarily *Enteromorpha* spp., have been observed from early spring to late summer (Pardal et al., 2000, 2004; Cardoso et al., 2002, 2004a), as a clear sign of nutrient enrichment. As a result of competition with algae, the extension of the seagrass meadows (mainly *Zostera noltii*) has been reduced, which caused a shift in primary producers. Through time, this process gave origin to a new trophic structure (Dolbeth et al., 2003; Cardoso et al., 2004a). The energy flow at the secondary and tertiary levels will be affected, which may finally affect the populations from the upper trophic level organisms, in this case dominated by wading birds (Cabral et al., 1999; Lopes et al., 2002). The Mondego estuary, along with other Portuguese estuaries (Tagus, Sado and Minho) and rias (Aveiro and Formosa), supports a large number of waders, due to the existence of suitable supratidal habitats and an important intertidal benthic macroinvertebrate community (Marques et al., 1993).

One of the great challenges in ecological integrity studies is to predict how anthropogenic environmental changes will affect the abundance of species or communities in disturbed ecosystems (Kareiva et al., 1993; Andreasen et al., 2001). Static models with fixed parameters are, in general, unable to estimate the structural changes when the habitat conditions are substantially changing (Jørgensen and Bernardi, 1997). Therefore, ecological integrity studies have been improved by creating dynamic and structural dynamic models that simultaneously attempt to capture the structure and the composition in those systems (Jørgensen, 1994; Chaloupka, 2002). The application of ecological modelling is able to synthesize the pieces of ecological knowledge, emphasizing the need for a holistic view of a certain environmental problem, such as the medium–long-term directional disturbances in stressed ecosystems (Brosse et al., 2001; Cabral et al., 2001; Voinov et al., 2001; Jørgensen, 2001; Santos and Cabral, 2003; Cabecinha et al., 2004). Nevertheless, environmental health assessment and community studies usually result in complex biological data sets. In order to find ecological relevant holistic patterns and tendencies from such sets of data it is necessary to synthesize all the information to a more simplified form (Pardal et al., 2004). In this scope, an expeditious Stochastic Dynamic Methodology (SDM) has recently been developed and successfully applied in relatively ecological stable systems, such as mountain freshwater running waters (Cabecinha et al., 2004) and mediterranean agroecosystems (Santos and Cabral, 2003).

Since many studies refer that changes in primary producers due to eutrophication affect the production of the other trophic levels (Flindt et al., 1999; Pardal et al., 2000, 2002; Beukema et al., 2002; Cardoso et al., 2002), the main objective of the present paper was to demonstrate the applicability of a holistic SDM approach in the scope of the trophic dynamics resulting from changing complex and variable environmental scenarios. Therefore, the goal of this study is to construct a simple demonstrative SDM model by focusing the interactions between conceptually isolated key-components in the Mondego estuary, namely between three selected trophic levels (primary producers, benthic macroinvertebrates and wading birds) and physicochemical conditions. A previous overview of this problematic in Mondego estuary, suggested that these trophic levels have several characteristics that justified their relevance as ecological indicators: (1) they usually occur in high densities/biomass in the studied areas, (2) they provide cheap and easy measurements if standard methodol-