Marine Pollution Bulletin 64 (2012) 500–511

Contents lists available at SciVerse ScienceDirect

Marine Pollution Bulletin

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

The use of diatom assemblages as ecological indicators in highly stratified estuaries and evaluation of existing diatom indices

L. Rovira *, R. Trobajo, C. Ibáñez

IRTA – Aquatic Ecosystems, Carretera Poble Nou KM 5.5, 43540 St. Carles de la Ràpita, Catalonia, Spain

ARTICLE INFO

Keywords:
Diatom indices
Stratified estuary
Ecological status
Indicator species
Salt wedge
Transitional waters

ABSTRACT

Diatom indices are used to evaluate the ecological status of rivers but they have been rarely applied in estuaries. This study aimed to identify the diatom species indicating the main environmental gradients and pressures in a highly stratified estuary; and to evaluate the applicability of existing freshwater diatom indices. Marine influence due to salt-wedge intrusion and sea water mixing appeared as the main factor affecting diatom community. Three diatom assemblages were identified: indicators of riverine conditions (without marine influence), indicators of estuarine conditions (heterogeneous conditions with higher conductivities due to marine influence) and those specifically indicating well-established salt-wedge situations. Nowadays, the main human pressure affecting diatom community in the Ebro Estuary is the hydrological alteration resulting from flow regulation and abstraction. Several limitations were encountered in the application of diatom indices (e.g. inverse response with nutrients; ecologically important species not considered). Therefore, their use in estuaries should be done cautiously.

1. Introduction

Estuaries and other transitional waters are dynamic ecosystems showing a high spatial and temporal physicochemical variability (Cloern et al., 1989; Rovira et al., 2009; Webster et al., 2000), and they can also present several pollution gradients due to the high number of human activities influencing them. Moreover, some natural stressors in transitional waters can be modified by human activities, making it very difficult to discern natural from anthropogenic stressors (Dauvin, 2007; Elliott and Quintino, 2007). Therefore, dominant estuarine flora and fauna will reflect this natural variability, but at the same time it may have features very similar to those found in anthropogenically stressed areas difficulting the detection of anthropogenic stress effects and, consequently, the accurate assessment of ecological status in estuaries (Elliott and Quintino, 2007).

The Water Framework Directive (WFD; EC, 2000) aims to assess the ecological status of all European water bodies (including transitional waters) using hydromorphological, physicochemical and biological indicators (i.e. phytoplankton, macroalgae, phytobenthos, macroinvertebrates and fish) (Allan et al., 2006; Borja et al., 2004; Logan and Furse, 2002). Due to its reduced mobility and short generation times, phytobenthos has shown a rapid response to environmental changes and can integrate environmental conditions better than other bioindicators (Smol and Stoermer, 2010); being commonly used in the assessment of the ecological status and monitoring of anthropogenic impacts. Diatoms are the main component of phytobenthos, being one of the most important algae groups used for ecological assessment (Descy and Coste, 1991; Kelly et al., 1995, 1998; King et al., 2006; Warwick et al., 1990). Their ubiquity, their direct and sensitive response to physicochemical changes, and their preservation in sediments for a long time makes them good water quality indicators for both present and past environmental changes (Smol and Stoermer, 2010).

In Europe there are about 20 diatom-based metrics that were initially developed to assess nutrient and/or organic pollution in rivers and, later, some of them have been adapted to fulfil the WFD requirements of assessing the ecological status of these ecosystems (Kelly et al., 2009). Nowadays, diatom indices are being routinely used in most EU member states to evaluate the ecological quality of rivers and streams. However, little information is available about the use of benthic diatoms as bioindicators in estuaries and other transitional systems, with only very few studies carried out in Europe (Bogaczewicz-Adamczak and Dziengo, 2003; Della Bella et al., 2007; Zgrundo and Bogaczewicz-Adamczak, 2004) and in USA (Bauer et al., 2007). The study of Della Bella et al. (2007) is the only one dealing with the controversies of water quality assessment in these complex water bodies.

The present study is the first attempt to evaluate the use of benthic diatoms to assess the ecological status in a highly stratified estuary. Highly stratified estuaries are usually characterised by weak tides, resulting in strong vertical water column stratification

* Corresponding author.
E-mail address: laia.rovira.torres@gmail.com (L. Rovira).

0025-326X/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.marpolbul.2012.01.005

that affects biological communities (Ibáñez et al., 1997; Nebra et al., 2011; Rovira et al., 2009). The study had two main objectives: the first was to identify the main environmental gradients in the Ebro Estuary and establish diatom indicator species associated with these gradients; the second objective was to identify the most relevant human pressures and evaluate the application of existing freshwater diatom indices to assess the ecological status of a highly stratified estuary, namely the Ebro Estuary.

2. Materials and methods

2.1. Study area

The Ebro Estuary covers an approximate area of 10 km^2 and is 40 km long with a mean width of 237 m and a mean depth of 6.8 m. It is considered a "micro-tidal salt-wedge estuary" with a tidal range around 20 cm. This weak tidal range favours the vertical stratification of the water column and the existence of a salt wedge, with a maximum intrusion in the Ebro River of 32 km. The hydrology and dynamics of this salt wedge are controlled mainly by the Ebro River flow, disappearing when the Ebro River flow is above 400 m^3/s. Between 250 and 400 m^3/s the salt wedge occupies the last 5 km of the estuary, and with discharges below 250 m^3/s, the salt wedge advances up to 18 km from the river mouth (this is the most frequent situation). When the river flow is less than 100 m^3/s, the salt wedge reaches its maximum extent (32 km from the river mouth), although this situation is much less frequent (Ibáñez et al., 1997). The lower Ebro River flow has been largely regulated since 1960s with two reservoirs (Mequinenza and Riba-Roja) situated 100 km upstream the river mouth for hydropower purposes, and it has decreased by 40% due to intensive water uses in the Ebro basin, with irrigation accounting for 90% of water consumed (Ibáñez and Prat, 2003).

2.2. Sampling

Eight sampling sites distributed every 3–6 km within the estuary were sampled every 3 months from October 2007 to December 2008 (Fig. 1). Benthic diatom samples were collected from both natural substrata (mainly macrophytes *Potamogeton pectinatus* and *Ceratophyllum* spp., and wood debris where macrophytes were not available) and artificial substrata (fired clay bricks). Fired clay bricks were placed at superficial (0.5 m) and deep (4–6 m) levels at each site. This sampling design allowed the gathering of both vertical and horizontal physicochemical gradients in the estuary. Artificial substrata were considered robust enough to resist high flows and sudden flow fluctuations that characterise the lower Ebro River. However, due to sudden increases in the river flow, some samples of artificial substrata were not recovered during the sampling period. An area of 4 cm^2 was scrapped off the artificial substrata and three fragments from natural substrata were included in each replicate. Two replicates from both artificial and natural substrata were processed in each site.

Water depth, temperature, electrical conductivity (EC_{25}), dissolved oxygen (DO_2), and pH were measured *in situ* using an YSI 556 multiprobe. Flow direction and velocity were also measured *in situ* using a BFM 001 current flow meter.

Lower Ebro River flow records (measured in Tortosa, 40 km upstream from the river mouth) were obtained from the Ebro Hydrographical Confederation (CHE) database. Historical data from 1913 to 2008 was used to analyse the annual average of daily flow and monthly fluctuation range (difference between maximum and minimum flow during 1 month) of lower Ebro River flow. The data from 30 days before sampling was used to calculate average, maximum, minimum, and fluctuation range of the lower Ebro River flow during each sampling campaign.

2.3. Nutrient and chlorophyll analyses

Water samples were collected both at superficial and deep water layers in order to determine nutrients and chlorophyll *a* content. Dissolved nutrients: silicate (Si-SiO_4^{4-}), nitrate (N-NO_3^-), nitrite (N-NO_2^-), phosphate (P-PO_4^{3-}), ammonium (N-NH_4^+); total nitrogen (TN) and total phosphorus (TP) were measured following Koroleff et al. (1977). Historical data for phosphate (P-PO_4^{3-}) and

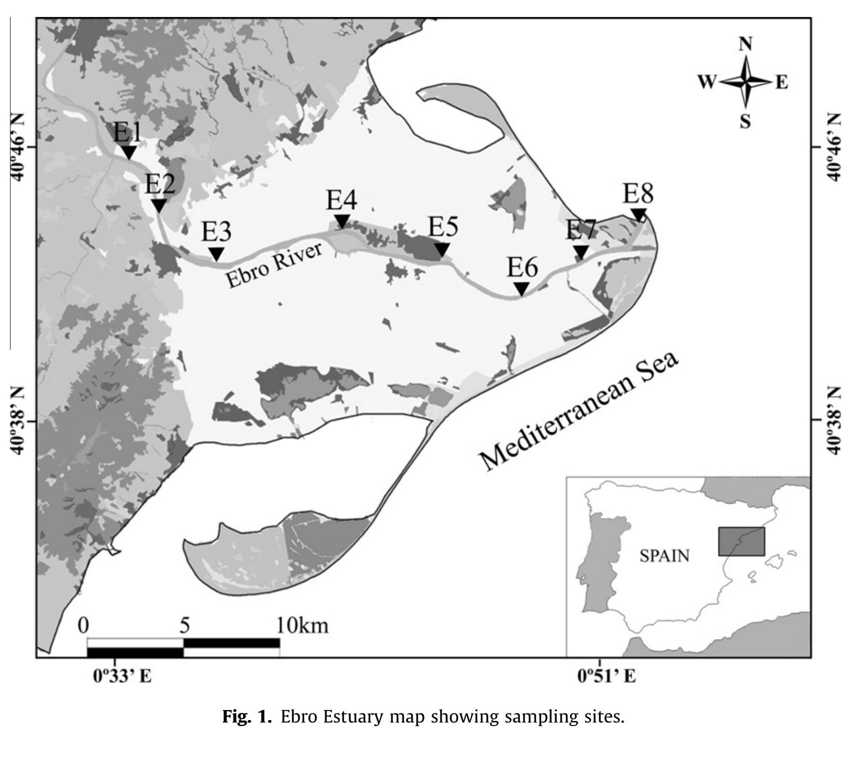

Fig. 1. Ebro Estuary map showing sampling sites.