Continental Shelf Research 88 (2014) 151–160

Contents lists available at ScienceDirect

Continental Shelf Research

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

Research papers

Assessing the susceptibility of two UK estuaries to nutrient enrichment

Margaret Kadiri [a,*], Bettina Bockelmann-Evans [a], William B. Rauen [b]

[a] Hydro-Environmental Research Centre, School of Engineering, Cardiff University, Queen's Buildings, The Parade, Cardiff CF24 3AA, UK
[b] Graduate Programme in Environmental Management, Universidade Positivo, Curitiba, PR, Brazil

ARTICLE INFO

Article history:
Received 2 August 2013
Received in revised form
29 July 2014
Accepted 5 August 2014
Available online 19 August 2014

Keywords:
Nutrients enrichment
Turbidity
Dissolved oxygen
Eutrophication
Severn Estuary

ABSTRACT

The susceptibility of two UK estuaries, the Severn and Solva Estuaries to the risks and impacts of nutrient enrichment was investigated in this study by examining nutrients, dissolved oxygen (DO) and turbidity concentrations in the estuaries and applying a risk assessment model based on the UK's Comprehensive Studies Task Team (CSTT) modelling approach. Both estuaries were found to be nutrient enriched. However, there was no evidence of oxygen depletion in the Severn and algal blooms were not observed due to high turbidity, strong tidal currents and tidally induced vertical mixing conditions in the estuary. Although algal blooms were observed in the Solva Estuary, the estuary was well-oxygenated due to the relatively high water exchange rate and consistent rapid flushing in the estuary. The conditions in the Solva Estuary were predicted to be favourable for phytoplankton productivity and the wider potential implications for future water quality protection strategies in the Solva were discussed.

1. Introduction

Nutrient enrichment in estuarine and coastal waters can elicit a variety of biological responses ranging from the prolific growth of phytoplankton and increased primary production to blooms of toxic algae and macroalgae, increased growth of epiphytic algae, loss of submerged vegetation, depletion of oxygen, alteration of species composition and increased mortality of aquatic invertebrates and fish populations (Bricker et al., 1999; Painting et al., 2007). This array of events, starting from nutrient enrichment to the responses at the community and ecosystem level, is often categorised under the term, ‘eutrophication’. Eutrophication is defined under the Urban Waste Water Treatment Directive (UWWTD; CEC, 1991) as the ‘enrichment of a water-body by nutrients, especially compounds of nitrogen (N) and phosphorus (P), causing the accelerated growth of algae and higher forms of plant life which produce an undesirable disturbance to the balance of organisms and the quality of water concerned’. Given the detrimental impacts and risks of nutrient enrichment on aquatic ecosystem functioning, an assessment of the response of estuaries to nutrient enrichments is important for effective estuarine management.

Several directives including the Urban Waste Water Directive (UWWTD, CEC, 1991) and the Water Framework Directive (WFD, CEC, 2000) have been introduced to manage the risks of eutrophication. Various approaches have been adopted for assessment under these directives. For example, the UK's Comprehensive Studies Task Team (CSTT), set up in response to the UWWTD, developed a model to assess the response of water bodies to nutrient enrichment in order to determine whether action should be taken under the directive to reduce nutrient inputs to a given water body. The model predicts the value of easily observed variables including phytoplankton chlorophyll biomass and by comparing the model outputs to defined thresholds, the model is used to diagnose potential eutrophication. Under the OSPAR Eutrophication Strategy, assessments have been based on Ecological Quality elements and objectives (OSPAR, 2005). The Ecological Quality elements are indicators of negative impacts of nutrient enrichment which are easily observable and amenable to quantitative analysis. There are several Ecological Quality elements including dissolved oxygen concentrations and water clarity. Ecological Quality objectives are the desired thresholds which have been defined for each element. For example, dissolved oxygen concentrations below 4–6 mg l^{-1} are considered to be indicative of undesirable disturbance. Nixon (1995) proposed thresholds for assessing trophic status in coastal marine water from primary production (i.e. oligotrophic: 0–100 g C m^{-2} y^{-1},mesotrophic: 100–300 g C m^{-2} y^{-1}, eutrophic: 301–500 g C m^{-2} y^{-1} or hypertrophic: $>$ 500 g C m^{-2} y^{-1}). However, this threshold scale has no direct bearing on the term ‘eutrophication’, as defined by the UWWTD (Painting et al., 2007).

Large differences have been found among estuarine and coastal systems in the magnitude and character of their responses to nutrient enrichment. Alpine and Cloern (1992) observed a reduction in phytoplankton primary production despite high nutrient loads in North San Francisco Bay. In contrast, Richardson and Heilmann (1995) observed increased phytoplankton production due to nutrient enrichment in the Kattegat. Likewise, high nutrient concentrations

* Corresponding author. Tel.: +44 2920876814; fax: +44 2920874939.
E-mail address: kadirimo@cf.ac.uk (M. Kadiri).

http://dx.doi.org/10.1016/j.csr.2014.08.002
0278-4343/

resulted in phytoplankton blooms, oxygen depletion and fish kills in the Vilaine Bay (Chapelle et al., 1994). However, these negative impacts were not observed in the nearby Bay of Brest despite increased nutrient loading to the estuary (Le Pape et al., 1996). Similarly, a fourfold increase in nitrogen loading to the Ythan estuary did not result in an increase in chlorophyll concentrations in the estuary (Balls et al., 1995). Also, Pennock et al. (1994) observed different phytoplankton biomass, primary production, and oxygen dynamics in the Delaware Bay and Mobile Bay, although these estuaries had comparable high rates of nutrient loading. These differences in the magnitude and character of the response to nutrient enrichment among estuaries show that, in addition to high nutrient loads to estuaries, other environmental factors can exert a control on the response to nutrient enrichment in estuaries (Cloern, 2001). For example, the transformation of nutrients into phytoplankton chlorophyll biomass requires solar energy to drive photosynthesis. Hence, turbidity which governs the availability of sunlight for phytoplankton growth in the water column can influence the way in which nutrient enrichment is expressed in an estuary.

Tidal mixing, water residence time, temporal and spatial distribution of nutrients, organic matter and phytoplankton grazing are among the factors that can exert a control on the response of estuaries to nutrient enrichment (Monbet, 1992; Pennock et al., 1994; National Research Council, 2000; Cloern, 2001; de Jonge and Elliott, 2001; de Jonge et al., 2002). These factors interact in many different ways and their degree of control on the response to nutrient enrichment would vary across estuaries, with some estuaries highly sensitive to nutrient enrichment and others more resistant (Cloern, 2001). Given the high degree of variability in the regulating environmental factors across estuaries, it is a difficult task to determine the response from theoretical considerations and important to assess the response in terms of nutrients concentrations and regulating factors.

In this study, we assess the relative susceptibility of two estuarine systems, the Severn Estuary and Solva Estuary, to the risks and impacts of nutrient enrichment. The approach to the study is based on the examination of measured nutrients, dissolved oxygen (DO) and turbidity concentrations in the estuaries and the application of a risk assessment model (Painting et al., 2007) which is based on the CSTT modelling approach to

(1) evaluate the response to nutrient enrichment in the estuaries;
(2) determine if the environmental factors play a dominant role in controlling the response to nutrient enrichment in these estuaries; and
(3) investigate the influence of different system-specific parameters on the model predictions to provide a sensitivity analysis to the model assumptions.

This study would provide valuable information for water quality protection strategies in these estuaries. In this study, DO concentrations below 6 mg l^{-1} were considered to be indicative of negative response to nutrient enrichment in the estuaries.

2. Materials and methods

2.1. Study areas

The Solva Estuary is a semi-enclosed estuary located in south-west Wales (Fig. 1a). This meso-tidal estuary (tidal range >2 m but <4 m) is approximately 1.5 km long and it is relatively shallow, with a mean water depth of approximately 4 m. There are rock cliffs on either side with a sand bank on the eastern side and a raised shingle storm beach located behind the eastern headland. It drains a catchment area of about 50 km^2, primarily rural in character and extensively used for rough grazing and agriculture. Human population living around the estuary is low, about 1420, with the main settlement being the Solva village. The main riverine nutrient input source into the estuary is the river Solva. Also, there is an additional small stream which feeds into the estuary. The main point source of nutrients to the estuary is treated effluents from a small sewage treatment works which is located in the lower reaches of the estuary.

The Severn Estuary is a semi-diurnal estuary located between the south coast of Wales and the north-east coast of Somerset, which enters into the Bristol Channel (Fig. 1b). The estuary and the adjoining Bristol Channel are about 250 km in length, with a spring tidal range of approximately 14 m and strong tidal currents, in excess of 2 m s^{-1} (Manning et al., 2010, Uncles et al., 2002). The water depth ranges from less than 10 m in the upper reaches of the estuary to over 50 m at the mouth of the estuary, with the strong tidal currents resulting in the thorough mixing of the water column (Manning et al., 2010, Uncles, 2010). This hyper-tidal estuary drains a total catchment area of approximately 25,000 km^2 (Jonas and Millward, 2010), a large proportion of which is used for animal husbandry and agriculture. There are several large industrialised urban centres situated along the estuary including Cardiff, Bristol, Gloucester, Swansea and Newport. The human population living around the estuary is large (in excess of 1 million). The main riverine nutrient inputs to the estuary are from five major rivers including the Wye, Avon, Parrett, Usk and Severn, all of which are affected by anthropogenic activities. However, there are 23 additional smaller rivers which feed into the estuary. The estuary also receives treated effluent inputs from 33 sewage treatment works which range from large to moderate sized works serving the domestic and industrial effluents of the towns, cities and rural areas located along the estuary and the Bristol Channel. The estuary has limited light availability and a vast expanse of intertidal mudflats. By virtue of the abundance of migratory and resident birds as well as invertebrate populations in the intertidal mudflats, the estuary is recognised as an area of major conservation importance. Hence, it has several national and international designations, including a Special Protection Area

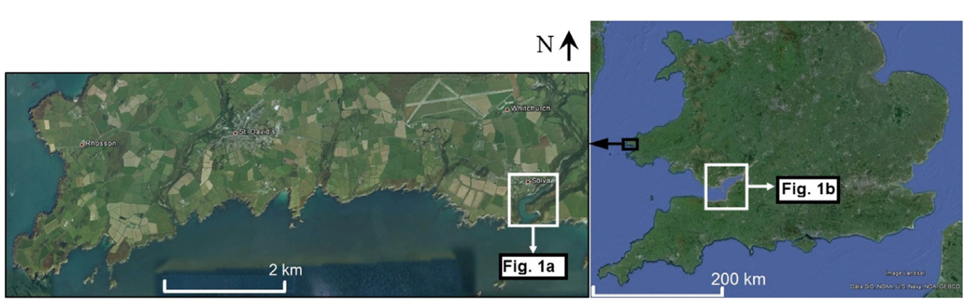

Fig. 1. Location of (a) Solva and (b) Severn Estuaries.