Estuarine, Coastal and Shelf Science 120 (2013) 21–32

Contents lists available at SciVerse ScienceDirect

Estuarine, Coastal and Shelf Science

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

Sediment macroinvertebrate community functioning in impacted and newly-created tidal freshwater habitats

Olivier Beauchard [a,b,*], Sander Jacobs [a], Tom Ysebaert [b,c], Patrick Meire [a]

[a] University of Antwerp, Ecosystem Management Research Group, Universiteitsplein 1, 2610 Wilrijk, Belgium
[b] Netherlands Institute for Sea Research (NIOZ), P.O. Box 140, 4400 AC Yerseke, The Netherlands
[c] IMARES, P.O. Box 77, 4400 AB Yerseke, The Netherlands

A R T I C L E I N F O

Article history:
Received 14 June 2012
Accepted 5 January 2013
Available online 8 February 2013

Keywords:
tidal freshwater habitats
restoration
ecological zonation
benthos
community composition
biological traits

A B S T R A C T

Although experiencing strong anthropogenic pressures in many estuaries, the ecology of tidal freshwater areas remains largely undocumented. As part of a restoration project in the freshwater zone of the Schelde estuary (Belgium), a new tidal habitat restoration technique (Controlled Reduced Tide system, CRT) was hypothesised to successfully compensate for the impairment of contemporary habitats. The suitability of this newly-created habitat (CRT) and the estuary was investigated over a period of three years for its macroinvertebrate community development. In both the estuary and the CRT, habitats along a flooding gradient were monitored. Differences between the CRT and reference sites in community functioning were explored according to environmental characteristics and organism biological attributes using the RLQ ordination analysis together with the fourth-corner method. Frequently flooded reference sites exhibited environmental characteristics resulting from a hydrological shear stress. In the CRT, after a rapid removal of the terrestrial fauna at low and mid elevations, the low-energy hydrology led to taxonomic and functional enrichment. The RLQ analysis produced significant environmental filtering of biological attributes mainly related to the terrestrial–aquatic transition and to the environmental stressors. This provides an example of life history modification via estuarine ecosystem management.

1. Introduction

Tidal freshwater wetlands are relatively rare but known to occur in the estuaries of the largest river drainages (Baldwin et al., 2009) but to date they have been mainly studied in North America. In Europe, most of them are found along the North Sea coast, in the Schelde, Maas and Elbe estuaries; almost 10% of them occur in the Belgian part of the Schelde estuary (Struyf et al., 2009). This estuary has been hugely impacted by human activities (industry and navigation), and embankments have led to a large-scale loss of 36% of the total surface of tidal habitats during the last century, while the remaining ones are under severe stress of changing hydrodynamic conditions (Meire et al., 2005).

Typically, tidal freshwater marshes bordering river channels consist of continua which extend over mudflat, helophyte and woody plant habitats where the daily flood interacts with elevation (Baldwin et al., 2009; Struyf et al., 2009). As low marshes in the Schelde estuary have now become rare through embankments, entire habitat gradients have also become rare (Struyf et al., 2009). In order to accommodate both ecological and economical problems, a long-term vision for the Schelde estuary was agreed to be the development of a healthy and multifunctional estuarine water system that can be used in a sustainable way for human needs (Van den Bergh et al., 2005). This vision includes the restoration of the intertidal habitats throughout the estuary, including the freshwater zone. In many coastal zones, restoration and creation of natural habitats are constrained by historic embankments and soil subsidence where mean high water level prevents a complete flooding gradient which in turn conditions habitat diversity (Beauchard et al., 2011). However, using a system of inlet and outlet culverts, controlled reduced tide (CRT) engineering is a new restoration technique to overcome this constraint. CRT was hypothesized to successfully restore intertidal habitats (Maris et al., 2007), and a pilot CRT was implemented in the freshwater zone of the Schelde estuary in 2006.

The ecological importance of tidal freshwater wetlands has been mainly attributed to the biogeochemical processes that they ensure in estuaries (Megonigal and Neubauer, 2009). However, the lack of knowledge of tidal freshwater ecology is well-recognized, particularly in invertebrate studies (Rundle et al., 1998; Reinicke, 2000;

* Corresponding author. University of Antwerp, Ecosystem Management Research Group, Universiteitsplein 1, 2610 Wilrijk, Belgium.
E-mail address: olivier.beauchard@ua.ac.be (O. Beauchard).

0272-7714/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ecss.2013.01.013

Sousa et al., 2005); invertebrates represent a key ecosystem compartment as they cycle energy between autotrophic and heterotrophic components. The many roles of sediment invertebrates include organic matter decomposition and mineralization, humification, sediment mixing, soil/sediment oxygenation and irrigation (Wallace and Webster, 1996; Herman et al., 1999; Lavelle et al., 2006), whereas the loss of functional groups may impair ecosystem performance (Thrush et al., 2006). In tidal freshwater and brackish zone, invertebrate biomass and density increase in response to nutrient enrichment (Oviatt et al., 1993; Frost et al., 2009); this underlines another crucial role of invertebrates in impacted estuaries by mineralising excess nutrients which otherwise cause adverse effects such as eutrophication (Jickells, 1998).

In the Schelde estuary, only a few studies, focussing mainly on the whole salinity gradient, reported invertebrate data from the freshwater zone (Ysebaert et al., 1993, 1998; Seys et al., 1999); locally, none of them took the flooding gradient into account, leading to incomplete description of intertidal communities. Furthermore, Ysebaert et al. (1998) advocated the need to focus on the functional role of organisms in the ecosystem and especially the relationships between species communities, environmental features and habitat use. This is typically interrogated using methods coupling sites × variables and sites × species matrices (Dray et al., 2003). However, the taxonomic nature of such investigations limits our understanding of the mechanistic processes explaining species occurrences along a gradient. Recent methodological advances (Dolédec et al., 1996; Legendre et al., 1997; Dray and Legendre, 2008) have allowed us to identify biological properties which determine species occurrences in a given environment, but there are still few published applications in estuaries. Therefore, this study aims: (1) to describe the current macroinvertebrate communities along a flooding gradient in the estuary, (2) to verify the suitability of CRT for invertebrate community development among the newly-created tidal habitats and (3) to compare the community functioning in CRT and reference adjacent estuarine habitats.

2. Methods

2.1. Study area

This study took place in the freshwater zone of the Schelde estuary, Belgium (51.086 °N; 4.171 °E; Fig. 1). The estuary is particularly characterized by the length of the tidal wave which influences the river and some tributaries, 235 km in total, encompassing 44 km^2 of tidal freshwater surface. At the study location, the estuary is a narrow tidal channel bordered with mudflats and high marshes, and the average tidal amplitude is ca.5.2 m. The first CRT system was implemented in the Lippenbroek polder (8.2 ha; Fig. 1B), where agriculture was practiced until 2000, whereas now it supports a pilot project for intertidal habitat restoration together with protection against flooding by storm surges and high tides. It is connected to the estuary by an inlet culvert and an outlet valve allowing water exchanges between the two systems (see Maris et al. (2007) and Beauchard et al. (2011) for technical details). The polder has been under the CRT tidal influence since March 1st, 2006.

2.2. Sampling site description

Eight field samplings were carried out from April 2006 to February 2008 (once each season) plus an additional one in summer 2009. In the CRT, the monitoring was conducted at four sites covering the whole gradient (Fig. 1B) with 3 sites covering the entire elevation range, giving rise to three flooding frequencies (Fig. 2): site H (high elevation, low flooding frequency), site M (mid elevation, moderate flooding frequency) and site L (low elevation, high flooding frequency). In general, site L is flooded on most days (87% of the tides) whereas site H is flooded less-frequently around spring tides (24% of the tides). Since a part of the CRT is permanently filled with water, the fourth site was considered as representative of this tidal pool (site P). Sediment deposition was rapid and elevation-dependent, with higher accretion rates in frequently flooded sites (Vandenbruwaene et al., 2011, Fig. 2). The soil at site L was covered by more than 15 cm of river sediments within a year.

Site H was covered with remnant terrestrial vegetation, mainly represented by *Urtica dioica*, and did not change notably. In contrast, site M was progressively colonized by wetland species such as *Epilobium hirsutum* and *Lythrum salicaria* (Jacobs et al., 2009). At site L, plant species turnover was complete after one season, where *Lythrum salicaria* and especially *Phragmites australis* replaced the terrestrial community.

In the adjacent estuary, three sites, as the most representative habitats of the area, distributed along the flooding gradient, were also monitored (Figs. 1 and 2): willow (site W, high marsh, mainly characterized by *Salix* sp.), reed (site R, monospecific coverage of *Phragmites australis*) and bare tidal flat (site F). As the result of tidal

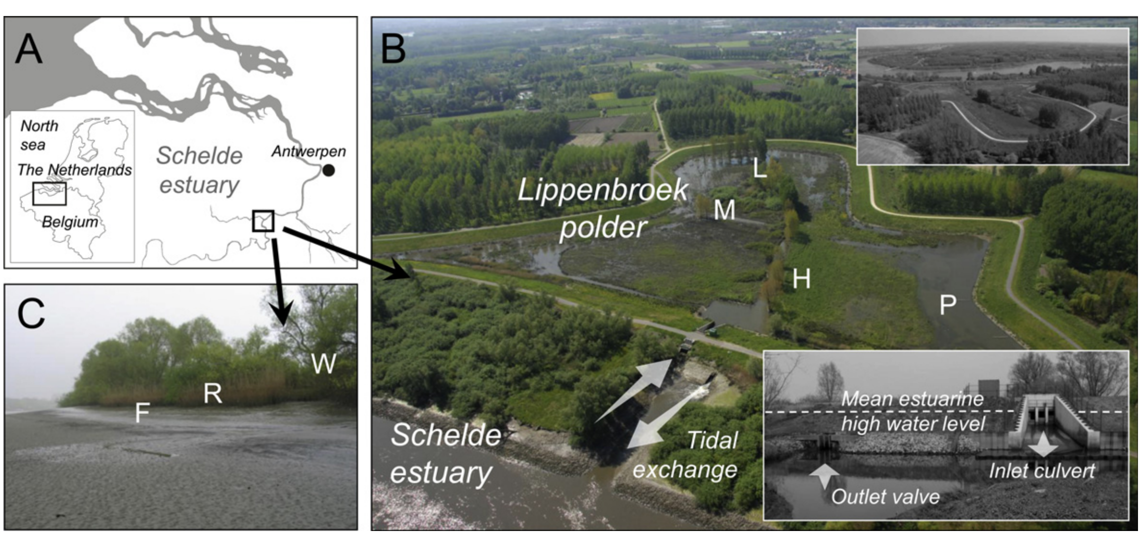

Fig. 1. A) Location map of the study area. B) Photograph of the experimental CRT; H, L, M and P for respectively high, mid, low elevation and pool; upper insert, global view of the location area; lower insert, water exchange system. C) Reference sites located 600 m upstream the polder: W, R and F for respectively willow, reed, flat.