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ORIGINAL PAPER

Sediment-benthos relationships as a tool to assist in conservation practices in a coastal lagoon subjected to sediment change

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Abstract This study explores the relation between sediment composition and intertidal macrobenthos populations in the Zwin nature reserve (Belgium and The Netherlands), a tidal lagoon that is included in the Ramsar list of wetlands of international importance and has been designated as Natura 2000 area, among others due to its function as wintering habitat for shorebirds that feed upon macrobenthic invertebrates. Species response models show highest biomass of these prey species in organically enriched cohesive sediments and a distinct decline in probability of occurrence for most species in coarse sediments. Further, the biomass of macrobenthos declined between 2003 and 2010 in the extensive low intertidal inlet channel concurrent with the coarsening of the sediment over time in this hydrodynamically stressed habitat. In contrast, macrobenthos biomass increased in a sheltered shallow intertidal habitat that acted as a catchment area for finer sediments, therefore facilitating the succession towards a higher elevated habitat with salt marsh vegetation establishment. Hence, spatio-temporal sediment dynamics decreased site quality for intertidal predators due to a reduction in feeding areas over time, and a change in

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physical sediment properties that alter the macrobenthos species occurrence and population biomass. This study thus illustrates that sediment transport dynamics may affect the functioning of coastal shallow soft-sediment habitats, like coastal lagoons. The presented macrobenthos species response models provide a tool to assist in management actions that enable the conservation of cohesive low intertidal habitats that provide a high food supply to shorebirds, fish and macrocrustaceans.

Keywords Coastal lagoon · Sand deposition · Ecological cascade · Integrated coastal zone management · Macrobenthos

Introduction

The biodiversity found in coastal habitats is on the frontline of current environmental change resulting from anthropogenic activities related to the expanding exploitation of coastal areas (Airoldi and Beck 2007; Lotze et al. 2006; Sutherland et al. 2012). For example, changes in sedimentation regimes and water-borne suspended sediment concentrations resulting from changes in land-use and engineering activities in the coastal zone (e.g. dredging, aggregate extraction, beach nourishment) affect biodiversity and ecological value in coastal soft-sediment habitats (Thrush et al. 2004). One such habitat are coastal lagoons where suspended sediments may deposit depending on interactions between geomorphological, hydrological and biological factors (De Backer et al. 2010; Duck and da Silva 2012; Plecha et al. 2012). Such infilling is enhanced in sheltered habitats and further facilitated by pioneering vegetation that trap fine sediment particles resulting in increasing elevation (Kirwan et al. 2010), and a reduction in inundation time and the surface of low intertidal areas, illustrative for the succession towards a marsh habitat.

Given the number of natural processes and linkages with adjacent terrestrial areas, as well as coastal marine areas, coastal lagoons, together with estuaries, may provide more ecosystem services and social benefits than other aquatic systems (Elliott and Whitfield 2011). For example, these shallow coastal waters represent a preferential habitat. Shorebirds and nektonic species (fish and macrocrustaceans) by providing a high biomass of intertidal prey organisms such as polychaetes and molluscs (Snelgrove 1999; Chapman 2012). These macrobenthic invertebrates exhibit clear sediment preferences (Ysebaert et al. 2002; Thrush et al. 2003) because physico-chemical sediment characteristics determine the environmental conditions these organisms inhabit. Shorebirds and nektonic species that prey upon macrobenthic invertebrates (Hampel et al. 2005; Van de Kam et al. 2004) are therefore likely to respond to changes in distribution and biomass of these prey species (e.g. Kraan et al. 2010; van Gils et al. 2006) that may result from altered sediment dynamics that change intertidal sediment properties. In addition to such change in sediment properties and the reduction in size of appropriate feeding areas, sediment deposition may further diminish site quality particularly for shorebirds because an enhanced elevation and concurrent salt marsh development may enhance accessibility and hamper detection of predators, e.g. Maslo and Lockwood (2009), Nordstrom et al. (2002).

This study explores the concurrent variability in intertidal sediment composition and macrobenthos communities in a coastal lagoon that is subject to change in sediment erosion–deposition dynamics resulting from natural aeolian and tidal sediment transport, and anthropogenic activities both in the vicinity and in the lagoon (i.e. beach nourishment and lagoonal hydrodynamic change due to sediment extraction, creek construction and the reduction of tidal outflow; Cosyns et al. 2013). We therefore (1) model the occurrence and biomass of macrobenthic species in relation to sediment median grain size, and (2) investigate the changes in macrobenthic species biomass associated with changes in the sediment composition between 2003 and 2010 in two contrasting habitats in the lagoon. This information provides a tool to assist in the proper management of the lagoon, enabling the conservation of a particular ecosystem service provided by the lagoon, e.g. as an important feeding habitat for shorebirds, fish and macrocrustaceans.

Materials and methods

Study site

The Zwin nature reserve (51°21′ N, 3°22′ E) is a coastal lagoon that extends 2.3 km along the North Sea coastline and is situated near the mouth of the Schelde estuary at the Belgian-Dutch border (Fig. 1). It has a total surface area of 158 ha and comprises dunes, salt marshes, salt pans, a tidal pond and two large inlet channels with a network of adjacent tidal creeks (Van Colen et al. 2006). The area is included in the Ramsar list of wetlands of international importance and has been designated as Natura 2000 area (EU Habitat Directive), among others due to its function as important breeding and wintering habitat for birds, especially shorebirds.

Sampling and analysing sediment composition and macrobenthic community

Samples were collected during low tide in autumn 2003 and 2010 according to a stratified random sampling design, encompassing the different intertidal habitat types in the nature

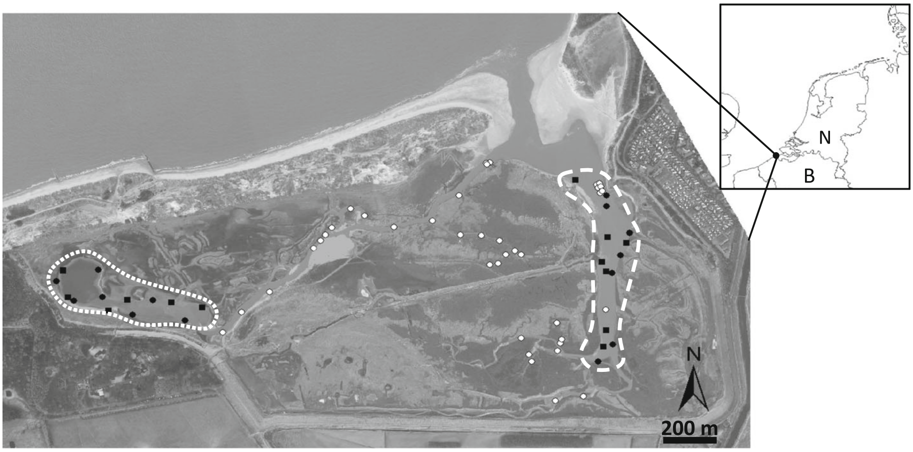

Fig. 1 Location of the Zwin tidal lagoon at the mouth of the Westerschelde estuary in the Southern Bight of the North Sea at the border between Belgium (B) and The Netherlands (N). *Filled symbols* indicate stations that were used to analyse variability in sediment characteristics and macrobenthos species biomasses between the deep tidal inlet channel (*dashed line*) and the intertidal habitat surrounding the tidal pond (*dotted line*) between 2003 and 2010 (locations sampled in 2003 are depicted as *squares*, location sampled in 2010 are depicted as *circles*). *White circles* indicate additional locations that were sampled in 2010 in order to construct species biomass response curves as a function of sediment median grain size in the lagoon

reserve: inlet channels, tidal creeks and the intertidal area surrounding the pond in the western part of the lagoon (Fig. 1). Between 27 October and 16 December 2003, 95 combined samples were collected (see Van Colen et al. 2009 for more details) and another 54 combined samples were collected during October 2010 (Fig. 1). Macrobenthos was sampled to a depth of 40 cm using a stainless corer (inner diameter = 12.5 cm), after which the samples were sieved over a 1 mm mesh-sized sieve. The residue was fixed and preserved with a 8 % formaldehyde-seawater solution awaiting species identification in the laboratory. Species population biomasses were determined from the pooled individuals per species present in the samples. Bivalve biomasses were obtained by determination of the ash free dry weight (4 h combustion at 450 °C of 24 h, 60 °C dried individuals) and the biomass of other macrobenthos species (mainly polychaetes) was calculated by multiplying the organisms' blotted wet weight with a species-specific ISO certified wet weight-ash free dry weight conversion factor (Sistermans et al. 2007).

Sediment samples for quantification of physico-chemical characteristics were collected next to the macrobenthos sample, using a perspex corer to a depth of 10 cm. Subsequently, these samples were homogenized and processed in the laboratory to obtain sediment median grain size (d_{50}) and mud content (% particles <63 µm) using Malvern laser diffraction, and sediment organic matter content (% loss on ignition at 500 °C for 2 h).

Modeling occurrence and biomass of macrobenthos as a function of sediment

Habitat occurrence of the polychaetes *Hediste diversicolor*, *Heteromastus filiformis*, and the bivalves *Scrobicularia plana* and *Macoma balthica* was determined by modeling the response of species occurrence and species population biomass to sediment median particle size.

Firstly, logistic regression of species presence/absence during both sampling campaigns was used to model probability of prey species according to $p(x)=[e(b_0+b_1x+b_2x^2)]/[1+e(b_0+b_1x+b_2x^2)]$; where p(x) is the estimated probability, x is the median grain size and b_0, b_1,and b_2 are the regression parameters. Using a logistic link function allows $p(x)$ to vary from a S-shaped function (first-order polynomial) to a bell-shaped function (second-order polynomial). Akaike's information criterion (AIC) (Johnson and Omland 2004) was applied to infer the most reliable model. These selected models had also the highest significance and percentage of concordance (i.e. percentage of correct predictions of the observed species presence or absence in a sample).

Secondly, logarithmic, second-order polynomial and Gaussian functions were applied to model the response of species biomass to sediment median grain size. Therefore, the sediment median grain size, which over all 54 samples varied from 60 to 476 µm, was divided into seven equal classes (60–125, 125.1–190 µm, etc.) and the average species biomass in the samples from that class was calculated. Subsequently, the average species biomass response to sediment class mid-point was modeled, weighted by the number of samples occurring in each class. Model fit was evaluated by visual inspection of half-normal plots, and the model that explained most of the variability and for which assumptions were met was selected. Both species probability of occurrence and biomass models were constructed using Statistica 5.5 (Statsoft Inc.). Long-term variation in biomass, independent of variability in sediment median grain size, exists in intertidal soft-sediments (e.g. Warwick et al. 2002). To avoid bias due to such temporal variability, only sediment and macrobenthos data collected in 2010 were used to develop the models of biomass response to median grain size ($n = 54$) since we were unable to construct a dataset for all four species biomasses in 2003 that consisted both of equal size classes and fulfilled assumptions for multiple regression.

Temporal and habitat specific variation of sediment composition and macrobenthic community

We applied two-way factorial analysis of variance (ANOVA, Statistica 5.5, Statsoft Inc.) to assess whether total macrobenthos biomass, sediment median grain size, mud content, and organic matter content varied temporally between 2003 and 2010 and between two contrasting habitats in the lagoon, using data collected at seven locations in 2003 and 2010 in both the eastern tidal inlet channel and the shallow intertidal habitat surrounding the tidal pond in the western part of the lagoon (Fig. 1). No data transformation was required to meet the assumption of within group variance homogeneity (Levene test).

Results

Variation of macrobenthos biomass and probability of occurrence across a sediment gradient

A wide variation in sediment composition was covered during both sampling campaigns; sediment d_{50} varied between 16.7 and 343.5 μm in 2003 ($n = 95$) and between 59.9 and 476.2 μm in 2010 ($n = 54$). In general, sediment mud -and organic matter content decreased significantly with increasing sediment median grain size (simple linear regression: mud content = 167.6–28.3 ln d_{50}, $r^2 = 0.86$, $n = 149$, $p < 0.001$; organic matter content = 19.7–3.3 ln d_{50}, $r^2 = 0.73$, $n = 95$, $p < 0.001$).

Logistic regression models revealed three types of responses curves that significantly related macrobenthos species occurrence to sediment median grain size (Fig. 2). In general, concordance was high, ranging between 65.1 and 87.3 % (Table 1). High probabilities of occurrence (90–100 %) of *H. diversicolor* were found in a relatively broad d_{50} range; i.e. 50–225 μm. Probability of occurrence of this species decreased rapidly in sediments with a coarser median grain size. In contrast, increasing median grain size had a clear positive effect on the prediction of occurrence for *H. filiformis*, with highest probabilities of occurrence (65–75 %) for this species in sediments with a $d_{50} > 250$ μm. *Scrobicularia plana* and *M. balthica* exhibited a skewed Gaussian-type of response model, reflecting a preference for sediment with a d_{50} between 70 and 140 μm for *S. plana* (~40 %) and between 100 and 200 μm for *M. balthica* (~20 %).

The biomass of macrobenthos species was significantly related to the variability in sediment median grain size (Table 2) (Fig. 2). The highest biomass of *H. diversicolor* and *S. plana* was found in sediments with a $d_{50} < 100$ μm. Similarly, the biomass of *H. filiformis* decreased with increasing median grain size, below a d_{50} of 100 μm. Biomass of *M. balthica* was highest in relatively coarse sediments with a d_{50} of 230–330 μm.

Variation of sediment composition and macrobenthos biomass across time and habitat

Temporal variability in total macrobenthos biomass, sediment mud and organic matter content between 2003 and 2010 depended on habitat type (Two-way Anova: Habitat × Year, $p < 0.05$; Table 3). Mud and organic matter content decreased in the inlet channel

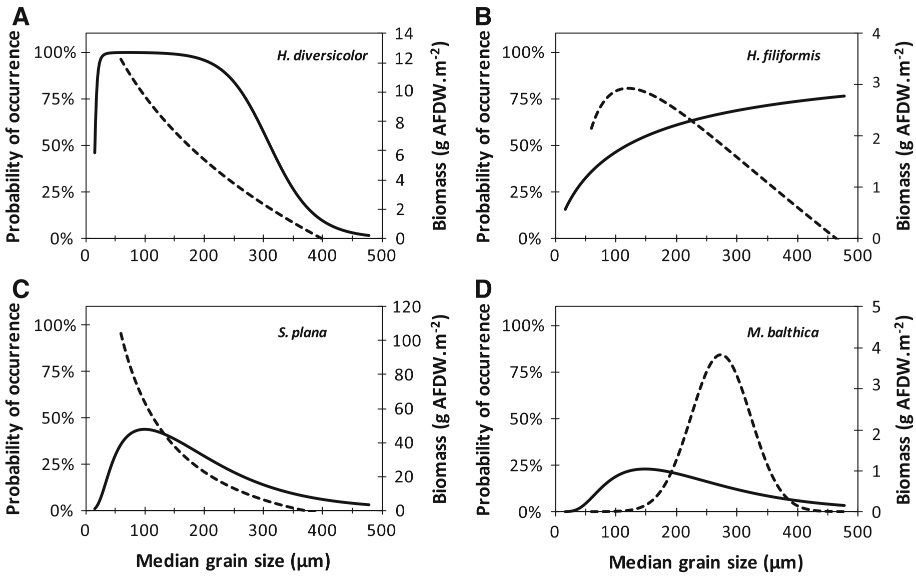

Fig. 2 Probability of occurrence (primary *y-axis*, *solid line*) and biomass (secondary *y-axis*, *dashed line*) for the four most dominant macrobenthos species in relation to median grain size: **a** *Hediste diversicolor*, **b** *Heteromastus filiformis*, **c** *Scrobicularia plana*, and **d** *Macoma balthica*. Model fits are restricted to the range of sediment median grain size that was sampled during the surveys (see methods)

between 2003 and 2010, while both sediment parameters increased in the intertidal zone surrounding the tidal pond over the same period. Particles <63 µm (i.e. mud) were not found in the inlet channel sediment in 2010, whereas mud content was, on average, c.a. 15 % in 2003. Concurrently, sediment organic matter content decreased 1.7 % between 2003 and 2010 (Fig. 3). In contrast, mud and organic matter content of the sediment in the intertidal habitat surrounding the tidal pond increased 7.4 and 1.2 %, respectively, between 2003 and 2010 (Fig. 3). Sediment median grain size did not differ significantly among habitats and between years (Table 3), despite median grain size was, on average, 46.6 µm higher in the inlet channel in 2010 in comparison with 2003 (Fig. 3). Between 2003 and 2010, the total biomass of macrobenthos decreased by 60.9 % in the inlet channel, while the opposite pattern was found in the intertidal habitat surrounding the tidal pond in the western part of the lagoon. The biomass of *H. diversicolor*, *M. balthica*, and *H. filiformis* decreased by >50 % in 2010 in the inlet channel, while the concurrent decrease in biomass of *S. plana* was less pronounced. The observed enhanced macrobenthos biomass in 2010 in the intertidal habitat surrounding the tidal pond was predominantly determined by an increase in biomass of *H. diversicolor* and *S. plana*.

Discussion

Biodiversity loss research has primarily focused on environmental impacts on single species or populations, but comparatively little attention has been given to cascade effects across species or functional groups (Brook et al. 2008; Tylianakis et al. 2008). Nevertheless, the loss or decline of particular species populations or functional groups, such as

Table 1 Logistic regression models predicting the probability of occurrence for *H.diversicolor*, *H. filiformis*, *S. plana*, and *M. balthica* in relation to sediment median grain size (d_{50})

Species	Concordance %	*p* (model)	AIC	Selected model
H. diversicolor	65.1	<0.0001	120.0	$e^{-44.78+23.84\ \ln d_{50}-2.80\ \ln {d_{50}}^2}\cdot\left(1+e^{-44.78+23.84\ \ln d_{50}-2.80\ \ln {d_{50}}^2}\right)^{-1}$
H. filiformis	65.7	<0.0001	191.9	$e^{-4.00+0.84\ \ln d_{50}}.\left(1+e^{-4.00+0.84\ \ln d_{50}}\right)^{-1}$
S. plana	70.2	0.0091	149.0	$e^{-28.02+12.06\ \ln d_{50}-1.31\ \ln {d_{50}}^2}\cdot\left(1+e^{-28.02+12.06\ \ln d_{50}-1.31\ \ln {d_{50}}^2}\right)^{-1}$
M. balthica	87.2	0.0486	113.7	$e^{-40.55+15.76\ \ln d_{50}-1.58\ \ln {d_{50}}^2}\cdot\left(1+e^{-40.55+15.76\ \ln d_{50}-1.58\ \ln {d_{50}}^2}\right)^{-1}$

Model form: species occurrence (%) $= e^{b_0\,+\,b_1\ \ln d_{50}\,+\,b_2\ \ln {d_{50}}^2}\cdot\left(1+e^{b_0\,+\,b_1\ \ln d_{50}\ b_2\ \ln {d_{50}}^2}\right)^{-1}$

Table 2 Variation in biomass of *H. diversicolor*, *H. filiformis*, *S. plana*, and *M. balthica* as a function of sediment median grain size (d_{50})

Species	r^2	*p* (model)	Model
H. diversicolor	0.97	<0.0001	$\text{Biomass} = 10.78 + 5.02 \ln d_{50} - 1.14 \ln d_{50}^2$
H. filiformis	0.96	<0.0001	$\text{Biomass} = -33.93 + 15.39 \ln d_{50} - 1.61 \ln d_{50}^2$
S. plana	0.82	<0.0001	$\text{Biomass} = 741.58 + 223.95 \ln d_{50} - 16.67 \ln d_{50}^2$
M. balthica	0.81	0.0054	$\text{Biomass} = 3.82e^{[(d_{50}-273.81)/49.3]^2}$

Table 3 Two-way factorial ANOVA results for sediment median grain size (d_{50}), mud content, organic matter, and total macrobenthos biomass (df = 1 for the factors habitat, year, and habitat × year; total model df = 27)

	Habitat			Year			Habitat × year		
	MS	F	*p*	MS	F	*p*	MS	F	*p*
Median grain size	31.816	0.010	0.922	3317.683	1.013	0.324	4323.627	1.320	0.262
Mud content	1.676	0.010	0.921	103.165	0.616	0.440	889.248	5.312	**0.030**
Organic matter content	33.639	0.104	0.750	0.017	0.000	0.994	1441.425	4.453	**0.045**
Total macrobenthos biomass	0.095	0.034	0.855	0.435	0.156	0.697	14.675	5.247	**0.031**

Significant results at $p < 0.05$ are in bold

basal organisms in food webs, can instigate a cascade of effects that have implications for interacting species and associated ecosystem functioning (Dunne et al. 2002). For example, Daborn et al. (1993) report changes in mudflat sediment stability in the Bay of Fundy associated with predator–prey dynamics between migrating shorebirds and the bioturbating amphipod *Corophium volutator* that forages on sediment-stabilizing diatoms. Research should thus aim to enhance the understanding of such multilevel and cascading interactions in order to assist in the implementation of proper management, particularly in those ecosystems that are vulnerable to environmental change. Here, we document change in macrobenthos species presence and biomasses in a coastal lagoon associated with spatio-temporal variation in their habitat (sediment composition) and food source (organic matter), and discuss the implications for the use of the lagoon by foraging predators, like nekton and shorebirds.

Between 2003 and 2010 mud -and organic matter content of the sediment decreased in the tidal inlet channel while the opposite pattern was found in the intertidal habitat in the western region of the study site. The prevalent asymmetric tidal dynamics with stronger flow velocities during incoming flood currents than the outgoing ebb currents (pers. obs.) stimulates such spatial segregation in sediment composition because suspended finer particles, i.e. clay and silt, deposit below a flow velocity threshold that is lower than for coarser sediments. The intertidal region in the western part of the lagoon therefore functions as a sink for fine particles, while the complete removal of mud (i.e. % <63 μm = clay + silt) in the upper 10 cm of the inlet channel suggests that previously deposited fine particles were progressively removed from this region. This mechanism thus shifts the inlet channel towards an alternate state consisting of non-cohesive sediment that has a larger median grain size. This sediment contains less organic matter and is prone to intense physical mixing and disturbance induced by hydrodynamic forces associated with

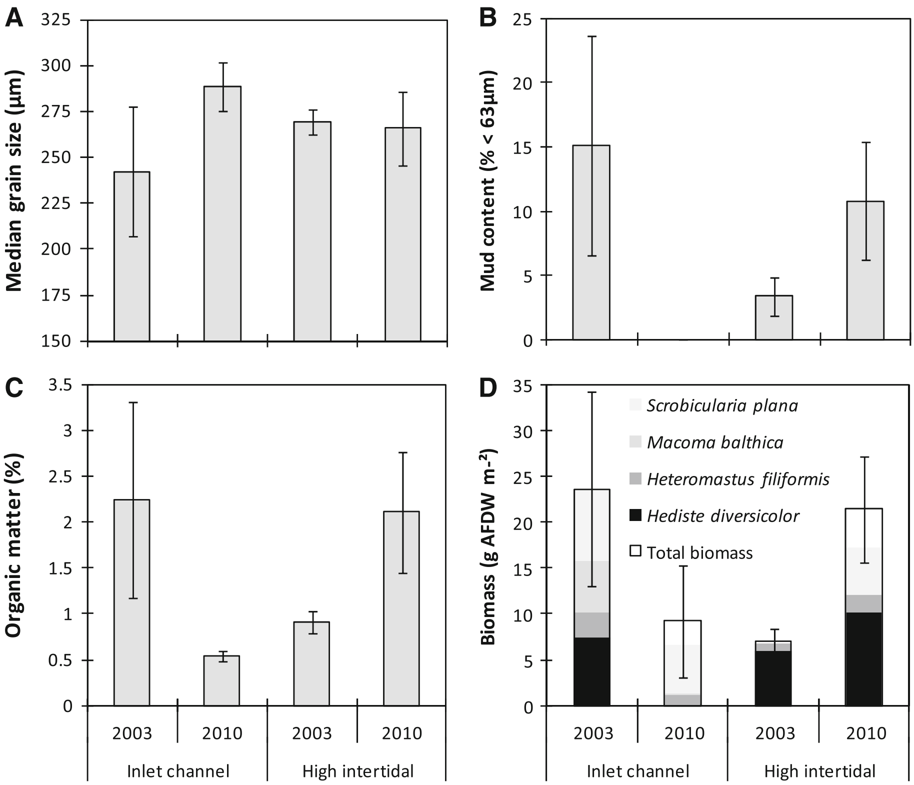

Fig. 3 Temporal variability in sediment composition, **a** median grain size, **b** mud content, **c** organic matter content; and **d** biomass of macrobenthos in the inlet channel and intertidal habitat surrounding the tidal pond. The top of the *stacked bar* represents the total biomass and the biomass of the four most dominant species in terms of biomass are depicted in *different colors* (see inset). *Error bars* are 95 % confidence intervals (note that mud content = 0 in 2010)

tidal currents and waves, while cohesive sediments consist of fine particles that are bound in a network structure through apparent cohesion forces and are therefore less susceptible to erosion (Grabowski et al. 2011 and references therein). Our models of species responses to sediment median grain size generally corroborate well the relationships found by other authors. The response in biomass in *H. filiformis* and *H. diversicolor* to sediment median grain size is similar to the predictions made by Van der Wal et al. (2008) for intertidal benthos on an intertidal flat in the Westerschelde estuary, i.e. maximum biomass in sediment with a $d_{50} \sim 100$ µm. Furthermore, highest abundances of *H. diversicolor* and *S. plana* in coastal lagoons and estuarine tidal flats are typically found in organically enriched muddy sediments (Carvalho et al. 2005; Alves et al. 2012), while highest biomasses of *M. balthica* in intertidal sediments are found in fine sandy sediments (d_{50} = 125–250 µm) (Ysebaert and Herman 2002). In general, total macrobenthos biomass was highest in sediments with a median grain size <150 µm, which contain >3.2 % of organic matter. Only *H. filiformis* is frequently present—though with a low biomass- in coarser sediments which illustrate this species' higher resistance to disturbance of the surface sediment bed and lower dependence of organic matter at the sediment surface in comparison with the other species, living and feeding in deeper layers (Van Colen et al. 2010a, b). In contrast, a threshold response with abrupt declining probability of occurrences for both *H. diversicolor* and *S. plana* was observed in sediments with a d_{50} >200 µm. This study thus corroborate the general pattern that non-cohesive coarse sediments contain a lower standing stock of benthic invertebrates, and thus food supply for shorebirds and nektonic species, than cohesive sediments (Raffaelli and Hawkins 1996).

The four macrobenthos species studied here represent some of the most common prey species for shorebirds in NW Europe (Van de Kam et al. 2004) and comprise ~95 % of the total intertidal macrobenthic biomass in the Zwin coastal lagoon (Fig. 3). Severe declines in species biomass of *M. balthica* (97 %) and *H. diversicolor* (99.6 %) occurred in the tidal inlet, concurrent with the coarsening of the sediment in that habitat between 2003 and 2010. In contrast, an increase in average biomass of *S. plana* and *H. diversicolor* per sample was noted in the shallow intertidal area surrounding the tidal pond where fine sediment accumulated over time. However, while a deposition of fine sediments in shallow areas may thus temporally enhance food supply, this mechanism will not sustain food supply at the longer term since the concurrent shorter inundation time results in a loss of intertidal feeding habitat surface due to natural successional elevation processes. Exact estimates of the total loss in such intertidal feeding grounds do not exist for the nature reserve, but shifts from low intertidal flats to high elevated marsh vegetation occurred over the course of this 8 year study period (pers. obs.). In addition, this fill-up of the floodplain has allowed ground predators, like Fox and Stone Marten to access formerly safe breeding and roosting sites for shorebirds (Herrier and Leten 2010). In general, the lagoon thus evolved towards a lower site quality for species that rely on low intertidal food sources, e.g. shorebirds. Densities of shorebirds that are wintering in NW European coastal lagoons and estuaries are declining for most of the populations, among others as a result of land reclamation and the invasion of alien marsh plants that reduce the size of available feeding areas (BirdLife International 2012). Shorebird winter population abundances in the studied lagoon corroborate this trend with distinct declines in abundances observed for e.g. Avocet, Dunlin, Grey Plover and Shelduck between 2003 and 2010 (Fig. A1). In addition to a lower prey abundance in non-cohesive sandy sediments, increasing sediment sand content decreases penetrability of the sediment which interferes with the detection and capture of prey, generally reducing predation success (Quammen 1982). The most pronounced decline in the lagoon was observed for *Tadorna tadorna* (Shelduck), with a significant decrease in average winter density over the study period (91 %, Fig. A1), while the population trend in this species' geographical range appears to be increasing (BirdLife International 2012). Shelduck is restricted to feed on shallow living intertidal invertebrates and organic matter from the surface sediment layer due to their bill morphology and therefore clearly prefer mudflats above coarse sand or salt marsh vegetation for ease of foraging (Van de Kam et al. 2004). We therefore suggest that specific processes in the studied lagoon, such as the coarsening of the surface sediment in the extensive inlet channel, contributes to this pronounced decline. Site-specific information about change in intake rates (e.g. Goss-Custard et al. 2006; Alves et al. 2012) is however needed to confirm this hypothesis.

In order to maintain the functioning and ecosystem services provided by coastal ecosystems, this study illustrates that an integrated coastal zone management should recognize the consequences of activities that alter sediment transport processes in the coastal zone (e.g. dredging, sediment extraction and beach nourishment) in addition to threats like organic loading, pollution, invasive species and sea level rise. We show that this is particularly needed for areas in the vicinity of lagoonal ecosystems that may function as a catchment area for suspended solids, therewith altering the habitat for benthic invertebrates that contribute to essential functions in the ecosystem, like the provisioning of food to higher trophic levels. The developed macrobenthos species response models provide a tool to assist such management implementations as the models allow assessment of prey species probability of occurrence and biomass in relation to sediment median grain size. In order to guarantee a proper food provisioning for shorebirds, fish and macrocrustaceans, the presence and high biomass of benthic prey species in organically enriched sediments with a median grain size <150 µm found in this study therefore support management actions that facilitate the maintenance of cohesive low intertidal habitats, like muddy intertidal marsh creeks and early succession tidal mudflats. Such management is particularly challenging given the dynamic morphological nature of these ecosystems related to tide-induced sediment transport. Next to the proper management of suspended sediment loads in the direct vicinity of the lagoon, specific actions in the lagoon that promote the conservation of habitats with desired sediment properties, may however aid the conservation of this lagoon as an important foraging habitat at the longer term.

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