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Shifting baselines in the Ems Dollard estuary: A comparison across three decades reveals changing benthic communities

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ABSTRACT

At a time when there is a growing discussion about the natural state of estuaries, a comparison of macrozoobenthos communities from two surveys conducted 30 years apart in the Ems Dollard estuary, in the eastern Wadden Sea, The Netherlands, provides a unique opportunity to compare changes over time. As expected, our comparison revealed a gradient in species composition from land (the Dollard) to sea (the Outer Ems) at both points in time, with brackish species in the Dollard and more marine species in the Outer Ems (Wadden Sea). Total richness increased over time; however, this mainly reflected the immigration of new species and sampling differences. In the Dollard, total biomass declined over time, most likely reflecting de-eutrophication in this area. Strikingly, at the meeting point between the sea and the brackish Dollard, i.e. the Inner Ems, the community composition changed from one dominated by bivalves (1970s) to one dominated by worms (since 2009). This change involved a reduction in total biomass, mainly of *Mya arenaria*, and immigration of polychaete worms (*Marenzellaria viridis* and *Alitta succinea*). In the Outer Ems, an increase in total biomass was observed, associated with the recent successful recruitment of *Cerastoderma edule*. This comparison highlights that historical data provides useful insights at large spatial scales. However, a full understanding of the complex dynamics of estuaries requires an analysis of continuous long-term monitoring series.

1. Introduction

Estuaries are generally defined as transitional coastal ecosystems that are found between the land and sea (Levin et al., 2001), which are characterized by varying and often unpredictable hydrological, morphological and chemical conditions (McLusky, 1993). Even though estuaries perform numerous and important ecosystem functions (Levin et al., 2001), historically (and even now) they are undervalued for the ecosystem services they provide. Thus they have been subject to numerous human exploitations including land reclamation, waste water drainage (e.g. from agriculture or industry), and dredging (de Jonge et al., 2014; Essink, 2003; McLusky and McCrory, 1989; McLusky, 1999). Indeed, European coastal estuaries are some of the most severely degraded coastal systems worldwide (Lotze et al., 2006).

Understanding baseline conditions in estuaries is often complicated by a lack of historical data (Lotze et al., 2006). Without a view to what happened in the past, we ignore the possibility that today's ecosystems look very different to what they were, i.e. a shifting baseline (Pauly, 1995). Thus, a first step in understanding the true dynamic and/or natural state of estuaries, is to compile available historical data to describe the baselines of these systems (Andersen et al., 2017; Kolbe and Michaelis, 2001; Villnäs and Norkko, 2011). Ecological baselines are by definition the point at which data describing a system is available, because even though changes might have occurred prior to the first point of measurement, without earlier information we cannot infer what changes occurred.

In the Wadden Sea, an intertidal system that extends from The Netherlands to Denmark, there are four major areas with a significant freshwater input: the remaining IJsselmeer (the former Zuiderzee), the Ems Dollard, Weser and Elbe estuaries. These estuaries have been subjected to human pressures over a long period of time. Of the three, the Ems Dollard estuary is well known for changes associated with land reclamation, eutrophication and sediment dredging. From the 16th to 19th centuries, the Dollard basin was largely reclaimed for agricultural

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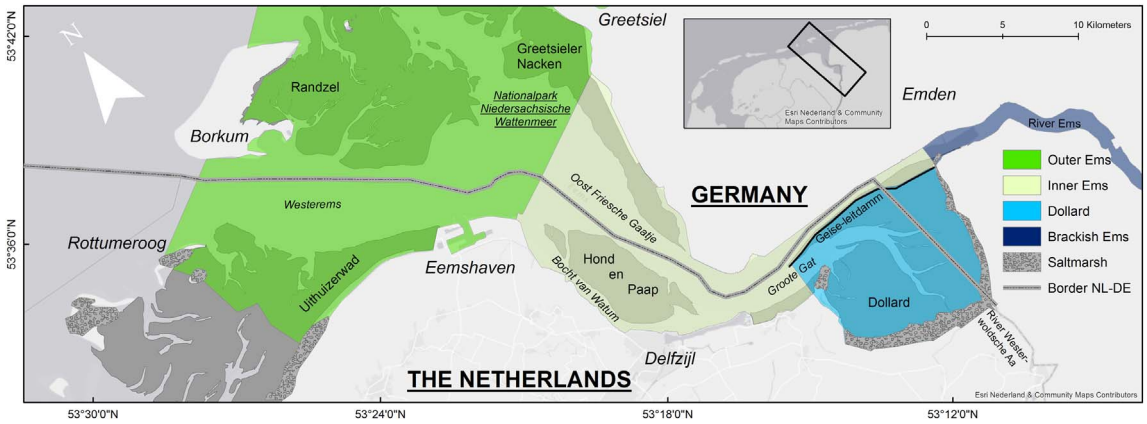

Fig. 1. Map with important physical locations and the three defined compartments of the Ems Dollard estuary.

land. Starting in the mid-19th century, large potato starch and cardboard factories were built in the surroundings of the Dollard. The organic and nutrient rich wastewater from these factories was dumped into the estuary until the 1990s mainly via the Westwoldse Aa (Arkel, 1977; Eggink, 1965; Essink, 2003). As this problem was so severe, it was then called the "biggest waste problem in the world" (Ribbius, 1961).

Nowadays, the waste water entering the Dollard is cleaner due to measures taken by the government to clean-up the waterways from the 1980s to the 1990s (Esselink et al., 1989; Essink, 2003). More specifically, the biochemical oxygen demand (BOD) declined from 25×10^6 kg BOD_5 in the 1970s to 10×10^6 kg BOD_5 in the 1980s to 0.5×10^6 kg BOD_5 in the 1990s (Essink, 2003). In the 1980s, as the era of industrial shipping developed, and ships got bigger, the channels in the estuary were, and are still, dredged for new harbours and for megaships to sail through. The deepening of the channels has caused significant changes to the hydrography and sediment dynamics (de Jonge et al., 2014). Possibly, the tidal asymmetry has changed, with increased landward transport of the fine sediments. The Inner Ems has also become an efficient sediment trap where high concentrations of fine suspended sediment are known to accumulate (Talke and De Swart, 2006). Furthermore, the estuarine turbidity zone in the Ems Dollard has become hyperturbid since the 1990s (van Maren et al., 2015).

The Ems Dollard is the only Wadden Sea estuary where quantitative ecological monitoring occurred on an estuary-wide scale in the 1970s (the first baseline study for this system). The study of multiple biological, hydrodynamic and chemical aspects of the estuary was completed during the Biological Research of the Ems Dollard Estuary (BOEDE; Anonymous, 1985; Baretta and Ruardij, 1988). This program was initiated to study the effects of waste discharge into the estuary from the potato and cardboard industries (de Wolf, 1977, 1978). During the BOEDE program, macrozoobenthos were one of the indicators used to study ecological change in the Ems Dollard. Macrozoobenthos are considered useful for monitoring the ecological health of estuaries because they cannot escape adverse conditions, are often short-lived (< 5 years in most cases, Beukema et al., 1999; Hewitt et al., 2005), have clear environmental associations (e.g. Compton et al., 2009; Kraan et al., 2010; Ysebaert and Herman, 2002), and are known to respond to stressors in the environment (Pearson and Rosenberg, 1978). Furthermore, they provide important ecosystem services like nutrient cycling, sediment stabilization and facilitation of other species (de Goeij et al., 2001; Donadi et al., 2013; Donadi, 2014; Lohrer et al., 2004; Thrush et al., 2006). Macrozoobenthos are also an important food source for a variety of fish and shorebird species. The Ems Dollard is known to be an important nursery and feeding area for juvenile fishes (Jager et al., 1993; Jager, 1999, 2001), and also a feeding area for migratory shorebirds (Prop et al., 2012). In addition, a recent study has shown that the macrozoobenthic communities in the Ems Dollard are unique in the context of the Dutch Wadden Sea (Compton et al., 2013).

The BOEDE program lasted from 1973 to 1982 (Anonymous, 1985; Baretta and Ruardij, 1988). Two macrozoobenthic surveys across the entire estuary were conducted over this period (Arkel, 1977; van Arkel and Mulder, 1979, 1982). After the BOEDE project, some additional sampling occurred in 1988 in the Hond and Paap area by the Rijkswaterstaat (Kleef, 1988). Since 2009, a Wadden Sea wide monitoring study began sampling in the Ems Dollard estuary: the SIBES program (Synoptic Intertidal Benthic Surveys, Bijleveld et al., 2012; Compton et al., 2013). A comparison of these programs, which are 30 years apart, provides a unique opportunity to explore the ecological changes across the Ems Dollard estuary. Thus in this study, we compare the macrozoobenthos communities from the BOEDE and SIBES sampling programs. Our aim is to describe any changes in these communities, while taking into account any methodological differences that have occurred between these two programs.

2. Material and methods

2.1. Study area

The Ems Dollard estuary is located within the Wadden Sea (53° 20′ 25″ N and 6° 58′ 24″ E, Fig. 1) and covers an area of 1071 km^2, of which 53% consists of intertidal flats. Most flats lie along the shore, but a large tidal flat (the Hond and Paap) divides the estuary into two parts creating two channels: Oost Friesche Gaatje and the Bocht van Watum. This system has a shared, and contested, border between The Netherlands and Germany (Fig. 1) and is co-managed by the two countries. The German part lies in the Nationalpark Niedersächsisches Wattenmeer.

Table 1
Total area of each compartment (km^2), and the area of the intertidal flats (%). The average exposure time (Exposure; −), average salinity at the bottom of the estuary (Salinity; PSU), median grain size (MGS; μm) and silt (%; < 63 μm), and the associated confidence intervals (± CI), are given.

Compartment	Total area	% flats	Exposure	Salinity (bottom)	MGS	Silt
Outer Ems	817	53	0.4 ± 0.02	30 ± 0.08	135 ± 2.4	9.8 ± 1.0
Inner Ems	151	38	0.3 ± 0.01	23 ± 0.12	102 ± 3.8	28.0 ± 2.2
Dollard	103	81	0.5 ± 0.01	15 ± 0.04	83 ± 2.8	40.5 ± 1.5