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From artificial structures to self-sustaining oyster reefs

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ABSTRACT

Coastal ecosystems are increasingly recognized as essential elements within coastal defence schemes and coastal adaptation. The capacity of coastal ecosystems, like marshes and oyster reefs, to maintain their own habitat and grow with sea-level rise via biophysical feedbacks is seen as an important advantage of such systems compared to man-made hard engineering structures.

Providing a suitable substrate for oysters to settle on offers a kick-start for establishment at places where they were lost or are desirable for coastal protection. Accumulation of shell material, through recruitment and growth, is essential to the maintenance of oyster reefs as it provides substrate for new generations (positive feedback loop), forming a self-sustainable structure. Insight in establishment, survival and growth thresholds and knowledge about the population dynamics are necessary to successfully implement oyster reefs in coastal defence schemes.

The aim of this paper is to investigate whether artificial Pacific oyster reefs develop into self-sustaining oyster reefs that contribute to coastal protection. Reef development was investigated by studying recruitment, survival and growth rates of oysters on artificial oyster reefs in comparison with nearby natural Pacific oyster reefs. The artificial reef structure successfully offered substrate for settlement of oysters and therefore stimulated reef formation. Reef development, however, was hampered by local sedimentation and increasing tidal emersion. Tidal emersion is an important factor that can be used to predict where artificial oyster reefs have the potential to develop into self-sustaining reefs that could contribute to coastal protection, but it is also a limiting factor in using oyster reefs for coastal protection.

1. Introduction

The integration of coastal ecosystems within coastal defence schemes is increasingly being proposed (Cheong et al., 2013; Duarte et al., 2013; Spalding et al., 2014; Temmerman et al., 2013). Particularly intertidal wetlands (salt marshes, mangroves) and reefs (shellfish, corals) provide coastal defence through enhanced wave attenuation, sediment capture, erosion reduction and vertical accretion (Gedan et al., 2011; Kench and Brander, 2006; Scyphers et al., 2011; Shepard et al., 2011; Zhang et al., 2012). The ability to maintain their own habitat through biophysical feedbacks (D'Alpaos et al., 2012; Kirwan and Megonigal, 2013; McKee et al., 2007) secures the long-term sustainability of ecosystem-based coastal protection, especially in case of accelerating sea level rise (Temmerman et al., 2013). Many studies focus on relatively short-term (1–2 years) influences of ecosystem engineers on the local environment, but long-term sustainability of the engineered structure is not always considered. Long-term sustainability is dependent on the ability of the ecosystem engineer to grow and maintain its own structure. Ecosystem-based coastal protection incorporating ecosystem engineering species (e.g. salt marsh plants, corals, oysters) requires knowledge about the life history, population dynamics and habitat requirements of the species under consideration. Such knowledge is essential, as this will determine both the predictability and reliability of their coastal protection function (Bouma et al., 2014).

Epibenthic bivalve reefs, as formed by bivalve species like oysters and mussels, deliver many ecosystem services and are abundant, persistent structures of marine and estuarine ecosystems worldwide (Grabowski et al., 2012; Grabowski and Peterson, 2007). Oysters form dense three-dimensional reef structures which can alter water flow and reduce wave action (Borsje et al., 2011), while trapping and stabilizing sediment (Walles et al., 2014). They also provide other ecosystem services as they create a habitat in coastal environments on which complex food webs are based (Scyphers et al., 2011; Spalding et al., 2014; Tolley and Volety, 2005). Oyster reefs are increasingly constructed for shoreline protection and erosion control. The construction of artificial reefs and restoration of natural reefs is often complicated by several factors, including sedimentation, substrate limitation, degraded water quality, predation and diseases which affect the oyster population. Burial by sediment causes significant loss of reef habitat (Powers et al., 2009;

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Rodriguez et al., 2014). To escape sedimentation, constructed reef height needs to exceed a certain threshold (Jordan-Cooley et al., 2011; Schulte et al., 2009; Taylor and Bushek, 2008). Substrate limitation can be attributed to construction/restoration material unsuitability (Nestlerode et al., 2007). Accumulation of shell material, through recruitment and growth, is essential to the maintenance of oyster reefs as it provides substrate for new generations (positive feedback loop), forming a self-sustainable structure that can persist for decades (Mann and Powell, 2007; Walles et al., 2015). Even after oysters die, their shell material remains and sustains the structure on which the living oyster population depends (Mann and Powell, 2007). A reef consisting of multiple year classes can buffer for annual recruitment variability, as long-lived oysters disproportionally add shell material to the reef structure (Schulte et al., 2009). In absence of continued growth, for example due to disease, parasites, predation or harvesting, a reduction in shell substrate is expected to affect the available settlement space, which in turn will decrease the shell accumulation negatively affecting the reef sustainability (Walles et al., 2015).

Whether oyster reefs can be incorporated into coastal defence and coastal adaptation schemes depends not only on their coastal defence value, but also on the long-term persistence or self-sustaining character of the reef over a specific time-frame. Within the Dutch innovation programme "Building with Nature" five artificial oyster reefs, consisting of gabions filled with oyster shells, were constructed on eroding tidal flats in the Oosterschelde estuary (Fig. 1). The aim of these experimental artificial oyster reefs was to investigate their potential in erosion mitigation of the tidal flats in the Oosterschelde and the ability to maintain their own habitat (De Vriend and Van Koningsveld, 2012). These tidal flats do not only provide foraging grounds for migrating water birds, they also provide foreshore protection by reducing wave energy to the dikes. Providing a suitable substrate for oysters to settle on offers opportunities for establishment at places where they were lost or are desirable as part of a coastal defence scheme (Bouma et al., 2014). But subsequently oysters need to settle, survive and grow at a specific site in order to achieve long-term, persistent structures. The locations of the artificial reefs within the "Building with Nature" programme were chosen based on hydromorphological conditions rather than requirements for oyster reef development. As these locations previously lacked natural reefs, the question rises what factors are preventing the occurrence of Pacific oysters here. If these locations are unsuitable for initial settlement artificial reefs may facilitate this. If these locations are unsuitable for growth, survival and recruitment of next generations, artificial reefs may never develop into self-sustainable reefs. The aim of this paper is to investigate if artificial Pacific oyster reefs, constructed for coastal management, develop into self-sustaining oyster reefs that contribute to coastal adaptation. Reef development was investigated by comparing the recruitment, survival and growth rates of oysters on the artificial with nearby natural Pacific oyster reefs in an observational and manipulative study. Comparison to natural reefs will determine if the artificial reefs are performing at the level of a healthy reef (Baggett et al., 2015). Furthermore, we investigated whether (local) sedimentation affects reef succession. Understanding the development of the reef structure and its consequences on reef sustainability will allow maximizing the long-term ecological function of oyster reefs within restoration and ecosystem-based coastal defence schemes.

2. Methods

2.1. Study area

The Oosterschelde estuary is a 351 km^2 tidal basin with tidal flats (118 km^2), artificial rocky shore habitats (dikes), deep gullies, and

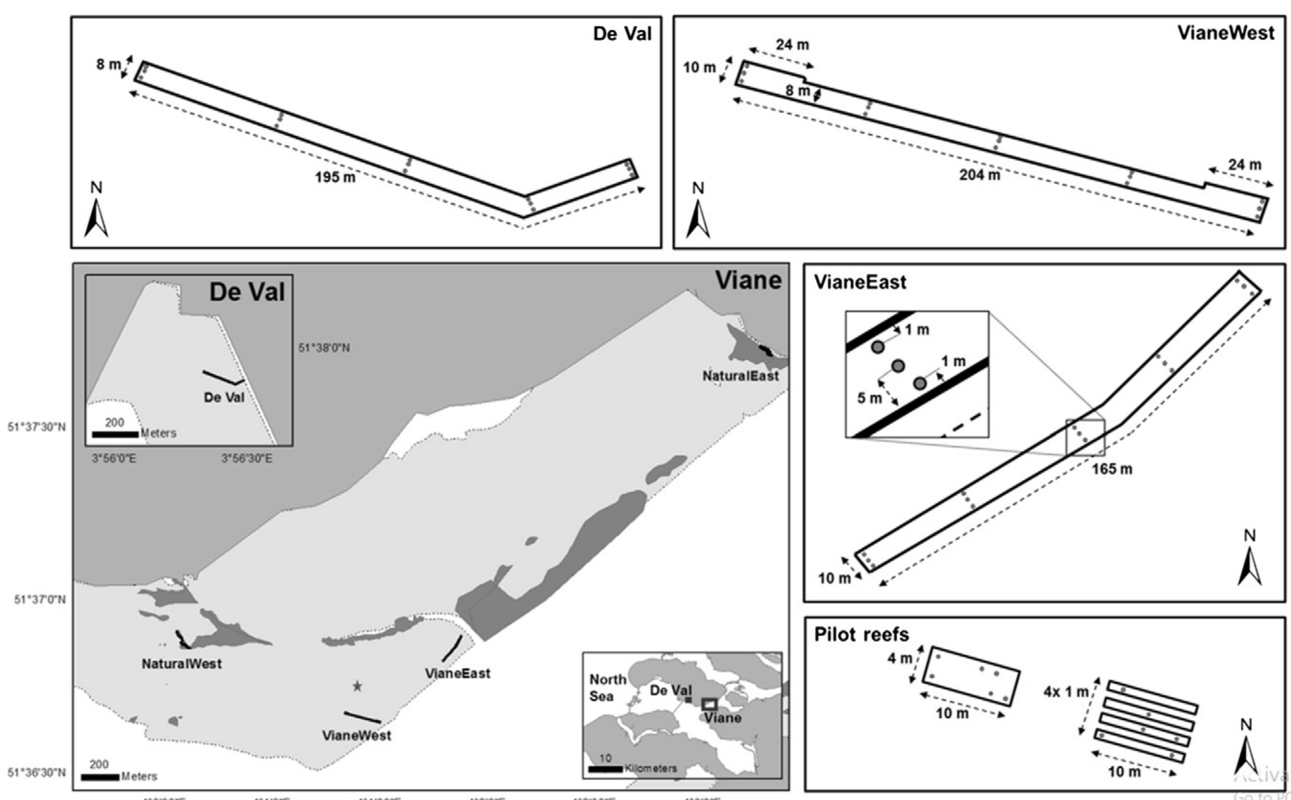

Fig. 1. Location of the five artificial Pacific oyster reefs (two Pilot reefs (indicated by the star), VianeEast, VianeWest and De Val) and two natural reefs (NaturalWest and NaturalEast) at two intertidal flats (Viane and De Val) in the Oosterschelde estuary (SW, The Netherlands). Dotted lines indicate the mean low tide level. Intertidal areas (light grey) covered with oysters in 2011 are indicated in dark grey. The height of the artificial reefs is 25 cm. Grey circles within the reefs indicate the position of fixed quadrant (0.25 m^2) in which recruitment and growth rates were measured.