Journal of Sea Research 82 (2013) 134–141

Contents lists available at SciVerse ScienceDirect

Journal of Sea Research

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

Persisting intertidal seagrass beds in the northern Wadden Sea since the 1930s

Tobias Dolch *, Christian Buschbaum, Karsten Reise

Alfred Wegener Institute for Polar and Marine Research, Wadden Sea Station Sylt, 25992 List, Germany

ARTICLE INFO

Article history:
Received 25 November 2011
Received in revised form 23 April 2012
Accepted 29 April 2012
Available online 8 May 2012

Keywords:
Long-term development
Intertidal seagrass beds
Aerial photographs
Eutrophication
Water Framework Directive
Sediment dynamics

ABSTRACT

In contrast to the global crisis of seagrass ecosystems, intertidal *Zostera*-beds in the Northfrisian Wadden Sea (coastal North Sea) have recovered recently. Present areal extent resembles that of the mid 1930s. In spite of an intermittent loss in area by about 60% in the 1970s to 1990s, beds have maintained their general spatial distribution pattern. Aerial photographs from parts of the region in 1935–37, and the total region in 1958–59 and 2005 were visually analysed, and seagrass beds were recorded and quantified with a geographic information system (GIS). Data from direct aerial mapping were added to extend the survey until 2010. From the mid 2000s to 2010, intertidal seagrass areas estimated from these records range between 84 and 142 km^2 (10–16% of the intertidal area), while records from the 1970 to 90s merely range between 30 and 40 km^2 (3–5%) (Reise and Kohlus, 2008). Despite variation in size, core positions of individual seagrass beds were identified and they shifted very little over the last decades. Most beds occur in the upper intertidal zone and where barrier islands offer shelter against swell from the open sea. While land claim activities since the 1930s have irreversibly eliminated at least 11 km^2 of seagrass beds, we suggest that intermittent losses of seagrass area were mainly caused by sediment dynamics and a phase of elevated eutrophication.

1. Introduction

On a worldwide scale, habitat building coastal organisms such as mangroves, corals and seagrass have declined over the past decades due to exploitation and habitat degradation, which also means a concomitant loss of ecosystem functions (Barbier et al., 2008; Lotze et al., 2006; Orth et al., 2006; Valiela, 2006; Waycott et al., 2009). Viable seagrass beds provide food, habitat and shelter, are spawning and nursery grounds, and also alter the sediment composition (Bos et al., 2007; Fonseca, 1996; Heck et al., 2003; Hosack et al., 2006; Larkum et al., 2006; Nacken and Reise, 2000; Polte and Asmus, 2006; Polte et al., 2005; van Katwijk et al., 2010a). Seagrass is regarded as an indicator for ecosystem health, particularly sensitive to human induced eutrophication (Burkholder et al., 2007; Cardoso et al., 2004; Orth et al., 2006; Short et al., 2011), and is used as such in the EU Water Framework Directive (Foden and Brazier, 2007; Krause-Jensen et al., 2005; Romero et al., 2007).

Two species of seagrass occur in the European Wadden Sea: *Zostera marina* and *Zostera noltii*, the latter being more common and more tolerant to low tide exposure than *Z. marina* (Leuschner et al., 1998). Germination of seagrass begins in May, maximum extent and cover of the beds occur in August, and in autumn, leaves are shed and migrant waterfowl commence grazing (Vermaat and Verhagen, 1996; Nacken and Reise, 2000). Thus, monitoring of intertidal seagrass has been focused on August, when beds are recognized by a conspicuous dark shade from the air (Borum et al., 2004; Reise and Kohlus, 2008).

Extensive beds of both intertidal and subtidal seagrass were common throughout the Wadden Sea, however, two separate crises have reduced the stock (Lotze, 2005). A so called 'wasting disease', caused by the slime-mould *Labyrinthula zosterae*, eliminated subtidal *Z. marina* from 1931 to 1934, and a subsequent return failed to appear until now (de Jonge and de Jong, 1992; den Hartog, 1987; Muehlstein et al., 1991; Reise et al., 1989). The second seagrass crisis in the Wadden Sea became evident on intertidal beds in the 1970–80s. It was presumably caused by anthropogenic eutrophication which resulted in increased water turbidity due to higher phytoplankton growth, a high amount of epiphytes attached to seagrass leaves and a strong development of green algae which regularly accumulated in areas where seagrass was growing (de Jonge and de Jong, 1992; den Hartog and Phillips, 2000; Duarte, 1995; Kolbe et al., 1995; Reise and Siebert, 1994; Short et al., 1995; van Katwijk et al., 2010b). High nutrient loads may also affect seagrass physiology because its metabolism is adapted to low nutrient conditions (Burkholder et al., 2007). However, a recovery has commenced since the 2000s (Reise and Kohlus, 2008; Reise et al., 2005; van der Graaf et al., 2009). In the present Wadden Sea, subtidal seagrass is still almost non-existent and extensive intertidal seagrass beds are confined to the northern region.

In this paper we analyse aerial photographs from the northern Wadden Sea where the largest intertidal seagrass beds occur and ask the question: Are current seagrass beds still the same regarding their size and location as several decades ago, indicating a recovery of healthy

* Corresponding author at: Alfred Wegener Institute for Polar and Marine Research, Wadden Sea Station Sylt, Hafenstr. 43, 25992 List, Germany. Tel.: +49 4651 956 4219; fax: +49 4651 956 200.
E-mail address: Tobias.Dolch@awi.de (T. Dolch).

1385-1101/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.seares.2012.04.007

seagrass habitats in the intertidal zone of the northern Wadden Sea? We use photographs from the mid 1930s, late 1950s and 2005 as well as data from direct aerial surveys from 1995 to 2010. Results are discussed with respect to plausible causes of an intermittent areal loss and to the high persistence of seagrass in the northern compared to the southern region of the Wadden Sea.

2. Materials and methods

2.1. Study area

The Wadden Sea at the south-eastern shallow fringe of the North Sea comprises the largest coherent tidal flats of the world (Reise et al., 2010), and the Northfrisian Wadden Sea is the major part of the northern Wadden Sea, stretching over 80 km from Eiderstedt peninsula to the German–Danish border (Fig. 1). It comprises a tidal flat area of about 870 km^2 (plain tidal flat area obtained from topographic GIS map 2003, issued by National Park Authority, Tönning; made available by Jörn Kohlus).

The Northfrisian Wadden Sea is characterized by a low riverine input and a chain of barrier islands and high sands facing westward, protecting the back barrier tidal basins from the prevailing westerly North Sea swell. These natural characteristics seem to facilitate the establishment of seagrass beds in this region. In 2006, 11% of the tidal flat area was covered with seagrass, which was more than in any other part of the Wadden Sea (Reise and Kohlus, 2008).

2.2. Analysis of aerial photographs

Data on the size and distribution of seagrass beds were obtained by remote sensing in the form of visual analysis of georeferenced, high-resolution aerial photographs, which were taken at low tide period (Fig. 2). For this long-term survey, three sets of aerial photographs from the periods 1935–37, 1958–59 and 2005 were available. Most aerial photographs had a ground pixel size of 0.4 to 0.5 m (ranging from 0.3 to 0.7 m), were of good quality and were taken between July and September, when seagrass attains its seasonal maximum cover.

Intertidal seagrass can be identified in aerial photographs on the basis of colour and texture. Beds contrast with bare tidal flat sediments by their dark greenish colour, tend to be dissected into irregular patches by branching tidal runnels, and often generate hummocks which give the bed a characteristic texture (Reise and Kohlus, 2008). Seagrass beds can be best distinguished from green algae by this texture, as mats of green algae are more homogeneous and tufts are aligned in current direction. The aerial photographs from 1935–37 and 1958–59 are black-and-white images, and in these cases seagrass was identified by its texture and darker shade of grey. Compared to mussel beds that are often covered by fucoid algae, seagrass beds show a more coherent structure (Fig. 2).

Seagrass beds were recorded by digitising their boundaries on-screen using the geographic information system (GIS) ArcGIS 9.3, ArcMap. Decisions on the extent of seagrass beds and the course of boundary lines get difficult at a low seagrass cover or when seagrass gradually declines which both leads to fuzzy transitions. Especially in these cases, the quality of the aerial photographs is the limiting factor for the accuracy and ground-truth data are helpful for validation. Extensive ground-truth field surveys were conducted with a differential GPS device with a resolution <1 m in July and August 2005 (Dolch, 2008). A comparison of field data and remote sensing data reveals that a cover density of about 20% is required to detect seagrass in the aerial photographs. This implies that there is actually more seagrass growing on the tidal flats than recorded by this remote sensing approach.

In GIS, seagrass beds are presented as polygons and a centroid is the geometric centre of a polygon (Fig. 2). The positional changes of a centroid between sets of aerial photographs are caused by both, changes of shape and changes of position. Therefore, this was taken as a measure for the spatial variability of individual seagrass beds. The coordinates of the centroids of those seagrass beds which could be identified in all sets of aerial photographs were calculated in ArcGIS 9.3, ArcMap (Fig. 3). The absolute centroid migration distances for these beds from the 1930s to the 1950s and to 2005 were determined with the same software mentioned above.

2.3. Direct mapping of seagrass beds from the air

Reise and Kohlus (2008) recorded seagrass bed areas from 1994 to 2006 by aerial mapping. Three surveyors mapped the seagrass distribution directly by flying in a four-seated Cessna airplane during low tide exposure at heights between 300 to 500 m above the tidal flats of the Northfrisian Wadden Sea. Sticking to this methodology, we here present total coverage for the period 1995–2010. Each surveyor performed mapping by drawing seagrass beds on satellite paper images during flights, and a synthesis from the three maps was transferred into GIS subsequently (Reise and Kohlus, 2008).

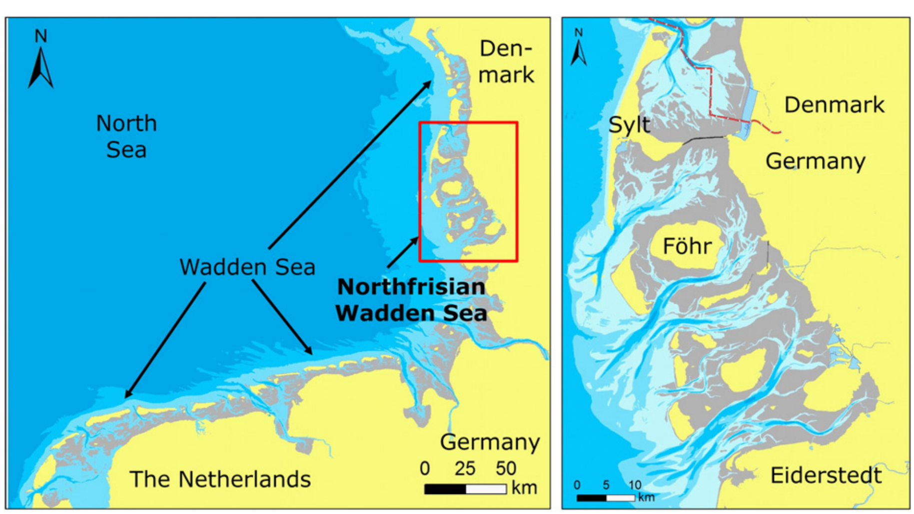

Fig. 1. The tidal flats (shown in grey) of the Wadden Sea (left) are the habitat of the intertidal seagrass beds and are mainly located behind barrier islands and high sands. The surveyed Northfrisian Wadden Sea (right) stretches from Eiderstedt peninsula to the German–Danish border. Subtidal zones are given in blue and land above spring high tide level in yellow.