Available online at www.sciencedirect.com
ScienceDirect
Estuarine, Coastal and Shelf Science 75 (2007) 296–307
ESTUARINE COASTAL AND SHELF SCIENCE
www.elsevier.com/locate/ecss

Diatoms inhabiting a wind flat of the Baltic Sea: Species diversity and seasonal succession

Jana Woelfel [a,*], Rhena Schumann [a], Sven Adler [b], Thomas Hübener [b], Ulf Karsten [a]

[a] Department of Applied Ecology, Institute of Biological Sciences, University of Rostock, Albert-Einstein-Strasse 3, 18051 Rostock, Germany
[b] Department of Botany, Institute of Biological Sciences, University of Rostock, Wismarsche Strasse 8, 18055 Rostock, Germany

Received 25 November 2005; accepted 30 April 2007
Available online 5 July 2007

Abstract

The seasonal succession of brackish microphytobenthos (consisting of diatoms and cyanobacteria) was studied at a wind flat at the southern Baltic Sea coast. Wind flats are coastal zones with a high degree of exposition becoming flooded irregularly as a function of sea levels, prevailing wind direction and speed. These extreme environmental conditions favour the formation of laminated microbial mats similar to those in tidal flats. Special attention was paid to the comparison of diatom compositions in a laminated microbial mat as a relatively steady biocoenosis, and compositions in sediment without a mat, probably a more disturbed area. Therefore, monthly sediment samples from March to November 2002 were examined at two adjacent stations (reference station without mat, microbial mat station). Biomass (chlorophyll *a* content), cyanobacterial and diatom abundance, species composition and diversity were determined. The main mat forming cyanobacteria were *Microcoleus chthonoplastes* and *Lyngbya aestuarii*. The laminated mat exhibited a larger total biomass from spring on, while diatoms at the reference station accumulated relatively more biomass until late summer. 93 diatom taxa were identified in total. The species compositions at both stations were similar compared to those inhabiting other sandy and shallow water areas of the Baltic Sea. However, in the mat inhabiting diatom community lower relative abundances of very small species (<15 μm) were determined. In contrast to tidal flats, diatoms of the wind flat were found in much deeper zones of the mat (down to 1 cm), which may contribute to less anoxic conditions. This occurrence may be influenced by the specific sediment features, such as larger sand grain sizes. Species numbers were moderate within a given sample, indicating that environmental conditions in wind flats are extreme and outside of the tolerance limits of many species. On the other hand, the Shannon–Weaver index was comparably high due to its evenness component, so that disturbances may have been too frequent to establish climax communities, i.e. supporting few strongly dominant species. Nevertheless, the total biomass accumulated in the range of many other microphytobenthos communities in spite of extreme conditions hinting on good adaptation and protection capabilities, e.g. mucous material with high water retention potential.

Keywords: diatoms; bacillariophyceae; benthic marine microbial mats; wind flats; Baltic Sea; microphytobenthos; cyanobacteria; laminated mats

1. Introduction

Coastal areas of the German Baltic Sea are barely influenced by tides (10 cm). Nevertheless, strong fluctuations of the water level occur, mainly induced by wind direction, wind speed and atmospheric pressure (Brosin, 1965). Depending on the flatness and exposure direction of the coastal zone, large areas of sediments can be flooded or fall dry irregularly in respect to time, frequency and extension (Eisma, 1998). These so-called "wind flats" resemble in some way tidal flats in respect to exposition and inundation, but both processes are predominantly a function of the prevailing wind conditions (Rippe and Dierschke, 1997). Since there are only few tideless brackish or marine systems with a respective topology, wind flats are rare and hence, ecologically poorly studied. There are similar ecosystems for example in the Black Sea, at the northern beaches of Caspian Sea or at Laguna Madre (Mexico/Texas) (Eisma, 1998).

The irregular water level fluctuations cause partly extreme environmental conditions or frequent strong changes in other

* Corresponding author.
E-mail address: jana.woelfel@uni-rostock.de (J. Woelfel).

0272-7714/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ecss.2007.04.033

abiotic parameters, e.g. photosynthetic active and ultraviolet radiation, temperature, salinity and nutrient concentrations. Under such unstable environmental conditions, laminated microbial mats are favoured, most likely due the vertical stratification with robust species at the surface protecting more fragile organisms below (Karsten et al., 1998). The reduction or absence of benthic fauna and, thereby, a low bioturbation and grazing pressure may also support a long-lived microbial community (Stal, 1995). Therefore, different microbial groups can establish stable, vertically stratified interdependent layers of heterotrophic, chemoautotrophic and photoautotrophic microorganisms on solid surfaces (Van Gemerden, 1993; Stal, 1995). Laminated microbial mats develop in many different environments, such as thermal springs, hypersaline ponds and lakes, dry and hot deserts, Antarctic and alkaline lakes as well as coastal intertidal sediments (Cohen and Rosenberg, 1989; Stal and Caumette, 1994). Most studies about these microbial mats have focussed on tidal marine environments (Stal and Krumbein, 1985; Van Gemerden, 1993; Stal, 1995, 2003; Karsten et al., 1998). Investigations of microbial mats from the non-tidal brackish-water Baltic Sea are very rare (Witte et al., 2004). Most laminated microbial mats consist mainly of cyanobacteria and bacteria of different metabolic abilities (Jørgensen et al., 1983). Besides these prokaryotes, diatoms may also contribute substantially to the photoautotrophic fraction (Witkowski, 1991, 1990). However, information on diatoms as a genuine component of laminated microbial mats—*in sensu strictu* of a stable vertically multilayered cyanobacterial / bacterial community—are scarce (Witkowski, 1990, 1991; Vinocur and Pizarro, 2000).

The aim of the present study was to describe the composition of the benthic diatom community of a wind flat at the southern Baltic Sea coast as well as the prevailing physicochemical conditions. Relative abundance, species composition, diversity and seasonal succession were investigated for diatoms inhabiting a laminated microbial mat in comparison to an adjacent mat-free sediment over one vegetation period from May to November. The influence of the laminated mat on the diatom assemblage was of special interest, because these diatoms may either benefit from the laminated mat structure by protection from, e.g., desiccation and UV radiation, or be restricted by shading and competition for nutrients or space. The importance of laminated mats for such wind-influenced exposed regions is discussed in respect to biomass production and sediment stability.

2. Material and methods

2.1. Site description

Sampling was performed at the wind flat ‘‘Bock’’ (eastern longitude: from 12°54′6″ to 13°3′4″, northern latitude: from 54°26′48″ to 54°28′3″) at the eastern end of the Darß-Zingst peninsula (Baltic Sea, Germany) (Fig. 1), which is part of the national nature reserve ‘‘Vorpommersche Boddenlandschaft’’. As a part of an inner coastal water system this is the largest wind flat area of the German Baltic Sea coast (Kube, 1992) extending over more than 1800 ha. There are places with altitudes of 15 cm below to 5 cm above mean sea level, which can all easily be flooded with adjacent Baltic Sea water. At a Baltic Sea level higher than 520 cm (measured at the gauging station of Barhöft, Agency for Water- and Navy, Stralsund) and during north-westerly or north-easterly strong wind situations (>8 m s^{-1}, measured at the biological station of Zingst), a large wind flat area may become submersed (Fig. 2). However, there were situations when the wind flat area was strongly flooded at sea levels slightly below 520 cm. During the study period in 2002, the wind flat was flooded for ca. 11 weeks, particularly in spring and autumn. The increase in mean sea levels varies usually between 5 and 30 cm per day, with a maximum of up to 70 cm (Fig. 3; Kube, 1992).

The predominant sediment type of the wind flat studied is middle-grained, well-sorted sand (modal particle size of 0.32–0.33 mm, Table 1). Sediment grain size was determined by wet sieving with different mesh sizes of 1 mm, 500, 200, 100 and 63 μm. The salinity of the adjacent Baltic Sea amounts to an average of 10 to 12 and that of the neighbouring inner coastal lagoon Grabow to 8 (Schumann et al., 2006). During the investigation period, the salinity of the water body covering the wind flat after flooding was 8–11. Salinity was measured as conductivity using the Practical Salinity Scale with a WTW Salinometer LF 197.

The organic content of the sediment samples taken from the reference was considerably lower than at the laminated mat station (Table 1, methods: organic content as the mass loss after 24 h heating at 550 °C; total phosphorus after organic matter ignition and boiled in 1 N HCl, Andersen, 1976; particulate organic carbon and nitrogen by element analysis in an Elementar Analyser, Verardo et al., 1990). Free dissolved plant nutrients were estimated after eluating dry or dried sediment samples (ca. 10 g) with 50 ml distilled water salted to 10 PSU with sea salt (hw-Meersalz Professional) for 30 min at room temperature and gentle shaking. The respective filtrates through Whatman GF/F filters were analysed for dissolved inorganic nitrogen (as the sum of ammonium, nitrate and nitrite) and phosphorus photometrical (Rohde and Nehring, 1979; Malcolme-Lawes and Wong, 1990). Both inorganic nutrients were slightly higher at the reference station. However, the total range over the growing seasons was high, thus no nutrient limitation influenced the data of species composition.

2.2. Sampling

Sampling took place monthly from March to November 2002 at two different sites. The first site without a microbial mat named ‘‘reference station’’ was located at 250 m distance from the second site ‘‘microbial mat’’. Sampling of the microbial mat station could not be started before May, since the first selected microbial mats were destroyed by a storm. The GPS positions of the sampling sites were: reference station: 54°44′393″ N, 12°92′540″ E; mat station: 54°44′405″ N, 12°92′609″ E. The microbial mat was situated approximately in the middle of the wind flat and covered an area of 10,400 m^2 (about 65 m × 160 m).