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ORIGINAL RESEARCH ARTICLE

Microbial enzymatic activity and its relation to organic matter abundance on sheltered and exposed beaches on the Polish coast

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Summary The activity of lipase, aminopeptidase, α-glucosidase, β-glucosidase was correlated and assessed according to an abundance of organic matter and total forms of nutrients in beach sediments characterized by different strength of anthropopressure and degree of sheltering. 76% of the data variance was explained by six factors identified by the use of principal component analysis: (1) anthropogenic rich in N, (2) microbial enzymatic activity, (3) labile organic matter, (4) bacterial growth, (5) anthropogenic rich in P and (6) hydrolytic. Differences in secondary bacterial production according to the distance from the water line, vertical cores and seasonality are limited by the accessibility of biochemical compounds (lipids, proteins, carbohydrates, total organic carbon), total phosphorus and nitrogen. Sediments collected in exposed beaches were not as rich in organic matter as these collected in sheltered ones due to the impact of sea waves of higher energy and backward current facilitating cleaning. The highest microbial enzymatic activity was observed in the beach infilled prior to the tourist season with well-aerated sand mined from the main harbor canal. Microorganisms induce α-glucosidase synthesis to decompose hardly assimilable COM during deficit of easily assimilable PRT and CHO. The lack of easily assimilable matter activates stronger hydrolytic activity in lower layers of core sediments.

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1. Introduction

Sea coasts are contact zones between the land and the sea or the ocean. One of the few possible types of coasts are beaches, which are the most common form of littoral accumulation. Sandy beaches being a buffer zone between the land and the sea are characterized by wide spectrum of sizes, morphologies and ranges of exposure to oceanographic conditions (Mudryk et al., 2011; Novitsky and MacSween, 1989; Rodil and Lastra, 2004). Those environments are very dynamic, as they are shaped by wind, sand and water remaining in constant motion (Germán Rodríguez et al., 2003; McLachlan et al., 1996; Rodil and Lastra, 2004; Schoeman et al., 2000). Marine beaches, sandy ones in particular, are often subjected to considerable anthropogenic pressure due to recreational and economic functions (Antonowicz et al., 2015; Węsławski et al., 2000). Diverse forms of organic matter including variety of its constituents (lipids, proteins, carbohydrates, total organic carbon, total phosphorus and total nitrogen) transform beaches into specific ecosystems inhabited by microorganisms which participate in the transformation and mineralization of the matter (Koop and Griffiths, 1982; Phillips et al., 2011), and hence sandy beaches play an important role in energy flow and organic matter turnover. Being considered an important component of sandy beach community, bacteria mineralize about 70% of organic matter. Beaches can also be considered huge water filters (approximately 10—70 $m^3\ m^{-1}\ d^{-1}$) (Brown and McLachlan, 1990; Heymans and McLachlan, 1996; Nair and Loka Bharathi, 1980). During water permeation, a large amount of organic matter is adsorbed by the sand grain surface as particulate (POM) and dissolved (DOM) organic matter (Mudryk and Podgórska, 2006).

Productivity of sandy beaches is ultimately limited by the nutrient load (Khiyama and Makemson, 1973). The rate of DOM and POM decomposition depends on the availability of nutriment, physiological properties and bacteria metabolic activity. According to Boetius (1995), production and activity of bacterial hydrolytic enzymes depend on availability, distribution and concentration of organic substrates. Therefore, the activity of enzymes in vertical profiles reflects the distribution of organic matter in water basin sediments. Organic matter accumulated in sediments is further utilized by interstitial organisms and returns to the sea in the form of nutrients. Therefore, on most beaches an interstitial system acts as a biological filter that enhances the mineralization of organic matter and purifies water. Heterotrophic bacteria inhabiting coastal ecosystems are not a homogeneous group of organisms. They represent the population of various physiological groups which is characterized by the ability to carry out the processes of depolymerization of a wide spectrum of macromolecular compounds (Krstulović and Solić, 1988; Mudryk et al., 1999, 2011).

Quality and quantity of organic matter in surface sediments have been considered a major factor in determining the amounts of material potentially available to consumer organisms, thus affecting community structure and benthic metabolism (Buchanan and Longbottom, 1970; Graf et al., 1983; Graf, 1989; Grant and Hargrave, 1987; Thompson and Nichols, 1988). Organic matter (OM) in the marine environment consists of labile and refractory compounds whose relative importance may have profound implications for OM diagenesis and organic carbon turnover (Danovaro et al., 1993; Daumas et al., 1983; Fabiano et al., 1995; Fichez, 1991a; Rowe and Deming, 1985). The labile portion contains mainly simple sugars, fatty acids and proteins that are rapidly mineralized. On the contrary, the refractory matter, which consists of substances like humic and fulvic acids and complex carbohydrates, is characterized by lower degradation rates (Biddanda and Riemann, 1992; Buscail et al., 1990; Danovaro et al., 1999a; Fabiano and Danovaro, 1994; Handa et al., 1972; Robinson et al., 1982; Sargent et al., 1983; Wilson et al., 1986). Sandy beaches usually receive large input of organic matter, which comprises an important source of nutrients for offshore production (Brown and McLachlan, 1990; Jędrzejczak, 1999). Local changes of sedimentary organic matter in the marine environment affect spatial distribution, metabolism and dynamics of all benthic components, from bacteria to macrofauna (Cividanes et al., 2002). Quantitative information on vertical fluxes of particulate proteins, carbohydrates and lipids is extremely rare (Danovaro et al., 1999b). In general, it is expected that labile carbon flux is coupled with surface productivity and decreases with depth (Carney, 1989).

Despite the fact that a range of studies have been conducted worldwide on microbial enzymatic activity on various beaches (Cividanes et al., 2002; Danovaro et al., 1993, 1999a,b; Danovaro, 1996; Dell'Anno et al., 2002; Fabiano et al., 1995, 2004; Fernandes et al., 2012; Fichez, 1991a,b; Graf and Meyer-Reil, 1985; Khripounoff et al., 1985; Meyer-Reil, 1983), only a few of them were focused on the comparison of microbial enzymatic activity. Few papers have attempted to analyze microbial enzymatic activity comprehensively according to biochemical composition of the sedimentary organic matter and specific characteristic of the beach. Moreover, to the best of our knowledge, in the case of the Polish coast only two scientific papers concern microbial enzymatic activity on sandy beaches (Mudryk and Podgórska, 2006; Perliński and Mudryk, 2016). Therefore, the aims of this study were to investigate: (1) the biochemical composition variability of the sedimentary organic matter and microbial enzymatic activity on 3 beaches subjected to a different degree of exposure and anthropopression, (2) the temporal changes in the quantity of sedimentary organic matter composition and microbial enzymatic activity in sheltered and exposed beaches, and (3) the variation of the above mentioned parameters according to the distance from the water line and vertical core depth.

2. Material and methods

2.1. Study area and sampling sites description

The study was carried out in three spots on 130 km long section of the Polish coast, between 232nd and 102nd km of the Polish sea border where the widest, the most beautiful and attractive, according to touristic activity, sandy beaches are located (Fig. 1).

Samples were collected in Ustka (54°34′N/16°51′E) on the eastern side of the mouth of the Słupia river, in Czołpino (54°43′N/17°14′E) and in Puck (54°44′N/18°24′E). Ustka, Czołpino and Puck are situated in northern Poland. They