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Studies concerning heterotrophic bacteria decomposing macromolecular compounds at two marine beaches

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Abstract

The potential capability to decompose macromolecular compounds was confirmed in heterotrophic bacteria isolated from two sandy beaches located on the southern Baltic coast. Proteolytic bacteria were the most numerous group, whereas lipolytic organisms were rare among bacteria inhabiting the studied beaches. All studied physiological groups of bacteria were considerably more numerous in the sand of the beach subject to stronger anthropopressure. The differences in bacteriological parameters across the horizontal profile of the beaches were noted. In both studied beaches a higher number of bacteria able to decompose macromolecular compounds were recorded in the surface as compared to the subsurface sand layer.

INTRODUCTION

Beaches are present along all coasts, at all latitudes and in all climates worldwide. They are characterised by a wide spectrum of sizes, morphologies, and ranges of exposure to oceanographic conditions and they constitute a buffer zone between the land and the sea (Novitsky and MacSween 1989, Rodil and Lastra 2004). Mainly water, wind, sea waves and human impact (Rodriguez et al. 2003) determine the structure of these extremely dynamic environments. Marine beaches can be regarded as gigantic filters through which large amounts of water are being filtered (Brown and McLachlan 1990, Heymans and McLachlan 1996, Olańczuk - Neyman and Jankowska 1998). While the seawater is being filtered, great amounts of organic matter are adsorbed on the sand grain surfaces in the form of dissolved organic matter (DOM) and particulate organic matter (POM). Both these forms of organic matter include proteins, starch, lipids, pectin, cellulose, chitin, lignin, nucleic acids and phospholipids (Martinez and Azam 1993, Arnosti et al. 1998). The main sources of DOM and POM in marine beach sand are phytobenthos assimilates, phytodetritus, products washed and leached out from the seaweed, animal faeces produced by meio- and macrofauna and the remains of plants and animals (Koop and Griffiths 1982, Brown and McLachlan 1990, Jędrzejczak 1999). According to Urban - Malinga and Opaliński (1999), as much as 1.1 kg of organic C m^{-2} could be introduced daily into the interstitial system of a marine beach. Such accumulation of organic matter generates optimal conditions for the growth of numerous heterotrophic microorganisms, mainly bacteria, which play a key role in the processes of decomposition and transformation of organic matter accumulated in sandy beach ecosystems (Mudryk et al. 2001, Malm et

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al. 2004, Misic and Harriague 2007). According to Koop et al. (1982), about 70% of organic matter reaching the ecosystems of marine beaches is mineralised by bacteria transforming it into their own biomass or utilizing it for respiratory purposes as a source of energy. Heterotrophic bacteria are able to decompose a very wide spectrum of organic compounds with molecules differing in size from monomers to biopolymers (Jacobsen and Azam 1984). Many heterotrophic bacteria are known to carry genetic and metabolic potentials to synthesise and control extracellular enzymes, which can degrade and modify a large variety of natural polymers in water ecosystems (Mudryk and Podgórska 2006).

The abundance and distribution of heterotrophic bacteria on marine sandy beaches have been documented in many parts of the world (Brown and McLachlan 1990, Kolm and Correa 1994, Olańczuk - Neyman and Jankowska 1998, Podgórska et al. 2008). However studies regarding the role of heterotrophic bacteria in the degradation processes of organic matter accumulated in marine beaches are very rare (Podgórska and Mudryk 2003) and our understanding of these problems is still incomplete and fragmentary. Consequently, the aim of the present study was to determine the capability of bacteria inhabiting two sandy beaches (in the southern Baltic Sea), which differed in the level of human pressure, to decompose selected macromolecular compounds.

MATERIALS AND METHODS

Study area and sampling

The study was carried out on two exposed sandy beaches (Ustka – 54°35`N, 16°51`E, Czołpino – 54°43`N, 17°14`E) on the southern Baltic Sea (Fig. 1). Both beaches, which are influenced by the conditions in the open sea, represent a dissipative beach type with longshore bars and troughs. Both beaches have a slope of 7° and they are both ca. 60 - 70 m wide. In general, fine and medium-grained sand predominates on the beaches. The sand grain-size is between 350 and 700 μm (Kramarska et al. 2003). The beaches differ in the level of human pressure. Ustka Beach, with its surf zone, is one of the most picturesque beaches in Poland and is very popular for swimming. Many Polish and foreign tourists and local inhabitants visit this beach and it is usually very crowded during the summer months. The mouth of the polluted Słupia River is in the eastern part of the beach. This river carries 15.5 m^3 s^{-1} of water into the sea, as well as 200 000 - 300 000 m^3 $year^{-1}$ of natural and anthropogenic sediments (Zawadzka 1996).

The beach near Czołpino is located in Słowiński National Park, which registered on the World List of Biosphere Reserves. Characteristic protected elements in the park are the sandbars with moving dunes - unique in Europe. Dunes moving with a speed of 5 - 30 m per year are covered by "sand-loving" saltgrass species, such as: *Cakile maritima* ssp. *baltica, Honckenya peploides*, *Ammophila arenaria, Calammophila baltica, Corynephorus canescens, Elymus arenarius, Helichrysum arenarium* and *Linaria odora.* Since the beach near Czołpino is located in the National Park, human pressure is relatively low there.

Some values of selected chemical parameters in the sandy beaches of Ustka and Czołpino are presented in table 1 (Jocz 2010, Piechocka 2010).

Sand samples from the beaches were collected four times along a transect perpendicular to the shoreline between autumn 2007 and summer 2008 with three month cycles. Four sampling sites were located along this transect (Fig. 1). Site 1 was located approximately 1 - 1.5 m offshore, at a depth of about 1 meter underwater. Site 2 was situated at the waterline. Site 3 was halfway up the beach, 30 m from the shore, and site 4 was a sheltered place among the dunes, about 60 - 70 m away from the shore.

Sand core samples, five per site, were taken with a hand-operated sampler (length - 30 cm, inner diameter - 15 cm). The sand cores, 15 cm long, were divided into two sections in the field (0 - 5 cm and 10 - 15 cm) and placed in sterile glass jars. The jars were put into containers with ice and transported to the laboratory. The time between sample collection and bacteriological analyses did not usually exceed 2 - 3 h.

Bacteriological analyses

Each of the 5.0 g sand samples was weighed aseptically and transferred to 45 cm^3 of sterile 8 PSU artificial seawater. Samples were sonificated for 60 seconds over an ice bath in a sonificator (Bandelin Electronic Sonoplus 70 W, 20 kHz) in order to desorb microorganisms stuck to the sand grains. Subsequently, serial tenfold dilutions of the obtained supernatant were prepared with sterile 8 PSU seawater to reach final concentrations ranging from 10^{-2} to 10^{-6}. These final samples, in the amount of 0.2 cm^3 by the spread plate method, were inoculated

onto different media containing various organic compounds:

1. The capability to hydrolyze proteins, starch, and lipids was tested in a medium prepared according to Jones (1971) and supplemented with gelatine (5.0 g per dm^3), starch (5.0 g per dm^3) or tributyrin (10 cm^3 per dm^3). Gelatine hydrolysis was determined with the use of the Frazier`s reagent poured over the plates. Starch hydrolysis was determined with the use of Lugol`s solution. Tributyrin hydrolysis was determined by formation of a clear zone around bacterial colonies.
2. The capability to decompose DNA was assayed in Fluka medium containing DNA (2.0 g per dm^3). After pouring 1 N HCl over the plates, DNA hydrolysis was determined by formation of a clear zone around the colonies.
3. The capability to hydrolyse chitin was tested in a medium prepared according to Helmke and Weyland (1986). Colloidal chitin was obtained with the use of chitin from Windsor–Berkshire (England) according to Lingappa and Lockwood (1962). Clear zones around the colonies indicated chitin hydrolysis.
4. The capability to hydrolyse cellulose was tested in the medium prepared according to Mudryk and Donderski (1997). Colloid cellulose was prepared from Cellulose Powder 11, Whataman, according to Halliwell (1962). Cellulose hydrolysis was determined by formation of a clear zone around the colonies.

Three plates from each tenfold dilution were

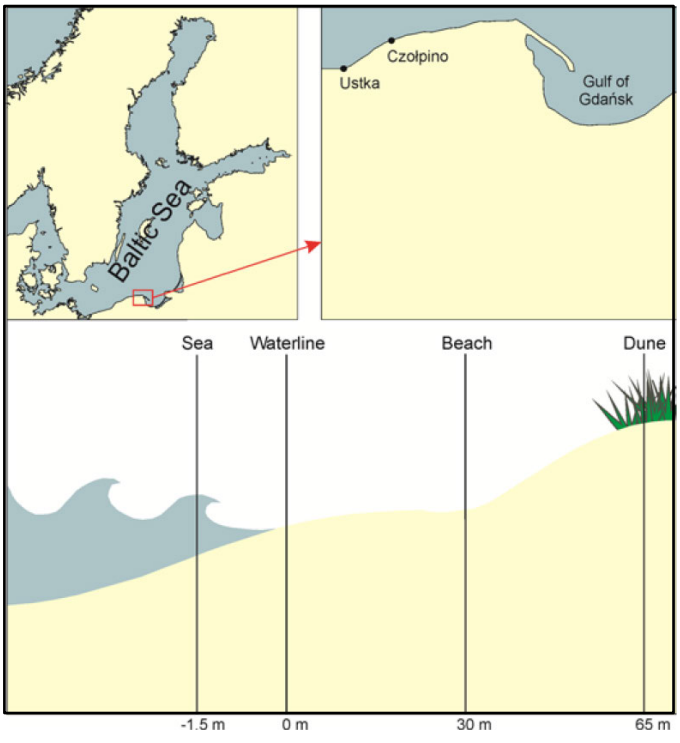


Fig. 1. Location of sampling sites on the sandy beach in Ustka and Czołpino.

Table 1

Values of selected chemical parameters in the sandy beaches of Ustka and Czołpino (Jocz 2010, Piechocka 2010).

Parameters – units	Ustka		Czołpino	
	mean	range	mean	range
Organic matter (mg g^{-1})	4.8	2.3 – 88.1	2.2	0.6 – 5.2
Organic carbon (mg g^{-1})	2.8	2.3 – 3.1	1.3	0.8 – 1.7
Proteins (µg g^{-1})	174.3	57.0 – 307.0	156.1	37.0 – 256.0
Lipids (µg g^{-1})	476.3	62.1 – 1316.1	352.0	61.6 – 929.6
Carbohydrates (µg g^{-1})	637.5	148.0 – 1380.1	569.0	137.6 – 817.1
Chlorophyll *a* (µg g^{-1})	0.5	0.1 – 1.2	0.5	0.1 – 0.6

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incubated for 7 days at 20°C (with the exception of chitin and cellulose hydrolysis tests, which were read after 21 days), after which the number of bacteria that decomposed organic compounds was counted. The results were calculated as the colony forming units (CFU) per 1 gram of the dry weight of sand. An additional sample of 10 g of sand was weighed and dried at 105°C for 24 h in order to determine the dry weight of sand.

RESULTS

The ability of bacteria, isolated from the sand of Ustka and Czołpino beaches, to decompose macromolecular organic compounds is summarised in Table 1. Proteolytic organisms were the most abundant bacteria inhabiting the sand of Ustka (433.8 × 10^3 CFU g^{-1} d.w. (dry weight) of sand)) and Czołpino (123.6 × 10^3 CFU g^{-1} d.w. of sand) beaches. These organisms made up over 40% of all the isolated bacteria. Amylolytic and chitinolytic bacteria were also relatively common (14 - 22%). In general the least numerous among the physiological groups of bacteria isolated from the sand of Ustka (49.8 × 10^3 CFU g^{-1} d.w. of sand) and Czołpino (6.4 × 10^3 CFU g^{-1} d.w. of sand) beaches were lipolytic organisms, which made up only 2 - 5% of all isolated bacteria. In the sand of Ustka Beach, which is subject to strong anthropopressure, the number of studied physiological groups of bacteria decomposing organic compounds was considerably higher (3 - 7 times) than in the sand of Czołpino Beach, which is not strongly affected by human activity. The largest difference between the two beaches was in the number of cellulolytic and lipolytic bacteria (Table 2).

Data presented in Figure 2 show that bacteria inhabiting the perpendicular profile of Ustka and Czołpino beaches were able to decompose macromolecular organic compounds, although their number varied depending on the site. In Ustka Beach the maximum density of all studied physiological groups of bacteria was recorded in the middle part of the beach, except for cellulolytic bacteria which occurred in the largest number on the dune. In Czołpino Beach, bacteria decomposing proteins, starch, DNA and lipids were most abundant in the middle part of the beach, whereas chitinolytic and cellulolytic bacteria showed maximum density on the dune. On both beaches the lowest density of all studied bacterial groups was noted in seawater and at waterline.

The distribution of various physiological groups of bacteria showed vertical stratification, and there was a difference between surface and subsurface sand layers (Fig. 3). Bacteria able to decompose all tested macromolecular organic compounds were more numerous in the surface (0 - 5 cm) than in the subsurface (10 - 15 cm) sand layer at both beaches. However the observed difference was more pronounced on Ustka Beach (2 - 24 times) than Czołpino Beach (1.5 - 3 times).

Bacteria decomposing organic macromolecules in both studied beaches showed considerable seasonal variation in occurrence (Fig. 4). In the sand from Ustka Beach the highest density of bacteria hydrolysing proteins, chitin, cellulose and DNA was noted in summer. The number of amylolytic bacteria was the highest in winter and summer, while lipolytic bacteria were highest in summer and autumn. In Czołpino Beach proteolytic, chitinolytic, and lipolytic bacteria as well as bacteria hydrolyzing DNA were the most numerous in winter and summer, whereas amylolytic bacteria dominated in summer and cellulolytic bacteria in autumn.

DISCUSSION

Heterotrophic bacteria inhabiting water ecosystems are not a homogeneous group of organisms. They are a population of various physiological groups, which are characterized by the ability to carry out the processes of depolymerization of a very wide spectrum of macromolecular compounds (Krstulović and Solić 1988, Mudryk et al. 1999). The intensity of decomposition of organic macromolecules in water basins depends on the number of bacteria capable of carrying out those processes, on the activity of their extracellular hydrolytic enzymes and on the quantity and quality of the organic matter (Jackson et al. 1995, Mudryk and Podgórska 2006).

The results of the present study showed that proteolytic bacteria were the most abundant physiological group of organisms inhabiting the sand of both studied beaches: they constituted over 40% of the total number of isolated bacteria. According to an earlier study by Podgórska and Mudryk (2003) about 80% of heterotrophic bacteria isolated from a sandy beach in Sopot on the southern coast of the Baltic Sea showed the ability to hydrolyse proteins. Bacteria capable of hydrolysing proteins also predominated in other water ecosystems, reaching as much as 70% to 100% of the total number of

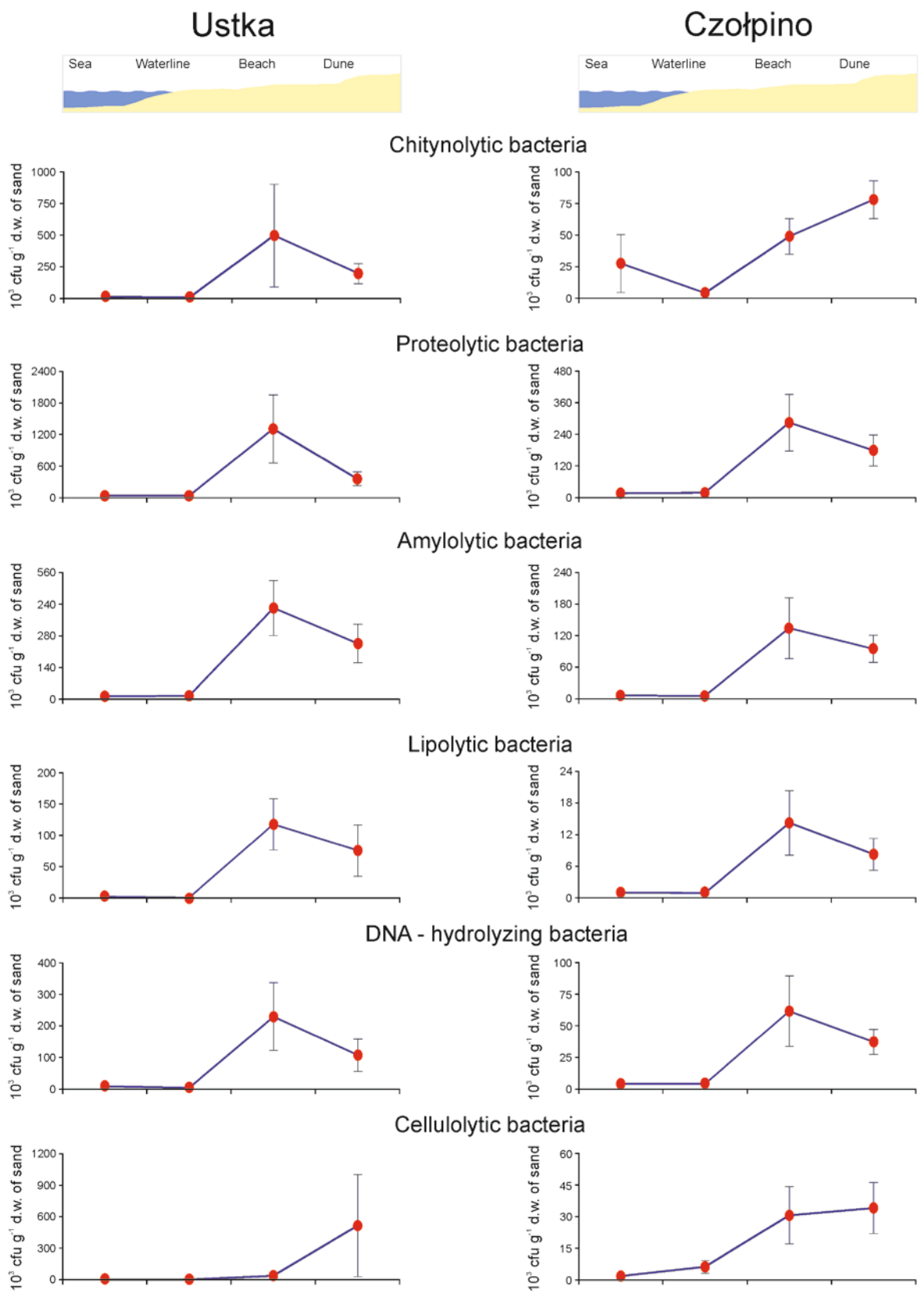


Fig. 2. Horizontal distribution of chose physiological groups of heterotrophic bacteria.

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Table 2

Number of bacteria decompose macromolecular organic compounds isolated from the sand of Ustka nad Czołpino beaches (10^3 CFU g^{-1} d.w. of sand).

Bacteria decomposing indicate substrates	Ustka				Czołpino			
	Mean	Min	Max	SD	Mean	Min	Max	SD
Chitin	178.7	0.4	3340.8	592.3	39.7	1.7	187.4	49.6
Protein	433.8	3.1	5634.9	1025.3	123.6	4.9	893.1	200.2
Starch	172.2	0.0	884.3	259.9	60.4	0.0	460.4	101.7
Lipid	49.8	0.0	305.3	80.2	6.4	0.0	51.5	11.2
DNA	89.6	1.3	735	184.2	26.7	0.9	247.2	46.6
Cellulose	139.8	0.4	3934	692.8	18.2	0.0	103	28.9

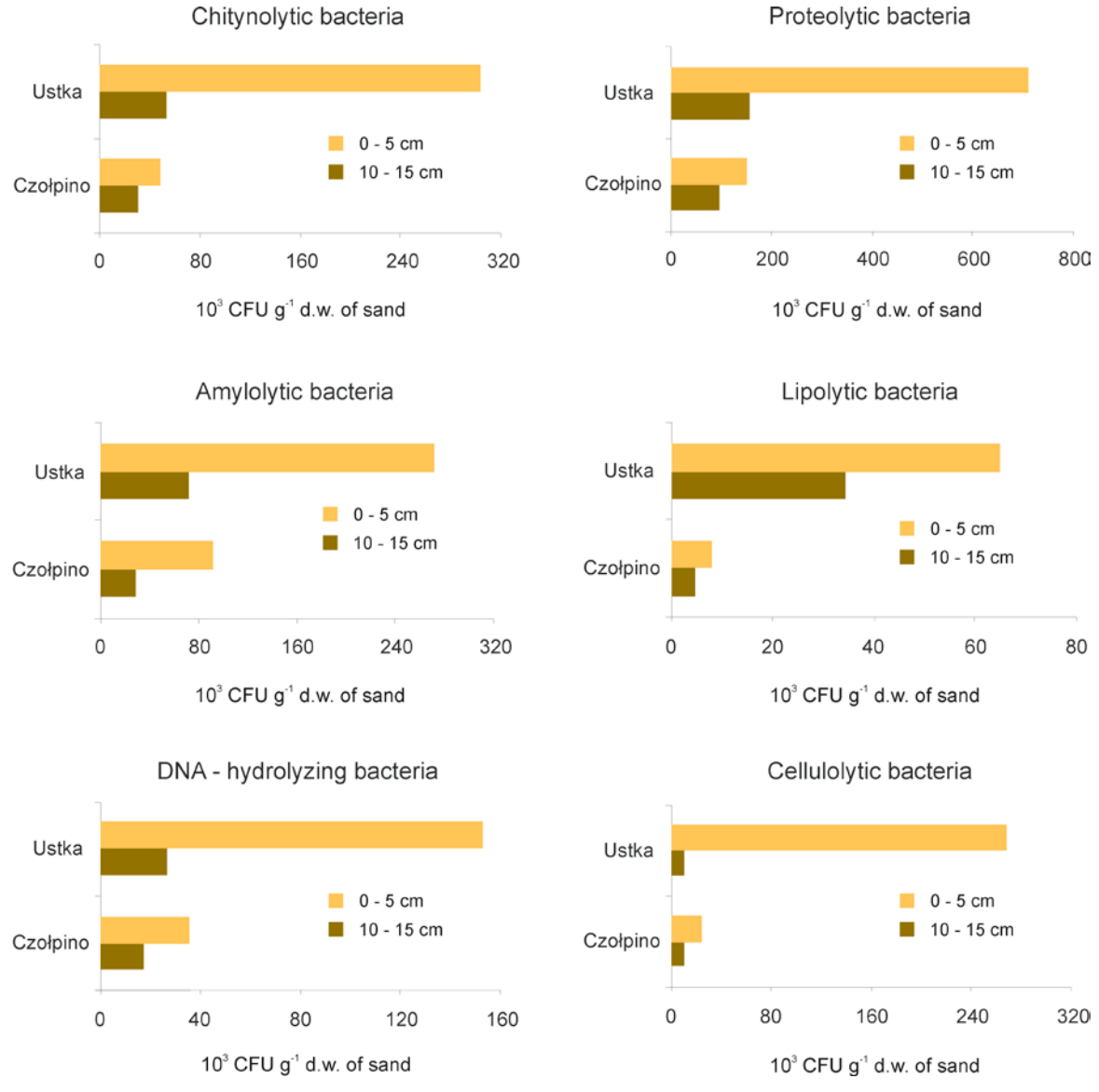


Fig. 3. Decomposition of some macromolecular compounds by heterotrophic bacteria inhabiting surface and subsurface sand layers.

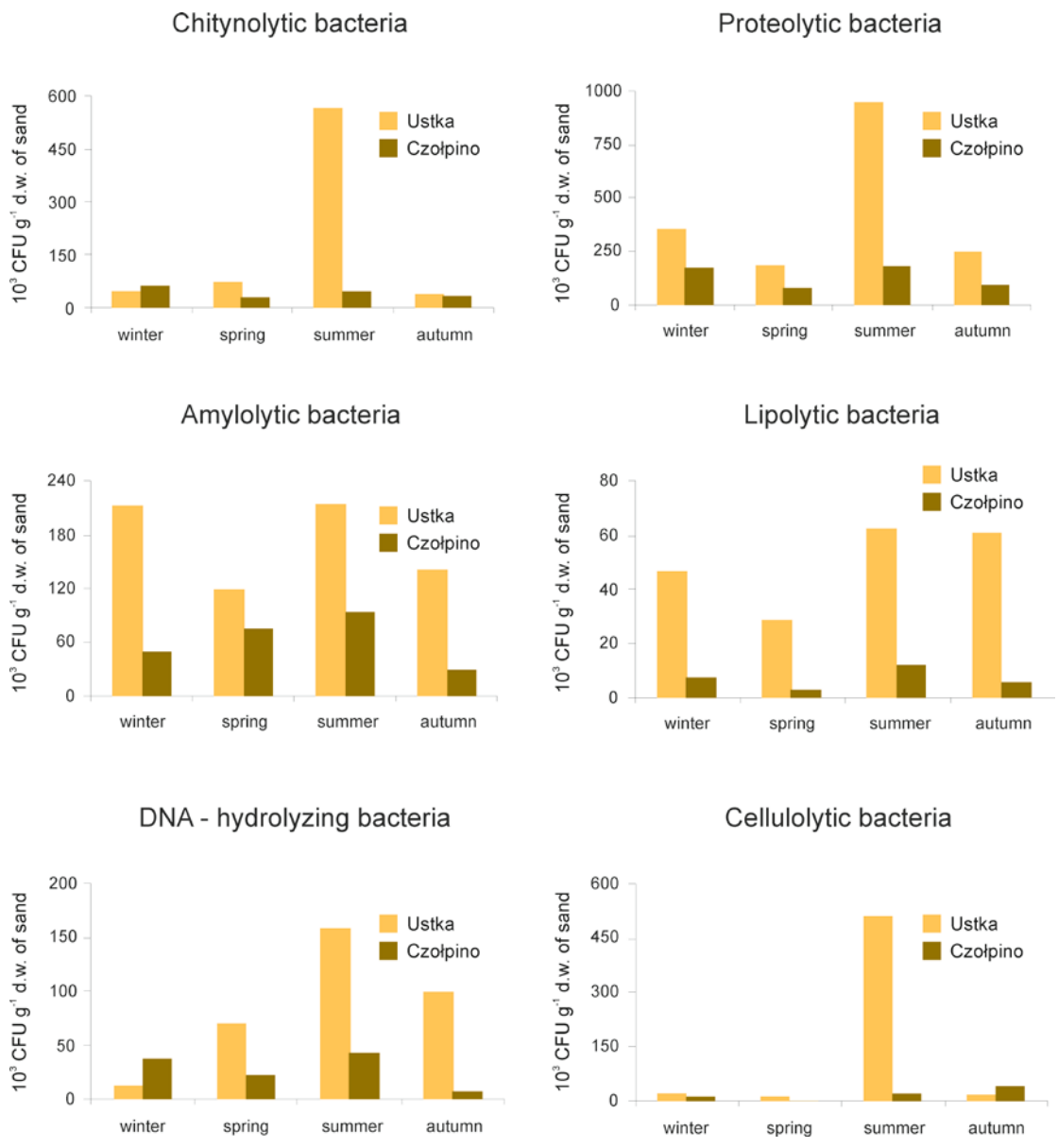


Fig. 4. Occurrence of bacteria able to decompose selected macromolecules in various season.

bacteria (Krstulović and Solić 1988, Mallet and Deboras 1999, Worm et al. 2000). According to Incera et al. (2003) proteins were the dominant (71 - 84%) class among labile organic compounds accumulated in marine beaches. The main sources of those compounds are the excretions of phytoplankton, phytobenthos, zooplankton and meio- and macrofauna as well as remains of plants and animals (Billen and Fontigny 1987). High concentrations of proteins, polypeptides and peptides in water bodies is a major factor in causing intensive growth of proteolytic bacteria (Patel et al. 2000). These organisms are able to easily utilize protein compounds as carbon, nitrogen and energy sources in their metabolic processes (Wehr et al. 1999, Kiersztyn et al. 2002).

Bacteria capable of hydrolyzing lipids were the least abundant bacterial group in Ustka and Czolpino beaches. One of the reasons for the rare occurrence of lipolytic bacteria in the sand of the studied beaches is the fact that microbiological depolymerization of lipids requires the synergic activity of many enzymes, which are produced by bacteria but also by fungi and actinomycetes (Gomes et al. 2008). In an earlier study, Mudryk and Podgórska (2007) reported that filamentous fungi,

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yeasts and actinomycetes were among the heterotrophic microorganisms inhabiting the sand of Czołpino Beach.

The authors are aware that the number of bacteria decomposing macromolecular compounds determined in the present study may be underestimated due to either the disintegration of microorganism cells during sonification or insufficient desorption from the sand grains, as has been already pointed out by Montagna (1982) and Mudryk and Podgórska (2007). Khiyama and Makemson (1973) showed that heterotrophic microorganisms living in interstitial water on sandy beaches constituted 22 - 46% of the total number of microorganisms; however their number was not determined in the present study. Newell and Fallon (1982), after several tests, estimated that the number of microorganisms recorded in the sand should be increased by 28%, because this was the average percentage of those organisms inhabiting interstitial water in sediments.

The number of microorganisms on a marine sandy beach depends on many environmental factors, such as grain size of the sand, wave intensity, temperature, pH, oxygen, and occurrence of bacterivores (Yamamato and Lopez 1985, Novitsky and MacSween 1989). On the other hand, according to Nair and Bharathi (1980) the most important factor determining the number of microorganisms in the sand of a marine beach is the supply and content of organic matter. Studies carried out by Pugh et al. (1974) and Novitsky and MacSween (1989) on British and Canadian beaches differing in the concentration of organic matter showed that the number of microorganisms was much higher on beaches characterized by high accumulation of organic matter. The results of the present study also support this finding. The number of studied groups of bacteria decomposing macromolecular compounds was much higher in the sand of Ustka Beach, where large amounts of organic matter were accumulated (4.8 mg g^{-1} d.w. of sand) (Table 1) compared to the sand of Czołpino Beach, where the concentration of organic matter was two times lower (2.2 mg g^{-1} d.w. of sand).

The horizontal zonation of distribution and physiological activity of bacterial communities is a well-known global phenomenon on marine sandy beaches (McLachlan and Jaramillo 1995, Olańczuk - Neyman and Jankowska 1998, Podgórska and Mudryk 2007). Results of the present study also indicate clear differences in the distribution of bacteria capable of hydrolyzing macromolecular compounds along the horizontal profile of the beach. Maximum density of all studied physiological groups of bacteria was noted in the middle part of the beach and dune in Ustka and Czołpino, whereas the minimum was noted in the seawater and at waterline. According to Boetius (1995) and Martinez et al. (1996), such horizontal variations in the occurrence of bacteria able to decompose organic macromolecules may reflect variation in the composition, availability and degradability of organic compounds, as well as differences in the composition of microbial populations. Therefore abundance of bacteria capable of decomposing macromolecular compounds can be expected to mirror the distribution of organic matter in horizontal profiles of the sand in marine beaches. Low numbers of bacteria decomposing macromolecular compounds noted in the seawater and at the waterline of the studied beaches are possibly the result of bacteria being consumed by bacterivores, especially macrofauna and meiofauna, which are numerous in these parts of the beach (Haque et al. 1996). According to Brown and McLachlan (1990) and Malam et al. (2004) macrofauna, meiofauna and ciliates for which microorganisms, mainly bacteria, are a basic source of food and a main energy input, are important factors in controlling the number of bacteria on marine beaches.

Generally, research carried out in different beaches (Boucher and Chamroux 1976, Olańczuk - Neyman and Jankowska 1998, Mudryk and Podgórska 2007) demonstrated that the greatest abundance of bacteria in the vertical profile occurred in the top layer of sand, and decreased with depth. Data on the number of bacteria decomposing macromolecular compounds in both studied beaches also indicated that these organisms occurred more frequently in the surface than in the subsurface sand layers. This distribution pattern is most likely a result of the fact that the concentration of organic matter (Mudryk and Podgórska 2007) and oxygen (Urban - Malinga and Opaliński 2001), which create optimal conditions for the development and growth of bacteria, decreases with depth. Moreover organic matter is less easily removed in the deeper layers and thus decomposition processes by bacteria progress at a much slower pace.

This paper shows that it is difficult to determine the role of heterotrophic bacteria in the decomposition processes of organic matter in marine beaches and it should be regarded as a result of the

interaction between the sources and rates of supply of natural substrates, physiological dispersion vs. growth, and mortality and perdition processes. Consequently, the occurrence of different physiological groups of bacteria and their distribution as well as their influence on decomposing organic matter in marine beaches are poorly documented and understood. We hope that our research provides additional information on the potential role of bacteria in the processes of organic matter transformation and self-purification of marine sandy beaches.

REFERENCES

Arnosti C., Jorgensen B., Sagemann J., Tramdrup T., 1998, *Temperature dependence of microbial degradation of organic matter in marine sediment: polysaccharide hydrolysis, oxygen consumption, and sulphate reduction,* Mar. Ecol. Prog. Ser., 165: 59-70

Billen G., Fontigny A., 1987, *Dynamics of a phaeocystis - dominated spring bloom in Belgian coastal waters, II. Bacterioplankton dynamics,* Mar. Ecol. Prog. Ser., 37: 249-257

Boetius A., 1995, *Microbial hydrolytic enzyme activities in deep-sea sediments Helgoland*, Mar. Res., 49: 177-187

Boucher G., Chamroux S., 1976, Bacteria *and meiofauna in an experimental sand ecosystems. I. Material and preliminary results*, J. Exp. Mar. Biol. Ecol., 24: 237-249

Brown A.C., Mclachlan A., 1990, *Ecology of Sandy Shores,* Elsevier, Amsterdam, pp. 328

Gomes D.N., Cavalacanti M.A., Fernandes M.J., Lima D.M., Passavante L.Z., 2008, *Filamentus fungi isolated from sand and water of "Bairro Novo" and "Casa Caida" beaches, Olinda, Pernambuco, Brazil,* Brazil. J. Biol., 68: 577-582

Haque A.M., Szymelfenig M., Węcławski M., 1996, *The sandy littoral zoobentos of the Polish Baltic coast,* Oceanologia, 38: 361-378

Helmke E., Weyland H., 1986, *Effect of hydrostatic pressure and temperature on the activity and synthessis of chitinases of Antarctic Ocean bacteria*, Mar. Biol., 91: 1-7

Halliwell G., 1962, *Methods of enzymatic analysis* [in:] *Cellulose*, Ed. Bergmayer, H.V., Academic Press, New York- London, 64-71

Heymans J.J., McLachlan A., 1996, *Carbon budget and network analysis of a high energy beach/surf-zone ecosystems*, Estuar. Coast. Shelf Sci., 43: 485-505

Incera M., Cividanes S.P., López J., Costas R., 2003, *Role of hydrodynamic conditions on quantity and biochemical composition of sediment organic matter in sandy intertidal sediments (NW Atlantic coast, Iberian Peninsula),* Hydrobiologia, 497: 39-51

Jackson C.R., Foreman C.M., Sinsabaugh R.L., 1995, *Microbial enzyme activities as indicator of organic matter processing rates in a lake Erie coastal wetland,* Fresh. Biol., 34: 329-342

Jacobsen T.R., Azam F., 1984, *Role of bacteria in copoepoded fecal pellet decomposition. Colonization, growth rates and mineralization*, Bull. Mar. Sci., 35: 495-502

Jędrzejczak M.F., 1999, *The degradation of stranded carrion on a Baltic Sea sandy beach*, Oceanol. Stud., 3/4: 109-141

Jocz J., 2010, *Dynamic concentration of protein and chlorophyll in sand beach of diffrent anthropopressure*, Master's thesis, AP Slupsk pp. 74

Jones J.G., 1971, *Studies on freswater bacteria factors which influence the population and its activity*, J. Ecol., 59: 593-613

Khiyama H.M., Makemson J.C., 1973, *Sand beach bacteria: enumeration and characterization,* Appl. Microbiol., 26: 293-297

Kiersztyn B., Siuda W., Chróst R., 2002, *Microbial ectoenzyme activity: useful parameters for characterizing the trophic conditions of lakes*, Pol. J. Environ Stud., 1: 367-373

Kolm H.E., Correa M.F.M., 1994, *Spatial distribution and temporal variability of saprophytic bacteria on the sandy beach of Pontal, du Sul, Parna State, Brazil*, Arq. Biol. Tecnol., 37: 391-402

Koop K., Griffiths C.L., 1982, *The relative significance of bacteria meio and macrofauna on exposed sand beach,* Mar. Biol., 66: 295-300

Koop K., Newell R.C., Lucas M.I., 1982, *Microbial regeneration of nutrients from the decomposition of macrophyte debris on the shore,* Mar. Ecol. Prog. Ser., 9: 91-96

Kramarska, R., Uscinowicz, Sz., Zachowicz, J., Przezdziecki, P., Warzocha, J., Netzel J., Janusz J., 2003, *Identification of submarine deposit drifts to artificial swelling,* Department of Marine in Slupsk (in Polish)

Krstulović N., Solić M., 1988, *Distribution of proteolytic, amylolytic and lipolytic bacteria in the Kastela Bay,* Acta Adria., 29: 75-82

Lingappa Y., Lockwood J.L., 1962, *Chitin media for selective isolation and culture of actinomycetes,* Phytopathology, 52: 317-323

McLachlan A., Jarmillo E., 1995, *Zonation on sandy beaches*, Oceanogr. Mar. Ecol. Ann. Rev., 33: 305-335

Malam T., Raberg S., Fell T., Carlson P., 2004, *Effects by beaches cleaning on litoral water quality microbial food web and macro faunal biodiversity,* Est. Coast. Shelf Sci., 60: 339-347

Mallet C., Debroas D., 1999, *Relations between organic matter and bacterial proteolytic activity in sediment surface layers of a eutrophic lake (Lake Aydat, Puy de Dôme, France),* Arch. Hydrobiol., 39: 145-156

Martinez, J., Azam F., 1993, *Periplasmic aminopeptidase and alkaline phosphatase activities in a marine bacterium: implications for substrate processing in the sea,* Mar. Ecol. Prog. Ser., 92: 89-97

Martinez J., Smith D.C., Steward D.F., Azam F., 1996, *Variability in ectohydrolytic enzyme actives of pelagic marine bacteria and its significance for substrate processing in the sea*, Aqua. Microbial Ecol., 10: 223- 229

Misic C., Harriague A.C., 2007, *Enzymatic activity and organic substrates on sandy beach of the Ligurian Sea (NW Mediterranean) influenced by anthropogenic pressure*, Aqua. Microbial. Ecol., 47: 239-251

Montagna P.A., 1982, *Sampling design and enumeration statistics for bacteria extracted from marine sediments,* Appl. Environ. Microbiol., 4: 1366-1372

Mudryk Z., Donderski W., 1997, *The occurrence of heterotrophic bacteria decomposing some macromolecular compounds in shallow estuarine lakes,* Hydrobiologia, 342/343: 71-78

Mudryk Z., Donderski W., Skórczewski P., Walczak M., 1999, *Neustonic and planktonic bacteria isolated from a brackish lake Gardno,* Pol. Arch. Hydrobiol., 46: 121-129

Mudryk Z., Podgórska B., Ameryk A., 2001, *Bacteriological characterisation of a Baltic sandy beach in summer*, Ecohydrol. & Hydrobiol., 4: 503-509

Mudryk. Z., Podgórska B., 2006, *Enzymatic activity bacterial strains isolated from marine beach,* Pol. J. Ecol., 15: 441 - 448

Mudryk Z., Podgórska B., 2007, *Culturable microorganisms in sandy beaches in south Baltic Sea*, Pol. J. Ecol., 55: 221-231

Nair S., Bharathi L., 1980, *Heterotrophic bacterial population in tropical sandy beaches,* Mahas. Bull. Nat. Inst. of Oceanogr., 13: 261-267

Newell S.Y., Fallon R.D., 1982, *Bacterial productivity in the water column and sediments of the Georgia (USA) coastal zone estimates via*

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direct counting and parallel measurements of thymidine incorporation, Mar. Ecol., 8: 33-46

Novitsky J.A., MacSween M.C., 1989, *Microbiology of a high energy beach sediment: evidence for an active and growing community*, Mar. Ecol. Prog. Ser., 52: 71-75

Olańczuk - Neyman K., Jankowska K., 1998, *Bacteriological investigations of the sandy beach ecosystem in Sopot,* Oceanologia, 40: 137-151

Patel A.B., Fukami K., Nishijama T., 2000, *Regulation of seasonal variability of aminopeptidase activities in surface and bottom waters of Uranouchi Inlet, Japan,* Aqua. Microbiol. Ecol., 21: 139- 147

Piechocka A., 2010, *Dynamic concentration of carbohydrates and lipids in sand beach of diffrent anthropopressure*, Master's thesis, AP Słupsk pp. 60

Podgórska B., Mudryk Z., 2003, *Distribution and enzymatic activity of heterotrophic bacteria decomposing selected macromolecular compounds in a Baltic Sea beach,* Estuar. Coast. Shelf Sci., 56: 539-546

Podgórska B., Mudryk Z., 2007, *Physiological properties of bacteria inhabiting polluted and unpolluted marine sandy beaches (Southern Baltic Sea)*, Pol. J. Ecol., 55: 15-26

Podgórska B., Mudryk Z., Skórczewski P., 2008, *Abundance and production of bacteria in a marine beach (southern Baltic Sea) in summer,* Pol. J. Ecol., 56: 405-414

Pugh K.B., Andrews A.R., Gibbs C.F., Davis S.J., Floodgate G.D., 1974, *Some physical, chemical and microbiological characteristics of two beaches of Anglesey,* J. Exp. Mar. Biol. Ecol., 15: 305-333

Rodil I.F., Lastra M., 2004, *Environmental factors affecting benthic macrofauna along a gradient of intermediate sandy beches in northern Spain,* Estuar. Coast. Shelf Sci., 61: 37-44.

Rodriguez J.G., Lastra M., Lopez J., 2003, *Meiofauna distribution along a gradient of sandy beaches,* Estuar. Coast. Shelf Sci., 58: 63-69

Uraban - Malinga B., Opaliński K.W., 1999, *Vertical zonation of the total, biotic and abiotic oxygen consumption in a Baltic sandy beach,* Oceanol. Stud., 28: 85-96

Uraban - Malinga B., Opaliński K.W., 2001, *Interstitial community oxygen consumption in a Baltic sandy beaches: horizontal zonation*, Oceanologia, 43: 455-468

Wehr J.D., Petersen J., Findlay S., 1999, *Influence of three contrasting detritial carbon sources on planktonic bacterial metabolism in a mesotrophic lake,* Microbiol. Ecol., 37: 23-35

Worm J., Jensen L.E., Hansen T.S., Sondergaard M., Nybroe O., 2000, *Interactions between proteolytic and non-proteolytic Pseudomonas fluorescens affect protein degradation in a model community*, FEMS Microbiol. Ecol., 32: 103-109

Yamamoto N., Lopez G., 1985*, Bacterial abundance in relation to surface area and organic content of marine sediments*, J. Exp. Mar. Biol. Ecol., 90: 209-220

Zawadzka, E., 1996, *Litho - morphodynamics in the vicinity of small ports of the Polish Central Coast,* [in:] *Partnership of the Coastal Management,* Eds. Taussik J., Mitchel J., Samara, Publ. Limited, Cardigan GB. pp. 353-360