Interstitial community oxygen consumption in a Baltic sandy beach: horizontal zonation

OCEANOLOGIA, 43 (4), 2001.
pp. 455–468.

KEYWORDS
Baltic Sea
Sediment oxygen consumption
Interstitial community
Carbon requirements
Sandy beach

Barbara Urban-Malinga*
Krzysztof W. Opaliński
Institute of Ecology,
Polish Academy of Sciences,
Dziekanów Leśny, PL–05–092 Łomianki, Poland

*address for correspondence:
Institute of Oceanology,
Polish Academy of Sciences,
Powstańców Warszawy 55, PL–81–712 Sopot, Poland;
e-mail: basiam@iopan.gda.pl

Manuscript received 2 July 2001, reviewed 18 July 2001, accepted 5 October 2001.

Abstract

The oxygen consumption of a sandy beach interstitial community was determined on four occasions (January, May, August, October) on the Gulf of Gdańsk (southern Baltic Sea). The study was carried out at four locations on the beach slope (littoral, waterline, splash zone and middle beach).

Oxygen consumption varied from 158–159 cm^3 O_2 m^{-2} h^{-1} at the underwater site and waterline to 20–36 cm^3 O_2 m^{-2} h^{-1} in the middle beach. According to these data, interstitial organisms are able to utilize from 206 to 1641 mg of organic carbon per square metre per day.

In general, metabolic activity decreased gradually from the waterline towards the middle beach, and a significant correlation was found between oxygen consumption and sediment water content. Changes in oxygen consumption on the beach slope were statistically significant.

1. Introduction

Marine sandy beaches receive a variety of organic materials from the sea: macrophyte wracks, dead animals, and dissolved and particulate organics are flushed into the sand by waves. Beaches process these organic materials through their interstices and return nutrients to the sea (McLachlan & Romer 1990, McLachlan & Turner 1994). These important functions are driven by the physical process of water filtration through the sand body of the beach: molecules and suspended particles of organic matter are adsorbed on to the sand grain surfaces. Such concentration of this material by sand allows its further utilization by interstitial organisms (McIntyre et al. 1970), so in most beaches the interstitial system functions as a biological filter that mineralizes organic material and thus cleanses the surf waters (McLachlan 1990, McLachlan & Turner 1994). As a consequence, despite low organic matter concentrations and low standing stocks of reactants sandy beaches may be, like other types of marine permeable sediments, biogeochemically active and play an important part in the cycling of carbon and other elements.

Almost all investigations on the metabolism and functioning of sandy beaches have been performed on exposed, oceanic, tidal beaches (McIntyre et al. 1970, Munro et al. 1978, Dye 1979, 1980, 1981, McLachlan et al. 1981, Malan & McLachlan 1991, Heymans & McLachlan 1996). In this respect, non-tidal beaches have been rather neglected. The purpose of the present study was to estimate the metabolic activity and carbon requirements of the interstitial community associated with a Baltic sandy beach system and to assess the role of a sandy beach in the energy flow and organic matter turnover in the coastal ecosystem of the Baltic Sea – a non-tidal, semi-enclosed marine area characterized by high levels of pollution and eutrophication (Wulff et al. 2001).

The various beach slope zones differ in terms of physical parameters (Jansson 1967a, b, c, 1968), bacteria (Olańczuk-Neyman & Jankowska 1998), and meiofaunal composition and abundance (Jansson 1968, Kotwicki – personal communication). The investigation by Fenchel (1969) on sandy sediment respiration was limited to the Baltic littoral zone only. This study aims to assess the potential diversity of metabolic activity on the horizontal beach profile.

2. Materials and methods

Study site and sampling stations

The sediment for measurements was collected on four occasions (January, May, August and October) on the sandy beach at Sopot on the Gulf of

Gdańsk – one of the open bays of the Baltic (Fig. 1). Although the average water salinity in the Gulf of Gdańsk ranges between 7 and 7.5 PSU, values below 7 PSU are nevertheless common in the coastal zone (Cyberska 1990). This particular beach has a slope of 7 degrees and a width of 46 m (Szałucha 1998). In general, fine and medium-grained sands are predominant at this site (Szałucha 1998, Jędrzejczak 1999). Poorly sorted sands of large particle diameter up to 0.8 mm are common only along the waterline (Jędrzejczak 1999), where fine sand makes up 4.5% dry weight (Szałucha 1998). Both the sorting index and the percentage of fines (up to 67% dry wt.) increase on the beach profile towards the dune.

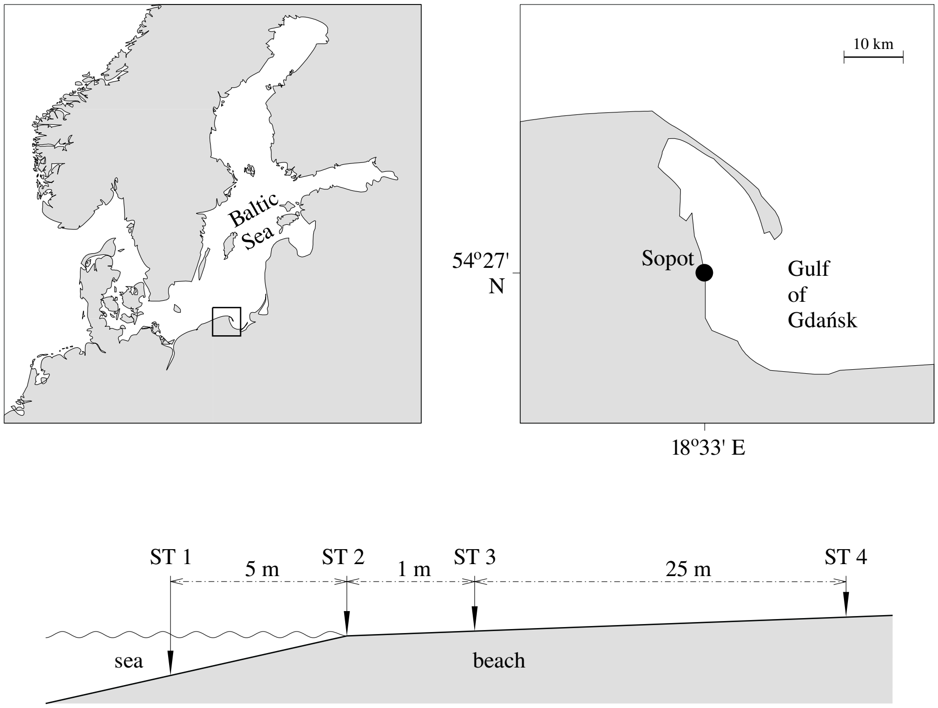

Fig. 1. Map of the study area: location of the stations on the beach profile

Nematodes, Turbellarians and Gastrotrichs are dominant in the meiofaunal community, reaching average densities of 900 individuals per 10 cm^2 (Kotwicki pers. communication); the average bacterial abundance is 10^8 cells per gram dry sand (Jankowska pers. communication). These values lie within the ranges typical of sandy beaches.

Sediment for oxygen consumption measurements was sampled along a single transect line at four stations on the beach profile: Station 1

– underwater station, 0.5–1 m water depth; Station 2 – at the waterline; Station 3 – in the splash zone; Station 4 – in the middle of the beach (Fig. 1).

Five sediment cores 6 cm in length were taken at random at each station with a hand core sampler 10 cm^2 in diameter. At Station 4 a surface layer of dry sand (approximately 2 cm) was discarded. Sediment cores were immediately transported to the laboratory (located about 15 minutes away from the study site), where oxygen consumption measurements were carried out.

Sub-samples were taken from the cores for organic matter and water content determination. The organic matter content in the sediment was determined by loss of weight on ignition. Water content was determined by loss of weight after dessication of the sediment.

Oxygen consumption measurements

Once the sediment was in the laboratory, oxygen consumption was measured immediately by means of the closed vessel technique; it was also measured in intact cores.

In the closed vessel technique, the sediment (approx. 50 cm^3) was transferred to 250 cm^3 conical flasks, which were filled with filtered water, tightly stoppered, immersed in a water bath and incubated at the temperature of the ambient sea water for 2 hours in the dark.

Five repetitions were made for each station. The oxygen content in the overlying water was measured with a WTW OXI 196 oxygen electrode after two hours of incubation. Oxygen consumption was defined as the decrease in oxygen content compared with the oxygen content in the control bottles containing filtered water only (no sediment).

On two occasions (August and October) oxygen consumption was also measured in intact cores. Five sediment cores 6 cm long were taken intact from each study site in PVC tubes 20 cm in length and 20 cm^2 in cross-section. The tubes were then filled with filtered sea water, sealed with rubber stoppers and incubated intact. The oxygen concentration in the overlying water was measured after 2 hours of incubation.

Energy calculations

Interstitial carbon requirements were estimated with a respiratory quotient (RQ) of 0.8 (Patching & Raine 1983). On this basis, 1 cm^3 of respired O_2 translates into 0.43 mg of utilized organic carbon. Respiration was converted into energy consumption units using an oxycaloric coefficient of 4.8 (Grodziński et al. 1975).

Statistical analysis

The non-parametric Mann-Whitney U-test was used to compare oxygen consumption results obtained by means of the closed vessels method with the results of the measurement in intact cores. Two-way ANOVA and post-hoc tests were used to examine differences in O_2 parameters among stations and to detect changes in oxygen consumption over time.

3. Results

The water content in the sediment ranged between 5% (ST 4) and 22% (ST 1) wet wt., and a high significant correlation was found between water content and distance of the station from the waterline ($r = 0.998$; $p < 0.05$) (Fig. 2).

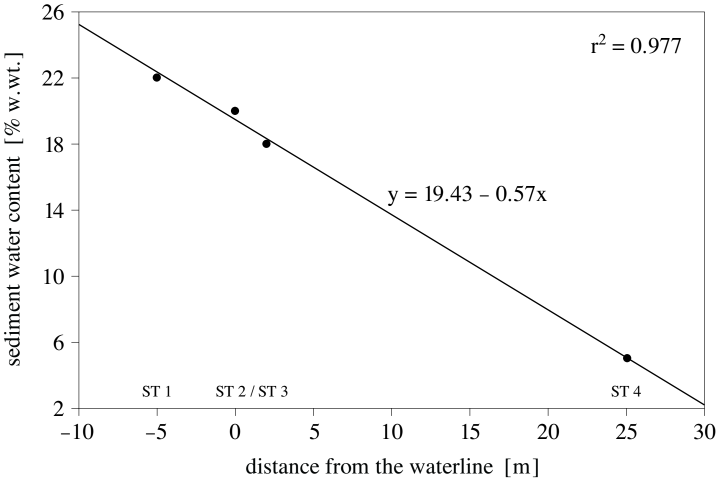

Fig. 2. Relation between sediment water content and distance of the study site from the waterline (zero point)

The organic matter content of the sandy beach ranged between 0.07–0.15% (ST 4) and 1.61% dry wt. (ST 1). The highest organic matter concentrations were found in January (Table 1).

The decrease in oxygen content in water following incubation varied between 5.0 and 22% of the initial concentration, with a mean of 10%. The oxygen consumption ranged between 158–159 cm^3 O_2 m^{-2} h^{-1} at the underwater site and at the waterline in August, and 20–36 cm^3 O_2 m^{-2} h^{-1} in the middle beach (Table 2). In general, oxygen uptake decreased gradually from the waterline towards the middle beach (Fig. 3). In January and

Table 1. Sediment organic matter concentration on a sandy beach profile

Month	Station	Concentration [% dry wt.]	Concentration [g dry wt. m^{-2}]
May	1	0.59	1459
	2	0.15	294
	3	0.14	286
	4	0.10	326
August	1	0.15	274
	2	0.43	828
	3	0.19	325
	4	0.07	119
October	1	0.27	433
	2	0.18	340
	3	0.73	1972
	4	0.11	354
January	1	1.61	2947
	2	0.69	1626
	3	0.75	630
	4	0.15	443

Table 2. Oxygen consumption results expressed in sediment area and sediment volume units

Month	Temperature [°C]	Station	O_2 consumption [cm^3 O_2 m^{-2} h^{-1}]	O_2 consumption [mm^3 O_2 cm^{-3} h^{-1}]
May	15	1	60 ± 3	0.55
		2	141 ± 9	1.28
		3	80 ± 7	0.73
		4	22 ± 1	0.20
August	22	1	158 ±10	1.44
		2	159 ± 5	1.45
		3	141 ± 6	1.28
		4	30 ± 3	0.27
October	9	1	36 ± 4	0.33
		2	97 ± 8	0.88
		3	51 ± 5	0.46
		4	36 ± 3	0.33
January	4	1	61 ± 6	0.55
		2	24 ± 2	0.22
		3	46 ± 4	0.42
		4	20 ± 3	0.18

August oxygen uptake at the underwater site was higher than at the other stations; in May and October it was highest at the waterline and in the splash zone.

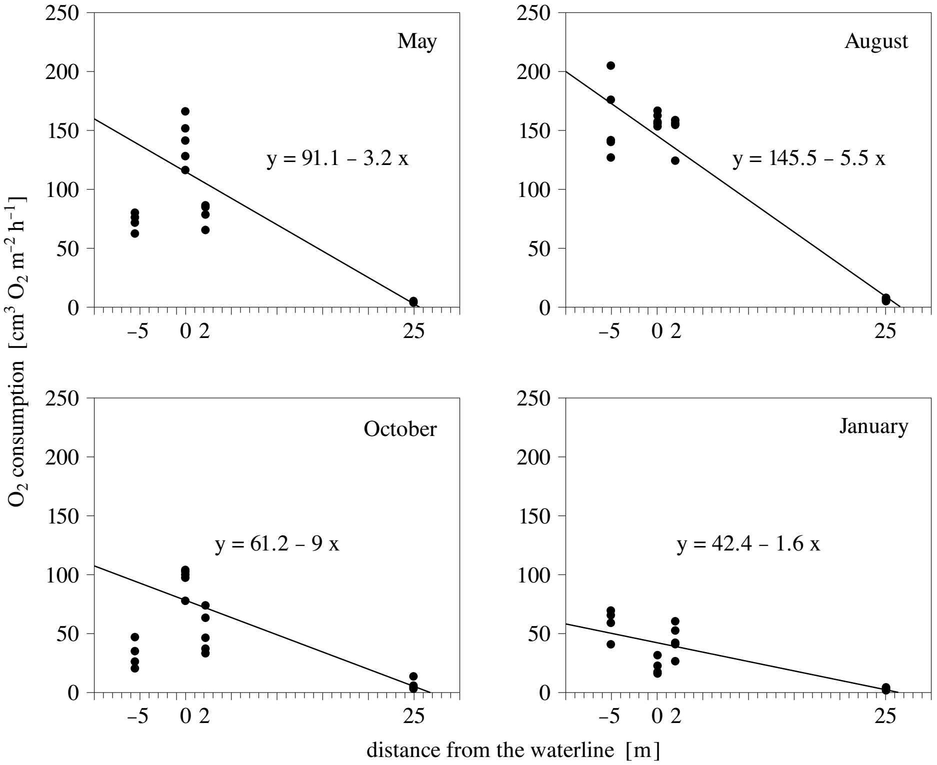

Fig. 3. Oxygen consumption on the sandy beach slope. Distances are given in relation to the waterline (zero point)

A correlation was found between oxygen consumption and sediment water content (distance from the waterline) ($r = 0.52$; $p < 0.05$).

The energetic equivalents of oxygen consumption are presented in Table 3. According to these calculations, interstitial organisms are able to utilize from 206 to 1641 mg of organic carbon per square metre per day.

Analysis of variance (Table 4) revealed significant differences in oxygen consumption on the beach slope in every month of the study. However, the results of post-hoc tests showed that there was no statistical difference between the results noted at stations 1 and 3, and at stations 2 and 3.

Changes in oxygen uptake over time were significant (Table 4). Metabolic activity was highest in August (Fig. 3).

Table 3. Energy parameters of the beach studied

Month	Station	Energy consumption [kcal m^{-2} d^{-1}]	Org. C utilized [mg C m^{-2} d^{-1}]
May	1	6.9	619
	2	16.2	1455
	3	9.2	826
	4	2.5	227
August	1	18.2	1631
	2	18.3	1641
	3	16.2	1455
	4	3.5	310
October	1	4.1	372
	2	11.2	1001
	3	5.9	526
	4	4.1	372
January	1	7.0	630
	2	2.8	248
	3	5.3	475
	4	2.3	206

Table 4. Results of two-way ANOVA analysis of oxygen consumption and two variables: sediment water content and temperature

Source of variation	df effect	MS effect	df error	MS error	F	p
water content	3	5.7	63	0.63	90.9	$p < 0.001$
temperature	3	4.3	63	0.63	69.1	$p < 0.001$
interaction	9	1.0	63	0.63	16.0	n.s.

n.s. – not significant.

Table 5. Comparison between the methods used – results of the Mann-Whitney U-test

Station	U effect	p
1	5	n.s.
2	9	n.s.
3	0	$p < 0.05$
4	4	n.s.

n.s. – not significant.

A significant linear correlation was found between the oxygen consumption rate and water temperature ($r = 0.63$; $p < 0.05$), and the sediment organic matter content ($r = -0.5$; $p < 0.05$).

Apart from Station 3, the results of the Mann-Whitney U-test did not indicate a significant difference in oxygen uptake obtained by the two methods used (Table 5).

4. Discussion

Comparisons of oxygen consumption results between the available data are often limited owing to the variety of methods used and, in many cases, because of the lack of information on the important parameters of the beach studied. Hence, such comparisons should be undertaken with cautious. Results from beaches in South Africa – by far the most frequently investigated region – are relatively low in comparison to our results. Dye (1981) noted in intact cores an oxygen uptake in the range 13.5–17.6 cm^3 O_2 m^{-2} h^{-1}, McLachlan et al. (1981) recorded an oxygen consumption of 13.0–55.7 cm^3 O_2 m^{-2} h^{-1}. Carbon requirements, estimated at 137 mg C m^{-2} d^{-1} in Scotland (McIntyre et al. 1970), 219 mg C m^{-2} d^{-1} in South Africa (Heymans & McLachlan 1996) and 450 mg C m^{-2} d^{-1} on a tropical beach in India (Munro et al. 1978), are also lower than in this study. However, it should be stressed that those studies were carried out on exposed, tidal beaches. The fact is that almost all investigations in tidal environments are made during low tide. Dye (1980) studied the tide-induced fluctuations in biological oxygen demand in tidal beaches and showed that tidal level and dessication cause large fluctuations in the biotic oxidation rate of over two orders of magnitude and, as a consequence, measurements of oxygen consumption made during low tide in such areas must surely be underestimated.

The only investigation of oxygen uptake in a Baltic non-tidal sandy beach is by Fenchel (1969). That study was carried out in sandy sediments under 20–30 cm of water at Asko. Respiration ranged between 492 and 508 mg C m^{-2} d^{-1}. As this author stressed, the locality was sheltered on all sides by rocks, and the oxygen content and 'oxygen availability' close to the sediment surface were already low. As a matter of fact, we have no data relating to Eh- and O_2-profiles in the sands that we studied. However, a comparison of the physical parameters of these two beaches shows that the sandy beach at Sopot is much more exposed to wave action and water flushing and is thus much better oxygenated than the beach studied by Fenchel. Therein could lie the main reason for the higher oxygen uptake results at Sopot.

Compared to the relatively low microphytobenthos primary production (gross PP 150 mg C m^{-2} d^{-1}) (Malinga & Wiktor – in preparation) – the only source of autochthonous organic matter in this system, the high organic matter utilization rates and high carbon requirements recorded in the Sopot beach (Table 3) reflect the considerable potential of a sandy beach in processing allochthonous organic materials. Neither the volume of water filtered by the sand body of the Sopot beach nor the amount of organic material introduced by waves into the interstitial system are known. However, considering that the DOM pool in the Baltic is about three to four times greater than that in the oceans (Wulff et al. 2001) and that POC values in the Gulf of Gdańsk in the vicinity of rivers estuaries may be as high as 3.03 g m^{-3} (Maksymowska 1998), one could risk the suggestion that in a Baltic sandy beach with high organic levels the interstitial activity is also high. According to a rough estimate by Urban-Malinga & Opaliński (1999), as much as 1105 mg of organic C m^{-2} could be introduced daily into the interstitial system of the beach by wave action. In view of the results of the present study (Table 3), this quantity may be wholly or to a large extent metabolized by the interstitial beach organisms.

A number of factors are subject to variation on the beach slope: grain size, water content, oxygen conditions, salinity and temperature. All these aspects have been studied in Baltic sandy beaches by Fenchel et al. (1967) and Jansson (1967a, b, c, 1968), who demonstrated that the range of wave impact is the most important factor determining physical conditions on the beach slope. Sediment grain size, porosity, permeability, the volume of the interstitial system, oxygen diffusion rate and 'oxygen availability' are highest at the waterline and their values decline landwards (Jansson 1968). Jędrzejczak (1999) reported on organic matter degradation rates in the Sopot beach, the highest rates being noted at the waterline and splash zone and the lowest at the high-beach stations. This is in agreement with the results of the present study, which show that metabolic activity declines towards the middle beach. The linear functions explaining this falling tendency, as shown in Fig. 3, aim to describe trends rather than the mathematical relationship; the latter would require more data and more sampling points on the beach slope.

The limited interstitial water flow in underwater sediments in comparison to the upper beach, where water is constantly filtered (McLachlan 1990), could be the main reason for the lower rates of oxygen uptake noted at the littoral station than at the waterline (as in May, October and August), but as this study has shown, higher rates have also been noted there (as in January).

The average contents of sediment organic matter recorded in this study generally lie within the ranges typical of sandy beaches: 0.0–0.5% dry wt. (McLachlan 1990). The highest concentrations – up to 1.61% recorded in January – were probably due to lower organics processing rates during the cold period. The negative correlation between oxygen uptake and organic matter content may in part be explained by the positive correlation between oxygen uptake and temperature: low temperature is the reason for the low interstitial activity and the consequent low processing rate of organic matter; its content in the sediment is thus high.

According to our results, the functional diversity on the beach slope was statistically significant. The oxygen consumption was correlated with sediment water content ($r^2 = 0.25$). According to Jansson (1968), sediment water content is a key factor regulating fauna distribution in the interstitial system. Kotwicki (pers. communication) reported on changes in the meiofaunal biodiversity on the beach slope in Sopot. Olańczuk-Neyman & Jankowska (1998) found different functional communities of bacteria on the same beach profile. Taking these facts and the results of the present study into consideration, it seems tempting to find links between biodiversity and ecosystem processes on sandy beach slopes. This problem certainly requires further research.

5. Methods

There are a number of standard methods used for estimating sediment oxygen consumption in a variety of environments but none of them seems to be appropriate for such a dynamic environment as a sandy beach. Methods relying on the measurement of oxygen changes in the water overlying cores of sediment restrict the flow of oxygen to that supplied by diffusion only. Therefore, results from surface respirometers must surely be underestimated, as oxygen consumption can be measured only in the top few centimetres of the sediment and it is not possible to define the volume of substrate being analyzed. This is of great importance in a three-dimensional system such as a beach. McLachlan (1979) pointed out that such methods are inadequate in a sandy beach system, where oxygen penetrates deeply due to flushing rather than diffusion from the surface, so the true sediment activity may be underestimated. According to Dye (1983), results from experimental systems should likewise be treated with caution, because of the large variation in the water flow rates used, usually with little indication of the real environmental conditions. Nowadays, the approach used in such studies is to measure *in situ* oxygen microprofiles using microelectrodes and benthic lander technology. The use of microelectrodes to measure benthic photosynthesis and respiration allows resolution of rate processes on much finer temporal and spatial scales than is possible with other methods. Nonetheless, microelectrodes are problematic if the measured oxygen profile is unstable, or if the rates exclude infauna and burrow walls (Revsbech & Jorgensen 1983, Jorgensen & Revsbech 1989).

The method used in this study was connected with the disturbance of the sediment (sediment transfer to the respiratory vessels), which might have resulted in an overestimation of oxygen consumption. Dye (1979) studied the effect of the sediment disturbance on the biological oxygen demand and found that oxygen consumption in disturbed sediment rose gradually over time by up to 40% in comparison to undisturbed sediment after 24 hours of incubation; however, the increase within the first two hours of incubation was no greater than 12%. Our measurements were made immediately after the samples had been taken, so we assume that our results lie within the 12% error range.

Moreover, in view of the results of our comparative study done on intact cores, it may be suggested that in such a dynamic environment as a sandy beach, where the mixing and movement of sand particles is a normal effect of wave action, such a disturbance is permissible.

Acknowledgements

The authors wish to express their thanks to all colleagues from the Department of Marine Ecology, the Institute of Oceanology PAS, for offering facilities, for helpful advice and for a pleasant working environment.

References

Cyberska B., 1990, *Water salinity in the Gdańsk Basin*, [in:] *The Gulf of Gdańsk*, A. Majewski (ed.), Wyd. Geol., 237–255, (in Polish).

Dye A. H., 1979, *Measurement of biological oxygen demand in sandy beaches*, S. Afr. J. Zool., 14 (2), 55–60.

Dye A. H., 1980, *Tidal fluctuations in biological oxygen demand in exposed sandy beaches*, Estuar. Coast. Mar. Sci., 11 (1)–(8).

Dye A. H., 1981, *A study of benthic oxygen consumption on exposed sandy beaches*, Estuar. Coast. Shelf Sci., 13, 671–680.

Dye A. H., 1983, *A synopsis of community respiration studies on exposed sandy beaches*, [in:] *Sandy beaches as ecosystems*, A. McLachlan, T. Erasmus & W. Junk (eds.), The Hague, 693–698.

Fenchel T., Jansson B. O., Thun W., 1967, *Vertical and horizontal distribution of the metazoan microfauna and of some physical factors in a sandy beach in the northern part of the Oresund*, Ophelia, 4, 227–243.

Fenchel T., 1969, *The ecology of marine microbenthos. IV Structure and function of the benthic ecosystem, its chemical and physical factors and the microfauna communities with special reference to the Ciliated Protozoa*, Ophelia, 6, 1–182.

Grodziński W., Klekowski R. Z., Duncan A., 1975, *Methods for ecological bioenergetics*, Blackwell Sci. Publ., IBP Handbook, 24 pp.

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

Jansson B. O., 1967a, *The significance of grain size and pore water content for the interstitial fauna of sandy beaches*, Oikos, 18, 311–322.

Jansson B. O., 1967b, *The availability of oxygen for the interstitial fauna of sandy beaches*, J. Exp. Mar. Biol. Ecol., 1, 123–143.

Jansson B. O., 1967c, *Diurnal and annual variations of temperature and salinity of interstitial water in sandy beaches*, Ophelia, 4, 173–201.

Jansson B. O., 1968, *Quantitative and experimental studies of the interstitial fauna in four Swedish sandy beaches*, Ophelia, 5, 1–71.

Jędrzejczak M. F., 1999, *The degradation of stranded carrion on a Baltic Sea sandy beach*, Oceanol. Stud., 28 (3)–(4), 109–141.

Jorgensen B. B., Revsbech N. P., 1989, *Oxygen uptake, bacterial distribution and carbon-nitrogen-sulfur cycling in sediments from the Baltic Sea-North Sea transition*, Ophelia, 31 (1), 29–49.

Maksymowska D., 1998, *The degradation of organic matter in the water and bottom sediments of the Gulf of Gdańsk*, Ph. D. thesis, Uniw. Gdańsk, (in Polish).

Malan D. E., McLachlan A., 1991, *In situ benthic oxygen fluxes in a nearshore coastal marine system: a new approach to quantify the effect of wave action*, Mar. Ecol. Prog. Ser., 73, 69–81.

McIntyre A. D., Munro A. L. S., Steele J. H., 1970, *Energy flow in a sand ecosystem*, [in:] *Marine food chains*, J. H. Steele (ed.), Oliver and Boyd, Edinburgh, 19–31.

McLachlan A., 1979, *Volumes of sea water filtered through eastern Cape sandy beaches*, S. Afr. J. Sci., 75, 75–79.

McLachlan A., 1990, *Sandy beach ecosystems*, [in:] *Ecology of sandy shores*, A. C. Brown & A. McLachlan (eds.), Elsevier, Amsterdam–Oxford–New York–Tokyo, 197–226.

McLachlan A., Romer G., 1990, *Trophic relationships in a high energy beach and surf zone ecosystem*, [in:] Proc. 24 Europ. Mar. Biol. Symp., M. Barnes & R. N. Gibson (eds.), Aberdeen Univ. Press, 356–372.

McLachlan A., Turner I., 1994, *The interstitial environment of sandy beaches*, P. S. Z. N 1: Mar. Ecol., 15 (3)–(4), 177–211.

McLachlan A., Dye A. H., Harty B., 1981, *Simulation of the interstitial system of exposed sandy beaches*, Estuar. Coast. Shelf Sci., 12, 267–278.

Munro A. L. S., Wells J. B. J., McIntyre A. D., 1978, *Energy flow in the flora and meiofauna of sandy beaches*, Proc. Roy. Soc. Edin., 76, 297–315.

Olańczuk-Neyman K., Jankowska K., 1998, *Bacteriological investigation of the sandy beach ecosystem in Sopot*, Oceanology, 40 (2), 137–151.

Patching J. W., Raine R. C. T., 1983, *Benthic metabolism and the supply of organic material to the sea-bed*, [in:] *Experimental biology at sea*, A. G. MacDonald & I. G. Priede (eds.), Acad. Press, London, 311–345.

Revsbech N. P., Jorgensen B. B., 1983, *Photosynthesis of benthic microflora measured with high spatial resolution by the oxygen microprofile method: Capabilities and limitations of the method*, Limnol. Oceanogr., 28 (4), 749–756.

Szałucha J. M., 1998, *Seasonal variations in grain size of contemporary sediments in a sandy littoral ecosystem*, M.Sc. thesis, Uniw. Szczecin, (in Polish).

Urban-Malinga B., Opaliński K. W., 1999, *Vertical zonation of the total, biotic and abiotic oxygen consumption in a Baltic sandy beach*, Oceanol. Stud., 28 (3)–(4), 85–96.

Wulff F., Rahm L., Larsson P., 2001, *Introduction*, [in:] *A systems analysis of the Baltic Sea*, F. Wulff, L. Rahm & P. Larsson (eds.), Ecol. Stud., Springer, 148, 1–17.