



Island Biogeography Theory in Coastal Ecosystem Protection: The Baltic Sandy Shores

Lech Kotwicki, Jan Marcin Węśławski, Katarzyna Grzelak,
Józef Wiktor & Marek Zajączkowski

Institute of Oceanology - Polish Academy of Sciences, Poland

Abstract

The authors present data on Baltic sandy shores biodiversity and ecology. The importance of littoral benthic assemblages for coastal waters ecology is discussed, with emphasis on meiofauna and macrofauna. The structure and function of sandy assemblages is presented according to the methodology proposed by McLachlan for sandy shores and adopted from the island biogeography theory of Wilson and McArthur.

Approximately 20 % of the Polish coastline has lost its naturalness due to the direct influence of constructions of various types of breakwaters, while a further 40 % is indirectly influenced by managing activities. The management of sandy shores rely partly on belief, that particular beach units are interconnected, due to the free larval drift (DEFEO & MCLACHLAN 2005). This shall be the case of Polish Baltic Sea coast, long, continuous line of exposed sandy beach, for almost 500 km. According to presented data, the authors suggest that Polish coastline can not be considered as one ecosystem. Single beach is unique and highly valuable and specific action in one coastal place could have significant consequences for the remaining coastline.

1 Introduction

Sandy shores, exposed for sea waves are by definition poor in species (McLachlan & Brown 2006). Worldwide, there is no more than some 100 marine macrofauna species adapted to this specific environment, and single beach in any locality rarely exceeds 20 species (McLachlan & Brown 2006). The meiofauna is more diverse, counts probably over 1000 sandy beach species worldwide (McLachlan & Brown 2006). The latitudinal cline is less clear, although there are only few locations where meiofauna was studied sufficiently detailed to species level. The best studied taxon are Nematoda, and survey from European beaches – from warm Mediterranean, temperate North Sea and cold Baltic beaches shown similar species count – about 60 species at each site (Gheskiere et al. 2005). The rough estimation of meiofauna richness (based on higher taxa count) along latitudinal gradient shows increase in temperate areas, since in the tropics, the meiofauna is partly replaced by larval and juvenile forms of macrofauna species (Kotwicki et al. 2005).

To date, the main task of managing the sandy coasts of Poland has been to fight erosion in order to protect and preserve roads and public and private housing. This has been achieved by beach nourishment with sand and the construction of various types of breakwaters. Approximately 20 % of the Polish coastline has lost its naturalness due to the direct influence of constructions, while a further 40 % is indirectly influenced (Zeidler et al. 1992). Developers are very keen to move into coastal areas since traditionally locations on the waterfront are highly priced.

The recommended by EU directives and HELCOM ecosystem approach to nature resources management takes into consideration the existence of complex biological and physical interactions and the course of natural processes and their consequences. This is fundamentally different from the “sectoral principle”, where biological, chemical, and physical variables are measured independently and qualified into indices. One of the key concepts in ecosystem management is the island biogeography theory developed by Wilson & MacArthur (1967, reprinted 2001). Recently this theory

has been successfully adapted to the sandy beach biodiversity analyses, with important implications for management practices (McLachlan & Dorvlo 2007). Authors have analysed over 150 marine sandy beaches worldwide and the key conclusion is, that the width of the beach is a most important factor determining the richness of its fauna. The management of sandy shores rely partly on belief, that particular beach units are interconnected, due to the free larval drift (Defeo & McLachlan 2005). This shall be the case of Polish Baltic Sea coast, long, continuous line of exposed sandy beach, for almost 500 km. On the other hand, this coast varies with the sediment type and beach width – two environmental characters of key importance for meiofauna occurrence (Giere 1983). Our study was performed to check the McLachlan and Dorvlo 2007, hypothesis, that the beach may be assessed as the island, with width as main factor related to species richness. The consequence of accepting or rejecting this hypothesis is of importance for management – if the metapopulation models and concept of continuity are correct, than specific action in one coastal place are of little consequence for the remaining coastline. In the second case, each beach unit is unique, and variability of shoreline width provides the changes in biodiversity.

2 Location and Methodology

The exposed sandy shore of the Polish coastline stretches almost 500 km and is interrupted by short lengths of moraine clay cliffs in only a few places (figure 1). The dominant form of the 500 km of Polish coastline is the sandy beach, which varies in width from less than five to more than 100 meters. The area of this narrow belt measures less than 20 km² and is of prime importance for recreation, tourism, and coastal development.

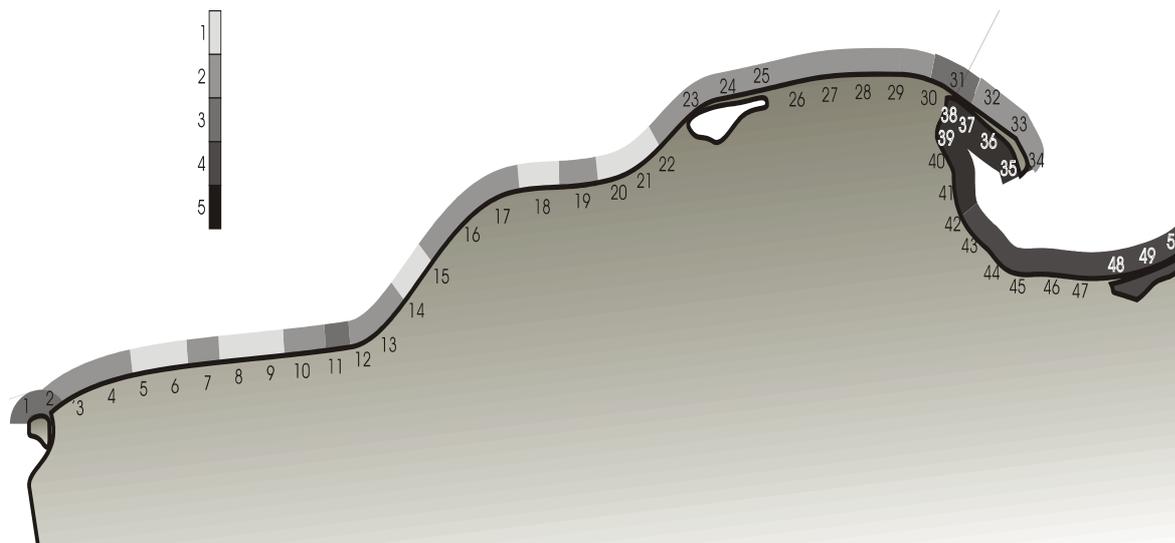


Figure 1: Physical characteristics of Polish coastline. Based on the Euclidean distance for beach width, exposure, mean grain size, maximal annual wave height – all parameters measured on 50 stations, 10 km apart. where 1 – narrow, abrasive beaches 2 – wide, dune beaches 3 – eroding, narrow, stony beaches, 4 – lagoon, dissipative, wide beaches 5 – Bay of Puck, sheltered beaches

For the present analyses the material collected in August – September along the Polish coastline during several projects performed between 1996 and 2006 was used. Most of the data have been published in the other context (e.g. Haque et al. 1996, 1997a, 1997b, Kotwicki 1997).

Beach parameters - the width of the beach have been measured from the lowest water line, to the highest water mark (driftwood), in effect indicating the area that might be occasionally inundated by storms. Slope of the beach was measured with the water weight (level) and measuring line.

Macrofauna sampling – on dry land macrofauna (no insects included) was collected from the series of 20x20 cm holes dug 20 cm deep into the sand, 2 rows of holes 1 m apart were made along the beach profile. Macrofauna from the inundated part of the beach was collected with 20 cm diameter perplex corer, inserted 20 cm deep into the sediment at 0.5 m depth. Three cores were taken at each of the studied localities. Samples were washed on 0.5 mm screen and preserved in 4 % formaldehyde. All macrofauna collections were performed in summer.

Meiofauna sampling was performed with perplex cylinders of 10 cm² area, triplicate cores of 5 cm depth were collected from the water line and 0.5 m depth. Sorting on 0.047 mm screen and identification to higher taxa was performed.

Statistical analyses - project package PRIMER (version 2005) have been used, with Bray Curtis similarity index calculated on square root transformed data for biological data, and Euclidean distance for physical parameters.

3 Results and discussion

Sandy beaches are frequently seen as ecological deserts and have attracted little ecological research. This is unfortunate because: they are home to numerous species, they have important linkages with adjacent ecosystem, they have large socio-economic values and they are vulnerable to increasing human pressures including climate changes (Węśławski et al. 2000) (table 1).

Table 1: Examples of valued goods and services of sandy shores in Poland (Węśławski et al. 2000, modified)

Type of goods or services	Method of valuation	Comments
Water filtration – biofiltering capacity of sandy shores	Replacement Costs Method	Renewable
Nursery for flatfish and other commercial species	Replacement Costs Method	Renewable
Tourism and recreation	Travel Costs Method, Contingent Valuation Method	Renewable
Sand and gravel exploitation	Productivity Change Method	Non- renewable

There is a full array of living organisms from bacteria, fungi, microphytobenthos, and protozoa to extremely specialized metazoan on the beach. Hundreds of species inhabit sandy beaches but most of them are small (less than a few mm) and buried. They occupy interstitial spaces between sand grains and include over 600 species. These sandy beach dwellers exhibit remarkable physiological and behavioral adaptation to changing conditions. Basic characteristics of Polish Baltic coast (sandy beach as an ecosystem) for bathing water are presented in table 2 (after Węśławski et al. 2005).

The relationship between area and species richness is one of the most widely accepted and intensively studied in ecology. Recently the island biogeography theory developed by Wilson & McArthur (1967) has been successfully adapted to the sandy beach biodiversity analyses, with important implications for management practices. The key conclusion of McLachlan & Dorvlo (2007) is that the width of the beach is a most important factor determining the richness of its fauna. The present work suggests that designation of exposed sandy beaches as physically controlled (McLachlan 1988) does not explain their biological variability (figure 2).

Table 2: Sandy beach as an ecosystem – basic characteristics of Polish Baltic coast – bathing water- data from watermark line to 0.5 m depth. All data cited after the book by Węśławski et al. 2005.

Feature	Average value
Solar radiation	300 MJ/h
Primary production - microphytobenthos	55 g C/m ² /year
Allochthonous organic matter	400 g C/m ² /year
Bacterial biomass	1 g C/m ²
Meiofauna biomass – Grazers & detritus feeders	1 g C/m ²
Small carnivores biomass	0,1 g C/m ²
Carnivores	0.01 g C/m ²

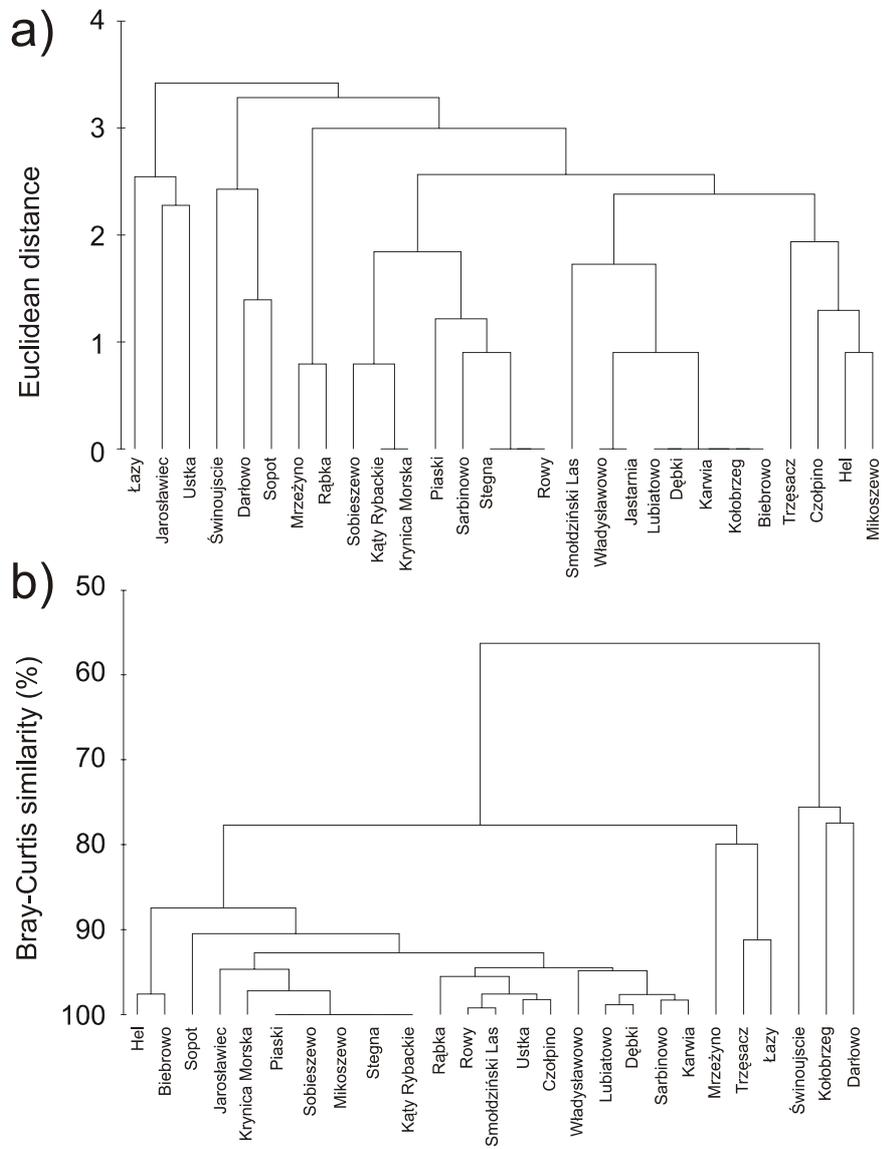


Figure 2: Similarity of the investigated beaches based on a) physical parameters, b) faunal assemblages

Although the present paper mainly relates physical factors to fauna distribution, some clear trends of niche segregation could be found. Community patterns and abundance in exposed sandy beaches have been assumed to be primarily controlled by specific responses to water percolation processes and sediment characteristics (McLachlan 1977, McLachlan et al. 1993). Exposed sandy beaches have been considered physically stressful environments, their faunal assemblages being best understood by observing responses to abiotic factors (Jaramillo & McLachlan 1993). The 'biotic factors in stable environment' theory of Hulings and Gray (1976) stated that biological interactions control fauna communities on atidal beaches, while on tidal beaches sediment characteristics are the major controlling factors.

Table 3: Main physical and biological factors of the Polish Baltic shore (27 sites), where beach width: A - narrow, B - intermediate, C - wide; beach slope: I - below 2 %, II - 2-4 %, III - over 5 %; exposure: 1 - less, 2 - more

Locality (coast unit)	beach width	beach slope	exposure	mean grain size (ϕ)	meiofauna biomass [g ww m ⁻²]	% of Nematoda in biomass	Macrofauna number of taxa
Świnoujście	C	I	1	1	1	6	4
Trzęsacz	B	II	2	1	2.91	29	2
Mrzeżyno	A	I	2	2.5	0.08	32	2
Kołobrzeg	B	I	2	2	3.98	9	2
Sarbinowo	B	II	1	1.5	1.13	83	2
Łazy	A	I	1	1	5.06	43	2
Darłowo	B	II	1	0.5	4.02	2	2
Jarosławiec	A	III	1	1	0.43	92	2
Ustka	A	II	1	2	0.96	70	2
Rowy	B	II	1	2	1	71	2
Smołdziński Las	B	II	1	2	1	72	2
Czołpino	B	II	2	2	1.1	73	2
Rąbka	B	I	2	2	1.2	74	2
Łeba	C	I	2	2	1.24	75	5
Biebrowo	B	I	2	2	2.01	60	2
Lubiatowo	B	I	2	2	1.98	82	2
Dębki	B	I	2	2	2.24	85	2
Karwia	B	I	2	2	1.37	86	2
Władysławowo	B	I	2	1.5	0.76	91	2
Hel	B	II	1	1	1.5	85	5
Sopot	C	I	1	2.5	0.7	85	2
Sobieszewo	C	I	1	2	0.7	85	2
Jantar	B	II	1	2	0.7	85	2
Sztutowo	B	I	1	2	0.7	85	2
Kąty Rybackie	C	I	1	2	0.7	85	2
Krynica Morska	B	III	1	2	0.7	85	2

Based on the results of cluster analysis using Bray-Curtis similarity index comparing the physical parameters (Euclidean distance) of the studied beaches parameters (table 3) it could be concluded that physical parameters alone cannot explain most of the variation (figure 2). The consequence this hypothesis is of importance for management. Variability of shoreline width is not the only factor

which provides the changes in biodiversity. The comprehensive influence both physical and biological factors cause that each beach unit is unique and specific action in one coastal place could have significant consequences for the remaining coastline.

4 Conclusions

Despite the fact that Polish coast of the Baltic Sea is continuous line of sandy beach we could not fully accept the theory of island biogeography. Even though the beach width is one of the most important factor for abundance and species richness of beach dwellers, it is not the only one. Meiofauna from wide, dissipative beaches represent higher abundance and higher share of Nematoda, while narrow, abrasive beaches are poorer in species but more diverse. The apparent pattern of taxa occurrence is not a continuity but patchiness.

The basic message for scientists, engineers, managers is rational and simple:

- follow HELCOM recommendations for natural coastline processes;
- keep developers away from the “technical belt” of beach and dunes;
- introduce laws that place the liability of violating natural processes on the violators;
- calculate the price of natural goods and services and update it as new ones emerge;
- concentrate facilities and upgrade the standard of selected recreational sites to keep mass tourism localized;
- educate the public at large about the values of the coastal ecosystem.

References

- Dahl, E. (1952): Some aspects of the ecology and zonation of the fauna of sandy beaches. *Oikos* 4, 1 - 27.
- Defeo, O. & A. McLachlan (2005): Patterns, processes and regulatory mechanisms in sandy beach macrofauna: a multi scale analysis. *Mar. Ecol. Prog. Ser.* 295, 1-20.
- Gheskiere, T., M. Vincx, J.-M. Węslawski, F. Scapini & S. Degraer (2005): Meiofauna as descriptor of tourism induced changes at sandy beaches. *Marine Environmental Research* 60, 245-265.
- Giere, O. (1993): *Meiobentology*. Springer-Verlag, Berlin, Heidelberg, 328 p.
- Haque, A.-M., M. Szymelfenig & J.-M. Węslawski (1996): The sandy littoral zoobenthos of the Polish Baltic coast. *Oceanologia* 38, 361-378.
- Haque, A.-M., M. Szymelfenig & J.-M. Węslawski (1997a): Small scale vertical distribution of zoobenthos in the sandy littoral of the Gulf of Gdańsk. *Oceanologia* 39, 433-446.
- Haque, A.-M., M. Szymelfenig & J.-M. Węslawski (1997b): Spatial and seasonal changes in the sandy littoral zoobenthos of the Gulf of Gdańsk. *Oceanologia* 39, 299-324.
- Jaramillo, E. & A. McLachlan (1993): Community and population responses of the macroinfauna to physical factors over a range of exposed sandy beaches in south-central Chile. *Estuar Coast Shelf Sci* 37, 615–624.
- Kotwicki, L. (1997): Makrozoobenthos of the sandy littoral zone of the Gulf of Gdańsk. *Oceanologia* 39, 447-460.
- Kotwicki, L., M. Szymelfenig, M. De Troch, B. Urban-Malinga & J.-M. Węslawski (2005): Latitudinal biodiversity patterns of meiofauna from sandy littoral beaches. *Biodiversity and Conservation* 14, 461–474.
- McLachlan, A. (1977): Composition, distribution, abundance and biomass of the macrofauna and meiofauna of four sandy beaches. *Zool Afr* 12, 279–306.
- McLachlan, A. (1988): Behavioral adaptations of sandy beach organisms: an ecological perspective. In: Chelazzi, G., Vannini, M. (eds) *Behavioral adaptation to intertidal life*. Plenum, New York, pp 449–475.
- McLachlan, A. & A.-C. Brown (2006): *The ecology of sandy shores*. Acad. Press NY, 392 p.
- McLachlan, A. & A. Dorvlo (2007): Species area relationships for sandy beach macrobenthos in the context of intertidal width. *Oceanologia* 49, 1-15.

- McLachlan, A., E. Jaramillo, T. Donn & F. Wessels (1993): Sandy beach macrofauna communities and their control by the physical environment: a geographical comparison. *J Coast Res* 15, 27–38.
- Węslawski, J.-M., B. Malinga, L. Kotwicki, K. Opaliński, M. Szymelfenig & M. Dutkowski (2000): Sandy coastlines – are there conflicts between recreation and natural values? *Oceanological Studies* 29, 5-18.
- Węslawski, J.-M., M. Szymelfenig & J. Urbański (2005): Sandy beach – users guide. IOPAN, Sopot, 115 pp, in Polish.
- Wilson E.-D. & R.-H. MacArthur (1967, reprinted 2001): *The Theory of Island Biogeography*. Princeton University Press, pp. 224.
- Zeidler, R. (1992): Assessment of the vulnerability of Poland's coastal area to sea level rise. HTS Gdańsk, 165 pp.

Acknowledgments

Colleagues from EU VI FP COSA and ELME projects are thanked for inspiring discussions and criticism.

Address

Dr. Lech Kotwicki
Institute of Oceanology – Polish Academy of Sciences (IO PAS)
Powstańców Warszawy 55
PL - 81-712 Sopot, Poland

lechk@iopan.gda.pl