AEOLIAN PROCESSES ON THE CLIFFS OF WOLIN ISLAND

MARCIN HOJAN

Kazimierz Wielki University, Institute of Geography

Manuscript received: September 17, 2009
Revised version: November 21, 2009

HOJAN M., 2009. Aeolian processes on the cliffs of Wolin Island. *Quaestiones Geographicae* 28A/2, Adam Mickiewicz University Press, Poznań 2009, pp. 39–46. 8 Figs. ISBN 978-83-232-2133-3. ISSN 0137-477X.

ABSTRACT. Aeolian processes are commonplace on sandy sea-coasts. Also, the slopes of the cliffs are subject to deflation as they are exposed to morpho-formative wind-directions. At present, these processes can be observed on the south coast of Baltic Sea, on the cliffs of Wolin Island. Fine sand blow away from cliffs and the dust carried by wind to the crown of the cliff, on which aeolian covers of various thickness and range. Research on Wolin Island demonstrated that winds of rarely occurring sectors but with greater speed have impact on the intensity of aeolian processes. The greatest dynamics of aeolian processes could be observed in deflation-rubble recess on clay and sandy fragment of the cliff. Plant life on the slope of the cliff in the proximity of the recess and vegetation growing on the crown of the cliff had considerable influence on the course of deflation, transport and aeolian accumulation processes.

KEY WORDS: Wolin Island, aeolian processes, cliff coast, aeolian covers

Marcin Hojan, Institute of Geography, Kazimierz Wielki University, ul. Mińska 15, 85-428 Bydgoszcz, Poland, e-mail: homar@ukw.edu.pl

Introduction

The existing research on aeolian processes on the sea-coasts focussed on beaches and their hinterland (Rosa 1963, Marsz 1966, Tobolski 1972, Miszalski 1973, Stankowski 1973, Borówka M. 1979a, 1979b, Borówka R.K. 1980a, 1980b, 2001a, Nowaczyk 1986, Borówka M., Rotnicki 1995, 1999, Hildebrandt-Radke 1999, 2001, Bauer, Sherman, Nordstrom, Gares 1990, Goldsmith, Rosen, Gertner 1990, Arens 1994, Carter R.W.G., 1998, Hesp, Short 2002, Łabuz 2004, 2005a, 2005b). The processes of erosion, transport and aeolian accumulation on cliffs were much more rare subjects of researches (Reinhard 1953/54, Jennings 1967, Jackson, Nevin 1992, Carter, Wilson 1993, Haslett, Davies, Curr 2000, Saye, Pye, Clemmensen 2006). Indeed, aeolian processes occur on cliffs on a smaller scale in comparison to beach or inland. They are, however, an essential factor of cliff modeling and their role in the determination of cliff recession rate cannot be overlooked. At present, aeolian covers of small spatial range are composed on the cliff shore of Wolin Island (Prusinkiewicz 1971, Hojan 2003, 2004, 2005a, 2005b, 2006, 2007). Aeolian covers can also be found in the areas of Ustka and Dębina (Florek, Grabowska-Dzieciątko, Majewski 2001).

Aeolian processes research on cliffs of Wolin Island was from own research sources of Geo-

ecology Department, Institute of Geo-ecology and Geo-information at Adam Mickiewicz University in Poznań, and in the period from Arpil 2004 to April 2006 from KBN grant: 2 P04E 014 26 entitled "Contemporary eolian processes at the top of the cliff on the Wolin Island coast".

Study area

Study area for the purpose of aeolian cliff reseach was located on Wolin Island, on the section of sea-shore 407.58–408.68 km UM (Fig. 1). In this part of sea-shore the alteration of coastline from SW–NE towards WSW–ENE takes place.

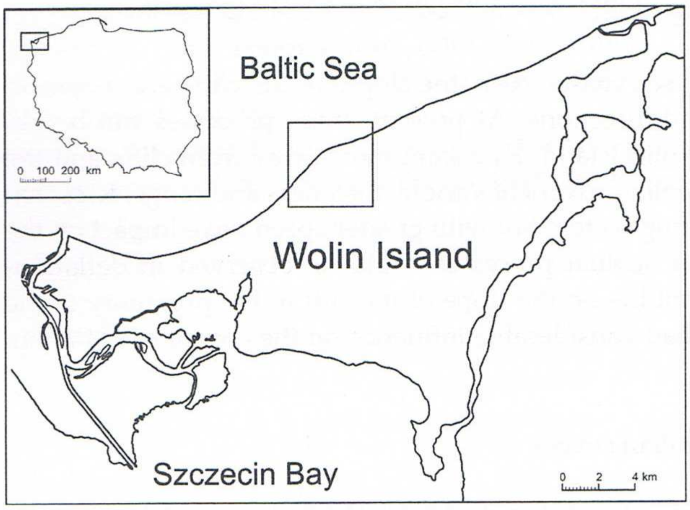

Fig. 1. Location of the study area

Study area was divided into three sections:

- Eastern (407.58–407.95 km UM). In this section the cliff is about 30 m high, above the sea level and consists mainly from brown and gray clay and in its top part- from glacial-fluvial sands;
- Central (407.95–408.20 km UM). This section of the cliff is about 40 m high, culminating gin Świdna Kępa in its central part, about 60 m high; consists mainly from troubled sands with mud interbeddings (Borówka, Goslar, Pazdur 1999a);
- Western (408.20–408.68 km UM) about 40–50 m high; cliff in this part of the study area is composed of brown and gray clay as well as fluvial-glacial sands. Differentiation of coast-line and height, morphology and lithology of the cliff located in the study area allowed for observation of various conditions for aeolian processes on substantially small sea-shore of the southern Baltic.

Research method

Measurements of height and spatial changeability of aeolian accumulation in the cliff crown were carried out from March 2001 to December 2004. Simultaneously the particularization studies were carried out up to 2006. In order to measure mineral material delivered from the slope of the cliff outside its top edge, the measurement network was positioned, initially consisting of 6 and finally of 15 profiles, perpendicular to the cliff edge. In these profiles from 3 to 6 measurement posts were located. The location of posts was strictly connected with cliff's morphology and lithology. In each post, in the profile there were three catchers and the amount of material deposited in them was averaged. The cathers were exchanged one a month in the open-air, at the turn of following survey months. In order to achieve comparable results, the cathers were located in more or less the same distances from the cliff edge.

Weather conditions

Among the conditions influencing the occurrence of aeolian processes, weather conditions play a very important role, especially wind speed and direction. What is also important is the precipitation and air temperature, having impact on the soil humidity and its vulnerability to erosion. On the basis of data obtained from Maritime Office in Świnoujście it can be stated that there is rarely silent in the study area. Silence constituted merely 0.17% of measurements in the period 1996–2005. For the sake of comparison – Warnowo, situated 6 km to the south from the study had 30% share of silence in measurements (wind-gauge in the post in Warnowo is situated in the shade of Wolin Terminal Moraine). In the study period in Świnoujście south-west direction of wind dominated, how

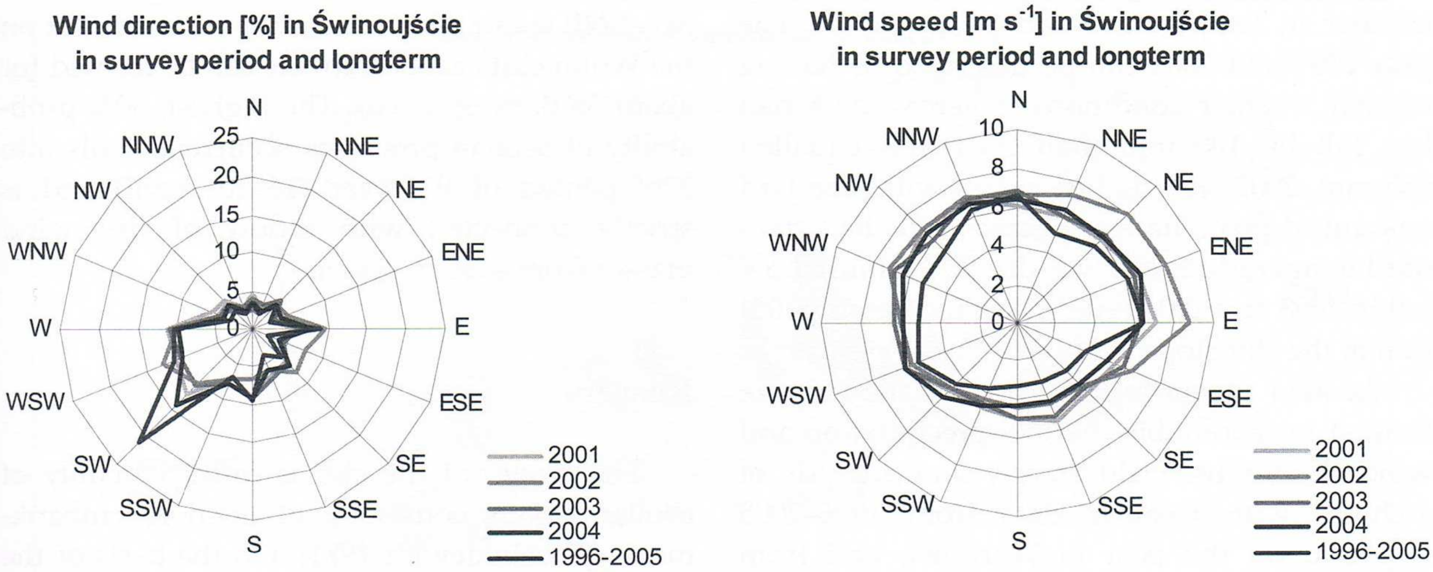

Fig. 2. Domineering wind directions and their speeds in Świnoujście in the survey period and longterm of 1996–2005

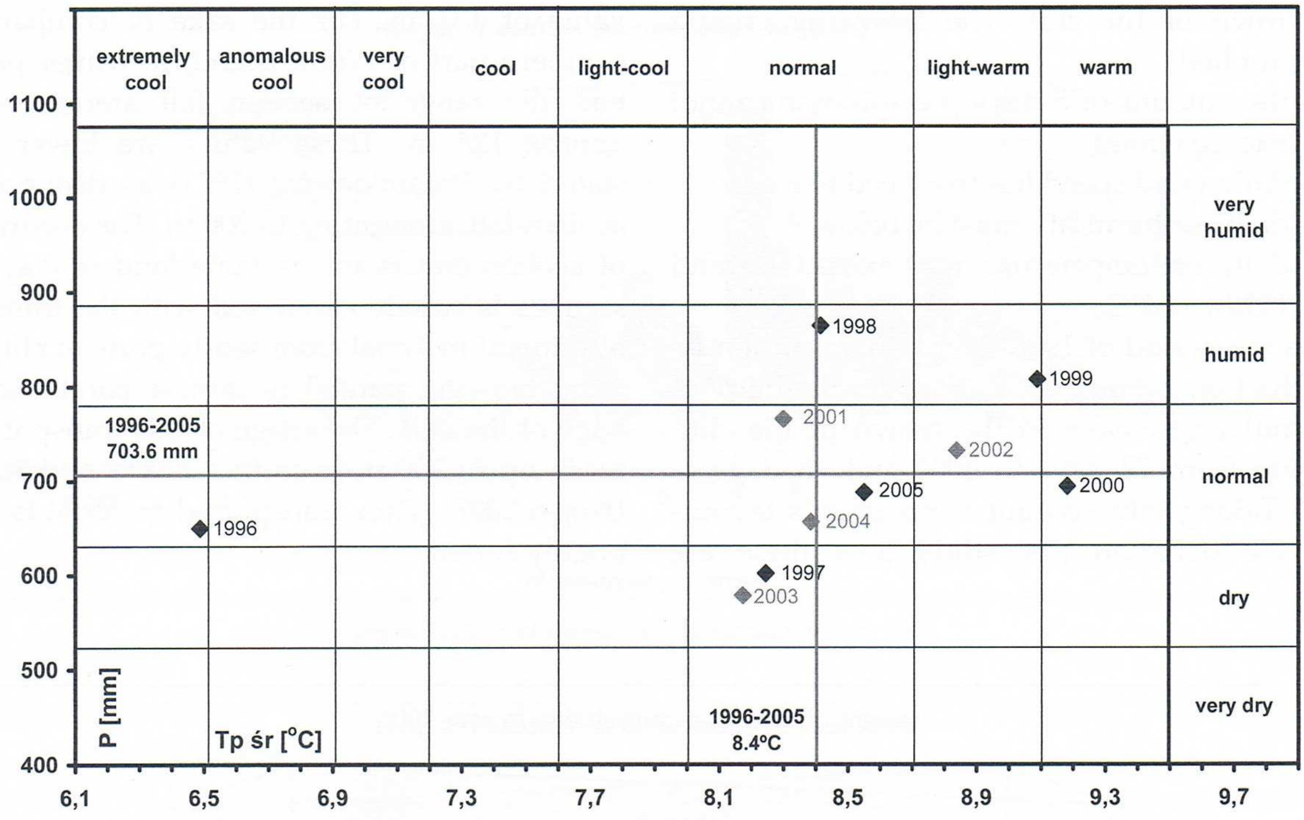

Fig. 3. Thermal and precipitation classification according to Lorenc (1998)

ever the highest average wind speeds were recorded for WSW–ESE sector. They exceeded, in 2001–2004 6 m s^{-1}, and in 2002 annual average for NE, ENE and E direction exceeded 8 m s^{-1} (Fig. 2). Maximum daily wind speed recorded was in 2003 and equalled 19 m s^{-1}. Differences of wind speed occur also in summer (April–September) semester, when average wind speed amounted to 5.7 m s^{-1} and winter semester (October–March) with average speed of 6.3 m s^{-1}. Despite higher wind speed in winter semester, aeolian processes are not so dynamic as during summer semester. In summer cliff surface dries quicker and, as a result, is more vulnerable to deflation.

On the basis of methodology recommended by Lorenc (1998), thermal and precipitation conditions for 1996–2005 decade were analyzed (Fig. 3). Particular years during which aeolian processes were examined, differed from one another in temperature and precipitation. The year 2001 and 2004 can be described as having normal weather conditions, whereas 2004 had less fall by 100 mm than 2001 and equalled 655 mm. 2002 was slightly warm with standard amount of precipitation whereas 2003 had standard temperatures but was dry (578.5 mm). Low fall in 2003 and 2004 reflected in increased deflation of the cliff slope.

Aeolian covers in the crown of the cliff are formed in favourable thermal-precipitation and wind conditions. Field survey and analysis of archives with weather data from 1996–2005 longterm on the post in Warnowo and from Maritime Office in Świnoujście allowed for specifying these days in the year on which potentially aeolian covers may be accumulated on the crown of the cliff. The following criteria were applied:

- the amount of 5-days precipitation cannot exceed 6 mm;
- daily wind speed has to exceed 6 m s^{-1};
- daily air humidity must be below 95%;
- daily air temperature must exceed 0°C and below -10°C.

In the period of 1996–2005 cliffs of Wolin Island had on average 49 days with possibility of accumulating covers in the crown of the cliff, ranging from 22 days in 2002 and 78 days in 1997. Taking into account wind speeds favourable for deflation (for study area these are SW–ENE sector directions), it was stated that on the Wolin cliffs aeolian covers can be formed for about 36 days in a year. The highest, 30% probability of aeolian processes occurrence falls into 22^{nd} pentad of the year (16–20 April) and is strictly connected with inflow of dry wind masses from eastern sector.

Results

The crown of the cliff is formed mainly of aeolian covers consisting of in-shore embankments (Prusinkiewicz 1971). On the basis of the research it was confirmed that covers formed at present are on average up to 75 m from the edge if the cliff, inland, at the maximum average value of 131 m. For the sake of comparison, southern part of Wolin Island, in winter period had the range of aeolian fall amounting to approx 125 m. These values are lower than stated by Prusinkiewicz (1971) as distances of aeolian fall, amounting to 200 m. The occurrence of aeolian covers in the hinterland of clay cliff sections is strictly connected with the transport of mineral material from sandy parts of cliffs by wind blowing paralel or almost paralel to the edge of the cliff. The range of this transport can reach up to 300 m from the source of deflation (Hojan 2007). Thus transported material is thoroughly sorted.

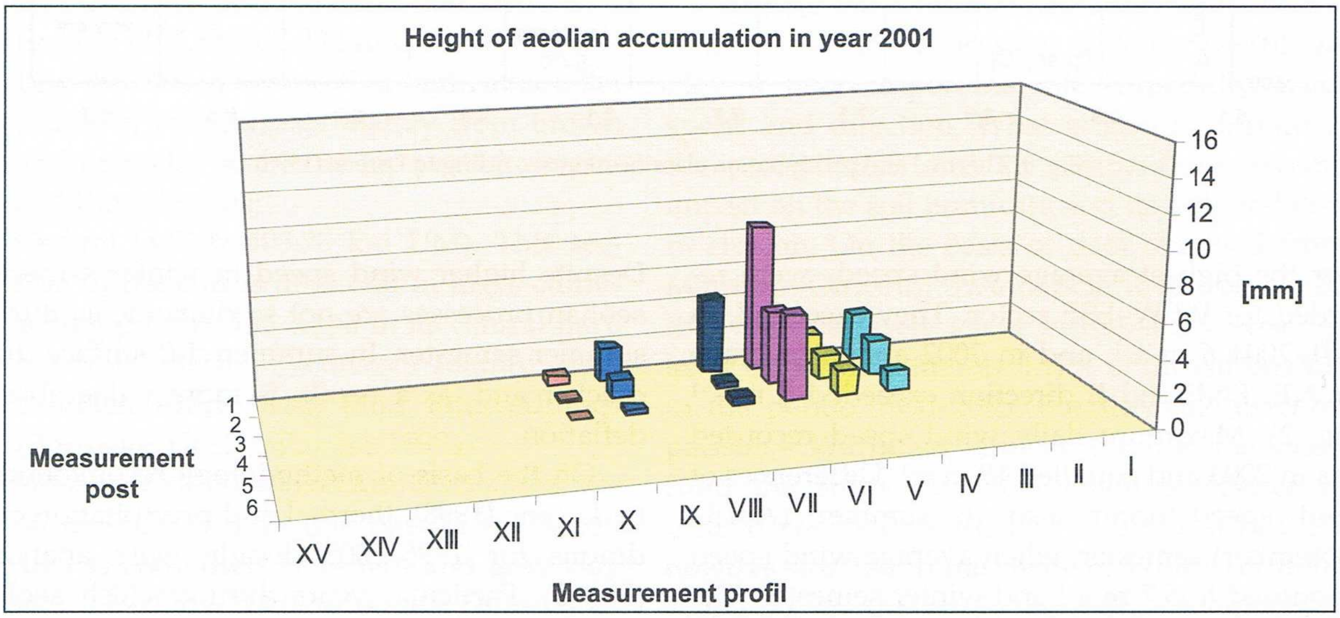

Fig. 4. Height of aeolian accumulation in year 2001

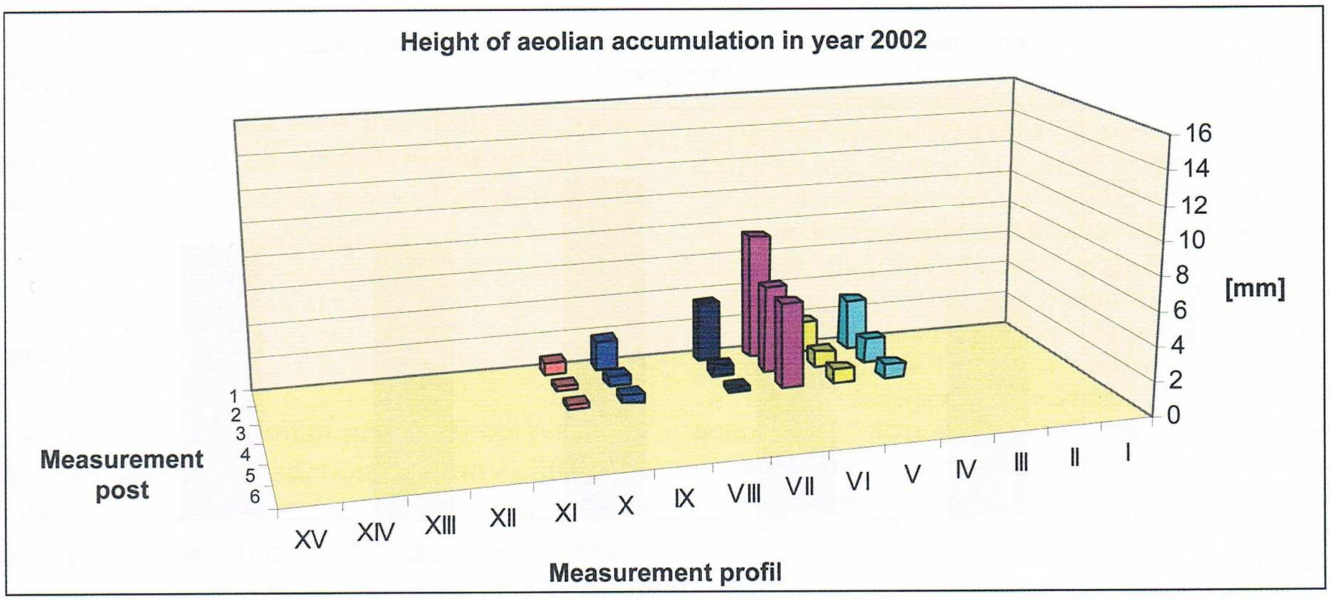

Fig. 5. Height of aeolian accumulation in year 2002

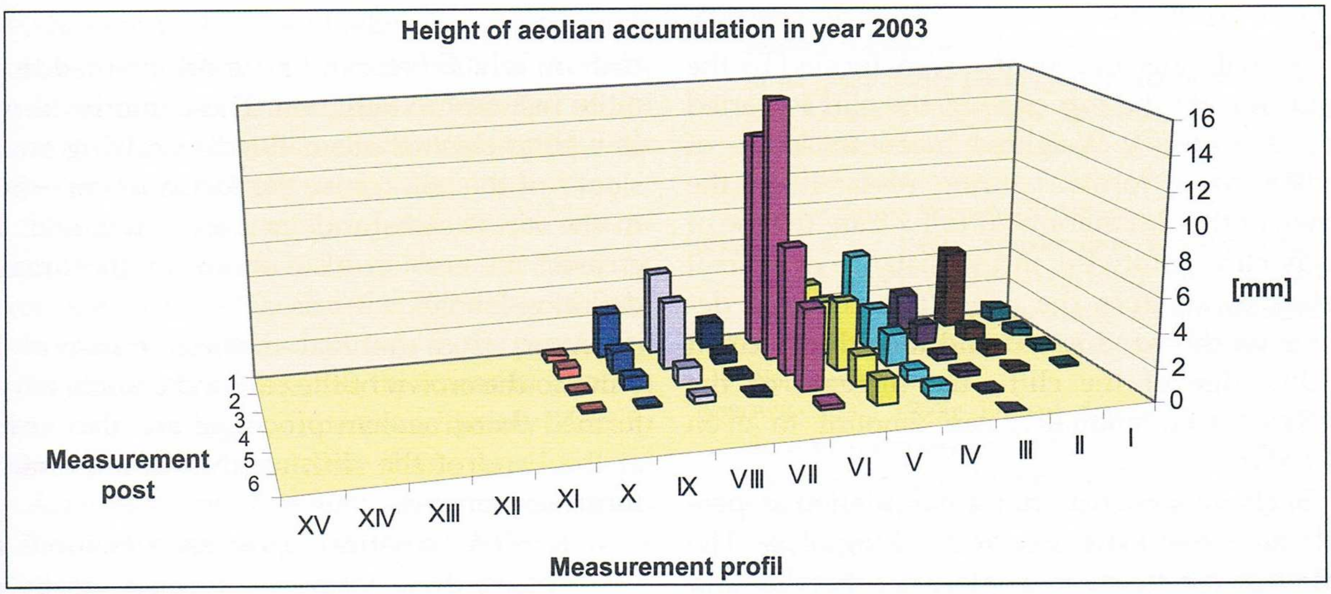

Fig. 6. Height of aeolian accumulation in year 2003

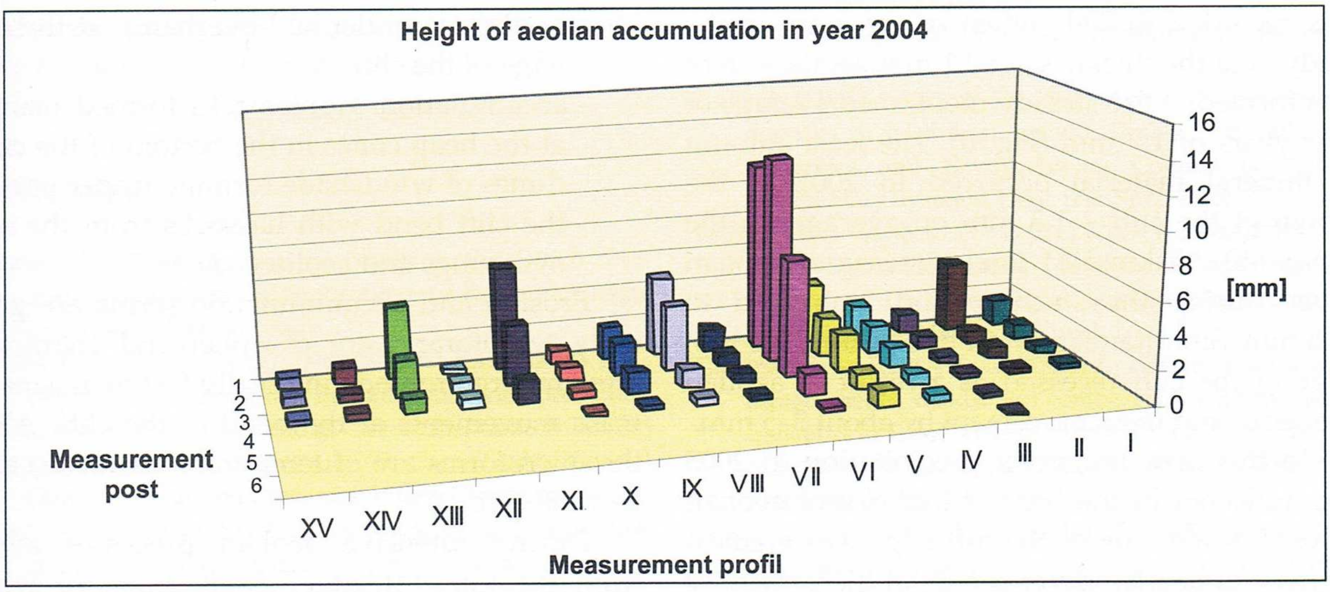

Fig. 7. Height of aeolian accumulation in year 2004

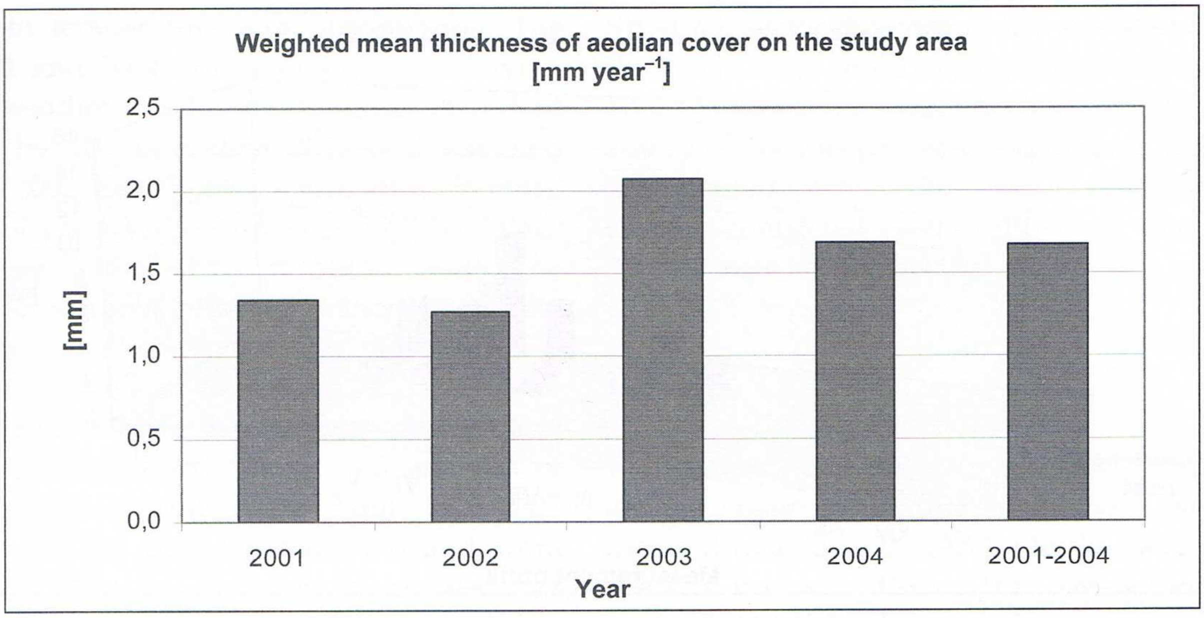

Fig. 8. Increase of the aeolian cover on the study area

Spatial range of aeolian covers formed by the wind outside the top edge of the cliff is varied (Fig. 4, 5, 6, 7). Weighted mean thickness of aeolian cover formed during research on the crown of the cliff amounted to 1.7 mm. In case of sandy cliff, pointwise, in the distance of several meters away from the edge (this distance depends on the wind speed and the whirl formed at the edge of the cliff), the increase of the aeolian cover, annually, can amount to even 80–100 mm.

Such mineral material accumulation is possible in case of extreme events taking place. The least cover increase took place on the clay and stabilized cliff fragment.

The greatest dynamics of aeolian processes was recorded in 2003 when on average on the study area the thickness of 2.1 mm aeolian cover was formed at the already mentioned average of four years of 1.7 mm (Fig. 8). The least amount of mineral material occurred in 2002 in the crown of the cliff – 1.3 mm on average. In the profile 407.95 km UM total increase of aeolian cover during the study period amounted to 21.8 mm. Simultaneously, in this profile, the tom edge of the cliff recessed as a result of aeolian processes and mass movement by about 3–5 mm.

In this area the small precipitation in 2003 was reflected in the highest increase of aeolian Cover formed outside the cliff edge. The greatest increase of aeolian cover occurs in the proximity of the deflation source, on sandy parts of the cliff, on which one can find mud interbeddings, more resistant to deflation. These interbeddings, as well as clusters of small trees growing on the slopes of the cliff, cause the formation of whirls in the air streams and increased deflation. Increased air erosion also occurs in the area of deflation-landslide recesses.

Apart from mineral material transport by wind to the crown of the cliff and aeolian covers formed there, aeolian processes are also visible at the bend of the cliff, on this various microforms are formed:

- erosion: cavities, grooves, deflation recesses; these forms are formed mostly on sandy cliffs having mud interbeddings and ferruginous inclusions. Deflation recesses occur also under soil overhangs at the top edge of the cliff.
- accumulation: ripplemarks formed mainly at the heap cones in the bottom of the cliff, dunes of windshade forming upper part of the cliff bend with hassocks from the soil overhangs and aeolian covers.

Erosion and accummulation forms are generaly temptorary, are of ephemeral character, they undergo remodeling really fast by means of mass movements at the bend of the cliff. Also, the microforms are of temporary character, and become extinct.

During intensive aeolian processes away from the top cliff edge, small dunes of wind shade are formed, too- mainly with hassocks, small shrubs and trees. They may reach 20-30 cm in height and 60-70 cm in length. On the edge of the cliff one can find also microform as minor sand dunes of 10 cm and 1 m long. Some of these forms have clearly marked edge between the proximal and distal slope.

Conclusions

Contemporary aeolian processes on Wolin Island lead to the degradation of sandy cliff slope by means of blowing away fine sand and dust to the crown of the cliff. At the same time erosion microforms occur on the slope of the cliff, causing mud interbeddings and sand fall downhill.

Greaterdynamics of aeolian processes on the cliff shore of Wolin Island takes place in summer period. The highest, 30% probability of Aeolian processes occurrence falls into 22nd pentad of the year (16-20 April) and is strictly connected with inflow of dry wind masses from eastern sector.

The anticipated range of Aeolian covers in the crown of the cliff is lower than expected by Prusinkiewicz (1971), also the thickness of covers is smaller. On the small area in the proximity of the deflation source the thickness of aeolian cover may be higher however, mainly due to aeolian processes of extreme character.

Accumulation of aeolian covers in the crown of the cliff may occur on about 10% of days in a year.

Aeolian processes are very essential factors having impact on modeling of the slope of cliffs and their role in determination of cliff recession rate cannot be overlooked.

References

ARENS S.M., 1994: Aeolian processes in the Dutch foredunes. Landscape and Environmental Research Group, University of Amsterdam.

BAUER B.O., SHERMAN D.J., NORDSTROM K.F., GARES P.A., 1990: Eolian transport measurment and prediction across a beach and dune at Castroville, California. [In:] K.F. Nordstrom, N.P. Psuty, B. Carter (eds): Coastal Dunes - Forms and Processes. Wiley, Chichester.

BORÓWKA M., 1979a: Przebieg procesów deflacji i akumulacji na powierzchni nadbrzeżnych wałów wydmowych. Badania Fizjograficzne nad Polską Zachodnią 32, Seria A. Geografia Fizyczna. Warszawa - Poznań.

BORÓWKA M., 1979b: Rekonstrukcja rozwoju rzeźby zaplecza plaży w środkowej części mierzei Łebskiej. Badania Fizjograficzne nad Polską Zachodnią 32, Seria A. Geografia Fizyczna. Warszawa - Poznań.

BORÓWKA R.K., GOSLAR T., PAZDUR A., 1999a: Wiek struktur glacitektonicznych na wyspie Wolin w świetle danych litostratygraficznych oraz datowań radiowęglowych. [In:] R.K. Borówka (ed.): Problemy geologii, hydrogeologii i ochrony środowiska wybrzeża morskiego Pomorza Zachodniego. Sesja referatowa i konferencje terenowe. LXX Zjazd Naukowy Polskiego Towarzystwa Geologicznego. Szczecin.

BORÓWKA M., ROTNICKI K., 1995: Balance of the Aeolian sand transport on the beach and the problem of sand nourishment of the active dune field on the Łeba Barrier. [In:] K. Rotnicki (ed.): Polish Coast. Past, Present and Future, Special Issue No 22, Journal of Coastal Research. An International Forum for the Litoral Sciences, Quaternary Research Institute, A. Mickiewicz University, Poznań.

BORÓWKA M., ROTNICKI K., 1999: Problem głównych kierunków transportu eolicznego piasku oraz jego budżetu na plaży barier piaszczystych (na przykładzie Mierzei Łebskiej). [In:] R.K. Borówka, Z. Młynarczyk, A. Wojciechowski (eds): Ewolucja geosystemów nadmorskich południowego Bałtyku. Bogucki Wydawnictwo Naukowe, Poznań - Szczecin.

BORÓWKA R.K., 1980a: Współczesne procesy transportu i sedymentacji piasków eolicznych oraz ich uwarunkowania i skutki na obszarze wydm nadmorskich. PTPN Prace Komisji Geograficzno-Geologicznej 20. Warszawa - Poznań.

BORÓWKA R.K., 1980b: Present day dune processes and dune morpfhology on the Łeba Barrier, Polish coast of the Baltic. Geografiska Annaler 62A.

BORÓWKA R.K., 2001: Natężenie transportu eolicznego i jego uwarunkowania na obszarze wydm nadmorskich Mierzei Łebskiej. [In:] K. Rotnicki (ed.): Przemiany środowiska geograficznego nizin nadmorskich południowego Bałtyku w vilstulianie i holocenie. Bogucki Wydawnictwo Naukowe. Poznań.

CARTER R.W.G., 1998: Coastal Environments. Academic Press. London.

CARTER R.W.G., WILSON P., 1993: Aeolian processes and deposits in northwest Ireland. [In:] K. Pye (ed.): The Dynamics and Environmental Context of Aeolian Sedimentary Systems. Geol. Soc. Spec. Publ. 72.

FLOREK W., GRABOWSKA-DZIECIĄTKO A., MAJEWSKI M., 2001: Dynamika zmian nadbrzeża morskiego na wschód od Ustki. Geologia i geomorfologia pobrzeża i południowego Bałtyku. Słupsk.

GOLDSMITH V., ROSEN P., GERTNER Y., 1990: Eolian transport measurments, winds, and comparision with theoretical transport in Israeli coastal dunes. [In:] K.F. Nordstrom, N.P. Psuty, B. Carter (eds): Coastal Dunes - Forms and Processes. Wiley, Chichester.

HASLETT S.K., DAVIES P., CURR R.H.F., 2000: Geomorfphologic and palaeoenvironmental development of Holocene perched coastal dune systems in Brittany, France. Geografiska Annaler 82A.

HESP P.A., SHORT A.D., 1999: Barrier morphodynamics. [In:] A.D. Short (ed.): Handbook of Beach and Shoreface Morpfhodynamics. Wiley. London.

HILDEBRANDT-RADKE I., 1999: Bilans transportu eolicznego na plaży Mierzei Gardnieńsko-Łebskiej. [In:] R. K. Borówka, Z. Młynarczyk, A. Wojciechowski (eds): Ewolucja geosystemów nadmorskich południowego Bałtyku. Bogucki Wydawnictwo Naukowe, Poznań - Szczecin.

HOJAN M., 2003: Zmienność depozycji eolicznej na wybrzeżu klifowym wyspy Wolin w latach 2001-02. [In:] A. Kostrzewski (ed.): Geneza, litologia i stratygrafia utworów czwartorzędowych. Materiały konferencyjne. Poznań.

HOJAN M., 2004: Zmienność depozycji eolicznej na wybrzeżu klifowym wyspy Wolin w latach 2001-02. [In:] A. Kostrzewski (ed.): Geneza, litologia i stratygrafia utworów czwartorzędowych. Poznań.

HOJAN M., 2005a: Monitoring opadu eolicznego na wybrzeżu klifowym wyspy Wolin w latach 2001-2002. [In:] A. Kostrzewski, R. Kolander (eds): Funkcjonowanie geoekosystemów Polski w warunkach zmian klimatu i różnokierunkowej antropopresji. Biblioteka Monitoringu Środowiska. Poznań.

HOJAN M., 2005b: Uwarunkowania i wielkość opadu eolicznego na wybrzeżu klifowym wyspy Wolin. [In:] R.K. Borówka (ed.): Plejstoceńskie i holoceńskie przemiany środowiska przyrodniczego Polski. Wybrane aspekty. Szczecin.

HOJAN M., 2006: Uwarunkowania, przebieg i skutki procesów eolicznych na wybrzeżu klifowym wyspy Wolin w latach 2001-2004. VII konferencja geologia i geomorfologia Pobrzeża i południowego Bałtyku. Słupsk - Ustka, 8-10 czerwca 2006.

HOJAN M., 2007: Ekstremalny opad eoliczny na wybrzeżu klifowym wyspy Wolin w dniach 29 i 30.06.2002 r. [In:] A. Kostrzewski, J. Szpikowski (eds), Funkcjonowanie geoekosystemów zlewni rzecznych. 4. Procesy ekstremalne w środowisku przyrodniczym. Bogucki Wyd. Nauk, Poznań,

JACKSON D.W.T., NEVIN G.H., 1992: Sand transport in a cliff top dune system at Fonte de Telha, Portugal. [In:] C. Carter, S. Sheeby (eds.): Coastal dunes. Rotterdam.

JENNINGS J.N., 1967: Cliff-top dunes. Australian Geographical Studies 5.

LORENC H., 1998: Ocena stopnia realizacji programu „obserwacje meteorologiczne i badania klimatyczne w systemie zintegrowanego monitoringu środowiska" oraz synteza uzyskanych wyników badań za okres 1994-1997. [In:] A. Kostrzewski (ed.): Zintegrowany Monitoring Środowiska Przyrodniczego. Funkcjonowanie i tendencje rozwoju geoekosystemów Polski. Biblioteka Monitoringu Środowiska. Warszawa.

ŁABUZ T.A., 2004: Coastal dune development under natural and human influence on Świna Gate Barrier (Polish coast of Pomeranian Bay). [In:] G. Schernewski, N. Löser (eds.): Managing the Baltic Sea. Coastline Reports 2. EUCC.

ŁABUZ T.A., 2005a: Present-day dune environment dynamics on coast of Świna Gate Barrier (West Polish coast). Estuarine Coastal and Shelf Science 62.

ŁABUZ T.A., 2005b: Brzegi wydmowe polskiego wybrzeża Bałtyku. Czasopismo Geograficzne 76 (1-2).

MARSZ A., 1966: Geneza wydm łebskich w świetle współczesnych procesów brzegowych. PTPN, Prace Komisji Geograficzno-Geologicznej 4 (6). Poznań.

MISZALSKI J., 1973: Współczesne procesy eoliczne na pobrzeżu słowińskim. Studium fotointerpretacyjne. Dokumentacja Geograficzna 3. IG PAN Warszawa.

NOWACZYK B., 1986: Wiek wydm, ich cechy granulometryczne i strukturalne a schemat cyrkulacji atmosferycznej w Polsce w późnym vistulianie i holocenie. Wydawnictwo Naukowe UAM, Seria Geografia nr 28. Poznań.

PRUSINKIEWICZ Z. 1971: Naspy przyklifowe - nowy typ gleb morskiego pobrzeża. Zeszyty Naukowe UMK w Toruniu, Geografia 26 (8): 133-157.

REINHARD H., 1953/54: Kliffranddünen und Branddungshöhlen der Insel Hiddensee. Wissenschaftliche Zeitschrift der Universität Greiswald. Jahrgang III. Mathematisch-naturwissenschaftliche Reihe Nr 8.

ROSA B., 1963: O rozwoju morfologicznym wybrzeża Polski w świetle dawnych form brzegowych. Studia Societatis Scientarium Toruniensis, sectio C, nr 6. PWN Warszawa.

SAYE S.E., PYE K., CLEMMENSEN L.B., 2006: Development of a cliff-top dune indicated by particle size and geochemical characteristics: Rubjerg Knude. Denmark. Sedimentology 53.

STANKOWSKI W., 1963: Rzeźba eoliczna Polski północno-zachodniej na podstawie wybranych obszarów. Prace Komisji Geograficzno-Geologicznej PTPN, vol. 4, no 1.

TOBOLSKI K., 1972: Wiek i geneza wydm przy południowo-wschodnim brzegu Jeziora Łebsko. Badania Fizjograficzne nad Polską Zachodnia. Seria B, Tom 25. Poznań.