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Coastal dune development under natural and human influence on Swina Gate Barrier (Polish coast of Pomeranian Bay)

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Abstract

In present times coastal dunes are rapidly changing by human impact and by waves due to increasing sea level. The most important factors in natural dune development are aeolian processes, dune vegetation cover and wind factor. In Poland different dune development stages affected by every mentioned factor may be studied on Swina Gate Barrier localised on Wolin and Uznam Islands along 16 kilometres of dune coast. On this area investigations are carrying by author since 1996. The aim of undertaken researches is to discover relations and connection between natural and antropogenic processes that are influences on coastal dunes. Driven researches consist of: (i) dune relief changes, (ii) plant vegetation dynamics, (iii) human or animal influence, (iv) storm surges impact, (v) wind factor impact, (vi) sediment diversification and dynamics analyses (surface and structures dynamics). These investigations are repeated four times per year according to the different seasons.
West winds (common during dune plants activity period) favour to dune development in contribution with dense plant cover in middle part of barrier. Strong Northeast winds (common in cold period) bring sandy material from abraded on NE cliffs. Storm surges are causing abrasion of the dunes but supply beach with material. Low thickness of sand helps in aeolian transportation along barrier beaches. Absence of mass tourism in middle part of barrier lead to natural development of this part and a lot of people on Świnoujście town beaches stops new dune development. Coast erosion and human presence in Międzyzdroje town lead to dune regression there. Since 1997 is observed increasing of the new dune ridge on developing beach on Wolin Island.

1 Introduction

Morphodynamic interactions in dunes are not well understood because the chaotic relief of many coastal dunes defies simple description (Carter, et al. 1990). Along many coast dunes threaten by storm surges are retreating. On many coast dunes are completely destroyed. The most important factors in dune development are aeolian processes, dune vegetation cover and wind factor. Other factors as human impact and storm surges also play important role in dune environment dynamics. In recent times human impact, especially tourism has a negative influence on the dunes development. Men activity causes changes in dune relief and vegetation cover (Carter 1980, Pye 1990, Olsauskas 1996, Isermann and Krisch 1995 and others).

Polish Baltic coast is also threatened by high waves and strong storm surges (Zeidler et al. 1995). Majority of Polish coast is being eroded by sea and retiring on the south (Zawadzka-Kahlau 1999). Accumulation on the coast is observed only in a few places. One of them is the Swina Gate Barrier (Musielak 1995) localised on Wolin and Uznam islands on the Pomeranian Bay coast. In Polish borders barrier has about 16 kilometres from morenic plateau in Międzyzdroje (Wolin Island) to country border in Świnoujście (on Uznam Island). The barrier is also continuating on German side along the Uznam coast. Both islands building barrier are crossed by Swina channel outlet, which is connecting Szczecin Lagoon and Pomeranian Bay (Figure 1). This barrier grown as a result of sea sand accumulation that comes from nearby abraded cliffs on Wolin and Uznam (Keilhack 1912).

Dune ridges covering barrier are coming from different accumulation stages since Atlantic period - 5 000 BP (Keilhack 1912, Prusinkiewicz and Noryśkiewicz 1966). They differ from each other by the morphology, lithology and ridges direction showing following phases of spit increase and development (Keilhack 1912, Osadczuk 2001). Also soil processes and plant succession is changing on older and younger ridges (Piotrowska and Celiński 1965, Prusinkiewicz and Noryśkiewicz 1966, Piotrowska 2002).

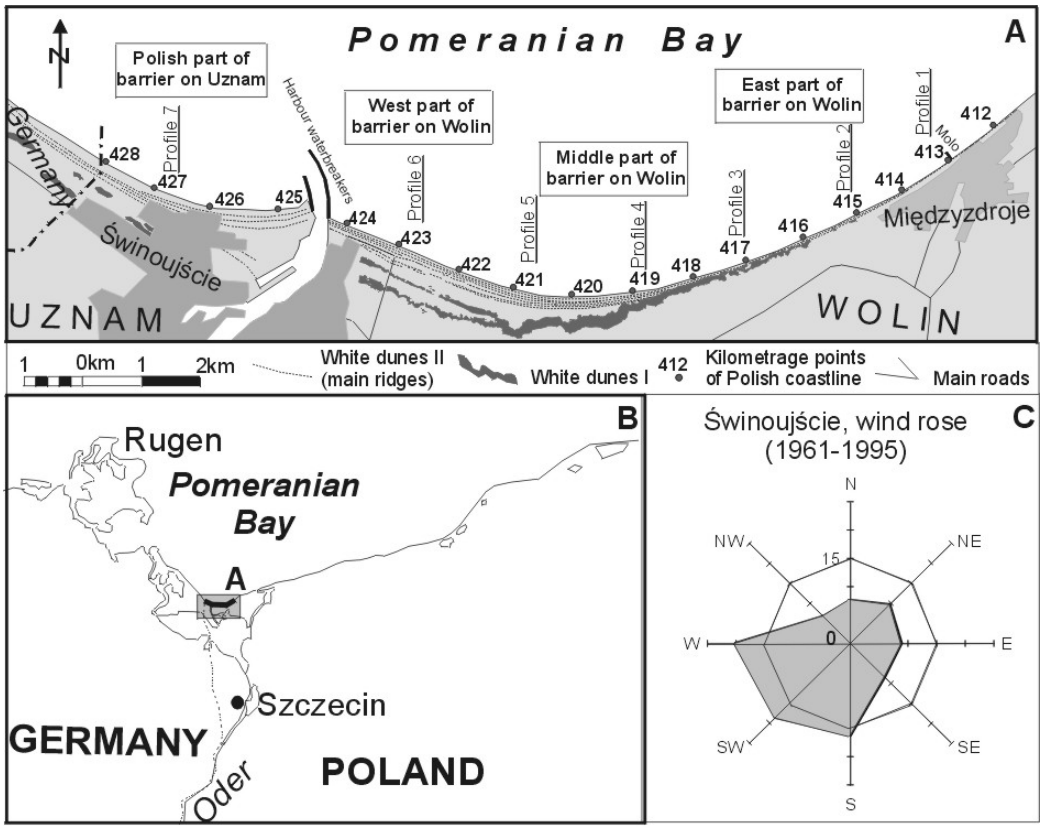

Figure 1: Study area. A - Polish part of Świna Gate Barrier with specified areas of development. Profiles relief see Figure 2. B - Location on South Baltic coast, C - Wind rose for Świnoujście.

2 Aim and methods of the study

Area of detailed fieldwork is situated on coast of Polish part of Świna Gate Barrier and stretches between 412 kilometre and 428 kilometre of Polish coastline classification (Polish Maritime Institute classification).

The aim of undertaken researches is to discover relations and connection between natural and antropogenic processes that are influences on dunes developing on the barrier. Driven researches consist of: (i) dune relief changes, (ii) plant vegetation dynamics, (iii) human or animal influence, (iv) storm surges impact, (v) wind factor impact, (vi) sediment diversification and dynamics analyses (surface and structures dynamics).

Majority of the measurements depended on levelling of beach and dune ridges and checking distances among forms and width of beaches on the same profiles (every one kilometre) and on very dynamics places. On these profiles also is marked kind vegetation (plant species and communities). Additional measurements on the profiles are: range of waves and storm surges and wind stream changing caused by obstacles (plants ant others) and dune relief on the profile. Surface relief changes and vegetation dynamic are checked on small plots (5x5m) localised on different part of dunes. During field

measurements were used geodesic tools, as leveller and theodolite. Also were used measure tapes and carpenter's metres. Wind parameters are measured using anemometers. Information about human impact on the dunes refers to: people effect on dune relief and vegetation, trash and savage presence left by tourist and thrown from the sea by waves. These investigations are repeated four times per year according to the different seasons.

The plots, profiles and other data are marked using topographical maps of this region (1: 25 000, 1: 10 000), Photointerpretation Atlas of Pomeranian Bay coastline made in scale 1:5 000 and map of technical belt of Polish coastline (1: 2 000). In many not measured areas were done numerous sketches of dune and beach relief, and drawing examples of the plants causing accumulation. Also photos of the plants, dune relief and human impact were made (for other information about fieldwork area see web page http://bramaswiny.szc.pl).

3 Coastal dune development

Obtained results give a lot of information about coastal dune environment on investigated area. They can be divided as a natural factors as: dune development, plants succession, sea impact, wind fields ect. and antropogrenic as: new infrastructure levelling dunes and beach surfaces (military and tourism buildings), tourists trampling, trashes and savages and protection management.

3.1 Influence of the natural factors

Average sea level and waves in Świnoujście are lower from other open Baltic coast stations (ASL in Świnoujście is 497.1 cm - Zeidler et al. 1995). Probability of strong storm surges is one of the lower from the Polish open Baltic coast (Zeidler et al. 1995). Lower part of the barrier is dangered by increasing sea level and increasing storm surges (Rotnicki, Borówka 1990). Many times in the past dune ridges of the barrier were broken by strong waves and water flooded land. Last such invent taken place in autumn 1995, when during strong storm (sea level about 1.6 m higher than ASL) dunes were badly abraded and water flooded Świnoujście streets closest to the harbour and land in few places behind dunes.

During last 3 years storm surges were often in autumn and winter 2001 (Table 1). In that time foredune ridge was badly abraded in middle part of barrier on Wolin and wash over along many sections in west and east part of Wolin barrier (Figure 2, profile 3 & 7). Then in end of the winter of 2002 ice sheets covered beach (no bigger storms). And again in winter 2003 storm has broken foredune again in west and east part of Wolin barrier. During these storms strong wind caused aeolian accumulation on surfaces so far fixed by mosses and lichens.

Date	Storm surges		Wind	
	Sea level [cm]	Sea waving [B]	Direction	Velocity [m/s]
02.11.01	573	5-4	NW-W	9-12
09.11.01	596	6	N	11-13
12.11.01	563	5	N-WNW	10-13
15.11.01	597	6	NW-NNE	11-14
22.11.01	598	7	NW	13-15
01.01.02	604	7	NNE	13-15
21.02.02	635	10-11	NE	16-18
06.04.03	586	7	NNE	14-15
06.12.03	594	7	N	14-16

Table 1: Storm surges during last 3 years noted in Świnoujście (497.1 cm ASL) that abraded foredune ridge (with 0.6 m higher sea level than ASL). (Storm data from Polish Maritime Inistiute)

Wind is the main factor of dune development. The effectivity of long period winds noted in Świnoujście (1961-1993) favours to transportation of material from beaches and accumulation at the back of the beach (Borówka 1999). The most numerous are winds from west and south directions (for years 1961-1995, see Table 2): S, SW and W (Łabuz 1998). Also old measurements (1876-1900) show dominance of south and west wind directions (Wernicke 1930). Winds from the west are often all the year. During winds blowing from west is observed material transportation along beach from west part of investigated area (nearest breakwater of Świna channel) to central area (Labuz 2003). Most strong winds blow from northern direction; NE and N. Probability of wind appearance from northern section also is greatest in spring, when plants start to grow (Łabuz 2003). Winds from north directions (especially from NE) causes the heaviest storm surges in autumn-winter period. In these seasons beach and dunes are suffering biggest abrasion. During field measurements of the wind were collected data showing wind stream velocity changes above surface topography. During the off shore winds the biggest velocity wind stream have over middle, upper beach and foredune (measurements 1 –1.5 m above the surface). The smallest one is just behind foredune and on older dune covered by shrubs. Also plant cover significantly stops wind (f.e. during the same wind conditions 4 m/s, wind behind the grass clump is one half smaller).

Years	N	NE	E	SE	S	SW	W	NW	calm
1876-1900	9.25	11.50	7.75	11.75	12.50	16.00	17.00	10.50	3.75
1961-1995	7.63	9.68	8.91	8.46	16.29	18.49	20.25	6.72	3.57

Table 2: Percentage wind directions in Świnoujście 1976-1900 (Wernicke 1930 after Hartnack 1926), 1961-1995 (Łabuz 1998)

Main source of sand for the dune building is coming not from adjoining beach (where sand deliveries depends on rare wave accumulation during season of main dune development) but is blowing by the wind from neighbouring beaches. So sand is drifting along the beach with prevailing winds until the obstacles stop it. Vegetation presence cause very rapid accumulation. If plants are growing on the beach sand is trapped there and is not transported on foredune. In this time foredune becoming stabilised and plants from next succession stages climb up on leeward (landward) slope. During long term stable winds from one direction a new embryo (shadow) dunes are built up on the beach (in places where grasses or other obstacles exists). But rapid change of the wind direction (on opposite) and increasing of its' velocity can blow out recently built hillocks. But still plants may fix part of the material until the very strong wind appears.

Special plant habitats are situated directly along the coast where the marine influence is highest (Piotrowska and Celiński 1965, Piotrowska and Gos 1995). These habitats are typical for flat accumulation coasts and rare on abrasive coasts. The process of sand accumulation and the appearance of plants, especially dune grasses like *Agropyron junceum*, *Ammophila arenaria, Calammophila baltica* (hybrid grass between *Ammophila baltica* and *Calammagrostis epigejos*), *Elymus arenarius* is there strongly visible (Figure 2, Table 3). On older partly fixed dunes appears *Helichryso-Jasionetum* - habitats less tolerant to moving sand. The final stage of succession on open dunes without shrubs or trees is a continental dune habitat with *Corynephorus canescens* and *Carex arenaria* (Piotrowska and Celiński 1965, Wojterski 1964). On forested dunes pine forests grow (*Empetro-nigri Pinetum*) (Wojterski 1964). On German side of Uznam there are similar kinds of vegetation on coastal dunes. Their width is also connected with dune relief and coastal dynamics. The widest habitats are on accumulated part of dunes and narrower on abraded part (Isermann 2000).

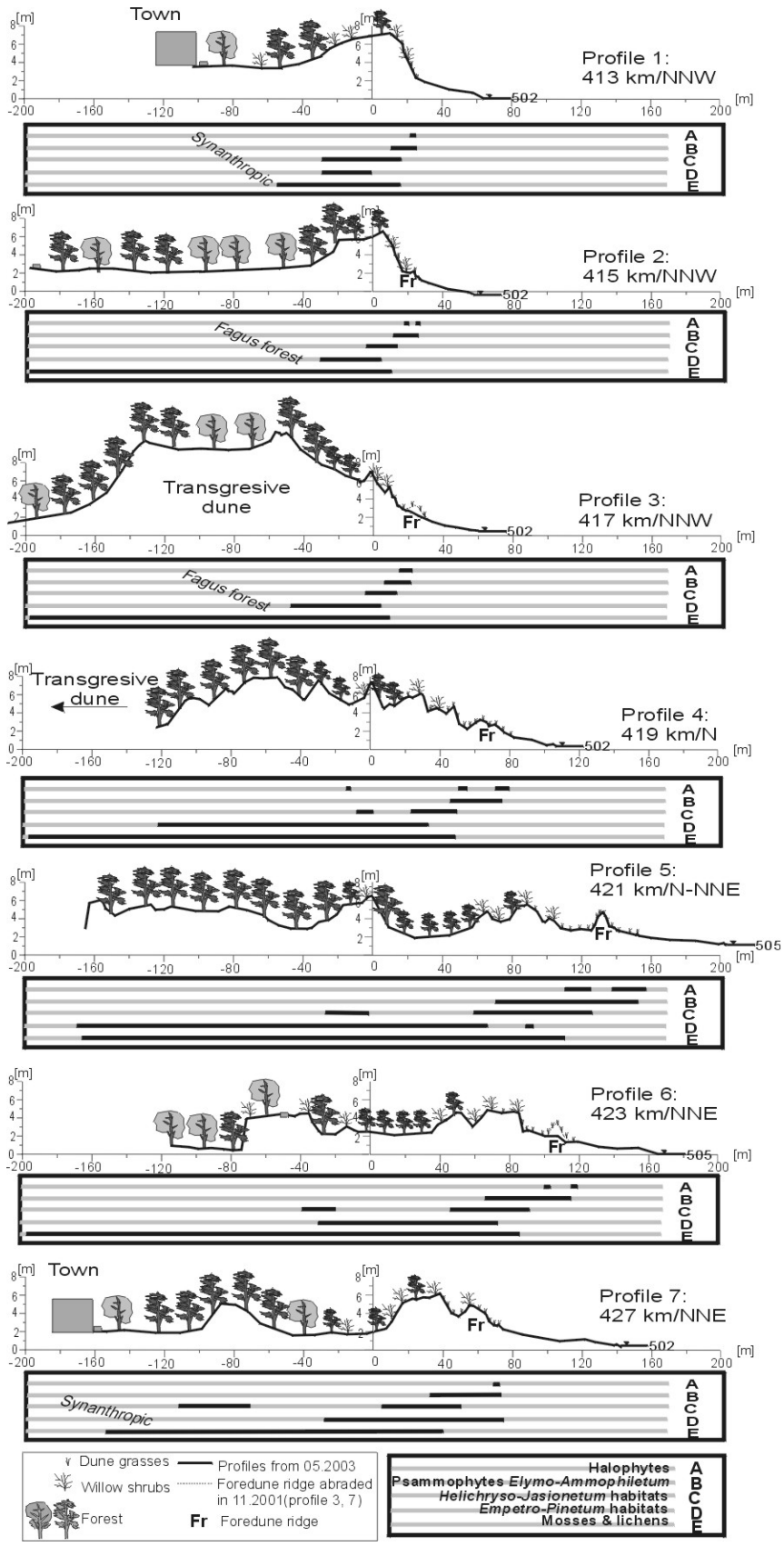

Figure 2: Morphology and plants habitats of the White Dunes of Świna Gate Barrier in year 2003 (profiles localisation marked on figure 1).

The wideness of plant habitats and species number is changing along the barrier with changing wideness of beach, dune ridges and deflation gutters between them (Figure 2). The widest habitats

grow in middle part of Wolin barrier. On coast where accumulation is low or not existing these habitats grow together on one abraded dune (in Międzyzdroje direction).

Plants	Dune hillocks			Blowouts		
	very dense	dense	rare	very dense	dense	rare
Honckenya peploides	+			+		
Ammophila baltica	+				+	
Ammophila arenaria	+					+
Elymus arenarius	+					+
Festuca rubra ssp. arenaria		+			+	
Cakile maritima		+			+	
Salsola kali		+			+	
Agropyron junceum		+				+
Petesities spurius			+			+
Phragmities communis			+			+

Table 3: Plants growing on the initial foredune field on the upper beach, Wolin part of Swina Gate Barrier (Łabuz 2003)

3.2 Influence of the human impact

Present day human impact on dunes is especially caused with increasing of tourism. On Polish part of barrier tourism is localised in two centres: Międzyzdroje and Świnoujście. Especially in touristic season human impact is the biggest one. Świnoujście and Międzyzdroje are health resorts opened whole year. In these towns beaches are „covered" by tourists. Beach management for tourism and recreation is causing beach plant vanishing as halophytic *Honcenya peploides*, *Cakile maritma* or *Salsola kali* and dune grass psammophytes (*Ammophila arenaria, Elymus arenarius*); (Figure 2, profile 1 & 7, lines A, B). This is clearly visible in Świnoujście town where a new dune due to wide beach should already be built but absence of plants (trampled all the year by people) on the beach lead to sand movement on still growing old foredune. People exploring (when tourists are doing physiological needs, sightseeing and heating) and crossing dunes are causing plant trampling and sand movement. In that way blowouts are appearing along footpaths on earlier fixed dunes. Only in middle part of Wolin barrier between 421 km and 418 km there are no tourist on dunes. Only beach is used for walks between these towns. So if tourists are rare there plants and dune relief can develop in natural conditions. Against tourists in these towns youngest dunes are fenced by steel line.

Sea sand sedimentation is greatest just next to the breakwaters as well as along the central part of the flat coast on Wolin. But increasing of the coast is the biggest on both banks of channel Świna protected by breakwaters. For example on air photos from 1937 waterline is localised where in 1996 existed second ridge – so increasing of coast and dune ridges is clearly visible. In Międzyzdroje exist mole that is crossing dunes and breaking sand transport along the coast from cliffs (Baraniecki and Racinowski 1996). Also close to the cliffed coast in east part of Międzyzdroje exist fishery harbour which completely destroyed dunes. In Świnoujście exist big harbour which completely changed dune surface on the Świna channel banks. Also touristic infrastructures in mentioned towns are localised on the dunes. But in Świnoujście due to coast progradation they are localised farther from the beach (there since 1942 to 2002 grown 300 m of the coast with two - three dune ridges).

In XVIII century during coastal harbour's development many of the forests were cut off. This was the beginning for transverse dunes development also on Świna Gate Barrier (Keilhack 1912, Prusinkiewicz and Noryskiewicz 1966). Aeolian processes caused landward transportation of uncovered sand from dunes. Now their heights reach 22 meters. Later, newly planted pine forests fixed them once again. Since that time a new white dunes have been growing.

On middle part of Wolin barrier on older dunes exist military area and a lot of fortifications from the Second World War that have been completely changed dunes ridges relief.

In relationship of coast accumulation coast protection on describing coast is still low. Only in towns, dunes are protected by branch fences against deflation and steel line fences against tourists. Also Świna channel mouth is protected by two long waterbreakers. Only in Międyzdroje protection consist of dune nourishment and some other interventions due to hotel Amber protection which is localised on first dune ridge. This structure is still dangered during winter storms. On the other hand people management leads to changes in specimen vegetation cover. The youngest pine plantation planted to stabilise dunes increased rate of forest habitat succession on herb dune habitats. In this way natural dune plant habitats are vanishing and with them vanishing some plant species (f.e. Sea holly - *Eryngium maritimum*).

4 Specified areas of coastal development

Along the barrier number and morphology of youngest ridges as dynamics of the beach are different in west, middle and east part of Wolin Island. Also on Uznam Island coastal dunes are different. The dynamics of these areas is different and caused by character of affecting on dunes factors, for example exposition on main wind stream, storm waves, human presence, plants dynamics.

4.1 Polish part of Uznam Island – Świnoujście town

On Uznam Island beaches are wide (110 – 130 m wide) but without plants and hillocks (caused by human impact). Accumulation exists only on the back of the beach - on old foredune ridge (7 m high). Very small embryo dunes and rare plants on beach are existing along 4 km of this part. Excerpt 426 km, where human impact is the biggest (it is the middle of the town beach). New foredune ridge is growing slowly on 427/428 km near country border (worth mention is wider and denser plants „carpet" covering more developed, 20 m wide piece of dunes laying between border fences) and faster on 425km - close to the waterbreaker. On 426 km where a lot of tourists are on the beach, accumulation exists only on the old dune. This ridge is still growing in height and intensive human impact stops new dune development (Figure 2, profile 7).

4.2 Western part of barrier on Wolin

In west part of barrier localised on Wolin Island ridges are smaller and closer each other (Figure 2, profile 6). The heights of dunes exceed 4 m. Depressions between them are narrow – about 15 m. Beach is flat, wide (100 m) and covered by small hillocks. But most common material on the beach is shell deflation pavement. Small embryo dunes and plants are there on upper beach. They become bigger in east direction. Since 1997 a new foredune ridge appeared on beach (1 – 2 m high) but was heavy affected during storms in autumn 2001 (water level 596-635 cm, see Table 1). This new, now cut of in many places ridge, starts to be rebuilt but again heavy storm in December 2003 (water level 594 cm) damage it. Human impact is there small because of difficult access caused by harbour areas.

4.3 Middle part of barrier on Wolin

In middle part ridges are higher but narrower. Depressions between them are wider (figure 2, profile 4, 5). Beach is still wide (70-90 m) and covered by large number of plants and by biggest dune hillocks. The field of aeolian accumulation on the beach is there the biggest one. Also there is the biggest number of youngest not-forested ridges. Since 1997 to 2001 a new foredune ridge appeared on beach (1 m high - now have 3 m). Year by year beach has been wider and covered by larger number of plants. These plants caused accumulation on the beach far from old foredune. In this way was built up a new foredune. It is consists of several hillocks jointed into irregular ridge. This new first ridge is also shaped by storm waves and then becomes real ridge parallel to the coastline. In east direction became wider but smaller (profile 4) and near Międzyzdroje exist as an embryo dunes/ hillocks on the beach (profile 3). Human impact is there the lowest one with only persons walking along waterline. This area has the biggest aeolian supply thanks to NE and W winds blowing all the year. Also plants succession on dunes seem to be the faster one.

4.4 Eastern part of barrier on Wolin – Międzyzdroje town

In east part (416 – 412 km) dunes are again high but narrow with mostly steep seaside slope (figure 2, profile 2, 1). Depressions and beach are narrow. Also plant number is smaller than in other parts. Near Międzyzdroje ridges, depressions and plants on the beach are vanishing. In Międzyzdroje exist only one ridge mainly covered by shrubs and artificially planted grasses. Beach is about 40 m wide. Also human impact on dunes and beach is again existing there.

5 Discussion

Decisive influences on development of sandy barriers have waves energy and constant delivery of sand (Bird 1969, Hesp, 1984, Psuty 1988, 1990, and others). Rate of every new dune development is not constant. It is varying in time due to wind and storm event presence. One year /season may be abundant in storms (like winter season 1995/6, 2001/02 or 2003/04 on studied area) or may be scare of it but very cold and abundant in ice sheets on coast, preventing beach against waves and stopping sand movements by wind. So climate changes have decisive influence on this process – may stop it, break or accelerate.

Coastal dunes come into being in result of aeolian accumulation of material blown from constantly supplied beach (Bird 1969, Hesp 1984, Carter, and Wilson 1990). Process this can reach the best development thanks to favourable wind speed, directions and influence of pioneer dune vegetation (Bird 1969, Psuty 1990, Hesp and Thom 1990, Arens 1994 and others). Winds existing in Świna Gate Barrier favour to dune development. This process is very rapid in middle part of Świna Gate Barrier.

The biggest efficiency for aeolian accumulation on beach has oblique wind to beach/ dune (Hesp and Thom 1990, Arens 1994). On investigated area the heaviest winds are oblique for part of coast exposed on NW and NE directions – outside of coast part on Uznam Island and west and eastern part of middle part of barrier on Wolin Island. That why there are observed the biggest embryo dunes covered by dense grass carpet. This is the visible sign of aeolian accumulation on the beach.

Plants break the wind speed causing sand accumulation and building up dunes (Bird 1969, Hesp 1984, Carter and Wilson 1990, Arens 1994 and others). A lot of plants growing on beaches of barrier causes aeolian accumulation also contemporary rare storms let to increasing of this process. Only increasing human impact can stop this development (Isermann and Krisch 1995). Now this process is observed in two towns localised on the barrier coast - Międzyzdroje and Świnoujście where aeolian processes are weak.

6 Conclusions

Developing coast and progradating dune system of middle Świna Gate Barrier is a rare phenomenon on Baltic coast. In present day on studied area belonging to Świna Gate Barrier are existing good conditions for dunes development. Mentioned factors favour to dune ridges development and vegetation succession. The wideness of plant habitats and species number is changing along the barrier with wideness of beach, dune ridges and deflation parts of coast.

First of all middle part of barrier on Wolin Island shows accumulative character of dunes. Other parts are under abrasion conditions (near Międzyzdroje) or under human impact (Świnoujście and Międzyzdroje). Seeing these processes Świna Gate Barrier can be divided into few different parts. One of them lies on Uznam Island where human activity stops aeolian accumulation on beaches. Second one lies on Wolin Island where we can find three different kinds of development. One of them is observed close to the waterbreaker in Świnoujście where shore sedimentation is big but aeolian accumulation is lower than in middle part. In middle part exist the biggest aeolian accumulation expressing in dune ridges growing. And last one near Międzyzdroje where abrasion and human activity stops aeolian processes and development of dunes is smaller than in other Wolin barrier parts.

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