INDEX COPERNICUS INTERNATIONAL

ORIGINAL ARTICLE

Bulletin of the Maritime Institute in Gdańsk

Changes of the Vistula River External Delta in the period of 2009-2014

Zmiany stożka ujściowego Wisły w okresie 2009-2014

Authors' Contribution:
A – Study Design
B – Data Collection
C – Statistical Analysis
D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
G – Funds Collection

Dr. Radosław Wróblewski [12CDEF], Prof. Stanisław Rudowski [1ADEF], Łukasz Gajewski [1C], MSc Patryk Sitkiewicz [2DE], Dr. Kazimierz Szefler [1EF], Dr. Maciej Kałas [1AC], MSc Jacek Koszałka [1B]

1 Maritime Institute in Gdańsk, Poland

2 University of Gdańsk, Poland

Article history: Received: 22.04.2015 Accepted: 11.06.2015 Published: 26.06.2015

Abstract: The aim of this study is to determine the state and changes of the Vistula Canal (Wisła Przekop) external delta relief, in the period of 2009-2014, and in relation to the assessment of the conditions of free runoff of the Vistula River waters. This is an important element for assessing the effectiveness of flood prevention in the area of Żuławy. The basis of the study are detailed bathymetry monitoring and morphometric measurements of the external delta with the supply channel. Modern equipment was used (mainly RTK and DGPS specialist navigation systems and multibeam echosounder), providing the obtainment of a digital model of the seabed surface, with decimeter accuracy of location points. In subsequent years, a series of bathymetric maps for the scale of 1:10 000 was made, as well as relief maps and maps of differential changes of the relief. The observed significant changes in the nature of the relief (with relatively small changes in the contours of the delta), indicate their important role in shaping the conditions of free runoff Vistula waters.

Streszczenie: Celem pracy jest określenie stanu i zmian rzeźby stożka ujściowego Wisły Przekop, w okresie lat 2009-2014, w relacji do oceny warunków swobodnego spływu wód Wisły. Stanowi to istotny element dla oceny skuteczności zapobiegania powodziom w rejonie Żuław. Podstawę badań stanowią szczegółowe, monitoringowe pomiary batymetrii i morfometrii stożka wraz z kanałem doprowadzającym. Stosowano nowoczesną aparaturę (głównie DGPS RTK i specjalistyczne systemy nawigacyjne oraz echosondę wielowiązkową) zapewniającą uzyskanie cyfrowego modelu powierzchni dna, z decymetrową dokładnością położenia punktów. W kolejnych latach wykonano serię map batymetrycznych dla skali 1:10 000, map rzeźby i map różnicowych zmian rzeźby. Stwierdzone znaczne zmiany charakteru rzeźby (przy względnie niewielkim zmianach konturów stożka), wskazują na ich istotna rolę w kształtowaniu warunków swobodnego spływu wód Wisły.

Introduction

An area of the Vistula River estuary is a vast, low-lying area of Żuławy, which is the inland Vistula Delta, with numerous arms and channels (Fig. 1). In 1895 a canal leading Vistula waters directly to the Gulf of Gdansk (*vide* Łomniewski 1960; Majewski 1969) was made here, bypassing the natural end of the trough running through Gdańsk (Fig. 2). The aim of the investment was and is the prevention of flood risk in the city and Żuławy due to congestion in the bed of the Vistula River. Upon opening the canal, the process of forming a new mouth fan started, outgoing beyond the Vistula delta range, known as the external delta (*vide* Koszka-Maroń 2009).

Surveys of the mouth fan of the Vistula River has been ongoing for many years (*vide* Graniczny *et al.* 2014; Kozakiewicz 2005; Łomniewski 1960; Majewski 1969; Słomianko 1956; Gajewski & Rudowski 1997; Lubomirski *et al.* 1999), since the creation of the ditch. Very rich material was collected, with which was recently summarized to the fullest in the work of D. Koszka-Maroń (2009, 2014), which is the essential basis for further monitoring studies.

The state and changes occurring in the estuary mouth of the Vistula River are important for assessing the flood risk relation to the conditions of free runoff of Vistula waters and flowing ice.

The basis for the survey of the estuary are the bathymetric surveys, carried out in subsequent years, using new, innovative

BMI 2015; 30(1): 16-22 DOI: 10.5604/12307424.1158154 www.bullmaritimeinstitute.com

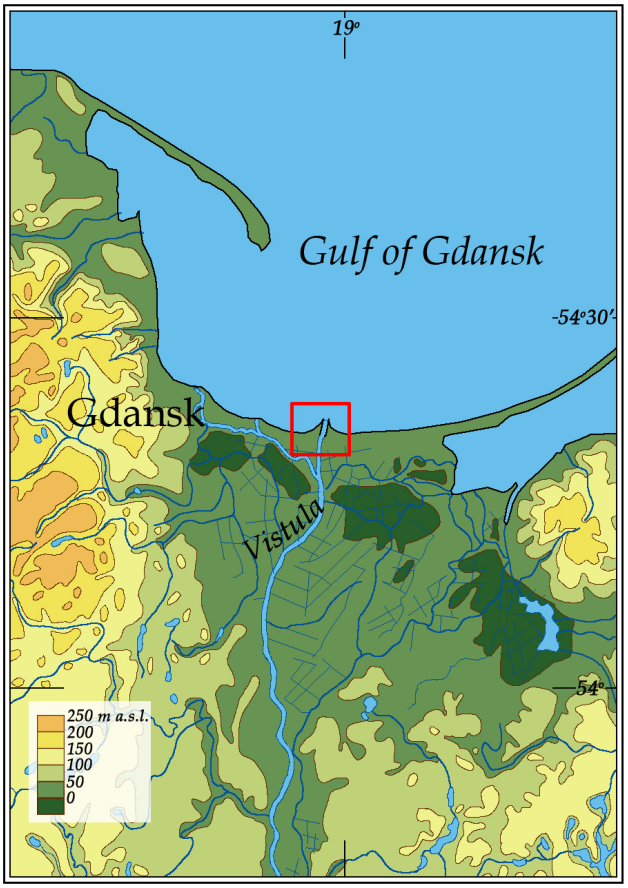

Fig. 1. Location of the study area (drown by R. Wróblewski)

and more accurate methods. The results of detailed monitoring research, conducted by the Maritime Institute in Gdansk in 2009-2014, were presented (Brzezińska *et al.* 2009; Kałas *et al.* 2013a, 2013b; Staśkiewicz *et al.* 2010, 2011; Szefler *et al.* 2014). These measurements allowed the preparation of the digital model of bathymetry and bottom morphology and then the development, of bathymetric isobaths maps for individual situations (Fig. 3), bathymetric profiles (Fig. 4) and relief maps (Fig. 5). The changes in bathymetry and essential units of the estuary relief were presented. The obtained results are of fundamental importance for the assessment of the estuary and tendencies of its development and thus for assessing the effectiveness of flood management, and direct and indirect impacts on its form and the environment of the shore.

This is the first study of a series of further monitoring and thematic studies (e.g. granulation, structure, hydrology and hydrodynamics, etc.), which are planned to be carried out in the upcoming years (with the continuation of bathymetric-morphometric studies.

Materials and Methods

Field work was performed in the years of 2009-2014. Registrations were carried out with a surveying cutter - IMOR-OS II. The Reson Seabat 7101 multibeam echosounder and Deso 15 single beam echosounder were used (in the shallows of the estuary that has a depth of less than 5 meters). The obtained bathymetric data was corrected in relation to the speed of sound propagation in water (measured by the Reson SVP 15 meter) and related to the level of the NN Amsterdam 1955. The location was performed using the DGPS Trimble RTK 851 navigation system in the „1992" (WGS84 ellipsoid) coordinate system. Data were collected and developed digitally in the Quinsy 8.1 System. In addition, direct measurements were performed of the current course of the coastline, and periodically emergent backwaters and sandy islands.

A detailed description of the used measurement equipment and the used survey methods is presented in the reports from different stages of research (Kałas *et al.* 2013a, 2013b; Staskiewicz *et al.* 2009, 2010, 2011).

Results

On the basis of the bathymetric maps of estuary mouth from consecutive years, a sketch was presented of the relief character including its main units: the supply channel and distribution channels, delta plain, delta front, and prodelta (Fig. 5). The resulting abundant collection of bathymetric data allowed the creation of a digital model of the bottom surface with high resolution, and then the creation of differential maps showing the changes of bathymetry and morphometry (Fig. 6 & 7).

The measurement results from previous years have a much less accurate location of points (both flat and depth coordinates) and can be used only for very general comparative analysis of the results of current research results.

Formerly a comparative analysis was used through mapping changes in positions of the selected bottom contours (plotted from line profiles). Mainly isobaths 0 m, 5 m, 10 m and 15 meters were used). However, the course of the bottom contours does not correspond to the contours of the main forms of estuary. The character of the seabed relief was developed on the basis of a detailed bathymetric map (scale 1:10 000, with a cut of bottom contours of 0.25 m).

Geomorphological determining of forms was made in relation to synthetic studies of deltas (mainly Allen 1970; Chudzikiewicz *et al.* 1979; Coleman & Prior 1981; Gradziński *et al.* 1976; Reineck & Singh 1980) and trough flows (Babiński 1992; Giżejewski 1973; Pasierbiewicz 1976; Zwoliński 1998).

Four main units of the seabed relief were identified with smaller mesoforms and microforms within them. These are: the supply channel – Vistula Ditch (with sand point bars and pools), Delta Plain (with distribution channels, bars, shoals and islands), Delta Front and Prodelta.

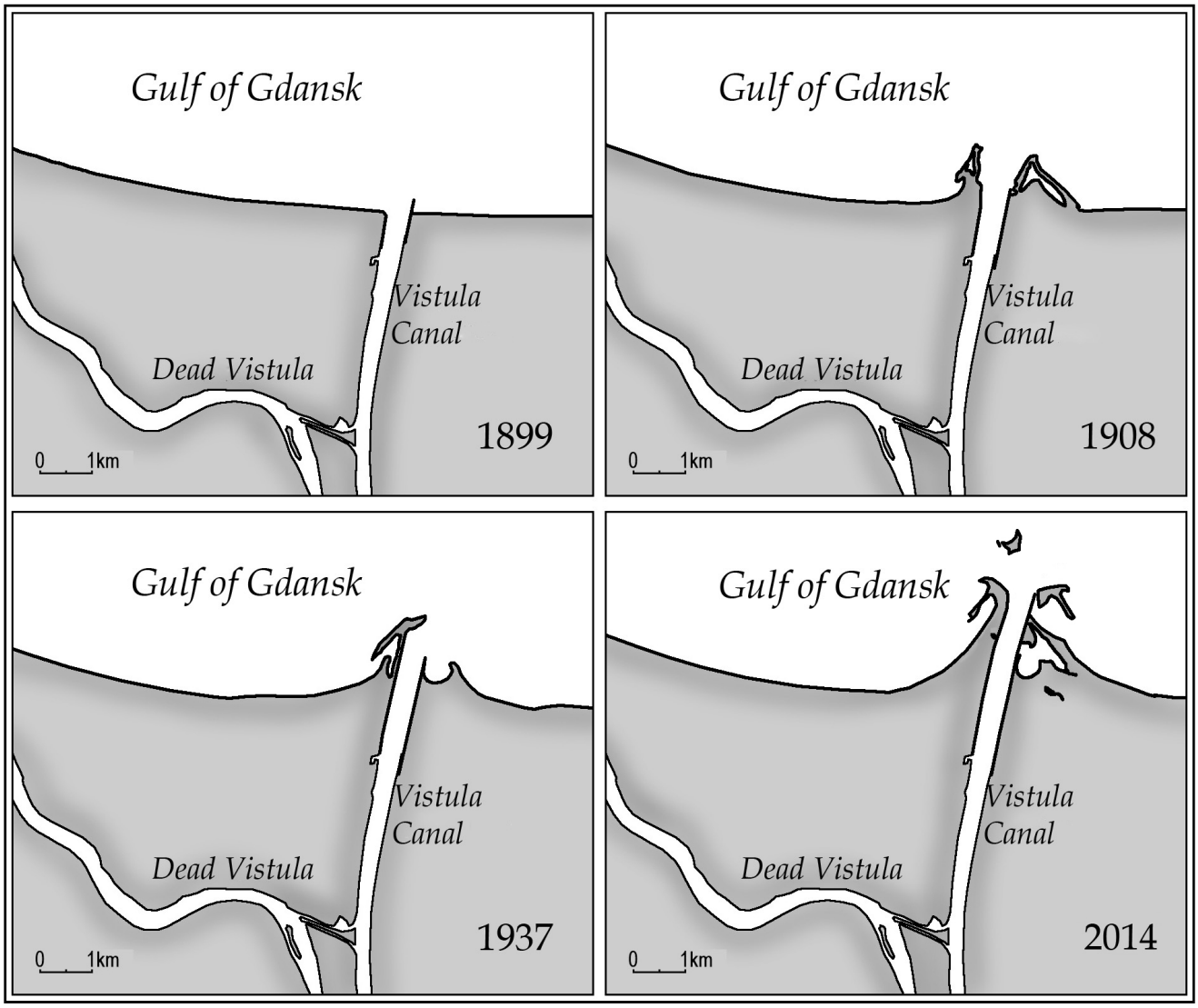

Fig.2. Changes of the Vistula outflow in period of 1899–2014 (drown by R. Wróblewski).

Supply channel

The Vistula Canal is an artificial channel leading Vistula waters to the lagoon, which flow over the delta estuary, which is being formed. The Vistula Ditch channel, along with the part contained by the breakwaters on the bottom of the Gulf of Gdańsk, has a length of about 3 kilometers and a width of about 500 meters. The channel bottom depth distribution is variable (Fig. 3, 4 & 5), from bars (even < 1 m) and pools reaching 7 meters deep. The distribution of bars and pools was subjected to changes in subsequent years (Fig. 5).

Delta Plain

The Vistula Delta is a young, but already well-shaped, underwater delta, with a clearly formed delta plain, slope of the delta front and prodelta. The area of the delta plain, with a depth of approximately 2-5 meters has denivelations to 2 meters, with bars and troughs of distribution channels and parts of shallow water with islands.

It draws attention to the change of the distribution channels as a result of the formation of shoals and islands in the front of the estuary. In 2009, there was only one distribution channel (Fig. 5A) running in the extension of the supply channel. In the following years (Fig. 5B-H) this channel underwent division and/or branching, with side channels, bypassing the frontally located island in, and other smaller arms of, the estuary.

Delta Front

The edge of the delta plain, located at the depth of 3-5 meters, is usually mildly outlined, locally acute in places of recent erosion cuts. The upper part of the slope is gentle of a few degrees, and has a depth of about 5 meters. Below (to a depth of 11-12 m), the slope is steeply inclined to about 15°,

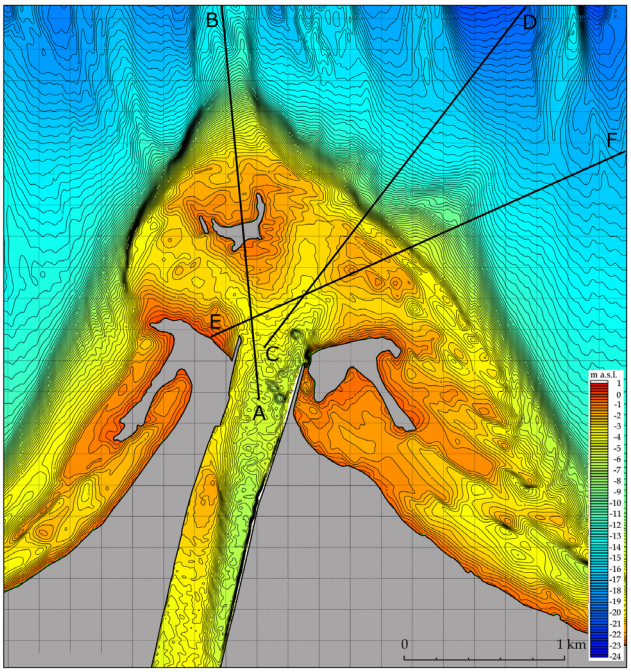

Fig.3. Bathymetric map of the Vistula River External Delta, October 2014. Locations of bathymetric profiles (Fig. 4) are shown.

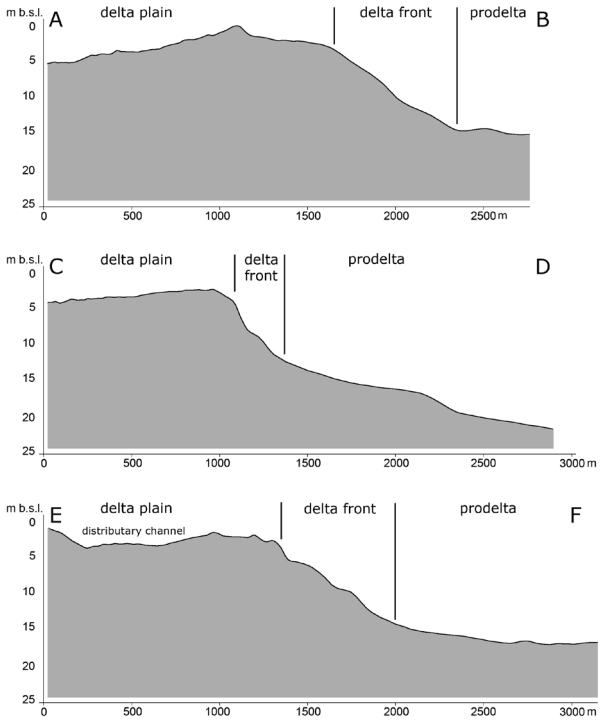

Fig.4. Bathymetric profiles across the Mouth Fan. Their locations are shown on Fig. 3.

and then (to about 15-16 m), the slope of the delta front is gently inclined about 5° and borders with the prodelta.

Prodelta

The prodelta in this case is the part of the seabed situated below the delta front, generally very weakly inclined (less than

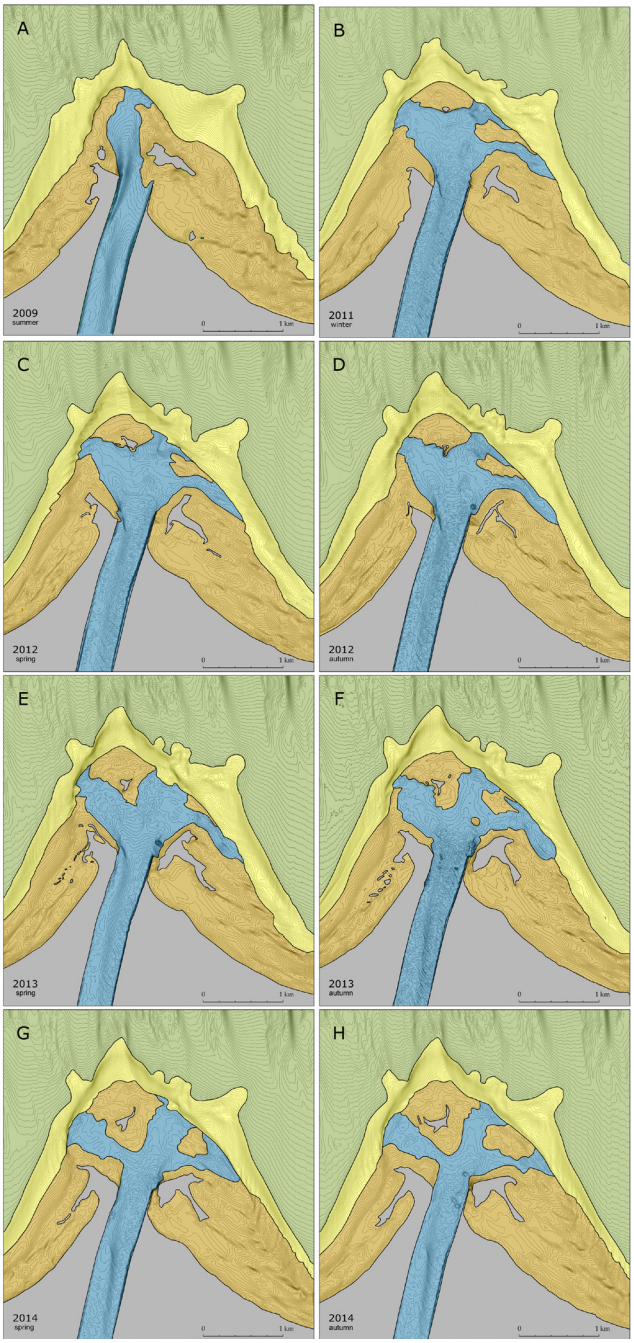

Fig.5. Geomorphological sketch of the Vistula River External Delta in years 2009-2014 (a-h).

3°). There are long, rounded forms of ridges, with gradually decreasing dimensions, entering far into the open body of water, even at a depth of over 20 meters.

The changes of the Vistula River estuary mouth relief in the years of 2009-2013

The changes of the mouth include both the changes of its outline as well as changes ofand the character of its surface. The changes of the mouth's outline were hitherto assessed on the basis of the changes of the location of 0, 5, 10 and 15 meter isobaths. The 5 meter isobaths corresponds to the delta plain/del-

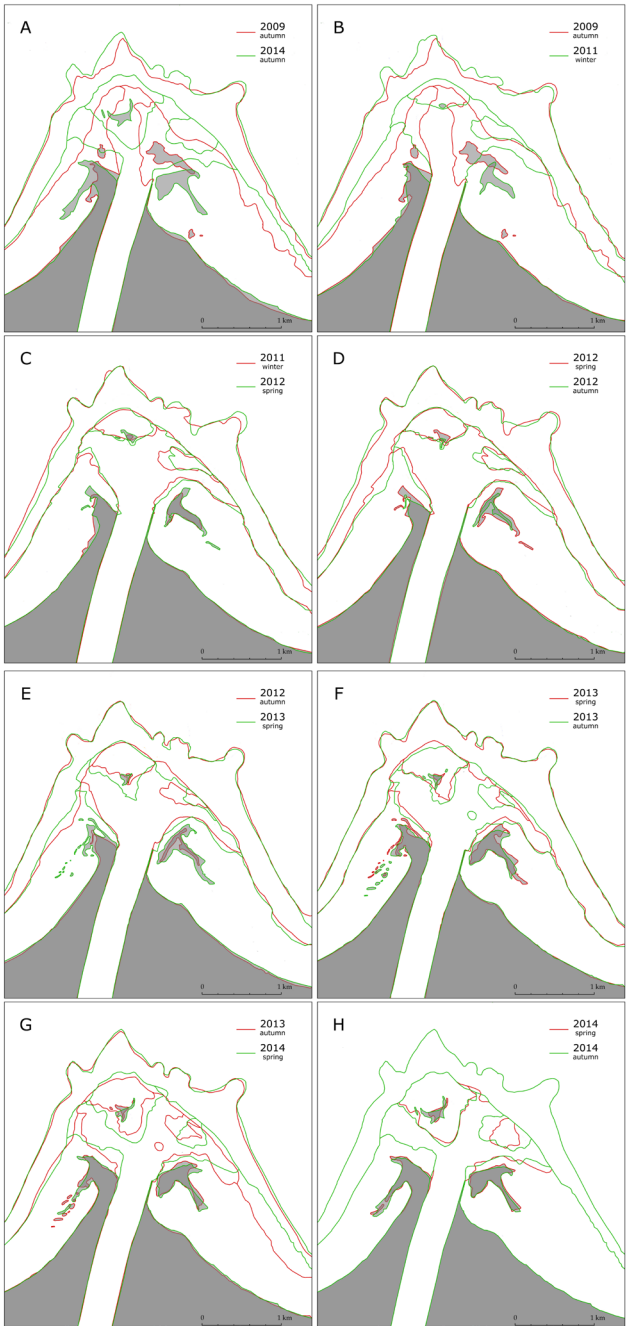

Fig. 6. Differential maps of location of borders units: delta plain/delta front and delta front/prodelta in years 2009-2014.

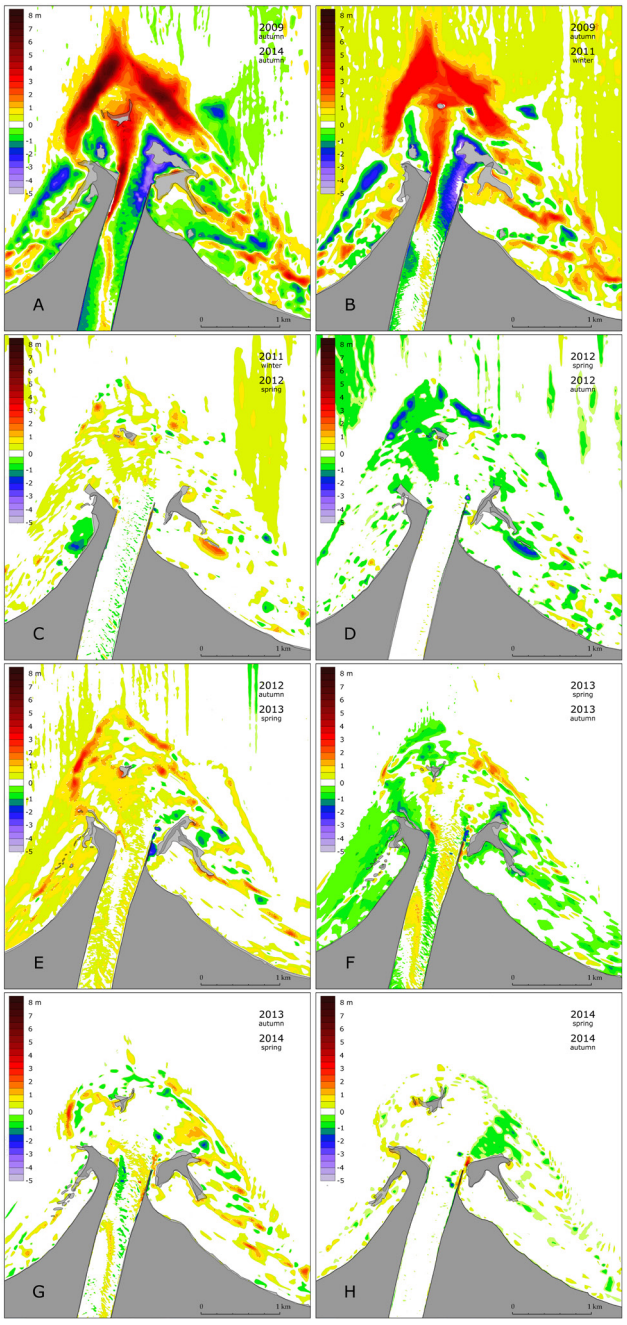

Fig.7. Differential maps of bathymetry of the Vistula River External Delta in years 2009-2014.

ta front outline, 10 meter isobaths to the delta front / prodelta; and 15 meter isobaths to the prodelta range. These isobaths were outlined on the basis of the location of adequate points on bathymetric profiles, which inevitably had limited accuracy of coordinate designation. The methods used in the presented study allow to obtain the cloud of points with precise coordinates, suitable for the development of a digital model of the bottom, and accurate maps. Based on the analysis of maps, the outlines of the contours of the mouth were plotted (delta plain border, the basis of the delta front and the prodelta range). They have variable depth values along the line of their location. Thus, the location of the selected isobaths do not match the position of the form's contours, which is visible even more clearly in differential studies.

Differential Studies of individual maps (Fig. 6 & 7) in the investigation period showed little change in the contours of the mouth, with great changes in the supply channel. Significant changes were however found in the relief character, especially the surface of the delta plain. This is clearly manifested by the changes of the position of channels and shoals.

In 2009, a single (Fig. 5A), relatively straightforward extension of the distribution channel constituted a supply channel, with

a conveniently open mouth. Reaching through the delta plain to its front, allowed free flow of the Vistula River waters. In the following years, the formation and development of the shallows in front of the delta plain (probably under the influence of changes in the supply of sediment, wave motion, the effects of dredging at the mouth of the supply channel, etc.) caused the separation of the distribution channel into two or even three arms. Such situations cause difficulties in collecting water and threaten the formation of sand dams by front bars and also by the accumulation of flowing ice.

Summary and conclusions

A true, highly accurate cartographic picture of the changes in relief was obtained and presented, which is the indispensable basis for further monitoring surveys and methodological studies.

The relief and changes of the estuary mouth indicate

- variable and meandering nature of the mainstream in the supply channel, shuffled from side to side and forming both bars and pools;
- gradual, slight increase of the delta plain and mouth front, in its central and eastern part;
- the far away taking out of bed material (accumulation streaks by K. Łomniewski 1960), which in the absence of forms indicating the along the shore transport demonstrates a lack of sediment supply for its construction cone as a result of wave motion (Słomianko 1956);
- indicative importance of the delta plain relief and especially the course of distribution channels, manifesting the difficulties in the flow of the Vistula waters which may pose a threat of flooding associated with the formation sandbar dams or heaps of ice.

The clear and slight increase of the estuary mouth was identified in its central and side right part of the front. Erosion usually occurred in the supply channel and on the front of the mouth, on the west side. Shoals and islands of varying size and in various positions, occurred periodically. The occurrence of large, elongated mouths at the bottom of the delta front, reaching the depth of 17-20 meters, indicated-ing little effect of waves on the state of the mouth during this period and the lack of clear lateral sediment transport, toward the east, on the shores of the Vistula Spit.

References:

[1] Allen J. R. L. (1970). Sediments of the modern Niger delta, a summary and revue. In: Deltaic sedimentation, modern and ancient. J. M. Morgan & R. H. Shaver (eds.). The Society of Economic Paleontologists and Mineralogists Special Publication 15: 138-151.

[2] Babiński Z. (1992). Współczesne formy korytowe dolnej Wisły. Inst. Geografii i Przestrzennego Zagospodarowania PAN, Prace Geograficzne 157: 1-171.

[3] Brzezińska A., Gajewski Ł., Hac B., Kałas M. , Nowak J., Rudowski S., Rybka K., Staśkiewicz A., Szefler K., Zelewska I. (2009). Badania batymetryczne ujścia przekopu Wisły. WW IM Nr 6469, Instytut Morski w Gdańsku, 17 p.

[4] Chudzikiewicz L., Doktor M., Gradziński R., Haczewski G., Leszczyński S., Łaptaś A., Pawełczyk J., Porębski S. J., Rachocki A., Turnau E. (1979). Sedimentation of modern sandy delta in Lake Płociczno, West Pomerania. Studia Geologica Polonica, Wyd. Geol., Warszawa. v. 53, 61 p.

[5] Coleman J. M., Prior D. B. (1981). Deltaic sand bodies. Coastal Studies Institute, Louisiana State Univ. AAPG Special Volumes, Tulsa, USA.

[6] Gajewski L., Rudowski S. (1997). Zmiany erozyjne stożka usypowego Wisły w okresie od 1980 do 1996. Mat. Konf. Nauk. Techn. „Ekonomiczno-Techniczne problemy ujściowego odcinka Wisły" 5 grudnia 1997, Politechnika Gdańska, 56-60.

[7] Giżejewski J. (1973). Uwagi o terminologii i klasyfikacji struktur sedymentacyjnych osadów rzecznych. Przegląd Geologiczny, 11: 602-607.

[8] Gradziński R., Kostecka A., Radomski A., Unrug R. (1976). Sedymentologia. Wyd. Geol., Warszawa, 614 p.

[9] Graniczny M., Janicki T.,. Kowalski Z, Koszka-Maroń D., Jegliński W., Uścinowicz W.,

[10] Zachowicz J. (2004). Recent development of the Vistula river outlet. PIG Spec. Papers 11: 103-108.

[11] Kałas M., Rudowski S., Lisimenka A., Nowak J., Spacjer R., Edut J., Gajewski Ł., Nowak J., Spacjer R., Konieczny W., Szyłejko W., Sosnowski D. (2013a). Monitoring zmian warunków batymetrycznych w obszarze stożka usypowego oraz przyujściowego odcinka Wisły. WW Instytutu Morskiego w Gdańsku Nr 6740.

[12] Kałas M., Rudowski S., Lisimenka A., Wróblewski R., Gajewski Ł., Nowak J., Spacjer R., Konieczny W., Szyłejko W., Sosnowski D. (2013b). Monitoring zmian warunków batymetrycznych w obszarze stożka usypowego oraz przyujściowego odcinka Wisły. WW Instytutu Morskiego w Gdańsku Nr 6810, 1-40.

[13] Kozakiewicz A., Ostrowski R. (2005). History and optimisation of the Vistula Outlet at Świbno (w:) W. Majewski i M. Robakiewicz (red.), Sediment Transport in Rivers and Transitional Waters. Proc. Conf. May 18-22 2005, Centre of Environmental Engineering and Mechanics, Institute of Hydro-Engineering PAS, Gdańsk, Book of abstracts, 20-24.

[14] Lisimenka A., Kałas M. and Rudowski S. (2013). Quantification of bedform roughness development in the Vistula River Mouth using multibeam echosounder bathymetry data. Conf. on Underwater Acoustics, Ed. J. S. Popodokis & L. Bjorne. Corfu, Greece 23-28 June 2013, 1421-1426.

[15] Łomniewski K. (1960). Ujście Wisły. Rocznik Polskiego Tow. Geologicznego, 29, z. 4. Kraków, 391-418.

[16] Majewski A. (1969). Rozwój hydrograficzny delty Wisły w okresie historycznym. Przegląd Geofizyczny, z.1, 3-42.

[17] Pasierbiewicz K. (1976). Prądowe formy depozycyjne występujące na dnie koryt aluwialnych w świetle badań laboratoryjnych. Postępy Nauk Geologicznych 7: 1-46.

[18] Reineck H.-E., Singh I. B. (1980). Depositional sedimentary environments. Springer Verlag, Berlin, 549 p.

[19] Słomianko P. (1956). Studium zapiaszczania ujścia Wisły pod Świbnem. Prace Instytutu Morskiego, Gdańsk, 10: 85-103.

[20] Staśkiewicz A., Gajewski J., Lisimenka A., Rudowski S., Przedrzymirska J. (2009). Szczegółowe badania batymetryczne stożka usypowego Wisły i jej przyujściowego odcinka w celu identyfikacji zjawisk hydrodynamicznych wpływających na ukształtowanie dna. WW IM Nr 6499, Instytut Morski w Gdańsku.

[21] Staśkiewicz A., Kałas M., Lisimenka A., Rudowski S. (2010).Szczegółowe badania aktualnych warunków istniejących w obszarze stożka usypowego Wisły powstałych w wyniku przepływu fal powodziowych w 2010 r. WW IM Nr 6569,Instytut Morski w Gdańsku.

[22] Staśkiewicz A., Kałas M., Lisimenka A., Rudowski S. Meler W., Szyłejko W., Szefler K., Konieczny W. (2011). Szczegółowe badania batymetryczne w ramach monitoringu stożka usypowego Wisły i jej odcinka przyujściowego. WW IM Nr 6648, Instytut Morski w Gdańsku

[23] Szefler K., Lisimenka A., Kałas M., Wróblewski R., Rudowski S. (2014), Geomorphology and changes of the Vistula River External Delta induced by fluvial and marine processes, 19th Congress of the Asia and Pacific Division of the International Association for Hydro-environment Engineering and Research IAHR-APD 2014, 21-24 September 2014, Water Resources University, Hanoi, Vietnam. 1-4.

[24] Zieliński T. (1998). Litofacjalna identyfikacja osadów rzecznych, In: E. Mycielska-Dowgiałło (eds.) Struktury sedymentacyjne i postsedymentacyjne w osadach czwartorzędowych i ich wartość interpretacyjna. Wydz. Geografii i Studiów Regionalnych Uniwersytetu Warszawskiego. Warszawa, 193-260.

Word count: 2200 Page count: 7 Tables: – Figures: 7 References: 24

Scientific Disciplines:

DOI: 10.5604/12307424.1158154

Full-text PDF: www.bullmaritimeinstitute.com/fulltxt.php?ICID=1158154

Cite this article as: Wróblewski R., Rudowski S., Gajewski Ł., Sitkiewicz P., Szefler K., Kałas M., Koszałka J.: Changes of the Vistula River External Delta in the period of 2009-2014: BMI 2015; 30(1): 16-22

Competing interests: The authors declare that they have no competing interests.

Corresponding author: Stanisław Rudowski, e-mail: starud@im.gda.pl