A human-influenced soil sequence in the Vistula River delta (Gdańsk, Poland)

Piotr Hulisz, Magdalena Lazarus, Marcin Świtoniak, Przemysław Charzyński

The research area includes right embankments of the Dead Vistula (Sobieszewska Pastwa, Sobieszewska Island) which is the right natural mouth of the Vistula River to the Baltic Sea. It was cut off from the mainstream by the construction of the artificial channel called the Vistula Cut in Świbno (1889–1895) and the lock in Przegalina (1914–1917) (Makowski, 1995). According to Kondracki (2014) it is a part of the Żuławy Wiślane – a mesoregion that was formed as a result of both alluvial processes and human activity (mostly drainage). The nearest city is Gdańsk (Sobieszewo district).

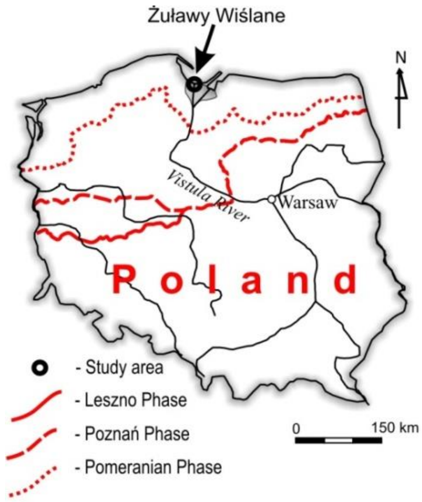


Fig. 1. Location

Lithology and topography

The Vistula River delta constitutes a vast delta plain. The whole area is geologically young and started forming around 6,000 years ago in connection with water level rises in the Baltic Sea during successive transgressions (Augustowski, 1972; Starkel, 1988). The area is flat and only slightly elevated above sea level. It is cut by river beds, drainage channels and ditches. A certain variety is added to the landscape by embankments built along larger watercourses (Mojski, 1990). The delta is built from different sediments, namely: riverine (sands and silts) and lake-swamp (clays, gyttja, peats). The largest area is occupied by alluvial soils (Witek, 1965). The construction of the Vistula Cut and the regulation works at the river mouth significantly contributed to the enlargement of the land area and transformation of the soil cover (Hulisz et al., 2015).

Land use

Due to the large hydrographical anthropogenic transformations, the Vistula River delta is an area of great agricultural importance. Meadow communities, especially prevalent on the river embankments, have a small share. Also, in swampy places or along the riverbeds, rushes develop. As a result of the separation from the main river course and thus greater inflow of brackish Baltic waters, an increase in water salinity is observed (Cyberski and Mikulski, 1976). This favours the local development of halophilous vegetation such as *Juncus gerardii*, *Aster tripolium*, *Glaux maritima* and *Plantago winteri* (Markowski, Stasiak, 1984; Lazarus and Wszałek-Rożek, 2016).

Climate

The region is located in the warm temperate, fully humid climate zone with warm summer (Kottek et al., 2006). The average annual air temperature for the period 1971–2000 is 8.7°C and the average annual precipitation is 515 mm (Filipiak et al., 2004). Winds from SW, W and NW directions prevail in this region. The average annual wind speed in the coastal zone may exceed 5 $m \cdot s^{-1}$, while in the interior zone only 2 $m \cdot s^{-1}$ (Kwiecień and Taranowska, 1974). Strong winds (above 10 $m \cdot s^{-1}$) occur for ca. 70 days a year (Kwiecień, 1990).

Profile 1 – Eutric Fluvic **Gleysol** (Arenic, Nechic, Protosalic)
Localization: Sobieszewska Pastwa, flat terrain, flood zone, 2 m a.s.l., reed rush (*Phragmitetum australis*)
N 54°19'9.42" **E** 18°51'48.61"

Morphology:

Az – 0–5 cm, humus horizon, sand, brownish black (10YR 2/2, moist), slightly moist, fine weak granular/single grain structure, fine and few roots, earthworm channels, moderately salty, irregular and diffuse boundary;

Az2 – 5–15 cm, humus horizon, sand, brownish brown (10YR 4/1, moist), slightly moist, weak granular/single grain structure, fine and very few roots, strongly salty, irregular and diffuse boundary;

Clz – 15–45 cm, sand, yellowish brown (2.5Y 6/3, moist), moist, single grain structure, medium and single roots, strongly salty, single weak iron concretions, smooth and diffuse boundary;

Clz2 – 45–(60) cm, sand, yellowish brown (2.5Y 5/3, moist), wet, single grain structure, strongly salty, iron concretions, fine and very few roots.

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm										Textural class
		> 2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.1	0.1-0.05	0.05-0.02	0.02-0.005	0.005-0.002	< 0.002	
Az	0–5	0	1	21	48	16	10	2	1	0	1	S
Az2	5–15	0	1	22	51	17	6	1	1	0	1	S
Clz	15–45	0	1	19	54	17	3	1	1	0	4	S
Clz2	45–(60)	0	1	29	55	13	2	0	0	0	0	S

Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	St [$g \cdot kg^{-1}$]	pH		C/N	C/S	$CaCO_3$ [$g \cdot kg^{-1}$]	EC_e [$g \cdot kg^{-1}$]
					H_2O	30% H_2O_2				
Az	0–5	19.2	1.88	2.82	6.3	4.1	10	7	1.00	3.89
Az2	5–15	6.70	0.70	1.60	6.2	4.5	10	4	0.00	4.12
Clz	15–45	1.00	-	1.96	6.4	4.5	-	1	1.00	4.05
Clz2	45–(60)	0.20	-	1.72	6.5	4.2	-	<1	0.00	5.12

Profile 2 – Eutric Fluvic **Gleysol** (Siltic, Protosalic)
Localization: Sobieszewska Pastwa, flat terrain, flood zone, 2.5 m a.s.l., unused meadows (*Molinio-Arrhenatheretea* class) transforming into herbaceous/rush communities, **N** 54°19'11.60" **E** 18°51'49.08"

Morphology:

Az – 0–12 cm, humus horizon, very fine sandy loam, brownish black (10YR 2/2, moist), moist, fine weak granular structure, fine/medium and few roots, earthworm channels, strongly salty, sharp and clear boundary;

Clz – 12–30 cm, very fine sandy loam, yellowish brown (2.5Y 5/1, moist), moist, medium moderate subangular structure, strongly salty, weak iron concretions, smooth and diffuse boundary;

Clz2 – 30–(60) cm, silt loam, yellowish brown (2.5Y 4/1, moist), wet, medium weak subangular structure, strongly salty, iron concretions.

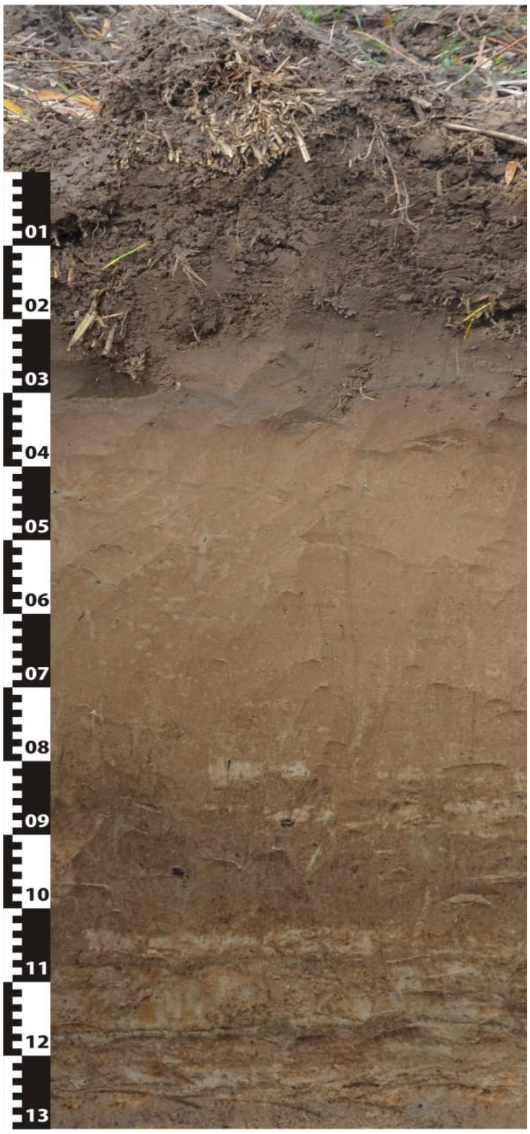
Table 3. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm										Textural class
		> 2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.1	0.1-0.05	0.05-0.02	0.02-0.005	0.005-0.002	< 0.002	
Az	0–12	0	0	5	8	18	41	13	7	2	6	VFSL
Clz	12–30	0	0	1	2	13	37	18	11	5	13	VFSL
Clz2	30–(60)	0	0	1	1	1	9	37	23	9	19	SiL

Table 4. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	St [$g \cdot kg^{-1}$]	pH		C/N	C/S	$CaCO_3$ [$g \cdot kg^{-1}$]	EC_e [$g \cdot kg^{-1}$]
					H_2O	30% H_2O_2				
Az	0–12	71.3	6.74	2.08	6.8	4.8	11	34	1.00	4.30
Clz	12–30	8.60	-	2.16	8.0	4.2	-	4	4.00	5.24
Clz2	30–(60)	8.40	-	1.78	8.2	7.4	-	5	16.0	8.08

Profile 3 – Eutric Endofluvic Endostagnic **Cambisol** (Aric, Loamic, Bathygleyic)
Localization: Sobieszewska Pastwa, flat terrain, inter-embankment zone, 3.5 m a.s.l., arable field
N 54°19'13.42" **E** 18°51'52.69"



Morphology:

Ap – 0–20 cm, plough humus horizon, sandy loam, brownish black (10YR 3/2), moist, medium weak granular structure, very fine and common roots, earthworm channels, abrupt and smooth boundary;

Ap2 – 20–30 cm, plough humus horizon, sandy loam, brownish gray (10YR 5/1), slightly moist, medium weak subangular structure, very fine and few roots, abrupt and wavy boundary;

Bw – 30–80 cm, sandy loam, yellowish brown (10YR 5/6), slightly moist, medium weak subangular structure (platy in the upper part), very fine and few roots, common mottles, very few small manganese and iron concretions, diffuse and smooth boundary;

C – 80–90 cm, layered loamy fine sand, light gray (10YR 8/1, 60%) and brown (10YR 4/4, 40%), slightly moist, medium weak subangular structure, few small manganese and iron concretions, clear and smooth boundary;

(Ab)C – 90–105 cm, sandy loam, brown (10YR 4/4, moist), slightly moist, fine weak subangular structure, few small manganese and iron concretions, clear and smooth boundary;

C(l) – 105–(130) cm, layered sandy loam, light gray (10YR 8/1), slightly moist, single grain structure, layered, many orange (7.5YR 6/8) and yellowish brown mottles (10YR 5/6), iron concretions.

Table 5. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm										Textural class
		> 2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.1	0.1-0.05	0.05-0.02	0.02-0.005	0.005-0.002	< 0.002	
Ap	0–20	0	0	1	3	33	25	18	7	4	9	SL
Ap2	20–30	0	0	1	3	31	31	14	7	5	8	SL
Bw	30–80	0	0	0	2	40	25	18	5	2	8	SL
C	80–90	0	0	0	1	46	34	11	2	1	5	LFS
(Ab)C	90–105	0	0	0	3	43	24	12	6	3	9	SL
C(l)	105–(130)	0	0	0	1	44	28	19	3	1	4	SL

Table 6. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	Nt [g·kg^{-1}]	St [g·kg^{-1}]	pH		C/N	C/S	$CaCO_3$ [g·kg^{-1}]	EC_e [g·kg^{-1}]
					H_2O	30% H_2O_2				
Ap	0–20	11.3	0.92	1.64	5.9	3.1	12	7	1.00	0.25
Ap2	20–30	9.80	0.89	1.82	6.0	3.1	11	5	1.00	0.56
Bw	30–80	3.90	-	1.68	6.3	4.3	-	2	0.00	0.42
C	80–90	1.50	-	1.82	6.9	5.2	-	1	1.00	0.68
(Ab)C	90–105	2.90	-	1.98	7.3	5.8	-	2	1.00	0.92
C(l)	105–(130)	1.60	-	2.04	7.7	6.8	-	1	1.00	0.35

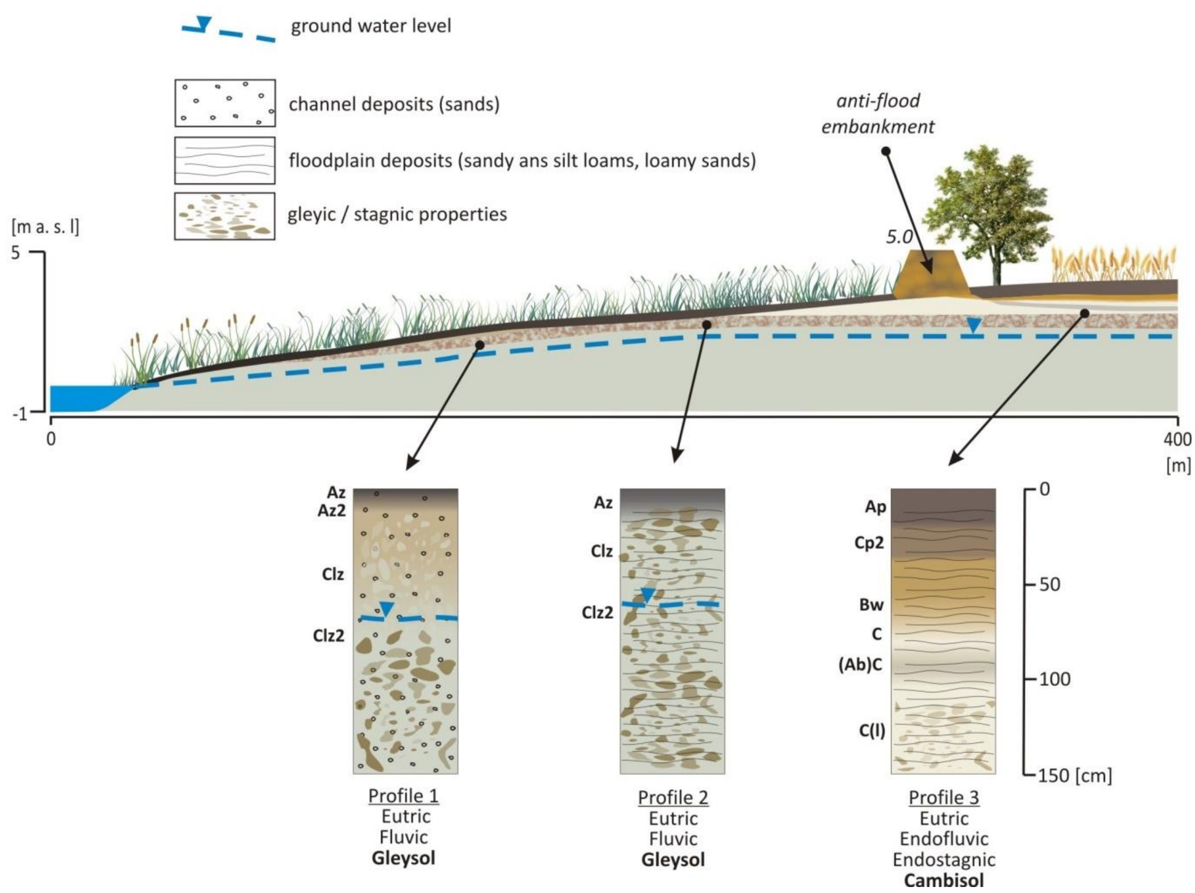


Fig. 2. A human-influenced soil sequence in the Vistula River delta (Gdańsk, Poland)

Soil genesis and systematic position

The river mouth areas are the most vulnerable sites for dynamic interaction of the fluvial and marine processes, which makes the environment very unstable (Wright, 1985; Jegliński, 2013; Hulisz, 2013). In such conditions, pedogenesis can usually be interrupted by geogenetic processes, which lead to the destruction or overbuilding of soil profiles. Another significant factor modifying the properties of soils is human impact, which is mainly seen in the fragmenting of river courses by dams and channel diversions (Maselli and Trincardi, 2013; Hulisz et al., 2015).

The parent materials of the studied soils were alluvial sediments: sands (***Arenic*** qualifier; profile 1), silt loams (***Siltic*** qualifier – profile 2) and sandy loams (***Loamic*** qualifier – profile 3). The accumulation of soil organic matter in those soils could have primarily occurred in different environments: either autochthonous or allochthonous. The stratification evidenced by decreased content of soil organic carbon (profile 1) or morphologically visible layers (profiles 2 and 3) met the criteria for a *fluvic* material. Moreover, uncoated mineral grains within the top 5 cm of the mineral soil surface (***Nechic*** qualifier) was observed in profile 1.

Due to the impact of shallow groundwater, profiles 1 and 2 were characterised by *gleyic* properties. Relatively high drops in pH after reaction of samples with 30% H_2O_2, and low C:S ratio values, may suggest the accumulation of sulphides (IUSS Working Group WRB, 2015; Hulisz et al., 2017), which was favoured by *reducing conditions*. However, a wider range of laboratory analyses is needed to ultimately verify the presence of *sulfidic* material.

Along with the distance from the riverbed, a greater alteration by pedogenic processes was visible, but it was mainly influenced by human activity (cut off from freshwater flooding, amelioration and agricultural soil use). This resulted in the disappearance of the original stratification, the development of the pedogenic structure (***Endofluvic*** and ***Cambic*** qualifiers) and the ploughing horizon (***Aric*** qualifier), and a significant lowering of the groundwater table (***Bathygleyic*** qualifier) in the soil behind the flood bank (profile 3).

Due to hydrotechnical transformation (sluice construction) the studied area is fed mainly by seawater during storms, and for this reason the waters of the Dead Vistula are brackish (Cyberski and Mikulski, 1976; Żakowski et al., 2014). Nevertheless, the salinisation that affected the soils represented by profiles 1 and 2 can also be considered a human-induced process. It seems to be relatively stable, which was confirmed by the occurrence of halophytes such as *Aster tripolium* in the immediate surroundings (Piernik, 2003; Lazarus and Wszałek-Rożek, 2016; Hulisz et al., 2016). These soils had EC_e values lower than 15 $dS{\cdot}m^{-1}$, which did not fulfil the criteria for a *salic horizon*. However, the presence of salinity features was expressed by the use of the ***Protosalic*** qualifier. The last soil (profile 3) was non-saline, which was caused by the land amelioration.

In addition, the ***Eutric*** qualifier was used to emphasise the pH values above 5.5 in H_2O in all soils, which can serve as an equivalent of the criterion of effective base saturation as suggested by Kabała and Łabaz (2018, in press).

According to the WRB system (IUSS Working Group WRB, 2015), the studied soils were classified as follows: profile 1 – ***Eutric Fluvic*** **Gleysol (Arenic, *Nechic, Protosalic*)**, profile 2 – ***Eutric Fluvic*** **Gleysol (*Siltic, Protosalic*)** and profile 3 – ***Eutric Endofluvic Endostagnic*** **Cambisol (*Aric, Loamic, Bathygleyic*)**.

Soil sequence

The studied soils were characterised by the low diversity of their morphology and other properties, which was conditioned by very local geomorphological and hydrological conditions, as well as human impact. That is why it is difficult to identify the soil cover patterns by referring to typical hydro-toposequences or chronosequences (Fig. 2).

The lithological variability along the transect is typical of lowland floodplains (Kordowski, 2001). The closest to the water line are Eutric Fluvic Gleysols formed on channel sands (profile 1), which are affected by shallow saline groundwater. Those soils may be flooded during the backflow of Baltic seawater during storm surges. Then, about 200–250 m further from the riverbed, the parent materials of these soils are silt loams (profile 2). Behind the flood embankment, Eutric Endofluvic Endostagnic Cambisol occurs, which is also developed from fine-grained floodplain sediments (profiles 3). The last soil profile shows some properties related to anthropogenic transformations, especially the construction of flood embankments and agricultural use (profiles 3), resulting in dehydration, desalinisation, changes in morphology (the presence of ploughing and *cambic* horizons). This sequence is an example of both direct and indirect human influence on coastal plain soils, which is often multidirectional (Witek, 1965; Phillips et al., 1999; Hulisz et al., 2015).

References

Augustowski, B., 1972. *Coastal lowlands (Pobrzeże Bałtyckie)*. In: Galon, R. (Ed.), Geomorphology of Poland, 2. PWN, Warsaw: 111–128 (in Polish).

Cyberski, J., Mikulski, Z., 1976. *Hydrological relations*. In: Augustowski, B. (Ed.), Żuławy Wiślane. GTN, Gdańsk: 239–288 (in Polish).

Filipiak, J., Miętus, M., Owczarek, M., 2004. Meteorological conditions. In: W., Krzymiński, E., Łysiak-Pastuszak, M., Miętus, (Eds.), Environmental conditions of Polish zone of the southern Baltic Sea in 2001. Materiały Oddziału Morskiego IMGW, Gdynia, 9–32 (in Polish).

Hulisz, P., 2013. *Genesis, properties and systematics position of the brackish marsh soils in the Baltic coastal zone*. Rozprawy habilitacyjne. Wyd. UMK: 137 pp. (in Polish with English summary).

Hulisz, P., Michalski, A., Dąbrowski, M., Kusza, G., Łęczyński, L. 2015. *Human-induced changes in the soil cover at the mouth of the Vistula River Cross-Cut (northern Poland)*. Soil Sci. Ann. 66, 2: 67–74.

Hulisz, P., Piernik, A., Mantilla-Contreras, J., Elvisto, T. 2016. *Main driving factors for seacoast vegetation in the Southern and Eastern Baltic*. Wetlands 36: 909–919.

IUSS Working Group WRB, 2015. *World Reference Base for soil resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps*. World Soil Resources Report No. 106. FAO, Rome.

Jegliński, W., 2013. *Development of the Gulf of Gdańsk coast in the area of the Dead Vistula mouth.* Przegl. Geol. 61, 10: 587–595.

Kabała, C., Łabaz, B. 2018. *Relationships between soil pH and base saturation – conclusions for Polish and international soil classifications*. Soil Sci. Ann. 69(4) (in print), DOI: 10.2478/ssa-2018-0021

Kondracki, J., 2014. *Regional geography of Poland*. PWN, Warsaw (in Polish).

Kordowski, J., 2001. *Lithology and genesis of the lower Vistula River overbank floodplain deposits between Górsk and Chełmno*. Przegl. Geogr. 73, 3: 351–369.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F. 2006. *World Map of Köppen-Geiger Climate Classification updated*. Meteorol. Z., 15, 259–263.

Kwiecień, K., 1990. Climate. In: A., Majewski, (Ed.). Gdańsk Gulf. Wyd. Geologiczne, Warszawa, 66–119 (in Polish).

Kwiecień, K., Taranowska, S., 1974. *Climatic conditions*. In: Moniak, J. (Ed.), Geographic, natural and economic study of the Gdańsk voivodship. GTN, Gdańsk: 91–143 (in Polish).

Lazarus, M., Wszałek-Rożek, K., 2016. *Two rare halophyte species: Aster tripolium L. and Plantago maritima L. on the Baltic coast in Poland - their resources, distribution and implications for conservation management*. Biodiv. Res. Conserv. 41, 1: 51–60.

Łomniewski, K., 1974. *Hydrological relations*. In: Moniak, J. (Ed.), Geographic, natural and economic study of the Gdańsk voivodship. GTN, Gdańsk: 145–191(in Polish).

Makowski, J., 1995. The hundredth anniversary of the creating the Vistula Cross-Cut 1895-1995. IBW PAN, Gdańsk (in Polish).

Markowski, R., Stasiak, J., 1984. *Anthropogenic changes in the flora of the estuary area of the Vistula Cross-cut in the last century*. – Zesz. Nauk. Wydz. BiNoZ UG, Biologia 5: 27–59 (in Polish with English abstract).

Marks, L., 2012. *Timing of the Late Vistulian (Weichselian) glacial phases in Poland*. Quat. Sci. Rev. 44, 81–88.

Maselli, V., Trincardi, F., 2013. *Man-made deltas*. Sci. Rep. 3, 1926: 1–7. DOI:10.1038/srep01926

Mojski, J.E. 1990. *The Vistula river delta*. In: Starkel, L. (Ed.), Evolution of the Vistula River valley during the last 15 000 years, part III. Geographical Studies, Special Issue 5, IGiPZ PAN: 126–141.

Phillips, J.D., Golden, H., Cappiella, K., Andrews, B., Middleton, T., Downer, D., Kelli, D., Padrick, L., 1999. *Soil redistribution and pedological transformations on coastal plain croplands*. Earth Surf. Proc. Land. 24: 23– 39.

Piernik, A. 2003. *Inland halophilous vegetation as indicator of soil salinity*. Basic Appl. Ecol. 4: 525–536.

Starkel, L. 1988. *History of the river valleys in the Holocene*. In: Starkel, L. (Ed.), Changes in the geographical environment of Poland. Ossolineum, Wrocław: 87–107 (in Polish).

Witek, J., 1965. *Soils of the Żuławy Wiślane*. Pamiętnik Puławski, Prace IUNG 18: 157–266 (in Polish).

Wright, L.D., 1985. *River deltas*. In: Davis Jr., R.A (Ed.), Coastal sedimentary environments. Springer New York: 1–76.

Żakowski, K., Narożny, M., Szociński, M., Darowicki, K., 2014. *Influence of water salinity on corrosion risk - the case of the southern Baltic Sea coast*. Environ. Monit. Assess. 186, 8: 4871–4879.