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Chapter II

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Mud habitats as interesting fluviogenic wetlands

INTRODUCTION

The term "mud" does not have an explicit definition. In soil science it means a swampy deposit forming in periodically flooded areas or at the bottom of water bodies as a result of advanced decomposition of plant and animal remains with an admixture of mineral fractions carried by river. Mud is an organic deposit having features in between peat and gyttja. It differs from peat in much higher degree of humification of organic matter and for that reason it is not possible to macroscopically distinguish plant remains in mud. It also contains many more mineral fractions than peat. Mud differs from gyttja in consistency of organic matter, which is humus-like in case of mud (OKRUSZKO 1969). Hydrogenic habitats, where accumulation of organic matter occurs in the form of mud, are called mud habitats.

Mud habitats and mud soils are not as well recognized as other hydrogenic habitats and soils. It is because there are not many sites like these preserved in good condition in our country and comparatively not much research has so far been carried out on them. The reason is also great complexity of the processes occurring in mud habitats, which causes difficulties in the classification of soil deposits and soils forming there. The Polish Soil Classification System (1989) does not mention the diversity of deposits and soils in mud habitats and for that reason it requires supplement within this scope.

The first and most extensive research on mud habitats was carried out by H. Okruszko and J. Oświt in the sixties of the last millennium (OKRUSZKO 1969; OKRUSZKO, OŚWIT 1969). The object of research was the Biebrza valley developed in the Lower Biebrza Basin, where the greatest number of natural mud habitats in the country can be found. The Biebrza River has formed an alluvial valley there, almost completely filled with muds (Fig. 1). Okruszko was the first person who specified mud-forming and mud soil-forming process and characterized mud soils in respect of their typological development and physical and chemical properties, which enabled better recognition of genesis and processes occurring in mud habitats. Extensive research of physical and chemical properties of soils in the Lower Biebrza Basin, including mud soils, was carried out at the end of the seventies under the supervision of J. Gotkiewicz (GOTKIEWICZ 1980). Later on, the arrangement and geomorphological conditions of mud soil development in the mentioned area were analysed by H. Banaszuk (BANASZUK 1980, 1987, 2000a, 2000b). Some research on mud habitats was also carried out in the Upper Narew Valley (OKRUSZKO, OŚWIT 1973; MISIEWICZ et al. 1980; SAPEK et al. 1988; BANASZUK 1996) and in other river valleys (OŚWIT et al. 1980; OKRUSZKO, CHURSKA 1988; PIAŚCIK et al. 2000; SMÓLCZYŃSKI et al. 2000). Considering a lot of unclear issues related to mud habitats the author took research in the years 2000-2002 regarding typological development and basic physical and chemical properties of mud soils and plant communities growing on them in the area of the Narew and the Biebrza alluvial valleys formed in the Lower Biebrza Basin (ROJ-ROJEWSKI 2003, 2006a, 2006b, 2007; ROJ-ROJEWSKI, BANASZUK 2004; Fig. 1).

GEOMORPHOLOGICAL AND HYDROLOGICAL CONDITIONS OF MUD HABITATS FORMATION

Hydrogenic habitats are formed mainly by waters whose inflow and outflow are dependent on geomorphological conditions of the ground (OKRUSZKO 1992). River valleys are characterised by great biotopic variability shaped by such components of natural environment as surface features and geological structure of adjacent lands, size of catchment, size of river and intensity of flood (OŚWIT 1991). Therefore, the ecological diversity of river valleys depends on mutual arrangement of geomorphological, hydrological and hydrogeological conditions. Water affects the habitat fertility, course of soil processes, character and properties of soil deposits and type of vegetation (OŚWIT 1977). Thus, the presence and distribution of water in the environment have strong impact on the development of various kind of wetlands (OKRUSZKO et al. 1997).

Genesis of muds in mud habitats is determined by the supply of mixed inflow of surface and underground water, with significant dominance of surface water, and by large fluctuations of ground water level (OKRUSZKO 1977). When taking into account the type of water supply, mud habitats belong to fluviogenic wetlands whose functioning is dependent on river floods. Mud is created as a result of mud-forming process taking place in specific water conditions characterized by periodically high ground water level, which can go down to about 0.5 m in the summertime and even to 1.5 m near the river-bed, and by long-lasting (4-9 months) or permanent river flood. The depth of flood may exceed even 2 m (BANASZUK 2000b). Therefore, the areas where mud is present are flood terraces and old river-beds. Flooded (telmathic) mud habitats with seasonal surface flood and sunk (limnethic) mud habitats with permanent surface flood are distinguished in soil-forming hydrogenic habitats classification with respect to hydroecological conditions (OKRUSZKO 1992).

According to Okruszko (1969, 1992) hydration state of mud habitats is very changeable and strictly dependent on the nature of river and water level in river-bed. River is usually strongly incised in the valley bottom and is characterized by high dynamics of flow and strong draining, which is weaker, however, in comparison with alluvial habitats. It has clearly marked, raised banks, steep or beach ones – depending on the position of a current. River water flows faster than in peat valleys, and the overgrowing of river is slight.

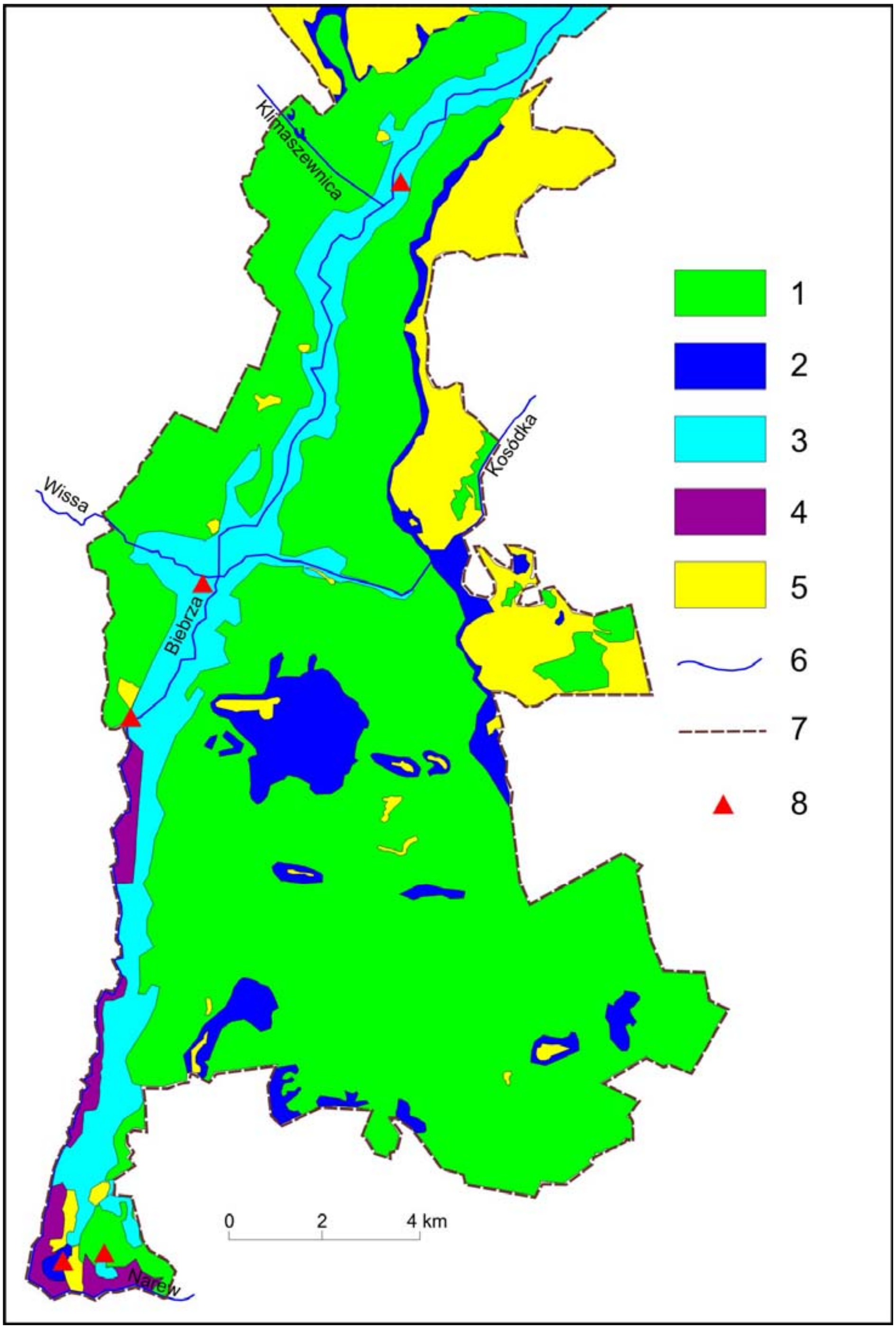

Fig. 1. Localization of study areas against a background of hydrogenic habitats in the Lower Biebrza Basin according to H. Jaros (JAROS 2004): 1 – peat habitats, 2 – boggy habitats, 3 – mud habitats, 4 – alluvial habitats, 5 – mineral areas, 6 – water currents, 7 – study areas

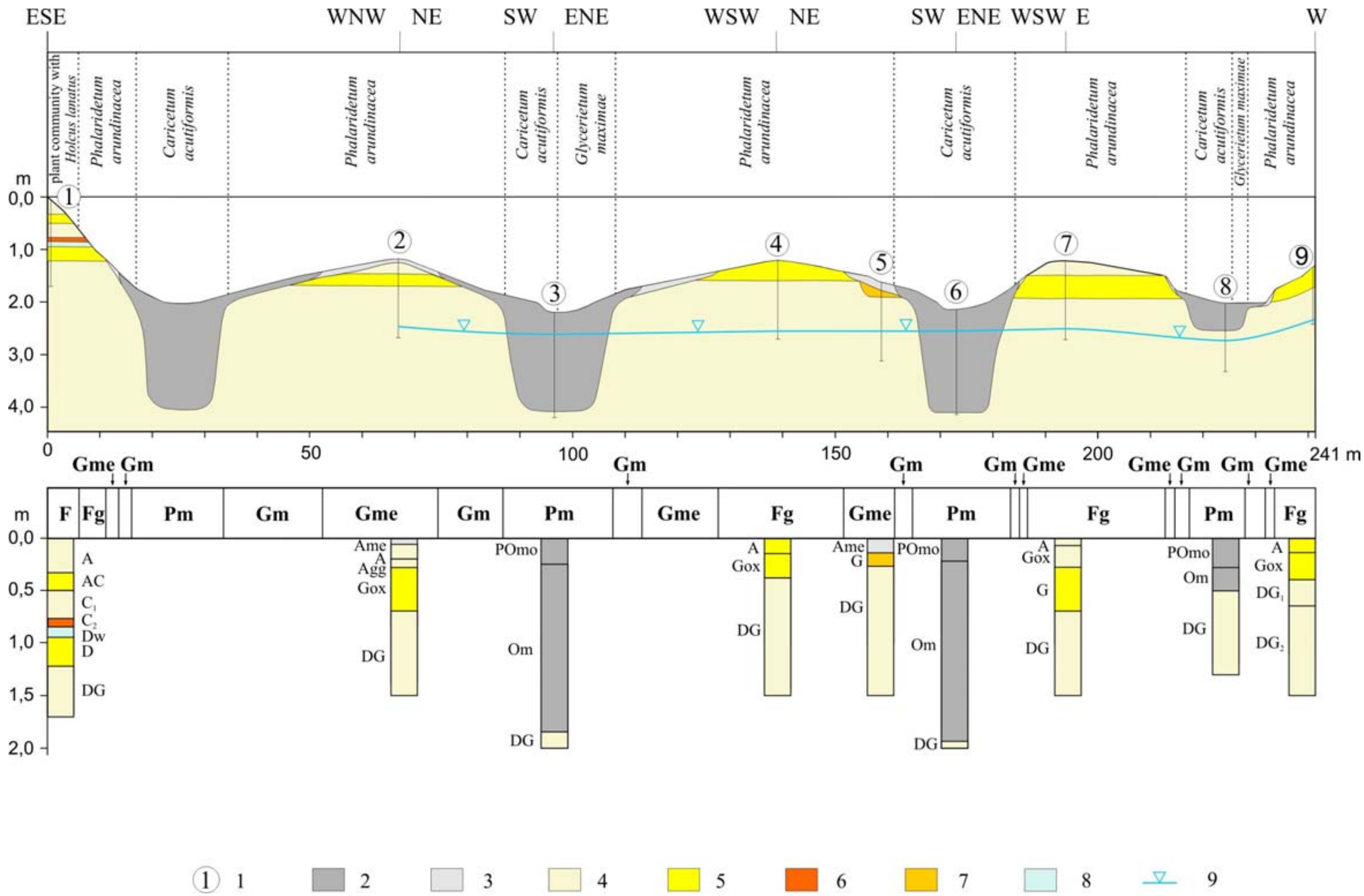

Fig. 2. Soil-plant section on Ruś study area near the confluence of the Biebrza and the Narew Rivers in the Lower Biebrza Basin: 1 – soil profile, 2 – mud, 3 – muddy-like deposit, 4 – sand, 5 – loamy sand, 6 – sandy loam, 7 – silt, 8 – meadow lime, 9 – ground water level 17.08.2000

Mud habitats occupy the areas with considerable microrelief near river-beds, which is connected mainly with river activity which while changing river-bed leaves sandbars, old river-beds, lowerings, lips and sandbanks built with deposits. As a rule, these habitats do not form dense, extensive areas (DEMBEK, OŚWIT 1992).

In the Lower Biebrza Basin mud habitats have been formed in the area of the present Narew and Biebrza flood valleys, in the immediate vicinity of river-beds or inside them, and in lowest and most humid locations of ground (BANASZUK 2000). Habitat formation is supported by strong hydration of river valleys and their less varied surface in comparison with adjacent alluvial areas. Muds started forming there a short time ago, in younger Holocene, mainly on alluvial soils accumulated in older Holocene. In the Narew valley mud habitats appear mainly on the young Holocene terrace in the confluence of the Biebrza and the Narew Rivers, and also locally – on the Atlantic terrace (BANASZUK 2000). It is the lowest part of the flood terrace of Narew, because it was shaped by river with small-radius curve meanders in the Atlantic period. Therefore, surface flood lasts longest and ground water lever appears lowest in the summertime there. On the contrary, the Biebrza alluvial valley is almost completely filled with muds. With respect to its age, that valley is similar to the young Holocene Narew valley. The Biebrza valley was formed by river within the reach of its meandering simultaneously with the growth of the adjacent peatlands. Its bottom lies a bit lower than peatland surface and therefore there are suitable conditions for muddy plants growing there. Due to that it is a young valley and it is characterized by high naturalness and specificity of soil and plant forming. The valley is quite narrow, 2-3 km wide, and the river flowing there meanders intensely (BANASZUK 2000).

VEGETATION COVER OF MUD HABITATS

For the above reasons geomorphological and hydrological conditions determine specific formation of mud habitats. Various arrangements of those conditions enable to distinguish subtypes of mud habitats, which are diversified by the depth of water lowering, its dynamics and intensity of surface flood, which affects the diversity of vegetation cover (OKRUSZKO 1977).

According to typological meadow habitats classification, mud habitats belong to floody marshy meadows (PROŃCZUK 1962; OKRUSZKO 1986). Typical plant communities growing on mud areas are rush communities belonging to the *Phragmition* alliance – reed sweet-grass *Glycerietum maximae* and to the *Magnocaricion* alliance – slender tufted-sedge *Caricetum gracilis* and reed canary-grass *Phalaridetum arundinaceae* (OKRUSZKO, OŚWIT 1969). Those communities definitely dominate on mud habitats in the Lower Biebrza Basin (BANASZUKet al. 1996; OŚWIT 1991; MATUSZKIEWICZ 2004) and also in the Middle Biebrza Basin (MATUSZKIEWICZ 2004) and in the Upper Narew Valley (SZEWCZYK 2004).

The most hydrated mud habitats are covered by rushes belonging to the *Phragmition* alliance. Apart from the above mentioned reed sweet-grass rushes a number of other communities from that alliance can be found there. The areas near active river-beds and old river-beds are occupied by common reed *Phragmitetum australis*. Many other plant communities, such as *Typhetum angustifoliae, Typhetum latifoliae, Oenantho-Rorippetum, Scripetum lacustris, Equisetum fluviatilis, Acoretum calami* and *Sparganietum erecti*, appear locally.

Plant communities belonging to the *Magnocaricion* alliance are distinctive in less hydrated mud habitats. Highly periodically wet mud habitats overgrown by sedge-grass plants belonging to the *Caricetum gracilis* association with the *Agropyro-Rumicion* alliance community also occupy a considerable area, especially in the Lower Biebrza Basin. On the contrary, changeably hydrated mud habitats overgrown by grass plants or sledge-weed plants belonging to the *Calthion palustris* and *Alopecurion pratensis* alliances, and relatively dry and dry mud habitats overgrown by plants belonging to the *Calthion palustris* alliance, appear very rarely (OŚWIT 1977). The results of our own research conducted in the Lower Biebrza Basin also indicate the presence of other plant communities such as *Caricetum acutiformis* and *Ranunculo-Alopecuretum geniculati* in the area of mud habitats (ROJ-ROJEWSKI, BANASZUK 2004).

GENESIS OF MUDS AND MUD SOILS

According to Okruszko (1969) mud is accumulated in aerobic-anaerobic conditions. In telmathic mud habitats the conditions of oxygen deficit prevail only during surface flood. After the withdrawal of flood significant lowering of ground water level occurs, especially in the summertime, which contributes to a very intensive humification and mineralization of organic matter and causes high fertility of the habitat. Because of the abundance of mineral compounds in habitat a luxuriant growth of plants, especially algas, occurs. They get decomposed shortly after decay and additionally fertilize the habitat (OKRUSZKO 1969). Muds of different depths are developed, depending on microrelief of flood terrace. In lower parts of the ground muds of high depth, containing great amounts of organic matter, are formed, and in higher locations more shallow muds with less organic matter are formed (OKRUSZKO 1969; ROJ-ROJEWSKI, BANASZUK 2004). Top horizon is prevented from excessive overdrying by underground inflow which through capillary suction provides sufficient hydration for root horizon of the soils where mud habitat plants grow (OKRUSZKO 1977). In such conditions last year's phytomass decomposes very quickly and for that reason mud accumulation happens very slowly, that is, 0.1 mm per year (OKRUSZKO, PIAŚCIK 1990).

Limnethic mud habitats occupy shallow water bodies, mainly old river-beds, where mostly megaplancton and sledge, reed-mace rushes etc. are developed. Megaplancton supplies a lot of oxygen, causing intensive humification of dead plants and mud depositing. The excess of phytomass cannot be digested by the benthos fauna and that is why gyttja is not formed there (OKRUSZKO 1969). Decomposition of plants occurs quickly, but slower, however, than in telmathic mud habitats and for that reason mud accumulation happens a bit faster. Limnethic muds depositing in such conditions are less solid and have darker colour.

Dominating mud-forming process in mud habitats is usually overlapped by other soil-forming and geological processes. Therefore, along with homogeneous deposits, that is, proper muds, one can often meet different forms of heterogeneous deposits as a transition form between mud deposits and alluvial or peat deposits. Thus, the areas of mud habitats are characterized by mosaic soil cover in which regularity of the arrangement of soil types is still poorly recognized. If soil-forming and geological processes occur alternately then layered deposits, such as muddy-alluvial, peaty-muddy or muddy-gyttja, are formed. However, if the whole soil deposit mass is heterogeneous then we deal with mixed deposits. Such deposits are formed mainly in high siltation conditions understood as a long-lasting process of saturation of soil deposit with extraneous matter during its forming.

In fact, siltation process is one of the elements of mud-forming process, but it can have different intensities of significant influence on physical and chemical properties of a forming deposit. Therefore, the author of this study, basing on his own research (ROJ-ROJEWSKI 2006), has suggested to divide mud deposits into two groups. Ash content equal to 55% of dry mass, which approximately corresponds to the lower limit of ash content in highly silted peats (OKRUSZKO 1976), has been proposed as a criterion of such a division. This value is based on the analysis of mud coming from the Lower Biebrza Basin and it requires verification through the analysis of muds from other river valleys. Due to the fact that mud deposits are usually intensely silted with the matter carried by river, mainly as floatable fraction and rarely as sand fraction, and are characterized by ash content >55% of dry mass, they should be named typical muds ("m" symbol). On the other hand, mud deposits formed by low intensity siltation and with ash content not exceeding 55% may be named organic muds ("mo" symbol).

DEVELOPMENT AND CLASSIFICATION OF MUD SOILS

Mud habitats and mud soils forming them are typical for many lowland rivers, but in most cases they occupy small areas and are usually heavily mucked. The Biebrza Basin is especially rich in mud habitats.

Mud habitats in the Lower Biebrza Basin cover the area of around 3 thousand ha, which makes 14.5% of the whole area of hydrogenic habitats in the Basin (BANASZUK 2000b, 2001; JAROS 2004). The greatest number of all those types of habitats was formed in the alluvial Biebrza valley. Such muds and mud soils in their classic shape have not been formed anywhere else in the country within such a large area and nowhere else they have been so well preserved (BANASZUK 2000b, 2001). Small areas of mud habitats can also be found in the Narew valley developed within the Lower Biebrza Basin on the younger, most lowered and most hydrated parts of flood terrace (BANASZUK 1980, 1987). Both in the Narew valley and in the Biebrza valley muddy-gley soils, with 20-25 cm mud thickness, definitely dominate (BANASZUK 2000b). Deeper limnethic muds, with thickness exceeding 50 cm up to almost 2 m maximum, are developed only locally in the old river-beds. Soils with mud thickness up to 70 cm form a large dense area only by the Wissa outlet to the Biebrza. Mud deposits mostly cover shallow alluvial soils with diversified granulometry, and rarely cover river bed sands. Muddy-gley soil profile, typical for the described part of the Biebrza valley, is shown in Table 1.

The presence of muds in their decession phase has also been found in a very small area next to the Wissa river. They are forming mud-muck soils moderately mucked MmII, containing up to 25 cm of muddy mucks in top horizon of the soil (ROJ-ROJEWSKI 2006a).

Table 1

Description of muddy-gley profile, typical for the Biebrza valley in the Lower Biebrza Basin (soil profile Uścianek, ground water level 65 cm, 22.08.2001)

Depth [cm]	Genetic horizon	Description of genetic horizon
0-10	AOmo	organic mud, dark brown, many plant roots
10-25	AOm	typical mud, with an admixture of clay, black, many spots of Fe concretions
25-35	AOmD	clay suffused with mud, black
35-40	D	clay with a little admixture of mud, dark grey
40-130	DG	sand, grey, with an admixture of organic matter in roof, rush peat insertions, total gleying

The research carried out in the Narew valley within the Lower Biebrza Basin enabled to distinguish soil catenas characteristic for this area, in which one can clearly see a strict connection of soils and plants with the microrelief of flood terraces, determining diversification of hydroecological conditions (ROJ-ROJEWSKI, BANASZUK 2004; ROJ-ROJEWSKI 2006a, Fig. 2). The most hydrated locations in ground lowerings are occupied by typical mud soils in their accumulation phase, which are overgrown by the *Glycerietum maximae*, *Caricetum acutiformic* and *Equisetum fluviatilis* communities. On a bit higher locations muddy-gley soils, covered with the *Glycerietum maximae*, *Caricetum acutiformis* and *Phalaridetum arundinaceae* communities, are found. At still higher level muddy-like gley soils and alluvial soils appear with the *Phalaridetum arundinaceae* communities, whereas in the highest parts humic alluvial soils and alluvial soils, overgrown by the *Molinietum caeruleae* community and the community including *Holcus lanatus*, are found. In the described sequence of soils, connected with the increase in relative height of the ground, ground water level becomes gradually lowered, which means the decrease in moistness.

Mud habitats also appear in other parts of the Biebrza Basin, but they occupy a smaller area and are not in such a typical form (the Upper Biebrza Basin – 17 ha, peaty-muddy soils; the Middle Biebrza Basin – around 1.5 thousand ha, mainly peaty-muddy soils, locally muddy-alluvial and typical mud soils, CHRZANOWSKI 2004a, 2004b).

Typical mud habitats can also be found in the Upper Narew Valley, where they occupy a very small area of 44 ha (BANASZUK 2004). The depth of muds in telmathic mud habitats usually comes to 20-70 cm and they lay on alluvial soils or river bed sands. Limnethic muds, 1.5-2.0 m thick, sporadically appear too. Peaty-mudddy soils definitely dominate in mud habitats of this area.

Quite a significant area of mud habitats appears in the Vistula delta, which, along with boggy habitats, occupy the area of 778 ha (PIAŚCIK et al. 2000; SMÓLCZYŃSKI et al. 2000). However, all mud soils of this area are entirely mucked. Muddy mucks are 25-31 cm deep. They have been formed from silted limnethic muds, 60-70 cm thick, laying on silt or sand deposits (SMÓLCZYŃSKI et al. 2000).

Because of the complicated genesis and small number of conducted research the position of mud soils in the Polish Soil Classification System (1989) is ambiguous, and taxonomic units do not include the whole diversity of soils characteristic for mud habitats. The present classification distinguishes the mud soil type which along with the peat soil type is placed in the bog soil order belonging to the hydrogenic soil division. Mud soil type is divided into three subtypes: typical mud soils, peaty-muddy soils and gyttja soils. Those soils undergo active mud-forming process, and the depth of mud (typical mud soils), peaty-muddy deposit (peaty-muddy soils) or gyttja (gyttja soils) layer is minimum 30 cm. However, the soils where mud-forming process appears but the mud layer does not exceed 30 cm have not been placed in the bog soil order. Those soils are distinguished as the muddy-gley soil subtype, in the gley soil type, boggy soil order and semi-hydrogenic division. Soils formed from muds undergoing muck-forming process, with thickness exceeding 30 cm, belong to the hydrogenic division, but to the post-bog order, muck type and muddy-muck subtype soils (Systematyka... 1989).

Basing on the research carried out in mud habitats of the Lower Biebrza Basin the author has suggested to supplement the Polish Soil Classification System with a new taxonomic unit – muddy-like gley soils Gme (ROJ-ROJEWSKI 2004, 2006). Those soils are located in mud-alluvial soil catenas between muddy-gley soils and alluvial soils. They are distinguished by the presence of organic-mineral deposits in the top horizon (contents of organic matter in the form of mud: 10-20% of dry mass) with maximum 30 cm thickness, which are called muddy-like. Muddy-like deposits are formed in alluvial soils of different consistencies, from sand to loam.

Mud soils are not classified as a separate taxonomic unit in international soil classification systems. They are placed in the same group as low moor peat soils and muck soils, defined in the Revised Legend of the Soil Map of the World FAO in the year 1988 as Terric Histosols and in the Classification of the World Soils WRB in the year 1994 as Eutri-Haplic Histosols (FAO 1988; MARCINEK 1997; BEDNAREK et al. 2003). Muddy-gley soils in the above mentioned international classification systems are included, along with peaty-gley soils, in the Histi-Mollic Gleysols unit. Mud soils are not distinguished, either, in classification systems of soils valid for the European countries and are treated simply as peat soils (OKRUSZKO, PIAŚCIK 1990).

PROPERTIES OF MUDS

The research conducted on mud habitats by the mentioned researchers, particularly by H. Okruszko and J. Oświt (OKRUSZKO 1969; OKRUSZKO, OŚWIT 1969), has provided a lot of valuable information on those habitats, but has not fully presented their specificity. Above all, clear physical and chemical indicators, which would allow for distinguishing muds from other soil deposits, especially peat ones, have been missing – and such distinction is often difficult.

According to H. Okruszko, the contents of organic matter in muds usually take up 30-40% of dry mass, reaching a wide range of values between 7 and 84% of dry mass (OKRUSZKO 1969). Such an attitude is inconsistent with the Polish Soil Classification System (1989) where muds are defined as exclusively organic deposits, that is, containing at least 20% of organic matter. Therefore, the author does not call the deposits formed in mud habitats, with the contents of 10-20% organic matter, muds, but introduces another name for them, that is, muddy-like deposits (ROJ-ROJEWSKI 2004, 2006).

The results of all research conducted on mud habitats of the Lower Biebrza Basin enable to establish a number of physical and chemical criteria defining muds in comparison with other soil deposits. The research on soil deposits coming from the Lower Biebrza Basin, carried out by the author, has shown many significant differences in comparison with physical and chemical properties of peats, where those differences are clearest in case of unsilted deposits and become diminished or disappear as a result of siltation (ROJ-ROJEWSKI 2006).

The basic indicator distinguishing mud deposits, similarly to other hydrogenic deposits, is ash content. According to own research, the ash content in muds of the Lower Biebrza Basin is included within a wide range between 25.8 and 80% of dry mass and on average it takes up 57.7% of dry mass (ROJ-ROJEWSKI 2006, Table 2). It is about 3 times higher that the average ash content in peats of the Lower Biebrza Basin, which takes up 17.6% of dry mass (BIENIEK et al. 2000; GOTKIEWICZ 1980; own research). High ash content affects the remaining physical properties of those deposits. The bulk density of muds oscillates between 0.122 and 0.865 $Mg \cdot m^{-3}$, with the average value of 0.308 $Mg \cdot m^{-3}$, and is almost twice as high as the average density of peats of the Lower Biebrza Basin (BIENIEK et al. 2000; GOTKIEWICZ 1980, own research – 0.160 $Mg \cdot m^{-3}$). Total porosity identified with maximum water capacity changes in case of the analysed muds from 0.615 into 0.949 $m^3 \cdot m^{-3}$ (average 0.849 $m^3 \cdot m^{-3}$) and shows significant statistical difference from the maximum water capacity of peats of the Lower Biebrza Basin (BIENIEK et al. 2000; GOTKIEWICZ 1980, own research – average 0.905 $m^3 \cdot m^{-3}$) when reaching lower values. Also other physical and water properties such as actual moisture, capillary water capacity or differential capacity indicate worse retention conditions of muds in comparison with peats.

When compared with peats, muds have less advantageous sorption properties and higher fertility resulting from a more intensified siltation process. They contain definitely more general forms of potassium, magnesium and iron, but much less nitrogen (Table 3). Apart from that, muds show worse sorption properties and lower pH values in water (Tables 3 and 4).

Also, considerable diversity of physical and chemical properties of different types of muds has been discovered. Telmathic muds are characterized with clearly higher density and ash content, and worse retention properties than those of limnethic muds (Table 2). They also have higher pH in water and are more abundant with total forms of potassium, sodium and magnesium, and poorer with nitrogen (Table 3). On the other hand, organic muds have significantly lower ash content and density but higher water capacities in comparison with typical muds (Table 2). They contain much more total Nitrogen and Calcium and show better sorption properties (Tables 3 and 4). That is why the genesis of muds and intesity of siltation play an important part in shaping the properties of muds.

Table 2

Basic physical properties of mud and peat deposits developed in the Lower Biebrza Basin

Soil deposit	Ash content [% d.m.]					Bulk density [Mg·m^{-3}]					Total porosity [m^3·m^{-3}]				
	n	min	max	$\overline{x}$	s	n	min	max	$\overline{x}$	s	n	min	max	$\overline{x}$	s
muds[1]	49	25.8	80.0	57.7	14.1	114	0.122	0.865	0.308	0.135	114	0.615	0.949	0.849	0.056
peats[2, 1]	415	4.2	83.5	17.6	12.0	596	0.059	0.854	0.160	0.067	592	0.734	0.989	0.905	0.027
thelmatic muds[1]	30	25.8	80.0	61.7	14.7	57	0.171	0.865	0.398	0.134	57	0.647	0.949	0.826	0.055
limnethic muds[1]	19	33.6	71.5	51.2	10.6	57	0.122	0.382	0.219	0.052	57	0.615	0.944	0.872	0.048
organic muds[1]	24	25.8	54.9	45.2	7.0	49	0.122	0.411	0.217	0.063	49	0.731	0.944	0.872	0.036
typical muds[1]	25	55.7	80.0	69.6	6.9	65	0.169	0.865	0.377	0.135	65	0.615	0.949	0.831	0.063

Explanatory notes: 1 – results of the own study, 2 – results of the other authors studies (OKRUSZKO 1969; OKRUSZKO, OŚWIT 1969; GOTKIEWICZ 1980; BIENIEK et al. 2000), n – number of samples, min – minimum, max – maximum, $\overline{x}$ – arithmetic mean, s – standard deviation.

PROTECTION OF MUD HABITATS

Wetland habitats, including mud habitats, are endangered by natural and anthropogenic factors. The most important natural factors reshaping wetlands are the climate change modifying their hydrological regime, and natural vegetation succession. Among other significant natural factors transforming wetlands one can find changes in hydrographic network associated with wetlands, eolic processes or denudation processes. However, anthropogenic factors are more destructive from natural processes. Functioning of such habitats is endangered especially by the eutrofication process induced by surface and ground water pollution or direct sewage disposal. In case of fluviogenic wetlands, to which mud habitats belong, river control and changes of regime have strong impact (DEMBEK, OŚWIT 1992). Degeneration of wetlands in the areas covered by muddy rushes is also connected with the abandonment of their traditional usage, that is, mowing plants. Such an activity intensifies the process of vegetation succession and in short time it brings transformation of ecosystems. Though, the greatest threat lies in the change of hydrological regime of wetlands, caused by drainage. Mud deposits are more susceptible to overdrying and become subject to mucking much faster than peat deposits due to a higher degree of decomposition of organic matter and higher ash content.

Table 3

Reaction and total forms content in mud and peat deposits developed in the Lower Biebrza Basin

Soil deposit	pH in H_2O					N [g·kg^{-1}]					Ca [g·kg^{-1}]					Mg [g·kg^{-1}]				
	n	min	max	$\bar{x}$	s	n	min	max	$\bar{x}$	s	n	min	max	$\bar{x}$	s	n	min	max	$\bar{x}$	s
muds[1]	49	3,15	7,32	5,32	0,74	52	2,25	32,07	18,30	7,56	52	5,24	336,24	30,51	48,65	52	0,504	6,765	2,964	1,31
peats[2, 1]	39	3,30	6,23	5,69	0,56	28	6,10	37,10	26,80	9,20	25	2,10	55,30	30,81	13,91	25	0,370	4,300	1,780	0,84
thelmatic muds[1]	30	4,75	6,70	5,65	0,47	32	2,25	32,07	16,28	7,15	32	5,24	111,76	26,24	27,37	32	1,706	6,765	3,262	1,40
limnethic muds[1]	19	3,15	7,32	4,79	0,79	20	7,90	31,91	21,54	7,21	20	11,17	336,24	37,34	71,08	20	0,504	5,672	2,488	1,03
organic muds[1]	24	3,15	6,02	5,07	0,67	23	16,27	32,07	24,95	4,34	23	14,72	111,76	35,21	29,50	23	1,363	6,765	2,916	1,57
typical muds[1]	25	4,03	7,32	5,55	0,74	29	2,25	22,97	13,03	4,92	29	5,24	336,24	26,78	59,96	29	0,504	5,710	3,002	1,09

Soil deposit	Na [g·kg^{-1}]					K [g·kg^{-1}]					Fe [g·kg^{-1}]					Al [g·kg^{-1}]				
	n	min	Max	$\bar{x}$	s	n	min	max	$\bar{x}$	s	n	min	max	$\bar{x}$	s	n	min	max	$\bar{x}$	s
muds[1]	52	0.000	3.138	0.390	0.666	52	0.350	2.205	1.224	0.414	52	3.98	98.66	21.86	14.65	52	4.70	114.53	18.55	19.87
peats[2, 1]	25	0.030	0.900	0.150	0.220	25	0.040	3.660	0.600	0.840	25	2.30	38.84	11.97	8.14	3	16.40	33.24	24.05	8.52
thelmatic muds[1]	32	0.000	3.138	0.533	0.794	32	0.536	2.205	1.397	0.403	32	3.98	98.66	21.47	17.31	32	8.58	86.60	18.52	14.95
limnethic muds[1]	20	0.000	0.849	0.161	0.273	20	0.350	1.330	0.947	0.252	20	6.33	44.09	22.47	9.30	20	4.70	114.53	18.60	26.35
organic muds[1]	23	0.000	3.138	0.369	0.765	23	0.829	1.788	1.245	0.295	23	8.18	44.09	21.02	7.80	23	6.05	86.60	18.47	19.71
typical muds[1]	29	0.000	2.179	0.407	0.591	29	0.350	2.205	1.207	0.493	29	3.98	98.66	22.52	18.49	29	4.70	114.53	18.61	20.34

Explanatory notes: 1 – results of the own studies, 2 – results of the other authors (OKRUSZKO 1969; OKRUSZKO, OŚWIT 1969; GOTKIEWICZ 1980; BIENIEK et al. 2000), n – number of samples, min – minimum, max – maximum, $\bar{x}$ – arithmetic mean, s – standard deviation.

Table 4

Sorption properties of mud and peat deposits developed in the Lower Biebrza Basin

Soil deposit	Ca^{2+} [mmol(+)·kg^{-1}]					Mg^{2+} [mmol(+)·kg^{-1}]					Na^{+} [mmol(+)·kg^{-1}]					K^{+} [mmol(+)·kg^{-1}]				
	n	min	max	$\bar{x}$	s	n	min	max	$\bar{x}$	s	n	min	max	$\bar{x}$	s	n	min	max	$\bar{x}$	s
muds[1]	51	208.6	1366.9	628.5	268.1	51	18.9	160.5	73.0	47.1	51	1.5	7.2	3.8	1.6	51	0.2	8.2	3.5	2.1
silted peats[1]	3	690.4	986.3	855.8	151.0	3	56.6	80.4	65.8	12.9	3	2.7	7.7	5.0	2.5	3	1.4	1.7	1.6	0.1
thelmatic muds[1]	31	302.7	1366.9	617.8	284.4	31	24.9	149.3	73.4	42.1	31	1.5	6.3	3.3	1.4	31	0.8	5.0	2.9	1.1
limnethic muds[1]	20	208.6	1309.9	645.1	246.7	20	18.9	160.5	72.3	55.1	20	2.1	7.2	4.5	1.7	20	0.2	8.2	4.5	2.8
organic muds[1]	23	491.7	1366.9	796.3	220.0	23	23.6	160.5	109.7	45.7	23	2.1	7.2	4.8	1.4	23	0.6	8.2	4.8	2.2
typical muds[1]	28	208.6	1309.9	490.6	223.4	28	18.9	94.7	42.8	17.6	28	1.5	6.3	2.9	1.2	28	0.2	5.2	2.4	1.3

Soil deposit	Hh [mmol(+)·kg^{-1}]					S [mmol(+)·kg^{-1}]					Th [mmol(+)·kg^{-1}]					V_S [%]				
	n	min	max	$\bar{x}$	s	n	min	max	$\bar{x}$	s	n	min	max	$\bar{x}$	s	n	min	max	$\bar{x}$	s
muds[1]	51	15,8	640,1	175,5	108,9	51	231,7	1523,2	708,7	301,2	51	370,3	1684,3	884,2	326,7	51	58,7	98,8	79,1	10,0
silted peats[1]	3	89,2	675,8	297,5	328,2	3	775,1	1055,8	928,1	142,0	3	864,3	1731,5	1225,6	451,3	3	61,0	89,7	79,6	16,2
thelmatic muds[1]	31	52,1	255,9	132,7	52,1	31	329,9	1523,2	697,3	322,0	31	495,1	1684,3	830,0	333,6	31	65,0	94,8	82,4	8,2
limnethic muds[1]	20	15,8	640,1	241,9	139,0	20	231,7	1348,7	726,4	273,0	20	370,3	1548,8	968,2	304,8	20	58,7	98,8	74,0	10,6
organic muds[1]	23	100,1	640,1	200,8	115,8	23	547,3	1523,2	915,6	242,3	23	653,4	1684,3	1116,4	253,9	23	58,7	90,4	81,8	8,8
typical muds[1]	28	15,8	529,2	154,8	100,2	28	231,7	1348,7	538,7	231,9	28	370,3	1406,1	693,5	247,8	28	62,4	98,8	76,9	10,5

Explanatory notes: 1 – results of the own studies, n – number of samples, min – minimum, max – maximum, $\bar{x}$ – arithmetic mean, s – standard deviation, S – sum of base cations, Th – cation exchange capacity, V_s – base saturation

The research on mud habitats of the Lower Biebrza Basin, conducted by the author, has enabled to determine their present condition and degree of drainage hazard and to take protective measures. During the analysed period (dry year 2000, average year 2001) ground water level in typical mud soils Pm and muddy-gley soils Gm was lowered quite significantly, that is, down to 40-80 cm (Table 5). In three profiles ground water appeared at the depth below 70 cm, which may be assumed as acceptable according to the research carried out on hydrogenic soils assigned to the Prognostic Soil-Moisture Complexes (SZUNIEWICZ, JAROS 1990). Yet, it has not been reflected in soil overdrying. Mud soils Gm and Pm in their accumulation phase showed such water content (0.670-0.838 $m^3 \cdot m^{-3}$) and air content (0.021-0.105 $m^3 \cdot m^{-3}$), which is sufficient for the needs of muddy plants (ROJ-ROJEWSKI 2006b). Quite different air and water conditions dominated in a small area of mud habitats undergoing mud-forming process. In muddy-muck soil MmII ground water was on a very low level of 95 cm, which resulted in a clearly lower water content (0.496-0610 $m^3 \cdot m^{-3}$) and higher air content (0.180-0.300 $m^3 \cdot m^{-3}$) in top horizon of the soil.

Plant communities which are found in the area of mud habitats, particularly Reed-Sweet grass meadows, are of great agricultural value. As opposed to other natural meadows, until recently they were eagerly mowed every year, which prevented succession processes and kept them in their present state of evolution (OKRUSZKO 1991). The abandonment of traditional usage of those areas, that is, mowing plants, causes the appearance of common reed *Phragmites australis*, which in a short time leads to the transformation of ecosystems. This phenomenon is not as intensified, however, as in the open areas of peatland.

Mud habitats form one of the most important and most valuable attractions of the Biebrza National Park. That is why it preserving those habitats in an unchanged, and at least close to the natural, condition is so essential. The most important preservation task in the area of mud habitats is ensuring optimum moisture. Present water conditions are proper for the needs of that type of habitats and therefore it is necessary to maintain them. Eliminating natural succession by mowing plants growing in mud habitats is also advisable.

Table 5

Water and air contents in top horizons of study soils in the years 2000-2001 and plant communities growing on them

Subtype of soil	Number of soil profiles	Ground water level [cm]	Current moisture [$m^3 \cdot m^{-3}$]	Current air content [$m^3 \cdot m^{-3}$]	Plant communities
typical mud soil Pm	5	40-80	0.741-0.835	0.021-0.105	*Glycerietum maximae* (2 profiles) *Caricetum acutiformis* (3 profiles)
muddy-gley soil Gm	3	44-80	0.670-0.838	0.042-0.080	*Glycerietum maximae* (2 profiles) *Ranunculo-Alopecuretum geniculati* (1 profile)
muddy-muck soil MmII	1	95	0.496-0.610	0.180-0.300	*Phalaridetum arundinaceae* (1 profile)

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