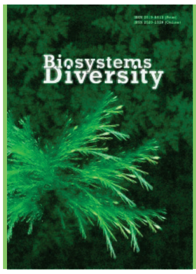

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The importance of relief for explaining the diversity of the floodplain and terrace soil cover in the Dnipro River valley: The case of the protected area within the Dnipro-Orylskiy Nature Reserve

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Floodplains are centers of species diversity, so floodplain habitats often contain protected areas. However, conservation strategies pay little attention to soils, on which the functional stability of both individual ecosystems and landscape chains as a whole depends. Soil morphology provides structural and functional information about floodplain ecosystems. The spatial and temporal heterogeneity of soil morphology is a cost-effective ecological indicator that can be easily integrated into rapid assessment protocols for floodplain and riverine ecosystem restoration projects. Therefore, the aim of our work was to consider the morphological features of soils of the Dnipro-Orylskiy Nature Reserve and assess the role of soil diversity as a factor of structural and functional sustainability of ecosystems of the protected area, as well as to identify the significance of geomorphological predictors for differentiation of soil types to create a soil map of the territory. The World Reference Base for Soil Resources reference soil groups were classified using geomorphological predictors. Soil types were able to explain 90% of the variation in elevation occupied by soils. Arenosols occupied a statistically significantly higher position in topography than other soil types. In turn, Eutric Arenosols occupied a higher position (68.91 ± 0.48 m) than Eutric Lamellic Arenosols (63.32 ± 0.54 m). Other soils occupied positions in the topography that were not statistically significantly different in height. Soil types were able to explain 38% of the variation in elevation that the soils occupied. The highest Topography Wetness Index values were found for Fluvisols (12.73 ± 0.23) and Solonetz (13.06 ± 0.28 m). Differences between these soils were not statistically significant. Topography Wetness Index was slightly lower for Cambisols (11.80 ± 0.21) and Eutric Lamellic Arenosols (12.21 ± 0.28), which also did not differ on this measure. The lowest Topography Wetness Index value was found for Gleysols (11.15 ± 0.17) and Eutric Arenosols (10.95 ± 0.24), which did not differ from each other on this index. Eutric Arenosols and Eutric Lamellic Arenosols are formed at great depths of the water table (7.89 ± 0.50 and 2.62 ± 0.46 m, respectively). Gleysol and Solonetz form at close groundwater level to the surface (0.28 ± 0.27 and 0.21 ± 0.46 m, respectively) compared to Fluvisol and Cambisol (0.46 ± 0.38 and 0.41 ± 0.35 m, respectively). Elevation was the most informatively valuable predictor, but Topography Wetness Index and Vertical Distance to Channel Network significantly improved discrimination. Arenosols were very different from other soils which occupy an automorphic position. Cambisols occupied a transitional position. Other soils occupied hydromorphic positions. Fluvisols and Solonetz occupied wetter positions, while Gleysol occupied less wet positions. Fluvisols and Solonetz differed in the groundwater table. Solonetz predominantly occurred at close groundwater levels. The classification matrix confirmed the possibility of using geomorphological predictors to build a model of spatial variation of soils in the study area. The spatial model demonstrates the organization of the soil cover of the reserve. Calculations showed that Cambiosols occupy 20.7% of the area, Eutric Arenosols occupy 16.0%, Eutric Lamellic Arenosols occupy 17.9%, Fluvisols occupy 15.2%, Gleysols occupy 28.7%, and Solonetz occupy 1.5%.

Keywords: landscape ecology, digital elevation model, soil morphology, catena, ecological monitoring.

Introduction

Floodplain landscapes are the most productive terrestrial ecosystems in the world and play a key role in ecological processes at different hierarchical levels (Sparks, 1995). Floodplain and terrace ecosystems are subject to intense anthropogenic pressures worldwide (Jakubínský et al., 2021), making them among the most threatened ecosystems (Tockner et al., 2010). Riparian forests and soils are highly sensitive to the global climate change (Stella & Bendix, 2018) and anthropogenic pressures (Sunil et al., 2011). Floodplain ecosystems depend on the cyclical influences under which they were formed, including river dynamics, traditional management practices, and herbivore activity. However, they exhibit significant degradation as a result of climate change, invasion by exotic species, river flow regulation, landscape fragmentation, and eutrophication (Gattringer et al., 2017). The construction of dams on rivers and the formation of reservoirs causes a change in the hydrological regime throughout a river valley (Słowik et al., 2021), which affects the state of ecosystems and can lead to their degradation (Marcinkowski & Grygoruk, 2017). The construction of dams in the Dnipro cascade has totally transformed the river's regime. Prior to the construction of the dams, the Dnipro's fluvial system was an undisturbed channel with a sandy bottom, but then it was turned from a fluvial to an anastomosing river system (Marcinkowski et al., 2017). This was possible due to rifts, where the vegetation concentration on the fine sediments created interstitial areas and islands. In the course of the hydrotechnical system, which was characterized by frequent artificial flows of short duration, the channels were cut and narrowed. The interstitial space was divided into islands. After switching to a flow-based operation, the islands began to merge again in the interstitial areas.

This was due to increased erosion processes in both the main and side channels. Changes in the flow regime and sedimentation processes in the river valley modified the natural evolution of the Dnipro fluvial system (Szmańda et al., 2021). Elimination of floods and lowering of the groundwater level allow for deeper penetration of plant roots, soil fauna and microorganisms into the soil, and create more favourable conditions for agricultural use of soils (Furtak et al., 2019). The transformation of the morphology and properties of agricultural alluvial soils in Europe has already been described in detail (Łabaz et al., 2014), while research in forest areas has focused mainly on the phytosociological transformation of plant communities and changes in stand productivity, while soil transformation remains insufficiently documented (Kawalko et al., 2021). Meanwhile, the correct recognition of phenomena occurring in all components of the forest environment is the basis for wise, ecologically oriented planning for sustainable, long-term forest management and nature conservation (Kawalko et al., 2021).

A large variety of plant and animal species find a suitable diversity of habitats and resources in floodplain forests (Havrdová et al., 2023). Floodplains and river terraces are actively used by humans and have an important economic significance (Tockner & Stanford, 2002). The structure of floodplains and terraces in the river valley is highly dependent on the climate regimes, but also valley ecosystems play an important role in mitigating the negative effects of global climate change (Lewin & Ashworth, 2014). Alluvial soils are of great importance for agriculture and forestry due to their special location in river valleys, moisture conditions and high potential productivity (Kabała, 2022). The formation of alluvial soil structure is a fundamental process in natural floodplains (Appling et al., 2014). Soils in floodplains and riparian lands are heavily influenced by the adjacent river. These soils are commonly referred to as alluvial soils because their physical, morphological, chemical, and mineralogical properties are shaped by the alluvial parent material coming from the river. The evolution of alluvial soils is highly dependent on the flow regime (Schomburg et al., 2019). Soils in river valleys are most affected by the annual hydrological trends (Halecki et al., 2022). They are formed by river transport, fluvial sedimentation, and surface and groundwater dynamics (Bertrand et al., 2012). Land use change and dam creation are significant anthropogenic factors that influence sediment supply to rivers. The key regulator of these processes is the state of dewiness on the soil cover in valley landscapes (Fang, 2017). Sediment transport and deposition are important processes for the genesis of alluvial soils (Goehring et al., 2021). The fluvial sedimentation process is a highly dynamic and irregular phenomenon in space and time, leading to large-scale variations in textural composition in vertical and horizontal dimensions of the soil profile (Bullinger-Weber & Gobat, 2006). One of the most important factors in the variability of valley ecosystems is soils which consist of spatially and vertically differentiated alluvial deposits (Hulisz et al., 2015). The sedimentation conditions can change significantly over time, so the stratification is the main feature of floodplain soils that affects their physical, chemical and water properties, as well as the productivity of alluvial soils (Dezső et al., 2019). Moreover, the sequences of sediment layers and soil horizons in soil profiles on floodplain terraces show alternation of stable periods with distinct pedogenesis and unstable geomorphologically active periods during which fresh alluvial layers accumulated (Saint-Laurent et al., 2010). Alluvial soils frequently include genetically young deposits of base-rich weathering material. The sequence of horizons in a soil profile at a given location is the result of sedimentation and pedogenesis. These two processes overlap, but inheritance often prevails (Mendonça Santos et al., 2000).

Alluvial soils are generally classified into the Fluvisols reference soil group in the World Reference Base for Soil Resources. Soils in the floodplain or valley zone that are exposed to groundwater and having typical gleyic properties can also be categorized as Gleysols (Rinklebe & Langer, 2008). Gleysols are usually located low in the landscape with a high groundwater table (Bedard-Haughn, 2011). The wide range of unconsolidated sediments in the landscape provides the parent material on which Gleysols can form (Ndjigui et al., 2015). Alluvial soils provide an understanding of historical and current river dynamics and ecosystem structure due to their specific morphology (Appling et al., 2014). Stratified alluvial soils, which often include buried upper soil horizons, are also important for reconstructing natural environmental changes and anthropogenic impacts on the landscape (Kabała, 2022). The groundwater level on the terraces is in dynamic equilibrium with the river water level. The interaction between rivers and groundwater in fluvial systems significantly affects ecological structures and functions (Brunke et al., 2003).

The average water table determines the total moisture content in the valley. Species richness, aboveground biomass, community cover, community height, projected leaf cover, and leaf area index significantly decreased with increasing water table depth. Water table depth was more important in explaining vegetation variance than soil properties (soil bulk density) and soil pH (Zhang et al., 2018). River terrace soils are generally associated with a higher water table than adjacent soils on higher ground outside the river valley (Huang et al., 2023). Abiotic and biotic soil factors play a key role in the dynamics of floodplain plant communities. Periodic floods are also important for the functioning of valley ecosystems, as they directly affect the moisture content of the surface soil layers, which results in soils in naturally functioning valleys retaining relatively high moisture content in both the upper and subsoil horizons even during dry periods (Kardol et al., 2006). Floods increase the nutrient content of soils (Tsheboeng et al., 2017), which leads to the formation of a specific floristic composition and increases the potential agricultural suitability (Długosz et al., 2018). Initially, large areas of alluvial soils on floodplain terraces were covered with floodplain forests (Saint-Laurent & Arsenault-Boucher, 2020), which are now among the most endangered forest communities in Europe (Havrdová et al., 2023).

Alluvial soils play a crucial role in the functioning of many natural and semi-natural ecosystems protected in river valleys (Kabała, 2022). Annual and seasonal dynamics of hydrological processes, specific microclimate, ecological relationships with abiotic and biotic elements of the environment provide for the special diversity and dynamics of river valley habitats (Ward et al., 2002). Stable soil structure is important for many ecosystem services and helps prevent riverbank erosion. The diversity of habitats affects plant communities, which reflect the zonation of the valley's ecological regimes and are also subject to succession processes intensified by human activity. The spatial distribution of floodplain forests is mainly influenced by the spatial heterogeneity of soil properties such as moisture content, bulk density, and soil particle size distribution. Temporal changes in vegetation were influenced by both spatial heterogeneity in soil moisture and particle size distribution and, to a lesser extent, by temporal changes in water availability (Ding et al., 2017). Floodplain forest degradation significantly reduces soil carbon, phosphorus, cation exchange capacity, silt content, total porosity and water content, and water infiltration rates (Celentano et al., 2017).

Soil plays a crucial role in ecosystem functioning and an important role in the provision of ecosystem services. In terms of ecosystem services, little attention is paid to soil cover (Adhikari & Hartemink, 2016). The soils of floodplains and above floodplain terraces perform important functions to provide the water quality of the rivers (Brinkmann et al., 2000). The role of floodplain soils in these processes is rather well documented (Elznicová et al., 2021), whereas the soils of the over floodplain terraces attract much less attention, which cannot be considered justified. Land cover studies are absent from most ecosystem service assessments. However, considering the soil-ecosystem linkages in land management has been shown to be important for assessing soil ecosystem services (McBratney et al., 2014). Floodplains provide a wide range of ecosystem services for which soils and their functional features are essential (Kanianska et al., 2022).

The first above floodplain terrace of rivers in Eastern Europe is represented by the sandy sediments of alluvial and aeolian origin (Matoshko, 2004). The sand soils act as a landscape filter, so that rivers receive recharge from groundwater, which is purified after passing through the sandy soils of the above floodplain terrace (Keesstra et al., 2012). The high filtration capacity of sandy soils is the reason why rivers are constantly supplied with water, even during the summer, when precipitation significantly decreases against the background of increased evaporation of water both from the open water surface and through the soil surface (Sahu et al., 2019). The specific thermal properties of sandy soils create conditions for the formation of condensation moisture, which can also be a source of additional water supply to rivers (Smits et al., 2013). On the other hand, the sandy soils are very sensitive to wind erosion and the condition of the vegetation cover, as well as the genetic features of the soils, influence the risks of wind erosion and the rate of sediment delivery to river waters.

River floodplains are centers of species diversity, so protected areas are common in floodplain habitats (Dong et al., 2021). However, nature conservation strategies pay little attention to soils, on which the functional stability of both specific ecosystems and landscape chains as a whole depends. Soil morphology provides structural and functional information about floodplain ecosystems. The spatial and temporal heterogeneity of soil morphology is a cost-effective ecological indicator that can be easily integrated into rapid assessment protocols for floodplain and riverine ecosystem restoration projects (Fournier et al., 2013). Therefore, the aim of our work was to consider the morphological features of soils of the Dnipro-Orylskiy Nature Reserve and to assess the role of soil cover diversity as a factor of structural and functional sustainability of ecosystems of the protected area and to reveal the importance of geomorphological predictors for soil type differentiation to create a soil map of the territory.

Material and methods

The research was conducted in the Dnipro-Orylskiy Nature Reserve. The current relief of the Reserve is very mosaic. The Dnipro floodplain is formed by furcation, and the meandering of the riverbed is almost undeveloped (Kunakh et al., 2023). The genetic zones of the modern floodplain, formed as a result of channel furcation, are superimposed on genetic zones associated with the degree of remoteness from the main channel, i.e. with the attenuation of alluvial intensity. The geomorphological structure of the Dnipro Valley is complicated by the geological activity of the Dnipro's left tributaries, the Oryl River and the Protoch River. The latter is currently a sequence of ancient lakes (Manyuk, 2019). The Quaternary rocks of the valley are represented by lake, lake-bog, alluvial, alluvial-diluvial and aeolian sediments (Gritsan et al., 2019). The relief of the Reserve's territory is represented by the alluvial forms of the Prydniprovska lowland. There are three terraces in the area of the Reserve. The lowest position in relation to sea level is occupied by a well-developed floodplain terrace, crossed in different directions by numerous channels, dotted with lakes and swamps. The floodplain terrace extends along the Dnipro River for 16 km within the reserve. In its widest part, in the Taromskyi ledge, it reaches 2 km, and in its narrowest part, in the Mykolaivskyi ledge, it reaches 1 km (Zymaroieva et al., 2022). The floodplain in the modern relief of the reserve corresponds to the first and second geostructural terraces of the Dnipro. The first geostructural terrace, due to its low hypsometric position (+48…+50 m above sea level), was almost completely flooded by the waters of the Dnipro and is present in the form of separate fragments in the modern mouth of the Protoch River. Most of the modern floodplain is located on the second geostructural terrace, the surface of which is at +50…+55 m above sea level. The floodplain is represented by layered modern alluvium. The lower layers of alluvium are represented by the channel facies formed as a result of sedimentation during the water level drop. There are numerous lakes in the floodplain, some of which have turned into swamps and are cut by a network of winding or sickle-shaped ditches and channels. The second geomorphological terrace corresponds to the third geostructural one, with elevations ranging from +55 to +65 m above sea level. It is a so-called arena. The arena is a large elevated massif of alluvial sands, processed and significantly complicated by aeolian processes to form a mound-hilly relief typical for the Prydniprovia region. Aeolian processes are manifested in the dispersal and re-suspension of alluvial sands in places where there is no soil and vegetation cover, mainly in the northwestern part of the Reserve. This results in the formation of mounds 4–6 m high. The highest mounds are developed on the border of the arena and the floodplain, near Lakes Mala Khatka and Horbove, where the alluvial sand hills rise to 70 m above sea level and rise to a height of 18–19 m above the floodplain. Aeolian deposits are represented by quartz light grey and yellow sands. The thickness of these deposits is 12–14 m.

The pits were excavated between May and September. The pits were excavated in approximately three transects that passed along the most significant relief gradients within the study area. Transect 1 embraced the floodplain of the Dnipro River and the first above-floodplain terrace (arena). Transect 2 covered the zone of transition of the above-floodplain terrace into the floodplain of the Protoch River. Transect 3 covered the floodplain of the Protoch River. Soil morphology was described according to the FAO Guidelines (WRB, 2015). The genetic type of soil profile was determined by Rozanov (2004). The type, shape, and intensity of redoximorphic features (mottling and concentration) as well as soil structure and colour in the upper and subsoil horizons were focused on. The soils were classified according to the WRB classification (WRB, 2015). Soil colour (when wet) was determined using Munsell colour charts.

The groundwater level was determined visually during inspection of the soil pits. If the groundwater was below the depth of the soil pit, then the level was estimated using the altitude above channel network. Altitude above channel network, or Vertical Distance to Channel Network (VDTCN), is the difference between elevation and channel network height (Olaya & Conrad, 2009). It is a reliable marker of the water table and can be used for soil mapping (Bock & Köthe, 2008). The spatial database (Valerko et al., 2022) was compiled in the software ArcGIS. Digital elevation model (DEM) is a presentation of the Earth's surface in numerical format. The Advanced Land Observation Satellite – ALOS (www.eorc.jaxa.jp/ALOS/en/index.htm) data were used to generate a digital elevation model. Spatial resolution for the study area is 30 m, nominal vertical accuracy and nominal horizontal accuracy is 5 m. By means of kriging procedure DEM was resampled to a resolution of 10 m (Susetyo, 2016; Kunakh et al., 2020; Zhukov et al., 2021). The kriging procedure also made it possible to obtain a DEM suitable for calculating the derived layer – Vertical Distance to Channel Network (VDTCN) (Hojati & Mokarram, 2016).

Results

Arenosols

Eutric Arenosol (Aeolic, Ochric)

The profile description was made on June 24, 2018 (Location 3). The pit was excavated in an area of artificial forest plantation in the Dnipro River arena, the Dnipro-Orylskiy Nature Reserve. The pit was located on a leveled area on a sandy hill near the Orlova Gully. The vegetation cover was an artificial plantation of *Pinus sylvestris* L., with *Robinia pseudoacacia* L. and *Gleditsia triacanthos* L. in the understory. The soil surface was relatively flat. There was a forest litter of pine needles 5–7 cm thick, projective coverage was 100%. The grass stand has a projective cover of 5–10%. The soil-forming rock was aeolian sand deposits. The disclosed groundwater level has not been established. Cracking was present in the humus layer, but not in the lower layers. The soil consistency was from loose to dense. The genetic type of the profile was undifferentiated (primitive).

O (7–0 cm) – forest litter, dry, compacted, well separated from the soil, has a layered structure. The first layer was formed by needles and whole leaf blades of broadleaf species, the second layer was well–decomposed needles and leaves, and the bottom layer of the litter was made up of sawdust.

Ah1 (0–14 cm) – surface humus–accumulative, sod. Brownish-grey. Dry. Sandy loam. Dusty-grained structure. Layered, loose consistency, moderately or weakly intertwined with root systems of herbaceous plants. Cracks were predominantly horizontal. The transition was sharp in colour, composition, and root saturation.

Ah2 (14–22 cm) – the second humus-accumulative. It was grey. Dry. Sandy loam. The structure was weakly expressed. Denser than the previous horizon, but easily crumbles under slight pressure. Roots of herbaceous plants and shrubs. The transition was sharp in color and composition.

CA (22–34 cm) – transitional. Fawn with grey or dark grey spots. Dry. Sandy loam. Unstructured. Dense, almost merged. Traces of humified root residues in horizontal direction. Single plant roots were found. Transition was gradual in colour, wavy for 2–3 cm.

C/A (34–87 cm) – fawn with grey or dark grey spots, dry, structureless sandy loam. Dense, almost cohesive. Traces of humified remains of large rounded roots 5–7 cm in diameter. Very few plant roots. The transition was gradual in colour and composition.

C (87–140 cm) – soil-forming rock. Dark fawn with grey or dark grey spots, fresh, loose, structureless sand. Similar to the previous horizon, there were traces of humified remains of large rounded roots 5–7 cm in diameter. Very few roots. The transition was sharp along the upper border of the pseudofibers.

Ct (140–155 cm) – the layer consists of thin brown compacted layers (lamellae) 0.5–0.7 cm thick, saturated with iron compounds and clay particles, alternating with layers of yellow sand. Moist. The transition was abrupt with the disappearance of compacted layers.

C' (155–200 cm) – light grey sand, moist, loose.

Eutric Arenosol (Aeolic, Ochric, Thaptoochric)

The profile description was made on June 18, 2018 (Location 5). The pit was made on the site of an artificial forest plantation in the Dnipro River arena, the Dnipro-Orylskiy Nature Reserve. The pit was located on a leveled area on a sandy hill near the Orlova Gully. The vegetation cover was an artificial pine plantation, with *Robinia pseudoacacia* and *Gleditsia triacanthos* L. in the understory. The soil surface was relatively flat. There was a forest litter of pine needles 3–4 cm thick, with a projective cover of 100%. The grass stand has a projective cover of 5–10%. The soil-forming rock was aeolian sand deposits. The disclosed groundwater level has not been established. Soil texture ranges from loose to dense. The genetic type of the profile was undifferentiated (primitive).

O (3–0 cm) – forest litter, dry, loose, well separated from the soil. The surface layer was made of needles of varying degrees of integrity, the lower layer of the litter was sawdust.

Ah (0–8 cm) – surface humus-accumulative, sod. Light grey in colour. Dry. Sand. Loose, moderately or weakly interwoven with root systems of herbaceous plants. Not aggregated. The transition was sharp in colour, composition and root saturation.

CA (8–25 cm) – transitional, light grey, dry, sand. It was denser than the previous horizon, but easily crumbles with slight pressure. Roots of herbaceous plants and shrubs. Unstructured. The transition was gradual in colour.

C (25–36 cm) – soil-forming rock. Fawn color. Dry. Sand. Dense, but easily crumbles under slight pressure. There were few plant roots. Unstructured. The transition was gradual in colour, wavy for 2–3 cm.

CAb (36–110 cm) was the first buried humus horizon. Light grey colour in the upper part and grey–pale in the lower part of the horizon. Dry sand of dense composition. Some pine roots. Unstructured. Transition was gradual in colour and composition.

C' (110–134 cm) was a soil-forming rock. Light fawn, fresh, loose sand. The transition was abrupt with the appearance of ferruginous compacted layers.

Ct (134–141 cm) – the horizon consists of thin brown compacted ferruginous lamellae layers 0.5–0.7 cm thick, alternating with layers of light brown sand. Fresh. The transition was abrupt due to the absence of compacted layers.

C'' (141–181) was a soil-forming rock. Light fawn, fresh, loose sand.

CA'b (181–200 cm) was the second buried humus horizon. Dark grey, fresh, loose sand. The transition was sharp in colour.

C''' (200–210 cm) was a soil–forming rock. Grey sand, damp, loose.

Eutric Arenosol (Aeolic, Ochric, Thaptoochric)

The profile was described on October 10, 2018 (Location 14). The pit was excavated in a section of psammophytic steppe in the Dnipro River arena, Dnipro-Orylskiy Nature Reserve. The pit was located on a leveled area at the top of a sandy hill. The vegetation cover was thickets of Tatar maple. The soil surface was relatively flat. There was a litter of herbaceous plants and dead leaves of nearby black chokecherry bushes, 0.5–1.0 cm thick, with a projective cover of 50–60%. The grass stand had a projective cover of 5–10%. The soil-forming rock was aeolian sand deposits. The disclosed groundwater level has not been established. Soil composition was loose, layered. The genetic type of the profile was undifferentiated (primitive).

O (1–0 cm) – dry residues of herbaceous plants, well separated from the soil. The leaf blades of fallen leaves were well decomposed.

Ah (0–14 cm) – surface humus–accumulative, sod. It was dark grey. Dry. Sandy. Not aggregated. Loose, strongly intertwined with root systems of herbaceous plants. The transition was sharp in colour.

C1 (14–52 cm) was a soil-forming rock. The sand was yellow, dry, unstructured, loose. There was horizontal layering. Separate roots of bushes. The transition was sharp in composition.

C2 (52–137 cm) was a soil-forming rock. The sand was grey-yellow, damp, unstructured, dense. Horizontal layering was present. The transition was sharp in colour.

CAb (137–145 cm) – buried transition horizon. Dark grey, damp, dense. Sand. The transition was sharp in colour.

C'2 (145–200 cm) was a soil-forming rock. The sand was grey-yellow, damp, dense. Horizontal layering was present.

Eutric Lamellic Arenosol (Aeolic, Ochric)

The profile description was made on September 19, 2017 (Location 24). The site of psammophytic steppe was located in the Dnipro River arena, in the Dnipro-Orylskiy Nature Reserve. The pit was located on a leveled area between sandy hills. Vegetation cover includes psammophytic steppe, some pine trees and a hill with thickets of Tatar maple. The soil surface was relatively flat. There was a layer of dead herbaceous plants and forest litter consisting of needles and leaves of black chokecherry bushes 4–5 cm thick, with a projective cover of 100%. The grass stand had a projective cover of 5–10%. The soil-forming rock was aeolian sand deposits. The disclosed groundwater level has not been established. Soil composition was dense. The genetic type of the profile was undifferentiated (primitive).

O (5–0 cm) – three-layer forest litter, dry, well separated from the soil.

Ah1 (0–12 cm) – surface humus-accumulative, soddy. Light grey in colour. Dry. Sandy. Not aggregated. Loose, moderately or weakly interwoven with root systems of herbaceous plants. The transition was gradual in color.

Ah2 (12–20 cm) – humus-accumulative. Light grey with a fawn tint. Dry. It was sandy. Not aggregated. Loose. Root saturation sharply decreases downward along the horizon. Dominated by humus material in the form of vertically oriented tongues. The transition was gradual in colour.

C/A (20–81 cm) – transitional. Light fawn colour. Dry. It was sand. Unstructured, loose. Only pine roots were found. Light grey irregularly shaped spots 5–7 cm in size and humus spots 15–20 cm in diameter stand out against the general background. The transition was sharp with the appearance of lamellae.

Ct (81–100 cm) was a horizon of bedrock containing thin brown compacted layers of lamellae 0.5–0.7 cm thick, alternating with layers of light brown sand. It was damper. The transition was abrupt due to the absence of lamellae.

Cc (100–143 cm) was a soil-forming rock. Light fawn in the upper part and grey with a fawn tint in the lower part. Sand, damp, unstructured. There were reddish and humus spots, the transition was sharp in colour.

C (143–200 cm) was a soil-forming rock. The sand was wet, pale grey, unstructured.

Cambisols

Eutric Cambisol (Humic, Loamic)

The profile description was made on September 11, 2017 (Location 2), in the Orlova Balka, Dnipro-Orylskiy Nature Reserve. The soil surface was relatively flat and carpet-like, with forest litter of undecomposed leaves, and projective cover of 90–100%. The herbage had a projective cover of 15–20%, nettles, and some clumps of cereals. The soil-forming rock was aeolian sand deposits. The unconfirmed groundwater level has not been established. Root depth of trees and shrubs was up to 200 cm. There were some traces of soil invertebrates, which do not have a significant impact on the mixing of horizons. The genetic type of the profile was isohumus. Intense CO_2 bubbles emission was observed after applying dilute hydrochloric acid from a depth of 127 cm. The soil-forming rock was alluvial deposits.

O (3–0 cm) was a three-layer forest litter. The surface layer was made up of whole leaf blades, the second layer was made up of well-decomposed leaves, and the bottom layer was made up of dead wood.

Ah1 (0–3 cm) – surface humus-accumulative, sod. Blackish-grey color (5Y 3/1). Dry. Sandy loam. Grainy-dusty structure, dominated by aggregates 0.5 mm in size. Loose texture, moderately or weakly interwoven with root systems of herbaceous plants. There was a lot of animal disturbance. The transition was sharp, in terms of composition and colour.

Ah2 (3–26 cm) was the second humus-accumulative layer. Dark grey (7.5YR 4/1). Dryish. Sandy loam. Very poorly aggregated. Dense. Some roots of bushes were present. The transition was sharp in composition and colour.

Ah3 (26–80 cm) – the third humus-accumulative. Lighter than the previous horizon, with a reddish-grey tint (7.5R 5/1), lightens with depth, and the reddish tint decreases. It was fresh. Sandy loam. The structure was weakly expressed. High density – cohesive composition. Roots of bushes. There were fragmentary inclusions of yellow sand. The transition in colour was gradual.

2BA (80–97 cm) was a transitional horizon. On a grey background (2.5Y 6/1), olive–grey (5Y 5/2) or bluish-grey (5PB 5/1) oval spots were vertically oriented, 1–2 cm wide and 7–12 cm high. Fresh. Sandy loam, cohesive composition. Very few roots. Colour transition, gradual and indistinct, 2–3 cm wide.

2B (97–127 cm) – greyish-brown background (2.5Y 5/2) with vertical oval dark gray spots (N 4/0) of humus material. Width 1 cm, height 3–4 cm. There were also some spots of rounded-irregular shape 7–8 cm in diameter, probably burrows of ground mammals filled with humified material. Fresh. Sandy loam. Dense merged compound. The transition was gradual in colour and texture.

2Bk (127–160 cm) – grey (2.5Y 6/1) with dark reddish (2.5YR 4/1) spots of humified material. Fresh. Lighter particle size distribution, coarse sand appears. Dense. Soft concretions at a depth of 130–140 cm. The transition was sharp in colour and mechanical composition.

3Ck (160–200 cm) was the parent rock. Greyish-brown (2.5Y 5/2) coarse-grained sand. It was damp and loose. Vertical spots with humified material, probably traces of decomposed plant roots. 1 cm wide, 15–20 cm high, 2–3 spots per 10 cm horizontally.

Eutric Cambisol (Loamic, Ochric)

The pit was surveyed on September 19, 2018 (Location 4). The pit was located in the upper reaches of Orlova Gully, Dnipro-Orylskiy Nature Reserve. The vegetation cover was meadow. The soil surface was relatively flat, carpeted, with 3–4 cm thick litter layer, and projective coverage of 90–100%. Soil-forming rock was alluvial sand. The disclosed groundwater level has not been established. The genetic type of the profile was isohumus. No CO_2 bubbles were observed after application of dilute hydrochloric acid to the soil surface, indicating the absence of carbonate minerals.

O (4–0 cm) – litter of dead and living herbaceous plants.

Ah1 (0–4 cm) – surface humus–accumulative, soddy. It was grey. Dry. Sandy loam. Weakly aggregated, crumbly, some aggregate units were bound by clusters of cereal roots, structure was granular-dusty. Loose composition, strongly intertwined with root systems of herbaceous plants. Transition in colour, structure and root saturation, sharp, wavy.

Ah2 (4–32 cm) – the second humus-accumulative. The soil was grey. Moist. Sandy loam. Weakly aggregated. Dense. Low content of root systems. The transition was gradual in colour and sharp in fracture.

B1 (32–71 cm) – light grey, fresh, sandy loam. It was cohesive, vertical cracks 0.2 cm wide form pedicles 15–20 cm wide. There were few roots. Transition in fracture was abrupt, in color – gradual.

B2 (71–110 cm) – light grey with fawn spots in the upper part of the horizon and fawn with vertical humus stripes in the lower part. Moist. Sandy loam. Cohesive, no cracks. The transition was gradual in colour, indistinct.

C1 (110–140 cm) – soil-forming rock. Fawn, lighter than the previous one, marbled with humus spots. Moist. Medium loam. Transition was abrupt in terms of mechanical composition and colour.

2C2 (140–180 cm) was a soil-forming rock. Grey-pale sandy loam with vertical humus spots in some places. It was damp. Loose composition.

3Cl (180–200 cm) – soil-forming gleyey rock. Greyish grey sand. Loose.

Eutric Cambisol (Loamic, Humic)

The profile was described on June 30, 2018, at the site of an artificial forest plantation in the Dnipro River arena (Location 18), the Dnipro-Orylskiy Nature Reserve. The pit was located on the slope of a sandy hill that descends to the floodplain of the Protoch River. The vegetation cover was an artificial pine plantation, with black elderberry in the understory. The soil surface was relatively flat. There was a forest litter of needles 4–5 cm thick, with a projective cover of 100%. The grass stand had a projective cover of 5–10%. The soil-forming rock was aeolian sand deposits. The unconfirmed groundwater level has not been established. The depth of tree roots was more than 200 cm. Cracking was present in the humus layer, but not in the lower layers. The soil texture was from loose to dense. The genetic type of the profile was isohumus.

O (5–0 cm) – forest litter, dry, compacted, well separated from the soil, has a layered structure according to the degree of decomposition of the fallen litter.

Ah1 (0–7 cm) – surface humus-accumulative, sod. It was dark grey. Dry. Sandy loam. Dusty-grained structure. Layered, loose composition, moderately or weakly intertwined with root systems of herbaceous plants. Cracks were predominantly horizontal. The transition was sharp in colour, composition, and root saturation.

Ah2 (7–51 cm) – humus-accumulative. Dark grey. Dry. Sandy loam. Dusty-grained structure, easily crumbles under slight pressure. Denser than the previous horizon. Roots of herbaceous plants, trees and shrubs. The transition was sharp in colour and composition.

ABh (51–81 cm) – transitional. It was grey. Dry. Sandy loam. Weakly expressed structure. Dense, almost merged. Humus material of root remains in horizontal direction. Plant roots were almost absent. Transition was gradual in color, wavy for 2–3 cm.

B (81–100 cm) – pale grey, dry, sandy loam. The structure was weakly expressed. Dense, almost merged. Humus remains of large rounded roots 5–7 cm in diameter. Few living roots were found. The transition was gradual in color.

C1 (100–150 cm) – bedrock – fawn, fresh, sandy loam. Unstructured, dense, almost merged. Similarly to the previous horizon, there were humified remains of large rounded roots 5–7 cm in diameter. There were few living plant roots. Transition in colour.

C2 (150–220 cm) – fresh, loose sand. The colour changes with depth from grey-pale to light grey.

Eutric Cambisol (Arenic, Protocalcic, Humic)

The soil profile was described on October 10, 2017, in the Dnipro River arena (Location 19), the Dnipro-Orylskiy Nature Reserve. The pit was dug in the area where the Dnipro River arena transitions into the fringe floodplain of the Protoch River. Vegetation was represented by oak woodland with fresh grasses with a semi-illuminated light structure. The soil surface was relatively flat and carpeted, with a forest litter of undecomposed leaves 5–6 cm thick, and a projective cover of 70–80%. The grass stand has a projective cover of 15–20%. The soil-forming rock was aeolian sand deposits. The groundwater level was 155 cm. There were some traces of soil invertebrates, which do not have a significant impact on the mixing of the horizons. Signs of glazing were found only for the bedrock in the area of its contact with groundwater. The soil was dense. The genetic type of the profile was isohumus.

O (6–0 cm) was a three-layer forest litter of tree leaves and dead herbaceous plants.

Ah1 (0–7 cm) – surface humus-accumulative, sod. Grey colour (N 5/0) with interspersed sand particles. Dry. Sandy loam. Very poorly aggregated, granular-dusty structure, dominated by 0.5 mm aggregates. Loose texture, intensively interwoven with root systems of herbaceous plants. Some animal disturbance. The transition was sharp, horizontal in composition and root saturation.

Ah2 (7–17 cm) was the second humus-accumulative. Gray (N 6/0) with interspersed sand particles. Fresh. Sandy loam. Unstructured. Dense. Some roots of shrubs. The transition was sharp in composition.

Ah3 (17–64 cm) – the third humus-accumulative. Dark grey (N 4/0) with interspersed sand particles. Moist. Lighter sandy loam. Unstructured. Dense to cohesive composition. Roots of shrubs. Colour transition was gradual.

ABk (64–105 cm) was a transitional carbonate horizon. Dark grey (7.5YR 4/1), lightens with depth. Moist. Sandy loam. Unstructured. Densely merged. Intense CO_2 bubbles emission was observed after applying dilute hydrochloric acid from a depth of 64 cm. Few roots. Transition in colour, gradual and not clear 2–3 cm wide.

Bk (105–120 cm) – light grey (N 7/0), moist, carbonate sandy loam. The folding was dense and merged. The transition was gradual in colour and texture.

Ckl (120–130 cm) – grey with a brownish tinge (10R 6/1), moist, carbonate, gley sandy loam. Lighter in particle size distribution, coarse sand appears. Dense. The transition was sharp in colour and mechanical composition.

Crk (130–155 cm) – parent clayey rock. Grey (7.5PB 4/2), wet, loose sand. Vertical spots with humified material, probably traces of decomposed plant roots. Groundwater from a depth of 155 cm. Characterized by highly reducing conditions.

Eutric Cambisol (Arenic, Protocalcic, Humic)

The soil profile was recorded on September 26, 2017, in a habitat near a relief depression that abuts the floodplain of the Protich River (Location 20.2), in the Dnipro-Orylskiy Nature Reserve. The pit was located on a relative elevation near a swamp. The vegetation was an elm oak forest. The soil surface was relatively flat and carpet-like, with a forest litter of undecomposed leaves 1–2 cm thick, and a projective cover of 80–90%. The herbage has a projective cover of 20%, nettles, and in some places clumps of cereals. The soil-forming rock was Aeolian sand deposits. The groundwater level was exposed from a depth of 200 cm. There were some traces of soil invertebrates, which influence the mixing of horizons in the sod horizon. Signs of glazing from a depth of 121 cm. Soil texture varies from loose to dense. The genetic type of the profile was isohumus. CO_2 bubbles emission was observed after applying dilute hydrochloric acid from the soil surface.

O (2–0 cm) – forest litter of well-decomposed fallen leaves, homogeneous, well separated from the soil.

Ahk1 (0–10 cm) – surface humus-accumulative sod carbonate horizon. Dark grey (N 4/0). Dry. Cohesive sandy loam. Very poorly aggregated, dusty-grained structure, aggregates were not stable and crumble. Loose texture, densely interwoven with root systems of herbaceous plants. Some animal disturbance. Transition was sharp, with folding and almost complete disappearance of herbaceous roots, horizontal, horizons were easily separated.

Ahk2 (10–31 cm) was the second humus-accumulative carbonate horizon. Gray (N 6/0). Fresh. Cohesive sandy loam. Very poorly aggregated, crumbly. Some roots of shrubs. The transition was sharp in composition.

Ahk3 (31–84 cm) was the third humus-accumulative carbonate horizon. Reddish-grey (10R 5/1). Fresh. Cohesive sandy loam. Structure was weakly expressed. Dense to cohesive composition. Roots of woody plants. Vertical passages of earthworms. Colour transition was wavy.

2Bk (84–121 cm) – carbonate, heterogeneously coloured. On a light grey background (2.5Y 7/1), grey (N 5/0) and very dark grey (N 3/0) irregularly shaped spots from the remains of decomposed woody plant roots. Fresh, unstructured, cohesive sand. Dense. No roots were found. Transition in colour, gradual and indistinct, 2–3 cm wide.

2Ckl (121–148 cm) was a gley carbonate horizon of the bedrock. Light greenish grey (5G 7/1) and irregularly shaped grey spots (N 5/0). Wet, dense sand. Transition was abrupt in color and texture.

2Crk (148–200 cm) was a parent gley rock, in the lower part of the horizon was characterized by strongly reducing conditions. Greenish-grey (7.5BG 5/2) with reddish spots, loose, damp sand. Vertical spots with humus material, probably traces of decomposed plant roots. Groundwater begins at 200 cm.

Fluvisols

Eutric Pantofluvic Fluvisol (Protocalcic, Humic, Loamic)

The description was made on October 3, 2018, on the bank of the Protoch River (Location 1), in the Dnipro-Orylskiy Nature Reserve. Plant cover was meadow vegetation. The soil surface was relatively flat carpeted, litter with a projective cover of 70–90%. Soil-forming rock was sandy loamy and sandy alluvial deposits. The groundwater level was revealed at a depth of 200 cm. The genetic type of the profile was hydrogen-differentiated. Rapid CO_2 bubbles emission was observed after applying dilute hydrochloric acid from 31 to 90 cm.

O (2–0 cm) – litter from living and dead herbaceous plants.

Ah (0–7 cm) – surface humus-accumulative, sod. Dark grey in colour. Moist. Sandy loam. Weakly aggregated, crumbly, some aggregates were fastened by clusters of cereal roots. Root-saturated, loose texture. Transition was sharp, wavy in composition and root saturation.

Ahk (7–48 cm) – the second humus-accumulative carbonate. Dark grey. Moist. Sandy loam. The structure was weakly expressed, dense. The content of root systems was much lower. The transition was sharp in colour.

CAk (48–75 cm) – transitional carbonate. Light grey, gradually lightens with depth. Moist. Sandy loam. Unstructured, dense composition. Roots were found. Colour transition was gradual.

Ck (75–113 cm) – carbonate horizon of the parent rock. Light grey, damp, cohesive, sandy loam. Humus spots of irregular shape 15–20 cm in diameter. Colour transition was gradual.

Cl1 (113–136 cm) was the first gley horizon of the parent rock. Grey with humic spots. It was damp. Sandy loam. Dense. Transition was clear in colour and particle size distribution.

Cl2 (136–152 cm) was the second gley horizon of the parent rock. It was grey. It was damp. Sandy loam. Dense. Transition was sharp in colour.

Cr1 (152–171 cm) was a soil-forming gley rock. The colour was typical for restored conditions – dark grey sandy loam with red spots. It was loose. Gradual transition in particle size distribution.

Cr2 (171–200 cm) – soil-forming gley rock. Wet dark grey sand with reddish spots. It was loose. Groundwater was present from the depth of 200 cm.

Eutric Gleyic Pantofluvic Fluvisol (Protocalcic, Humic, Loamic, Nechic)

The soil profile was described on May 5, 2018, in the floodplain of a tributary of the Protych River (border of the Dnipro River arena) (Location 25). Vegetation cover was forest vegetation (white poplar). Herbaceous cover was mainly lily of the valley and bindweed, with a projective cover of 25–30%. The soil surface was relatively flat, carpet-like, with a forest floor 5–6 cm thick, and a projective cover of 90–100%. The soil-forming rock was sand of the boreal terrace. On May 5, the water table was 90 cm, then it rose to 80 cm. On June 2, the water table was 122 cm. There were some traces of soil invertebrates, which do not have a significant impact on the mixing of the horizons. Rapid from the surface CO_2 bubbles emission was observed after applying dilute hydrochloric acid. The genetic type of the profile was hydrogen-differentiated, and its structure was polycyclic.

O (6–0 cm) was a single-layer forest litter, dry, consisting of individual leaf blades.

Ahk1 (0–7 cm) – surface humus-sod carbonate. Dry. Dark greyish brown with interspersed sand particles (10YR 4/2). Sandy loam. Loose consistency, abundantly interwoven with roots of herbaceous plants. The structure was granular-dusty. Transition in colour, texture and root saturation, clear, horizontal 2–3 cm.

Ahk2 (7–35 cm) – humus-accumulative carbonate horizon. Fresh. The colour was similar to the surface horizon. Sandy loam. Poorly compacted, structure was poorly expressed. Occasional roots of bushes were observed. Transition was gradual in colour, particle size distribution and density.

Bk (35–58 cm) was the first transitional carbonate horizon. Wet. Black (2.5Y 2.5/1). Medium loam, viscous, sticky. Composition was dense, structure was weakly expressed. Roots of bushes. The transition was gradual in colour and particle size distribution.

BCkl (58–80 cm) was the second transitional gley carbonate horizon. Moist. Gray (10YR 6/1) with elements of gley colour in the lower part. Sandy loam with sandy dusting. Dense composition. Roots were not found within the soil section. Transition was abrupt in colour and composition.

Ckl (80–112 cm) was a gley carbonate horizon with accumulations of organic matter. Wet. Bluish-grey (10B 5/1), gradually lightening with depth, sandy loam. Dense, almost cohesive, sticky and plastic. Transition in color and particle size distribution was sharp.

Crk (112–122 cm) was a carbonate gley soil-forming rock with strong reducing conditions. Wet, light olive grey (5Y 6/2) cohesive sand. Dense, disintegrates into large sandy clods that break up when pressed by fingers. Groundwater at the level of 122 cm.

Eutric Gleyic Panthofluvic Fluvisol (Arenic, Ochric, Thaptoochric)

The profile was described on 3 October 2017. The Dnipro-Orylskiy Nature Reserve. The Dnipro river floodplain (Location 26). Vegetation was elm oak. The soil surface was wavy and levelled. The forest litter was composed of undecayed leaves, 1.5–2.0 cm thick, with a projective cover of 30–40%, and was intensively torn by wild boar. Soil-forming rock was alluvial sand. The water table was 171 cm. The bulk of the roots of trees and shrubs can be found to a depth of 70 cm. There were some traces of soil invertebrates, which do not have a significant impact on the mixing of horizons. The genetic type of the profile was hydrogen-differentiated, and its structure was polycyclic and layered.

O (2–0 cm) – forest litter consisting of leaves of trees and herbaceous plants of varying degrees of destruction.

Ah1 (0–7 cm) – surface humus-accumulative, soddy. Light grey, dry, sandy loam. Unstructured, loose, abundantly interwoven with root systems of herbaceous plants. Transition along the fold, abrupt.

Ah2 (7–24 cm) – humus-accumulative. Light grey, fresh, sandy loam. Unstructured, dense, moderately root-saturated. The transition was smooth in colour and texture.

ACc (24–43 cm) was a transitional horizon. Heterogeneous grey-pale colour darkening with depth, occasionally reddish spots. Moist, sandy loamy, unstructured, dense. Some roots of shrubs and trees were found. There were root passages with dark–coloured humus material of loose composition and vertical humus seeps. Sharp wavy transition in colour and particle size distribution.

Cc (43–54 cm) was the alluvial horizon of the bedrock. Light grey with rusty spots that increase with depth. Fresh, unstructured sand. Vertical humus seeps were occasionally found. The transition was not clear, 2–3 cm wide in colour.

ACcb (54–69 cm) – buried humus-accumulative horizon. It was dark grey. Contains fragments of roots. Fresh, structureless sand of dense composition. Occasional vertical humus streaks. Colour transition was smooth, transition zone was 1.5 cm wide.

CAcb (69–94 cm) – buried transitional gley horizon. Heterogeneous dark grey with dark red irregular spots 3–5 cm in diameter. Fresh, sandy, dense composition. Fragments of roots were found. Occasionally vertical humus streaks. The transition was abrupt in composition and colour.

Cl (94–133 cm) – alluvial gley horizon. Colour varies with depth from pale grey to grey and red. Loose, moist sand. Vertical humified subsoils.

Cr (133–171 cm) – alluvial gley horizon with strong reducing conditions in the lower part of the horizon. The sand was moist, dark grey, loose. Groundwater was present from the depth of 171 cm.

Eutric Gleyic Pantofluvic Fluvisol (Protocalcic, Humic, Loamic, Thaptoochric)

The site was surveyed in the floodplain of the Dnipro River (Location 27). The soil surface was relatively flat and carpeted, with forest litter with a projective cover of 70–80%. The soil-forming rock was alluvial sand. The water table was 117 cm. Root development depth of trees and shrubs was up to 70 cm. There were some traces of soil invertebrates, which do not have a significant impact on the mixing of horizons. There was a tendency to glaze in the form of reddish spots at a depth below 50 cm. The soil profile was layered, has a series of buried humus-accumulative horizons, the transitions were sharp in colour. CO_2 bubbles emission was observed from a depth of 53 cm after applying dilute hydrochloric acid. The genetic type of the profile was hydrogen-differentiated, its structure was polycyclic, layered.

O (2–0 cm) – forest litter of undecomposed and semi-decomposed leaves.

Ah1 (0–6 cm) – surface humus-accumulative, sod. Dark greyish-brown in colour, fresh. Medium loam, loose texture, heavily interwoven with root systems of herbaceous plants. Aggregated, fine-porous structure, dominated by 5–8 mm aggregates. There were cracks up to 1 mm wide, 2–3 cm long, running in different directions. There was some animal disturbance. Transition in colour, structure and particle size distribution, sharp, wavy.

Ah2 (6–18 cm) – humus-accumulative. Greyish-brown with a fawn tint, fresh. Sandy loam. Nutty-lumpy structure, dense compaction. Abundantly root-saturated. There were root passages filled with humified loose material. The transition was smooth in structure and composition.

AB (18–38 cm) was a transitional horizon. Greyish-brown with a fawn tint, fresh. Sandy loam. Lumpy structure. Composition was denser than the previous horizon. Abundantly root-saturated. There were root passages filled with humified loose material. The transition was clear in colour, wavy.

C (38–46 cm) – alluvial bedrock horizon. Light yellow with rusty stains. Fresh, unstructured sand. Fragmentary roots of woody and shrubby plants were observed. The transition was not clear, 2–3 cm wide in colour and grain size distribution.

Ahkb (46–62 cm) was the first buried humus-accumulative carbonate horizon. The colour within the horizon was a smooth transition from dark brown to light brown. Fresh. Unstructured sandy loam. Fragmentary roots were found. Boils from a depth of 53 cm. Colour transition was smooth, transition zone 1.5 cm wide.

Ckc (62–73 cm) was an alluvial carbonate horizon of the bedrock. Marbled: rusty spots 1.5–2.0 cm in diameter against a light-pale colour background. Fresh, unstructured sand. The colour transition was sharp.

Ahkcb (73–82 cm) was the second buried humus-accumulative carbonate horizon. Light grey with rusty spots. Sandy, unstructured. There were interspersed root passages filled with humus material. The colour transition was sharp.

Ckl (82–93 cm) was an alluvial carbonate horizon of the bedrock. The colour was heterogeneous, similar to the Ckc horizon. Internal horizontal layering in colour: reddish spots and dark grey wavy micro-layers were predominantly horizontal. Occasionally, there were highly decomposed root remains. The colour transition was sharp.

Ahklb (93–106 cm) was the third buried humus-accumulative carbonate gley horizon. It was light grey with rusty spots. In the middle part of the horizon, there was a light ash band. Sandy, unstructured. Colour transition was sharp.

Crk (106–117 cm) was a gley carbonate horizon of alluvial bedrock with strong reducing conditions. It was of sandy granulometric composition, grey. Wet as it was located within the capillary rim.

Eutric Gleyic Pantofluvic Fluvisol (Humic, Loamic, Thaptoochric)

The site was surveyed in the floodplain of the Dnipro River (Location 28). The soil surface was evenly carpeted, there was a forest litter of undecomposed leaves 2–3 cm thick, and the projective coverage was 80%.

O (2–0 cm) – forest litter of undecomposed and semi-decomposed leaves.

Ah1 (0–10 cm) – surface humus-accumulative, sod. Dark grey, fresh. Sandy loam. Well-structured, lumpy-grained, contains coprolites. Loose texture, abundantly interwoven with root systems of herbaceous plants. Cracks, 1.5–2.0 mm wide and 2–3 cm long, with irregular orientation, were found along the peds. The transition was smooth in composition.

Ah2 (10–19 cm) was humus-accumulative. Grey with a fawn tint. Sandy loam. The structure was lumpy. Folding was denser than in the previous horizon, no cracks were observed. Less root-saturated, fibrous root systems of herbaceous plants and roots of tree and shrub forms. Within the horizon, the colour becomes lighter with depth and was compacted by folding. The transition was smooth in colour and structure.

AC (19–31 cm) was a transitional horizon. It was lighter in colour and more moist. The sand was cohesive. A heterogeneous mixture of sand and more humus material. The colour transition was sharp, the border was wavy.

C (31–44 cm) – alluvial horizon of the bedrock. It was grey. Colour was light grey with fawn tint and reddish streaks. Unstructured sand. Roots of shrubs or woody plants only. Vertical humus stripes were the remains of large decomposed roots. Colour transition, wavy.

ACb (44–55 cm) was the first buried humus-accumulative horizon. The sand was cohesive. Grey with a fawn tint. Structurally unstructured, moderately root-saturated. Inclusions of humus material along decomposing roots of woody vegetation. Colour transition, wavy with streaks.

Cl (55–74 cm) – alluvial gley horizon. Grey with a fawn tint, rusty spots and humus material in the upper part of the horizon. Roots were not found. Sandy, unstructured. The transition was sharp in colour, the border was wavy.

CAlb (74–82 cm) was the second buried gley horizon of organic matter accumulation. Moist. Grey with increasing dark shade with depth. Sand. Layered distribution of humified material. Sharp colour transition.

Cr (82–103 cm) – alluvial gley horizon with strong reducing conditions. Moist. In the upper part it was pale grey with rusty spots oriented mainly in horizontal direction. Humus streaks 0.5 cm wide and 2–3 cm long were oriented in a vertical direction. The lower part of the horizon above the groundwater table was grey wet sand. The groundwater level ranged from 94 to 103 cm during different periods of the study.

Gleysols

Eutric Fluvic Calcic Mollic Gleysol (Humic, Loamic)

A pit was excavated in a forest in the floodplain of a tributary of the Protych River on 12 May 2018 (Location 16). The pit was located on a relative rise in relief at a distance of 50 m from the swamp. The vegetation was an elm oak forest. The soil surface was relatively flat and carpet-like, with a forest litter of undecomposed leaves 2–3 cm thick and a projective cover of 20–30%. The leaf blades of fallen leaves were moderately decomposed, the litter was homogeneous, dry, and well separated from the soil. The grass stand has a projective cover of 70–80%. The soil-forming rock was alluvial sand deposits. The groundwater level was uncovered from a depth of 101 cm. On 26 May, groundwater was at a depth of 65 cm. No large off-horizon cracks were observed. There were some traces of soil invertebrates, which influence the mixing of horizons in the sod horizon. Signs of glazing from a depth of 38–65 cm. No carbonates and readily soluble salts in the form of morphological elements were observed. The soil texture varies from loose to dense. The genetic type of the profile was humus differentiated. CO_2 bubbles emission was observed from the soil surface after applying dilute hydrochloric acid.

O (3–0 cm) – forest litter with a projective cover of 20–30%.

Ahk1 (0–13 cm) – humus-accumulative carbonate horizon. Grey (N 5/0). Grey. Cohesive sandy loam. Loose texture, moderately interwoven with root systems of herbaceous plants. Very poorly aggregated, dusty-grained structure, aggregates were not stable and crumble. There were no cracks. Some animal disturbance. Transition was gradual in composition, colour and particle size distribution.

Ahk2 (13–38 cm) – humus-accumulative eluviated carbonate horizon. Dark grey (N 4/0). More damp. Sandy loam. Dense compositions. Individual roots of bushes. Not aggregated. Transition was gradual in colour and particle size distribution.

ABk (38–65 cm) – upper transitional carbonate horizon. Dark olive grey (2.5GY 4/1). Moist. Sandy loam of heavier texture, more sticky. Dense. Not aggregated. Roots of woody plants. Colour transition was gradual.

CBkl (65–83 cm) was a transitional carbonate horizon. Olive-grey (2.5GY 5/1). Sandy loam with sandy dusting. Moist. Dense. Small content of roots. Colour transition, gradual and not clear, 2–3 cm wide.

Ckl (83–98 cm) – gley carbonate saline horizon. Greenish grey (10Y 5/1) with reddish spots. Moist. Grain size distribution was sandy loam. Dense. Buried humus layers 3–4 cm thick. Transition was abrupt in colour and texture.

Crk (98–101 cm) – bedrock – gleyey saline alluvium with strong reducing conditions. Intensely bluish bluish-grey (2.5PB 5/3) with reddish spots, moist. Grain size distribution was sandy loam. Loose. Vertical spots with humus material, probably traces of decomposed plant roots. Groundwater from a depth of 101 cm.

Eutric Calcic Mollic Gleysol (Humic, Loamic)

The survey was carried out on 10 October 2017 (Location 20.1). Plant cover was marsh vegetation, projective cover was 100%. The soil surface was relatively flat, carpet-like, with dead plant remains on the surface, 0.5 cm high, and projective cover of 15–20%. The soil-forming rock was sand of the boreal terrace. The water table was 140 cm, then rose to 135 cm. There were some traces of soil invertebrates, which do not have a significant impact on the mixing of the horizons. There was a tendency for glazing in the form of reddish spots at a depth below 68 cm. The genetic type of the profile was hydrogen-differentiated. CO_2 bubbles emission was observed from the surface after applying dilute hydrochloric acid.

O (0.5–0 cm) – residues of dead plants.

Ahk1 (0–17 cm) – surface soddy carbonate. Very dark grey (N 3/0) with interspersed sandy particles, densely intertwined with plant roots. Fresh. Sandy loam. The structure was dusty-grained, brittle, forms beads along plant roots. Heavily transformed by animals. Loose composition. Shells of aquatic molluscs were found. Transition in colour, structure and root saturation, clear, wavy.

Ahk2 (17–75 cm) – humus-accumulative carbonate, clayey. Dark grey (N 4/0) with interspersed sandy particles. In the lower part of the horizon, reddish and ochre shades of colour due to claying. Moist. Loam, viscous when wet. Predominantly lumpy structure. Dense. The roots of bushes. The transition was gradual in colour.

Bhk (75–115 cm) – glued carbonate. Greenish-grey (10Y 5/1), gradually lightening with depth, moist. Sandy loam. Dense, plastic. Gradual change in colour and mechanical composition. On the border with the next horizon, there were spots of humus material 13–14 cm in diameter, probably decomposed roots of woody plants.

Crk (115–135 cm) was a carbonate gley soil-forming rock. Grey (5B 6/1) coarse cohesive sand with rusty spots. Moist. Loose. Groundwater was present from the depth of 135 cm.

Eutric Fluvic Calcic Mollic Gleysol (Arenic, Humic, Salic)

The record was made on 18 June 2017 (Location 21.2). The habitat was the floodplain of the Protoch River, the Dnipro-Orylskiy Nature Reserve. The vegetation cover was a wet meadow. The soil surface was relatively flat carpeted, with litter and moss cover 2–3 cm thick, and projective cover was 100%. Soil-forming rock was alluvial sand. The disclosed water table was 83 cm. There were some traces of soil invertebrates, which do not have a significant impact on the mixing of the horizons. There was a tendency for glazing in the form of reddish spots at a depth below 68 cm. The soil texture was loose. The genetic type of the profile was hydrogen-differentiated. CO_2 bubbles emission was observed from a depth of 18 cm after applying dilute hydrochloric acid.

O (4–0 cm) – moss cover and litter.

Ah1 (0–10 cm) – surface humus-soddy saline. Black, densely intertwined with plant roots. Moist. Sandy loamy. Aggregated, crumbly, granular structure. Loose composition. Transition in colour, structure and root saturation, gradual, wavy.

Ah2 (10–18 cm) – humus saline. Dark grey. Dense, moist. Sandy loam. The structure was nutty, not preserved when wet. Moderate saturation with roots. The transition was gradual in colour, composition and aggregate structure.

Bhk (18–38 cm) was the second humus saline carbonate. Dark grey to black, moist, sticky loam. The structure was less pronounced, granular. Denser than the previous one. Colour transition, gradual, wavy.

Bkl (38–68 cm) was a transitional carbonate gley. Dark grey with rusty spots, gradually lightens with depth. Moist, plastic sandy loam, dense composition. Colour change was gradual.

Crkz (68–83 cm) was an alluvial saline carbonate with spots of glaze. Dark grey, with rusty spots. Loamy. Moist. It was characterised by highly renewable conditions, groundwater from the depth of 83 cm.

Fluvic Gleysol (Arenic, Ochric)

The description was made on 5 October 2018 (Location 29.1). Dnipro-Orylskiy Nature Reserve. Riverine floodplain. Elm-oak forest. The surface was wavy, levelled, with forest litter of undecomposed leaves 2–3 cm thick, projective cover was 30–40%. The projective cover of the grass stand was 40–60%. Soil-forming rock was alluvial sand. The water table was 140 cm. Root depth of trees and shrubs was up to 70 cm. No large off-horizon cracks were observed. There were some traces of soil invertebrates, which do not have a significant impact on the mixing of horizons. The soil composition was dense. The soil was layered, the transitions were sharp in colour. The genetic type of the profile was differentiated humus. There was no CO_2 bubbles emission after applying dilute hydrochloric acid.

O (3–0 cm) – forest litter consisting of leaves of trees and herbaceous plants of varying degrees of destruction.

A1 (0–2 cm) – surface humus-accumulative, sod. Light grey, dry, sandy loamy. Unstructured, loose, abundantly intertwined with root systems of herbaceous plants. Easily separated from the next horizon. The transition was sharp in colour, structure, density and root saturation.

A2 (2–13 cm) – humus-accumulative. Brown-grey with humus spots, fresh, sandy loamy. Root-saturated. The structure was dusty-grained, the aggregates were not stable, easily crumble when pressed with fingers. The composition was dense. The transition was gradual in colour.

A/C (13–23 cm) was a transitional horizon. The colour was heterogeneous – against the background of the main mass of brown colour, there were spots of light yellow colour of various sizes with diffuse contours. Sandy loamy, moist, structure was dusty-grained, aggregates were easily destroyed when pressed. Composition was dense. There were roots of bushes and trees. There were root passages with dark-coloured humus material of loose composition. Sharp wavy transition in colour, particle size distribution, structure and density.

C1 (23–79 cm) was the first alluvial horizon. Light yellow in colour with rusty spots that increase with depth. Sandy, structureless, fresh. Occasional vertically oriented streaks of organic stained material. The transition was not clear, 2–3 cm wide in colour.

C2 (79–97 cm) was the second alluvial horizon. Light grey, layered. Layers of humus material 0.5–1.0 cm thick at intervals of 1.5–2.0 cm.

Darker coloured layers 0.5–1.0 cm thick alternate with light grey material 1.5–2.0 cm thick. Sandy, dense, moist. Tree roots were found. Transition in colour and moisture content was smooth, transition zone was 1.5 cm wide.

Cl1 (97–116 cm) was the first alluvial gley horizon. It was rusty grey with rusty spots and horizontal bands of humified material. Sandy, loose composition. The transition in colour and moisture content was sharp.

Cl2 (116–140 cm) was the second alluvial gley horizon. Loose wet sand Brownish-grey and bluish-greyish colouration corresponds to the renewable conditions and properties of gleyic. From a depth of 140 cm – groundwater.

Eutric Fluvic Mollic Gleysol (Humic, Loamic)

The description was recorded on 5 October 2018 (Location 29.2). Dnipro-Orylskiy Nature Reserve. The pit was located in a localised depression of the riverbed floodplain. Vegetation was an elm-oak forest, with a projective grass cover of 10–20%. Forest litter 5–6 cm thick, projective cover was 30–40%. Soil-forming rock was alluvial sand. The water table was 110 cm. There were some traces of soil invertebrates, which have a limited pedoturbation impact. There was no CO_2 bubbles emission after applying dilute hydrochloric acid. The genetic type of the profile was hydrogen-differentiated, by the type of structure – polycyclic, layered.

O (5–0 cm) was a stratified forest litter consisting of tree leaves and remains of herbaceous species. Dry, easily crumbles.

A1 (0–7 cm) – surface humus-accumulative, sod. Colour was brown and dark grey. Fresh. Sandy loam. Loose texture, abundantly interwoven with root systems of herbaceous plants and decaying leaves. Fine lumpy-grained, aggregates easily crumble when pressed. Horizon material was easily separated from the next horizon. The transition was sharp in colour, structure and root saturation.

A2 (7–29 cm) – humus-accumulative. Brownish-grey with spots of more humus material. Moist. Sandy loam. Structure – dusty-grained, aggregates were not stable, easily crumble when pressed. The composition was loose. Shrub roots were present. The transition was sharp and wavy in colour.

ACc (29–41 cm) was a transitional horizon. Grey with dark grey or rusty spots. Moist. Sandy loam. Unstructured, loose composition. There were some roots of bushes and trees. The transition was gradual in colour, not clear.

Cc (41–53 cm) was the first alluvial horizon. Light grey with irregularly shaped rusty spots, which were mostly extended horizontally. Moist, sandy, unstructured, loose. Roots of tree species were present. The transition was not clear, 2–3 cm wide in colour.

Clc (53–79 cm) was the second alluvial sandy horizon. It was moist. Motley coloured rusty grey, greyish-blue, brownish. Layers of humus material 0.5–1.0 cm thick at intervals of 1.5–2.0 cm. Darker coloured layers 0.5–1.0 cm thick alternate with light grey material 1.5–2.0 cm thick. Loose, structureless sand. Roots of tree species were found. The transition in colour and moisture content was sharp.

Cl (79–110 cm) – alluvial gley sand horizon. Colouration was typical of the renewed conditions – greyish-blue, rusty-grey and dark grey. It was loose with horizontal dark grey gley spots and rusty layers. Groundwater was present from a depth of 110 cm.

Calcic Mollic Gleyic Solonetz (Fluvic, Humic, Loamic)

The survey was carried out on 18 June 2017 (Location 21.1). The habitat was located in the floodplain of the Protoch River, in the Dnipro-Orylskiy Nature Reserve. The vegetation cover was halophytic meadow. Soil surface was relatively flat carpeted, with 3–4 cm thick litter, projective cover was 90–100%. The soil-forming rock was alluvial sand. The water table was 115 cm. There were some traces of soil invertebrates, which do not have a significant impact on the mixing of the horizons. There was a tendency for glazing in the form of reddish spots at a depth below 98 cm. There were no visible neoplasms, carbonate fragments, or salt accumulation. The soil was dense or cohesive. The genetic type of the profile was eluvial-illuvial-differentiated. CO_2 bubbles emission was observed from the depth of 31 cm after applying dilute hydrochloric acid.

O (4–0 cm) – litter with a projective cover of 60–80%.

Ah1 (0–3 cm) – surface humus-accumulative, sod. Grey. Dry. Sandy loam. Weakly aggregated, crumbly, some aggregate units were bound by clusters of cereal roots, granular-dusty structure. Loose composition, heavily intertwined with root systems of herbaceous plants. Transition in colour, structure and root saturation, sharp, wavy.

Ah2 (3–18 cm) – humus-eluvial (supra-saline) carbonate. Light grey. It was merged. Dry. Sandy loam. The number of roots was insignificant. Transition was abrupt in composition, mechanical composition and fracture, sharp.

Bthn (18–31 cm) – illuvial clay-humus (saline). Dark grey, fused. Fresh. Loam. Horizon surface was hilly. The number of roots was insignificant. Transition by folding and fracturing, sharp, wavy.

Bhkz (31–50 cm) – sub-saline carbonate saline. Dark grey, moist, loamy, plastic, no cracks. Colour transition was gradual.

Bklz (50–65 cm) – carbonate saline with spots of glaze. Light grey, slightly marbled with inclusions of rusty or humus spots. Loamy. Moist. Transition was gradual, wavy, indistinct. On the border between the next horizon there was a molehill 12–15 cm in size.

Cklz (65–98 cm) was the first alluvial carbonate saline with spots of glaze. It was light grey, lighter than the previous one, marbled with inclusions of rusty or humus spots. Loamy. Moist, unstructured. The transition was smooth, wavy, in colour.

Crkz (98–115 cm) was the second alluvial horizon, gley. Cold grey with rusty spots. Moist. Sandy loam. Characterised by highly renewable conditions, groundwater from the depth of 115 cm.

Map of soils in the Reserve

WRB Reference Soil Groups were classified using geomorphological predictors (Fig. 1). Soil types were able to explain 90% of the variation in the elevation of the relief that soils occupy (R_{adj}^2 = 0.90, F = 165.5, P < 0.001). Arenosols occupied a statistically significantly higher position in the relief than other soil types (planned comparison F = 671.3, P < 0.001). In turn, Eutric Arenosols occupy higher positions (68.9 ± 0.48 m), than Eutric Lamellic Arenosols (63.3 ± 0.54 m) (F = 61.6, P < 0.001). Other soils occupied positions in the relief that did not differ statistically significantly in elevation (F = 0.18, P = 0.67). Soil types were able to explain 38% of the variation in the elevation of the relief that the soils occupied (R_{adj}^2 = 0.38, F = 12.6, P < 0.001). The highest TWI values were found for Fluvisols (12.7 ± 0.23) and Solonetz (13.0 ± 0.28 m). The differences between these soils were not statistically significant (F = 0.80, P = 0.37). The TWI was a little lower for Cambisols (11.8 ± 0.21) and Eutric Lamellic Arenosols (12.2 ± 0.28), which also did not differ in this indicator (F = 1.50, P = 0.23). The lowest TWI value was found for Gleysol (11.15 ± 0.17) and Eutric Arenosols (10.95 ± 0.24), which did not differ from each other on this index (F = 0.45, P = 0.50). Eutric Arenosols and Eutric Lamellic Arenosols are formed at great depth of groundwater table (7.80 ± 0.50 and 2.60 ± 0.46 m, respectively). Gleysol and Solonetz form in the conditions of near groundwater level to the surface (0.28 ± 0.27 and 0.21 ± 0.46 m respectively) in the comparison with Fluvisol and Cambisol (0.46 ± 0.38 and 0.41 ± 0.35 m respectively).

Elevation was the most informatively valuable predictor, but the topographic wetness index (TWI) and the topographic groundwater depth estimate (VDCN) significantly improved the quality of discrimination (Fig. 2). Arenosols were very different from other soils, which occupy automorphic positions. Cambisols occupied a transitional position. Other soils occupied hydromorphic positions. Fluvisols and Solonetz occupied more humid positions and Gleysol occupied less humid positions. Fluvisols and Solonetz differed in groundwater levels. Solonetz predominantly occurred at the near-surface water table. The classification matrix confirmed the possibility of using geomorphological predictors to build a model of spatial variation of soils within the study area (Table 1). The spatial model demonstrates the organization of the soil cover of the reserve (Fig. 1). Calculations revealed that Cambisols occupy 20.7% of the area, Eutric Arenosols occupy 16.0%, Eutric Lamellic Arenosols occupy 17.9%, Fluvisols occupy 15.2%, Gleysols occupy 28.7%, Solonetz occupies 1.5%.

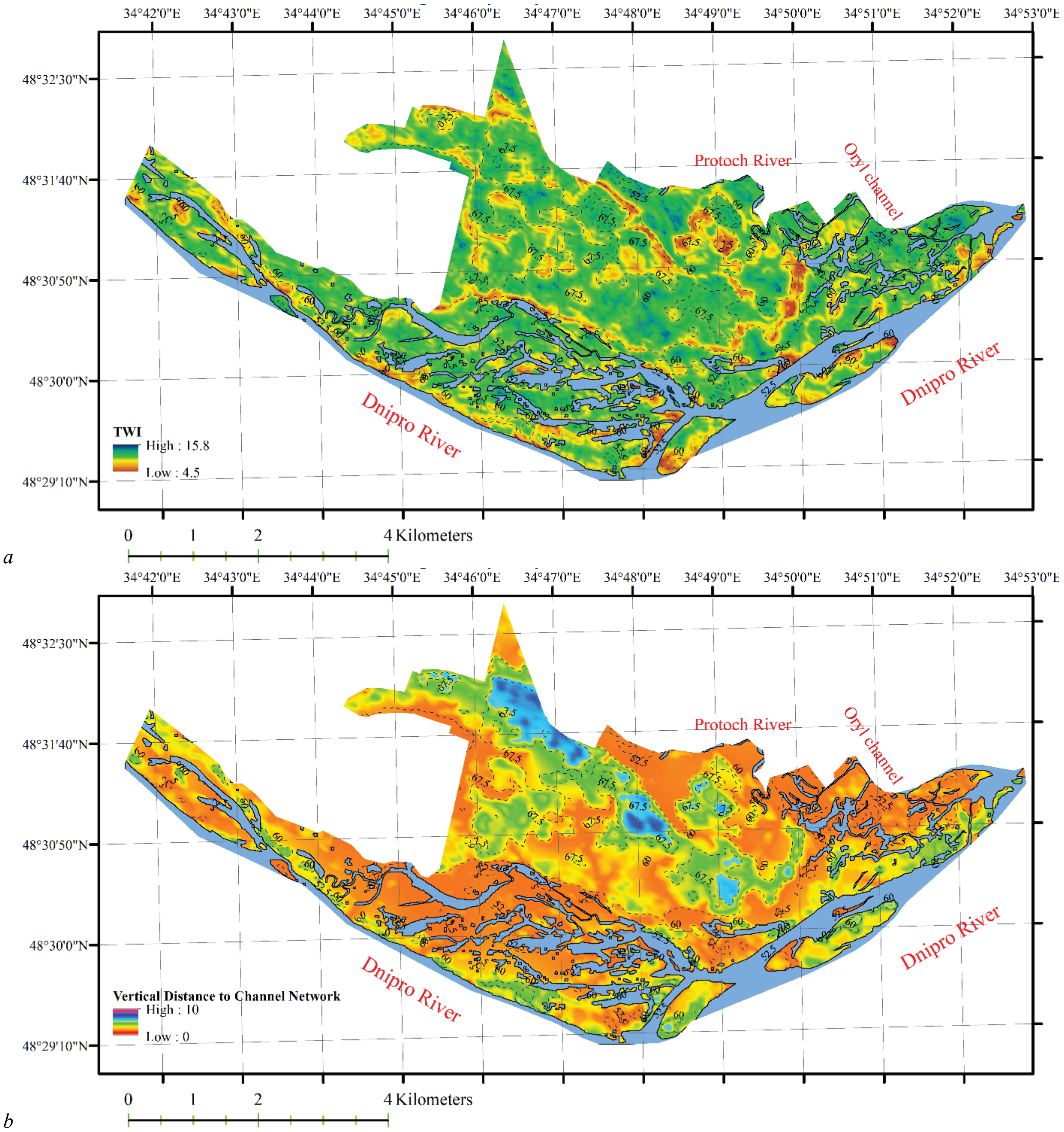

Fig. 1. Spatial variation in elevation (shown by the contour), topographic wetness index (shown by the colour) (*a*), and vertical distance to channel network (*b*)

Discussion

Soil genesis depends on the soil-forming factors, which include parent rock, climate, relief, living organisms, and time (Jenny, 1941). In river valleys, the terrain is the most significant driver of soil formation, as it also correlates with other soil formation factors (Xu et al., 2008). Floodplain and above floodplain terrace are clearly differentiated in terms of relief elevation (Yan et al., 2018). These geomorphological structures also have peculiarities of their geological formation, which affects the character of soil-forming rock (Celarino & Ladeira, 2017). This explains the result that geomorphological predictors, which are derived from a digital elevation model, are able to distinguish well between soil types in the floodplain and terrace landscape. The relief elevation is able to distinguish between floodplain and terrace floodplain soils. But there are overlapping lists of soil types within these geomorphologic zones, so the elevation alone, is not sufficient to effectively distinguish soil types. Eutric Arenosols occupy the highest landform positions. Eutric Lamellic Arenosols are placed slightly lower. Arenosols occupy almost the entire elevated part of the terrace and are formed on the sandy hills of the near-river floodplain. An important factor that affects the features of the soil formation process is the moisture regime (Childs, 1940). There are two sources of water inflow to the soil: atmospheric and soil supply (Zhou et al., 2023). The topographic wetness index is a geomorphological marker of soil moisture supply of atmospheric origin. An indicator of the role of ground supply of soil cover is vertical distance to channel network. The topographic wetness index distinguishes on the one hand Fluvisol and Solonetz as soils that occupy positions where atmospheric moisture accumulation occurs, which is redistributed under the influence of topography. On the other hand, the topographic wetness index differentiates Gleysol and Cambisol, which are placed in the transit positions with a significantly worse supply of moisture of atmospheric origin. The mentioned pairs differ in the soil groundwater supply index. In the pair Fluvisol and Solonetz, the latter occupies the positions with the groundwater level close to the surface. In the pair Gleysol and Cambisol the positions with the groundwater level close to the surface are occupied by Gleysol. Certainly, the differentiation of these soils is also influenced by the granulometric composition of the soil-forming material, which cannot be estimated from remote sensing data. The predominance of sand fraction contributes to the improvement of filtration properties of soils. This improves the aeration regime, which ultimately leads to differences between Cambisol and Gleysol. Or increases the intensity of salt leaching from the soil profile, which distinguishes Fluvisol and Solonetz.

Geomorphological predictors were best able to distinguish Eutric Arenosol and Eutric Lamellic Arenosol from other soil types. Apparently, the elevation of the relief closely correlates with the distribution of soil-forming deposits of different granulometric composition. On the terrace, dunes are formed, which consist of sand, where Arenosol is formed. In the floodplain there is a diversity of soil-forming rocks with different granulometric composition. The different sedimentation rate of suspended particles of different size during floods is the cause of spatial differentiation of floodplain soils. The levee berms consist of sand and also have relatively the highest elevations of the medium of all positions in the river floodplain. In the central part of the floodplain, the proportion of clay and silt particles increases, and the greatest proportion of the finest-sized particles is usually found in the near-riverine floodplain. However, this "classical" sequence is strongly influenced by secondary factors that resulted from anthropogenic transformation of the hydrological regime of the river.

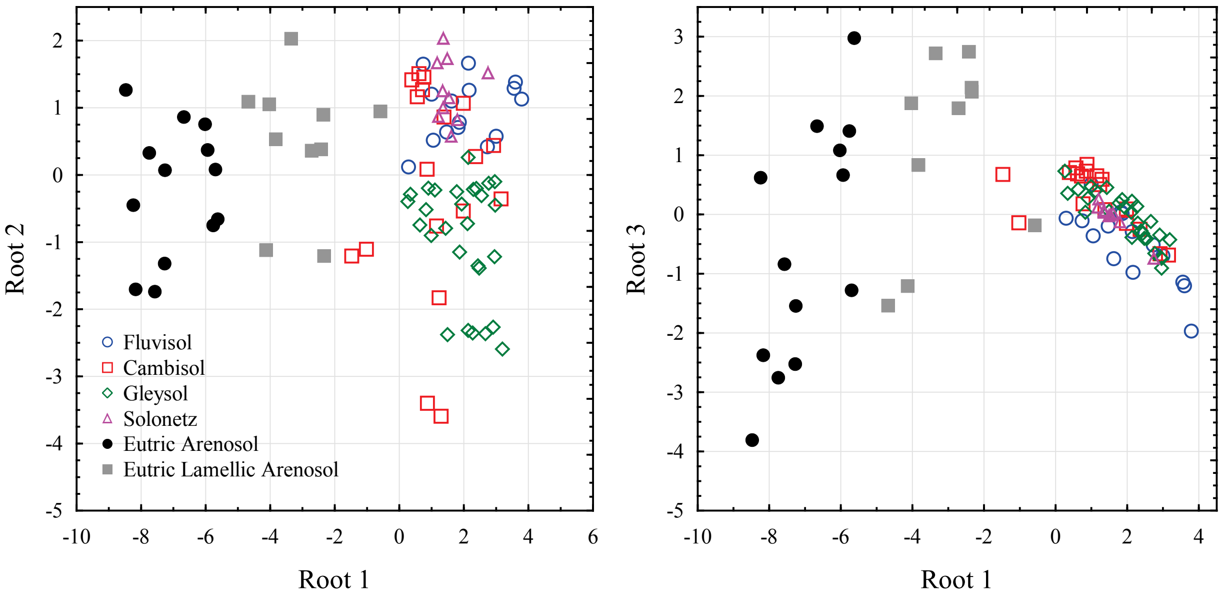

Fig. 2. Location of soils in the space of discriminant roots: Root 1 ($\lambda = 10.7$) was statistically significantly correlated with relief elevation ($r = -0.88$, $P < 0.001$), Root 2 ($\lambda = 0.7$) was statistically significantly correlated with relief elevation ($r = 0.23$, $P < 0.001$) and TWI ($r = 0.95$, $P < 0.001$), Root 3 ($\lambda = 0.7$) was statistically significantly correlated with elevation ($r = -0.89$, $P < 0.001$) and VDCN ($r = 0.95$, $P < 0.001$)

Table 1
Classification matrix of soils according to the results of discriminant analysis based on geomorphic predictors

Soils	Percent Correct	Fluvisol	Cambisol	Gleysol	Solonetz	Eutric Arenosol	Eutric Lamellic Arenosol
Fluvisol	73.3	11	2	0	2	0	0
Cambisol	16.7	3	3	7	4	0	1
Gleysol	78.6	0	6	22	0	0	0
Solonetz	40.0	4	2	0	4	0	0
Eutric Arenosol	92.3	0	0	0	0	12	1
Eutric Lamellic Arenosol	70.0	0	1	0	0	2	7
Total	62.8	18	14	29	10	14	9

Note: rows are the observed classifications, columns are the classifications obtained as a result of the analysis.

The role of geomorphological predictors for distinguishing floodplain soils is greatly reduced. This is probably due to two reasons. First of all, the variability of the floodplain soil cover is extremely large and the sizes of the ranges of soil types are strongly decreasing, for which reason the 10-meter resolution of the digital elevation model becomes insufficient to accurately represent the relief features of the floodplain area. Prediction success is known to be often directly dependent on the resolution of the image. Maps with a resolution of 2 to 10 m were shown to provide a reasonable delineation of colluvial soils as part of the soil cover (Penížek et al., 2016). Another reason is disturbance of correlation between soil types and soil-forming factors, which occurs as a result of anthropogenic influence. Anthropogenic influence removes the natural system far from the equilibrium state, to which the correlation between the object of nature and the factors of soil formation corresponds to the greatest extent. Floodplain ecosystems within the reserve remain most subjected to anthropogenic influence in comparison with terrace ecosystems. Such a situation cannot remain outside the reserve, as the ecosystems, which are formed on Arenosol are extremely sensitive to anthropogenic impact and one can predict the violation of the correlation between the factors of soil formation and soil types in terrace ecosystems outside the reserve.

In the terrace above the floodplain, the soil-forming rocks are alluvial and aeolian sands (Wierzbicki et al., 2020). The factor of wind erosion leads to the homogenization of sand soil-forming rock. Nevertheless, sand dunes and interdune depressions differ in their complexity, which is the reason for differentiating Arenosols into two groups: Eutric and Eutric Lamellic. Eutric Arenosol occupy sand dunes, while the interdune depressions usually contain Eutric Lamellic Arenosol. Thus, the spatial arrangement of sand dunes within the first floodplain terrace determines the spatial relationship between Eutric Arenosol and Eutric Lamellic Arenosol. The dunes, which are composed of loose sand, have a relatively large contact surface with the atmosphere because of their hemispherical shape. A thin layer of topsoil with a low concentration of organic matter does not promote much vegetation, which also promotes better contact of the soil surface with the environment and heat exchange, which is not hindered by ecological structures such as vegetation cover or a layer of dead organic matter. Dunes heat up quickly under the influence of solar radiation, but also cool down quickly, thus creating a condensation effect. When sandy soils become very dry, evaporation no longer proceeds from the soil surface, and the position of the evaporation front moves downward along the profile. Therefore, condensation of water vapor moving down the soil profile occurs at night due to a decrease in atmospheric temperature caused by the radiative cooling of the sandy soil. The sequestration of atmospheric water vapor in the soil profile was detected in the diurnal dynamics of overheating during the day and cooling at night of sandy soils (Shimojima et al., 2011). Condensed moisture easily penetrates deep into the dune because the loose sand has a high filtration capacity. Lamellic structures act as a water retaining structure along which condensed moisture can move towards the river channel. Thus, the spatial organization of Arenosol can be considered as a factor providing the river with additional water supply through condensation of water and its migration. Sand dunes act as moisture condensers, and interdune depressions provide moisture transport due to the presence of lamellar structures.

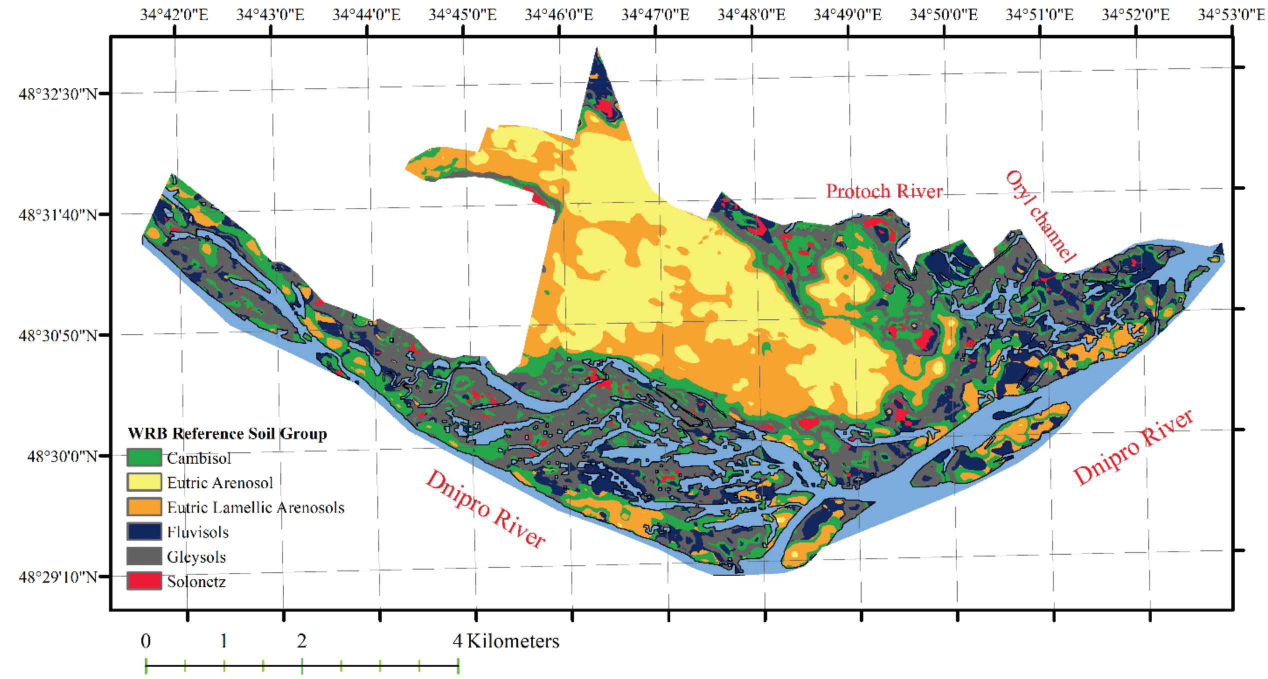

Fig. 3. Map of soil distribution within the Dnipro-Orylskiy Nature Reserve

The importance of studying the soil cover within protected areas should be noted, especially because little attention is paid to this in the procedures prescribed for environmental monitoring in Ukraine. Thus, in the approved Program on Preparation of the Annals of Nature (Paton, 2002) (the standard form of the annual report of the scientific unit of the reserve on its studies of biota), recommendations for the study of the soil cover are very poorly presented and they are extremely outdated. Obviously, this situation is not acceptable. Thus, Article 43 of the Law of Ukraine "On the Nature Reserve Fund of Ukraine" states that the Annals of Nature is main form of summarizing the results of scientific research and observations of the state and changes in natural complexes carried out in nature reserves, biosphere reserves, and national nature parks, the materials of which are used to assess the state of the environment, develop measures for the protection and efficient use of natural resources, and ensure environmental safety. The study of soil cover in the reserve should be a standard aspect of ecological monitoring. Such procedures should comply with internationally accepted modern standards.

Conclusion

The soil cover within the Dnipro-Orylskiy Nature Reserve is represented by Arenosol, Cambisol, Fluvisol, Gleysol, and Solonetz. The geomorphological predictors are able to effectively differentiate the above soil types, which made it possible to produce a soil map of the reserve on the basis of point data. The elevation of the relief is the most significant predictor, which reflects the heterogeneity of soil-forming material at the meso-level. Higher positions in the terrace are occupied by sand dunes, while lower floodplain soils are formed under conditions of significant diversity of soil-forming rock in terms of granulometric composition. The topographic wetness index describes the role of topography in the redistribution of water supplied to the soil from the atmosphere. Fluvisol and Solonetz are formed under the conditions of water accumulation of atmospheric origin, while Gleysol and Cambisol are formed under the conditions of water outflow of atmospheric origin. The vertical distance to channel network indicates the role of groundwater as a source of water supply to the soil. Solonetz and Gleysol are formed under the conditions of the groundwater table close to the soil surface.

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