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Ecological Successions of Urban Landfills of the Western Forest Steppe of Ukraine

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ABSTRACT

The most acceptable way to prevent and eliminate negative phenomena arising from devastating landscapes is phytomelioration. To assess the suitability of the landfill's surface for phytomelioration measures, it is necessary to determine the species composition, physiological stability, density, and completeness of the tree stand (in case of the tree species development) already developing as a result of natural overgrowth. The present work examines the ecological succession of three large urban landfills within the Western Forest Steppe of Ukraine - Lviv, Ternopil, and Lutsk. It was established that the maximum phytomass is characteristic of the gentle slopes of landfills with relatively stable moisture index, and developed soil, which gives reason to attribute the plant groups to the endoecogenesis stage while there are no garbage dumping processes. Three stages of overgrowth were identified for all landfills – syngenetic succession, initial endoecogenetic succession, and mature endoecogenetic succession. The taxonomic structure of the flora of the urban landfills of the Western Forest Steppe is represented by the divisions *Magnoliophyta, Pinophyta, Polypodiophyta, Bryophyta,* and the classes *Magnoliopsida, Liliopsida, Pinopsida, Equisetopsida, Polytrichopsida*. The phytomeliorative efficiency of vegetation at solid waste landfills shows that the surface of landfills in the Western Forest Steppe is dominated by stunted plants and the phytomelioration coefficient is low. Thus, the surface of the landfill is suitable for phytomelioration and reclamation works and landfill decommissioning. The phytomeliorative efficiency of vegetation at solid waste landfills shows that the surface of landfills in the Western Forest Steppe is dominated by stunted plants and the phytomelioration coefficient is low. Thus, the surface of the landfill is suitable for phytomelioration and reclamation works and landfill decommissioning.

Keywords: landfill, ecological succession, ecological safety, the taxonomic structure of flora, phytomelioration.

INTRODUCTION

The investigation of the urban environment and related theoretical and applied ecological issues is extremely relevant [Sukopp, 1990; Ziemba, 1998]. The problems of urbanization, environmental safety, and the deterioration of the life quality of the urban population became global [Kucheriavyi, 2020].

One of the biggest environmental problems of humanity is the technogenically dangerous impact of landfill components on air, water bodies, and soils [Kasassi et al., 2008]. As they migrate, dangerous substances and compounds accumulate in components of the environment. In particular, the high content of heavy metals in plants and macromycetes leads to their physiological changes [Adamcova et al., 2017; Akanchise et al., 2020]. The problem for scientists is leachate accumulated at the foot of landfills. It is saturated with a large number of heavy metals and chemical compounds [Dan et al., 2017; Kulikowska et al., 2008; Suchecka et al., 2006.]. In the global context, there are many ways to neutralize hazardous factors of landfill leachate, but they have not been globally implemented, but are being applied regionally [Deng et al., 2006; Heavey et al., 2003; Renou et al., 2008; Uygur et al., 2004].

Among the biosphere components, the most significant factor in neutralizing air pollution is vegetation, especially tree and shrub plantations and natural forests. Green spaces perform various functions in the formation of the urban environment: sanitary-hygienic, architectural-aesthetic, emotional-psychological, etc. The sanitary and hygienic role of plants is the most important for creating favorable conditions for human life. Being a kind of living filter, they absorb chemical toxins from the air and retain a significant amount of dust on the surface of the assimilation organs. In addition, green spaces participate in the formation of the microclimate and provide human protection from adverse climatic influences.

The most acceptable way to prevent and eliminate negative phenomena caused by devastated landscapes is phytomelioration [Kucheriavyi, 2003; Tymchuk et al., 2021]. To assess the suitability of the surface of landfills for phytomelioration, it is necessary to determine the species composition of vegetation, physiological stability, density, and completeness of the tree stand (in case of the tree species development) already developing as a result of natural overgrowth [Bégin Y. et al., 2010; Businelli et al., 2009; Skyba et al., 2020].

To carry out artificial phytomelioration, first of all, it is necessary to stop taking garbage to landfills, recover leachate, and acid tar, eliminate combustion centers, introduce waste processing plants and installations, carry out mining engineering (by stabilizing and strengthening slopes) and biological (applying layers of fertile soil mixtures, planting grass and afforestation according to legal requirements) stages of recultivation [Gautam et al., 2019; Oziegbe al., 2021].

During investigation of coenoclines, the structure and dynamics of coenoses reflecting different levels of hemerobium, V. P. Kucheriavyi [Kucheriavyi, 2003] classified the phytocenoses types according to the degree of habitat changes: slightly changed habitats are phytocenoses in which recovery occurs with a slight change in the conditions of native type habitats (after gradual and selective felling, self-regrowth of fresh forest cuts or reforestation by planting on fresh felling); medium-changed habitats - turfed forest cutting areas, burnt places, dry meadows covered with forest in the past, as well as arable land on former forest habitats, in which there was no significant deterioration of soil and hydrological conditions; highly changed habitats – park biogeocenoses on eroded soils classified, according to the degree of soil erosion, as moderately eroded, where from 1/3 to 2/3 of the humus has been washed away, there has been a change in the forest area, and there has been a transition of habitats to another group of species diversity; very strongly changed habitats are represented by eroded lands, classified as strongly eroded according to the degree of soil erosion (more than 2/3 of the humus horizon), as well as quarries, dumps, terricones, landfills – places of formation of polyhemerobic biogeocenoses and habitats where infertile dead substrate has been formed, as a result of technogenic soil pollution.

During reclamation works (artificial afforestation) at solid waste landfills, it is recommended to use avant-garde species of trees and shrubs to promote rapid soil development [Semenenko et al., 2020; Xiaoli et al., 2007]. Under this condition, it is not desirable to plant coniferous trees and birch. The created plantations require constant care, therefore, it is necessary to create conditions for the prevention of unwanted competition of plants. As a result of the analysis of the possibility of the landfills phytomelioration, it should be stated: the failure to comply with primary legislation governing solid waste management leads to problems for the population of technogenically overloaded regions; the morphological composition of Ukrainian solid waste landfills is suitable for the formation of humus and organic substances, and self-covering with vegetation and carrying out phytomelioration measures on them; the investigation of successional processes in landfills, caused by natural overgrowth and artificial afforestation, remains relevant [Popovych et al., 2023].

MATERIALS AND METHODS

The research was conducted using complex theoretical and field approaches. Such methods as typology, synthesis, logical constructions, and analysis were used during theoretical research. The description and analysis of micro-associations were carried out according to the methodology of V.P. Kucheriavyi. In order to investigate the similarity of the flora of the chosen sites of landfills, the Jacquard coefficients of floristic similarity were used.

The objects of research are landfills that operate within the Western Forest Steppe of Ukraine (Western Ukrainian Forest Steppe District). The Western Ukrainian Forest Steppe district is located in the western part of the Forest Steppe zone. The following geomorphological subregions are distinguished within the Western Forest Steppe: Volyn Upland, Male Polissya, and Podilsk Upland (Fig. 1).

The administrative boundaries of the Western Forest Steppe include the south of Volyn Oblast, part of the southern districts of Rivne Oblast, central and south-eastern Lviv Oblast, Ternopil, Khmelnytskyi, and northern Ivano-Frankivsk Oblast. The northern border of the Western Forest Steppe runs along the line Volodymyr – Volynskyi – Lutsk – Rivne – Korets. The southern border runs along the line Mostyska – Sudova Vyshnia – Rudky – Dniester River. The western part is bounded by the state border with Poland; the eastern border passes through Polonne, Staryi Ostropil, Samchyntsi, Dunaiivtsi, Stara Ushytsia. Thus, in addition to household waste, the landfills studied in the urban areas also contain hazardous waste from various industrial enterprises. Due to the closure of many enterprises, most hazardous waste is no longer stored at landfills. Now, with the promulgation of landfill regulations, it is forbidden to mix hazardous waste with household waste. However, the regulations do not regulate the issue of hazardous waste that is accumulating at existing landfills. These landfills pose a double threat to the environment and people.

RESULTS AND DISCUSSION

Overgrowth of landfills within the Western Forest Steppe occurs at the foot and, partly, on the side surfaces. Small overgrown areas on the surface of landfills are the result of reclamation works (mining and biological stages). However, the reclamation works did not involve a preliminary study of phytocenoses, and their selection was not carried out correctly, resulting in the death of forest crops.

In general, the presence of ruderal vegetation at landfills indicates that it has entered the stage of synergistic succession. The study of spontaneous plant communities and their habitat conditions at solid waste landfills allows for the effective design of biological reclamation stages at

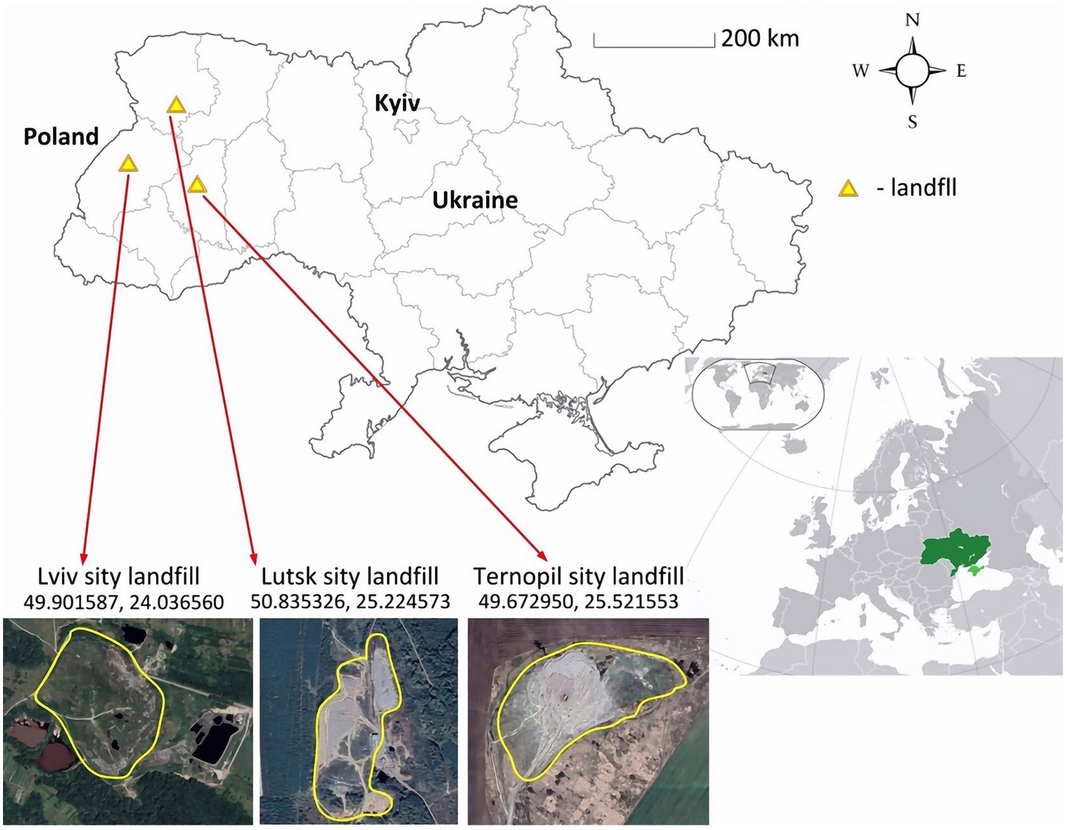

Figure 1. Location of the investigated landfills on the map of Ukraine

operating landfills in order to decommission these facilities that adversely affect biota. Of course, the development of plants depends on the geographical area in which they grow and is determined by the following characteristic temperatures: the minimum temperature at which plants begin to grow, the optimum temperature that is most favourable for growth and the maximum temperature at which growth stops. At landfills, the optimal temperature for heat-loving plants is +30 to +45 °C, and the minimum temperature is + 10 °C. For cold-tolerant plants, the optimal temperature is between +23 to +30 °C, the minimum temperature is 0 to +5 °C, and the maximum temperature of most plants is from +32 to + 45 °C.

Ecological successions of the Lviv city landfill

The Lviv city landfill is characterized by the accumulation of a large number of filtration reservoirs and tar accumulations at the foot. Research in [Malovanyy et al., 2021; Odnorih et al., 2020; Popovych et al., 2021; Tymchuk et al., 2020] is devoted to the hazard of leachates and acidic tar reservoirs.

In general, on the surface of the Lviv landfill, we've distinguished three stages of vegetation cover succession: the syngenetic stage, the initial endoecogenetic stage, and the mature endoecogenetic stage. Species composition of vegetation with high classes of constancy, i.e. the most often found in these phytocenoses: the syngenetic succession (*Chenopodium urbicum* L. *Plantago major* L. *Arctium lappa* L. *Artemisia vulgaris* L. *Artemisia absinthium* L.); the mature endoecogenetic succession (*Chenopodium urbicum* L. + *Plantago major* L. + *Artemisia vulgaris* L. + *Calamagrostis epigeios* L.) (Roth. + *Eutrigia repens* L. + *Humulus lupulus* L. + *Hippophae rhamnoides* L. + *Betula pendula*) Roth.; the initial endoecogenetic succession (*Chenopodium urbicum* L.+ *Plantago major* L. + *Arctium lappa* L. + *Artemisia vulgaris* L + *Calamagrostis epigeios* L.) (Roth. + *Eutrigia repens* L. + *Humulus lupulus* L.).

Ruderal species are partially replaced by more resistant perennials *Calamagrostis epigeios* L. Roth., *Eutrigia repens* L., *Humulus lupulus* L. The initial endoecogenetic succession at the Lviv landfill is characteristic of the top (fragments), the western exposure of the slope, the depressions of the relief, and the places of waste landslides.

Mature endoecogenetic succession appears after 10–12 years and is accompanied by the development of perennial grasses (*Calamagrostis epigeios* L. Roth., *Eutrigia repens* L., *Humulus lupulus* L.), shrubs (*Hippophae rhamnoides* L.) and trees (*Betula pendula* Roth). Ruderal species at this stage of succession are in small numbers. A mature endoecogenetic succession at the Lviv landfill is observed on the northern exposure of the slope and at a certain distance from the foothills on the eastern side. Plant micro-associations of different slopes exposures of the Lviv landfill are shown in Fig. 2.

The theoretical justification for the use of the renaturation approach to the ecological rehabilitation of man-made geosystems is based on numerous investigations of the natural restoration of plant cover and the recent (new) soil formation in these geosystems [Kucheriavyi, 2003]. The maximum phytomass is intrinsic to gentle slopes with relatively stable moisture, and developed soil, which gives reason to assign plant communities to the endoecogenesis stage, while there are no garbage dumping processes.

Currently, the mining and technical stage of recultivation is taking place at the Lviv municipal solid waste landfill, and garbage dumping has been stopped.

Ecological successions of the Ternopil city landfill

Natural phytomelioration processes at the Ternopil city landfill are observed on the surface of the first part of waste backfilling, where garbage dumping is stopped. The second part of backfilling is partially covered with sandstones in order to carry out the mining and technical stage of recultivation (Fig. 3). Frequent fires at solid waste landfills that occur on the northern and western exposures of the slopes slow down phytoreclamation processes.

On the surface of the landfill, there is an extremely depleted species composition of vegetation: grass cover – *Calamagrostis epigeios* L. Roth., *Eutrigia repens* L., *Artemisia absinthium* L., *Artemisia vulgaris* L., *Fragaria vesca*, *Daucus carota* L., *Carex pilosa* Scop., *Taraxacum officinale* Wigg., *Tussilago farfara* L., *Heracleum sosnowskyi* Manden., *Trifolium pratense* Schreb., *Urtica dioica* L.; tree and shrub – *Sambucus nigra* L., *Salix caprea* L., *Prunus cerasifera* Ehrh., *Prunus avium* L., *Betula pendula* Roth. Mainly trees and shrubs develop on the northern exposure of the landfill slope. During field research, the sites were laid out with respect to the relief, since all landfills have a complex structure and

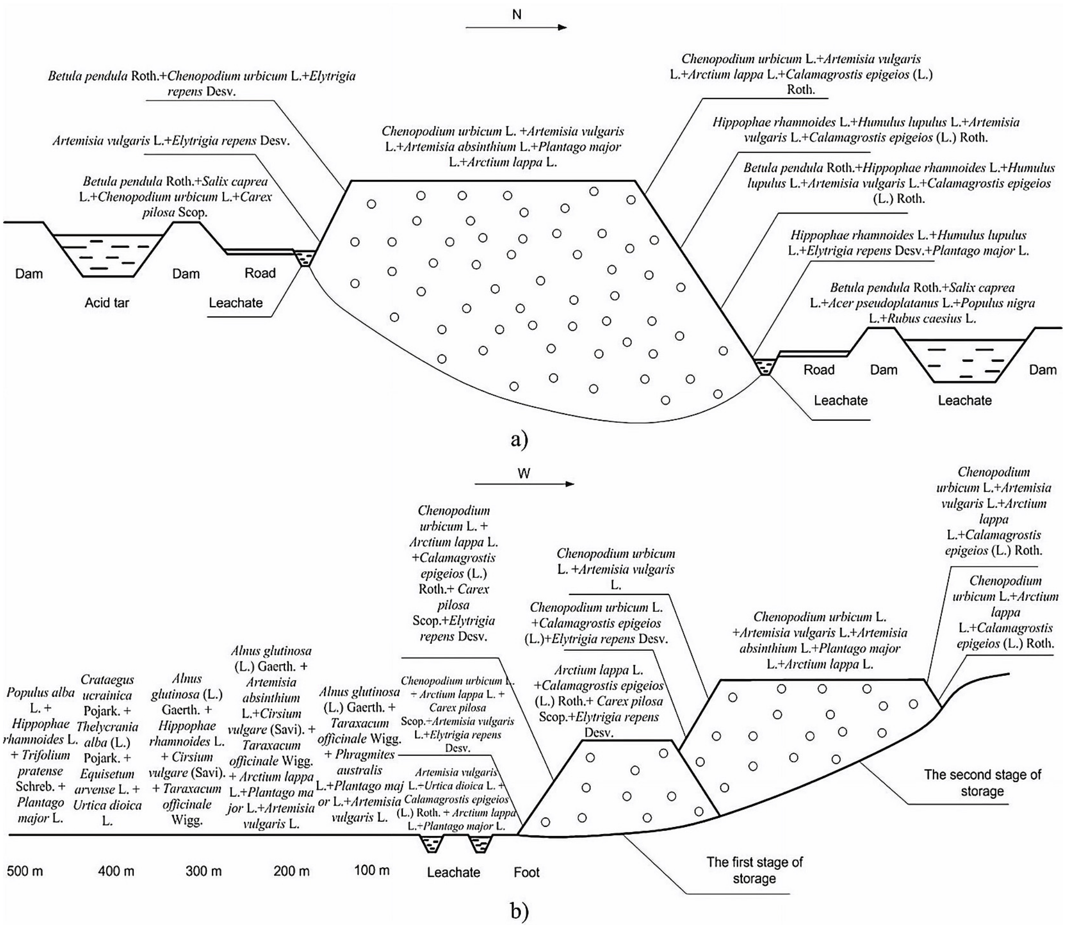

Figure 2. Vegetation micro-associations of the Lviv landfill: (a) south-north site; (b) east-west site (developer V. Popovych)

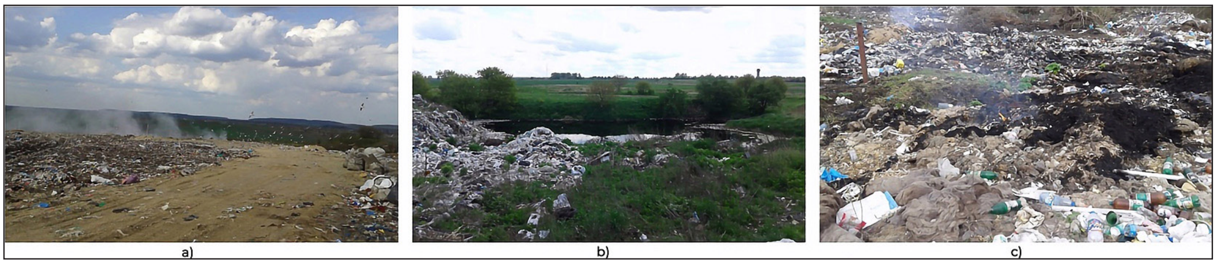

Figure 3. Natural phytomelioration and the process of landfill combustion: (a) Ternopil; (b) Tysmynets; (c) Sokal (photo by V. Popovych)

surface heterogeneity (there are the following parts: the top, from where the washing of small particles and nutrients occurs, the transit zone: the slopes along which small particles are transported to the foot of the dump and the so-called accumulative zone, where substances washed from the top accumulate and create favourable conditions for the vegetation development).

To analyze the similarity of the areas around the burning sites with the rest of the landfill, the Jacquard floristic similarity coefficient was used. The obtained coefficient ($Kj = 0.26$) indicates a low level of similarity of the above-described flora. Near the places where garbage is burned, the species composition is represented by thermophilic plants that tolerate high substrate temperatures. In the remaining areas, the species inherent in the North-West Podil Forestry District are developing.

At the Ternopil landfill, we distinguished three stages of vegetation cover successions: syngenetic stage, initial endoecogenetic stage, and mature endoecogenetic stage, in the species composition of vegetation of high constancy classes, that is, those that are most often found in these phytocenoses.

As can be seen from the table, the syngenetic stage of succession at the solid waste landfill is represented only by ruderal species. These species do not join each other in aggregation and are located spontaneously. The initial endoecogenetic succession is inherent in those areas of the landfill that are provided with a sufficient amount of moisture: lows, northern exposure of the slope, and surface sections. This stage is characterized by the springing of grass, which displaces weeds and increases the area of projective cover. Mature endoecogenetic succession is accompanied by the meadow (*Trifolium pratense* Schreb) and forest vegetation (*Fragaria vesca*), as well as young trees (*Betula pendula* Roth.). The progression of this succession is observed in the areas where there is no dumping of waste: the northern and western sides of the landfill.

Ecological successions of Lutsk city landfill

The species composition of the vegetation, taking part in natural phytomelioration processes, was established in the studied areas. There is no vegetation on the surface of the landfill due to the constant uncontrolled dumping of garbage. Recently, the entire surface of the landfill has been leveled with construction equipment to accumulate more waste.

Zonal vegetation is developing on the northern side of the landfill, namely *Pinus sylvestris* L. The species is undemanding to edaphic conditions and develops well in arid places. On the western side of the landfill, protective forest strips have been created with *Populus alba* L. Single-row planting of this species does not fulfill the designed tasks – it does not protect the adjacent agricultural lands from the hazardous factors of the landfill and does not add aesthetics to the devastated landscape. At the foot of the landfill, ruderal vegetation has developed on all sides, but it is often destroyed due to trampling: *Chenopodium urbicum* L., *Arctium lappa* L., *Plantago major* L., *Taraxacum officinale* Wigg., *Urtica dioica* L.

The species composition of ruderal and tree-shrub vegetation increases with distance from the landfill. The test plots at 20 m and 100 m from the foot of the landfill allow assessing the species' participation in the creation of a phytomeliorative cover only at a certain distance from the landfill. It is obvious that, after canceling the bulldozers' work, most of the described species will develop on the surface of the landfill. Twenty meters from the landfill we found such species as *Urtica dioica* L., *Artemisia absinthium* L., *Artemisia vulgaris* L., *Carex pilosa* Scop., *Trifolium pratense* L., *Achillea millefolium* L.; trees – *Robinia pseudoacacia* L., *Pinus sylvestris* L., *Populus tremula* L. 100 m from the landfill the following species were found: ruderal – *Leontodon autumnalis* L., *Plantago lanceolata* L., *Achillea millefolium* L.; moss – *Polytrichum commune* L.; trees - *Pinus sylvestris* L., *Betula pendula* Roth., *Populus tremula* L., *Populus alba* L., *Carpinus betulus* L., *Quercus robur* L., *Juglans regia* L. (stand-alone), *Aesculus hippocastanum* L. (stand-alone). The Jaccard coefficient of floristic similarity was used to compare the degree of similarity and difference of the species on the studied sites. The obtained coefficient of floristic commonality (Kj = 0.15) indicates a low level of similarity of the above-described flora. This indicator is low due to the excellent conditions for vegetation growth around the landfill and at a certain distance from it. It is obvious that the development of vegetation around the landfill is inhibited by hazardous factors like the burning of garbage, leachate, and biogas. Natural regeneration of trees occurs at a distance of at least 100 m from the foot of the landfill (Fig. 4).

Despite the constant leveling of the plateau by bulldozers, zonal vegetation is developing at the Lutsk landfill and in its impact zone. It should be noted that a syngenetic stage of succession is observed on the surface of the landfill, which is represented by ruderocenoses – *Chenopodium urbicum* L., *Arctium lappa* L., *Plantago major* L., *Taraxacum officinale* Wigg., *Urtica dioica* L. These species develop in places with increased substrate humidity and relief lowering. These are mostly areas on the northern side of the landfill. The initial endoecogenetic succession is represented by species typical for the Volyn Upland – *Pinus sylvestris* L. and *Carex pilosa* Scop. It was highly developed on the northern side of the landfill. At the same time, the self-seeding of Scots pine is inhibited by uncontrolled waste-dumping processes. A mature endoecogenetic succession inhibits the development of ruderal species, and trees prevent the growth of the moss *Polytrichum commune* L. Such a succession is observed at a distance of 50–100 m from the sides of the landfill and is characterized by stable tree species that enhance the aesthetics of the area.

Figure 4. Natural regeneration of *Pinus sylvestris* L. 100 m from the landfill (photo by V. Popovych)

The phytomeliorative efficiency of vegetation at solid waste landfills shows that the surface of landfills in the Western Forest Steppe is dominated by stunted plants and the phytomelioration coefficient is low. Thus, the surface of the landfill is suitable for phytomelioration and reclamation works and landfill decommissioning. The phytomeliorative efficiency of vegetation at solid waste landfills shows that the surface of landfills in the Western Forest Steppe is dominated by stunted plants and the phytomelioration coefficient is low. Thus, the surface of the landfill is suitable for phytomelioration and reclamation works and landfill decommissioning.

CONCLUSIONS

On the plateau and the slopes of all city landfills, mostly ruderal vegetation grows, being the natural phytomeliorants. The vegetation of these areas, in most cases, is different from the vegetation of the areas located at the foot of landfills, on dams of filtration reservoirs, and in the impact zone of landfills. This is evidenced by the calculated Jacquard floristic similarity coefficients.

It has been established that the phytocenoses of the Lviv landfill are mostly characterized by syngenetic succession, which grows best on the northern exposures of the slopes. Uncontrolled waste-burning processes, an abandoned leachate accumulation and removal system, and landfill gas are detrimental to successional processes. These processes inhibit humus formation and the accumulation of phytomass in landfills in general.

At the Ternopil landfill, self-ignition processes occur in those places where natural phytomelioration processes are already taking place. Among the ruderal species that grow around waste smoldering sites, the following were found: *Taraxacum officinale* Wigg., *Taraxacum hybernum* Steven., *Chenopodium urbicum* L., *Eutrigia repens* L., *Heracleum sosnowskyi* Manden., *Arctium lappa* L., *Daucus carota* L., *Artemisia vulgaris* L. The temperature of the substrate around the smoldering sites is not critical (+24–26 °C), but it is well tolerated by the plants (the temperature of the substrate in the unburnt areas was +20 to 21 °C. All these ruderal species develop well in conditions of high substrate temperatures and are gas and salt-resistant. The projective cover of weeds around burning sites is 60–70%. An important observation is that there is no tree-shrub vegetation on the surface of the Ternopil landfill, especially around the burning sites.

When studying the peculiarities of the formation of a phytomeliorative cover at the Lutsk landfill, it was established that: there is no vegetation on the surface of the landfill due to the constant uncontrolled processes of garbage dumping;

the development of vegetation around the landfill is inhibited by hazardous manifestations (burning garbage, leachate, biogas), and the natural regeneration of trees occurs at a distance of at least 100 m from the foot of the landfill; the Jacquard flora similarity coefficient for sample plots of the investigated landfills is 0.15 and is low due to the excellent conditions for vegetation growth around the landfill and at a certain distance from it; during the floristic descriptions of the studied areas, stand-alone and not inherent to the conditions of local growth phytocenoses were found (*Juglans regia* L., *Aesculus hippocastanum* L.).

The study of successional processes on the surface of urban landfills is an important issue of recent ecological research due to the search for the main directions of a renaturalization approach implementation for man-made hazardous objects.

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