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UNDERGROUND MINING LONG-TERM IMPACTS ON FOREST LANDS

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Underground mining of oil shale in northeastern Estonia causes changes in the exterior of the local landscape in the form of depressions with a depth up to 1.7 metres. As a result of the changing water regime (formation of small water-bodies and marshy areas) the environmental conditions in subsided areas will be affected as well, influencing the development and alternation of local plant communities. Researches and surveys in the subsided area, which was formed 20 years ago in the area of room-and-pillar mining, prove that the former forest has become a poor fen that may further develop to a swamp forest or a transitional bog forest. The affected areas are of great interest from the viewpoint of landscape diversity.

Introduction

The underground and opencast mining in northeastern Estonia has generated serious changes in the exterior of the local landscape, entailing subsequent environmental problems [1, 2]. The artificial forms resulting from human activities do significantly influence the relations predominating in ecosystems in influenced areas, causing the aberration of the development of local natural communities from the natural path of succession [3].

Opencast mining results in an entirely new landscape as after the closure of mining works the affected areas will be recultivated as a rule. While the restoration of nature and recultivation of openpits have been relatively well explored [4–7], the results of underground mining on the landscape are still less researched. As a matter of fact the extraction of oil shale seam will often result in surface deformations (ground movements or depressions) that cause subsequent changes in water regime and therefore in surface plant

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communities as well, including the vegetation in forest areas and grasslands. By now the total deformed area covers about 230 km^2, including stable 130 km^2 and unstable i.e. potentially endangered area some 100 km^2, mined with room-and-pillar method. On unstable area (about 2.5 %) the ground is spontaneously subsided already [1]. According to prognostications their share in the industrial landscapes of northeastern Estonia will further increase.

The land deterioration frequently concurrent with such depressions also causes changes in land use. Up to now the influence of ground deformations and water regime changes on agricultural lands have been explored from the viewpoint of land quality and its productiveness mainly [8]; the value of agricultural lands and forestlands in areas affected by underground mining has also been investigated [9, 10]. Nevertheless, such problems as habitat diversity, course and speed of the stabilization of new plant communities in affected areas, etc. have remained unclear and there are no studies about the communities in subsided areas available yet.

The purpose of the given study is to describe the changes in forestland vegetation during 20 years since the preliminary subsidence, as well as to evaluate the changes in plant communities that have taken place during this time and to propose some future vegetation development tendencies.

Study Area and Used Methods

All methods used by underground mining in the area of Estonian oil shale deposit (long-wall, room-retreat, room-and-pillar) are characterised by stoop mining, whereby the mined area is covered by a network of mined out rectangles – mining plots. In the bedrock of these rectangles the geotechnical processes will occur according to roof control methods. As in the areas of room-and-pillar mining the ground surface subsidence (up to 1.7 m) is most extensive [1] and spontaneous (unpredicted) deformations will continue during a longer time, a rock caving area in forestland over the *Ahtme* Mine (plots Nos. 26 and 27) was chosen as the study area. This area is located within one kilometre south-east from the Ahtme quarter of the town of Kohtla-Järve (Fig. 1).

In this area of room-and-pillar mining six post-subsidence negative surface forms with a depth of 1.3–1.5 m are located close together with a total area of 1,000–5,000 sq metres, which is constantly overflooded (Fig. 1, Pos. *9*). There is also an adjacent larger area of 5 hectares formed during the last 20 years as a result of depression of the mining plot No. 27, originally as a body of water and since 1984 as a mainly marshy area (Fig. 1, Pos. *8* and *6*). Post-subsidence negative forms in Fig. 1 are marked with roman numerals: plots on mining plot No. 27 as I–III and plots on No. 26 as IV and V, respectively. Two water-bodies are located in marshy area, others surrounded by forest. During the course of work all plots were mapped.

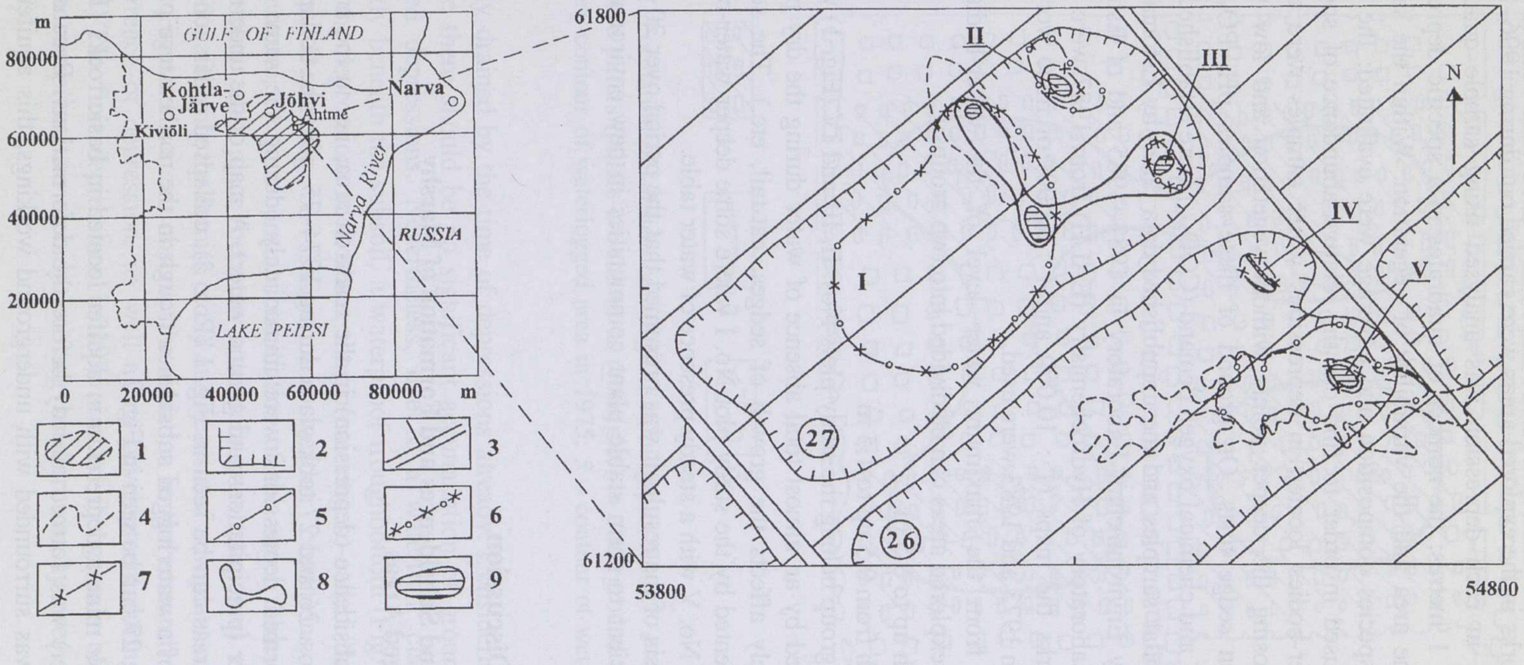

Fig. 1. Location of the study area and development of the ground subsidence areas. *1* – underground mining area (the mines of *Kohtla, Sompa, Ahtme, Viru* and *Estonia*); *2* – general contour of subsidence trough (in 1975); *3* – underground workings (borders of the room-and-pillar mining plots); *4* – the contour of marshy area prior to ground subsidence in 1975; *5* – marshy area in 1983; *6* – marshy area in 1983–1999; *7* – marshy area in 1999; *8* – waterlogged area in 1975; *9* – waterlogged area in 1999; 26 and 27 – numbers of the mining plots; I–V – numbers of the study plots (post-subsidence negative forms)

The field works in the explored areas were carried out during 1996–1999. The vegetation in each depression was analysed using sample quadrates measuring 1 × 1 metres; the number of quadrates in a specific depression depended on the area and the variability of vegetation. Within the sample quadrates the species composition and coverage were evaluated; the latter indicator was used in order to find out the relative abundance of species. From the water-bodies located in depressions water samples were taken, preferably choosing the deeper points without vegetation and low water regions between sedge turfs. On ground of these samples pH, PO_4^{3-}–P, NO_3^-–N, SO_4^{2-} and chemical oxygen demand (COD_{Mn}) were established. For comparison similar samples and the unpublished data taken by Estonian Oil Shale Company Environmental Laboratory in 1983–1985 and of Estonian Amelioration Laboratory of Hydrochemistry (EALH) from 1987 were used. During the works the maps (1 : 10,000 and 1 : 5,000) of mine workings originating from 1973 and 1983 were used.

Proceeding from the maximum water level of the water-bodies in depression, the explored areas can be divided into two groups:

- Water depth up to 0.5 m
- Water depth from 0.5 up to 1.5 m

To the first group belong the study plots Nos. II, III and IV (Fig. 1) which are characterized by an almost total absence of water during the dry period (which positively affects the growth of sedges, cat-tail, etc.). The second group is represented by the study plot No. I where some deeper water-bodies are located and No. V with a steady presence of water table.

In the analysis of the results it was presumed that the period over 20 years has been sufficient to form stable plant communities in new environmental conditions.

Results and Discussion

History: Ground Subsidences and Formation of Marshy and Waterlogged Areas

The primary subsidence (depression) in the research area, i.e. in the area of mining plots Nos. 26 and 27 took place during 1974–75, after the collapse of pillars. The formed depressions were immediately (during the same year) filled with water (precipitations and ground water). A map of the undermined and subsided areas can be seen in Fig. 1 (Pos. *2*); collapsed pillar zone and the formation of a waterlogged subsidence trough in the northeastern part of mining plot No. 27 can be seen in Fig. 2.

In the *Ahtme* mine a depression in aquifer located in basic rocks (Keila-Kukruse aquifer) was formed already before the deformations. Because the area of plots was surrounded with underground workings, this aquifer was

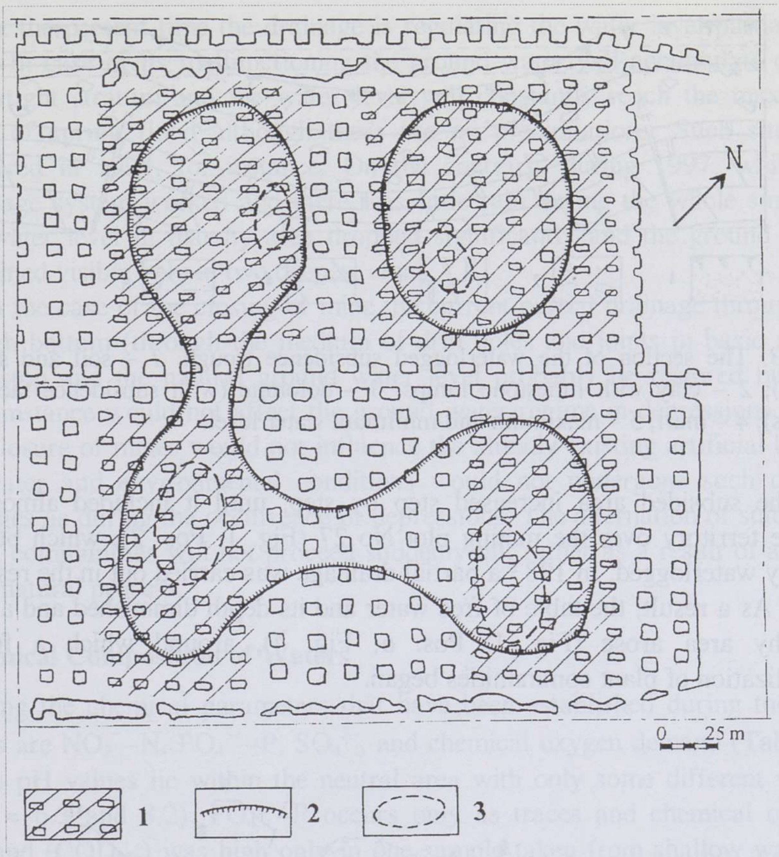

Fig. 2. Formation of subsidence trough in mining plot No. 27. *1* – primary area of collapsed pillars (pillars are shown as rectangles) in underground mining area; *2* – primary contour of waterlogged area in 1975; *3* – contour of waterlogged area in 1999

mostly drained by the time of depressions already. Considering this circumstance there should be no significant accumulation of ground water in the formed depressions. Nevertheless, due to a watertight clay soil stratum directly beneath the subsoil, a waterproof troughbottom (Fig. 3) was formed after the depressions took place, thus preserving so-called "hanging" ground waters. Depending on seasons and weather conditions (precipitations, temperature, etc.), a constant vacillation of the water table (niveau) in the depression took place between a certain maximum and minimum value (Fig. 3), affecting the demise of old and genesis of new plant communities.

In Figure 1 we can observe the situation in the research area before the occurrence of depression, as well as its development during the following years. The first depressions in 1975 caused the genesis of a water-body, which comprised an already existing smaller marshy area (Fig. 1, Pos *4* and *8*).

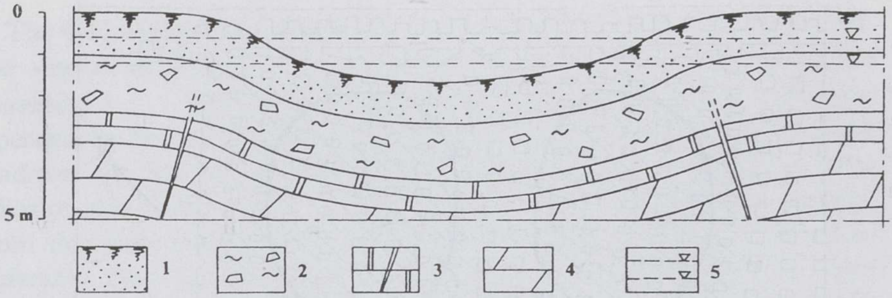

Fig. 3. The section of the waterlogged subsidence trough. *1* – soil and subsoil (sand); *2* – clay with limestone lumps; *3* – dolomite (with subsidence factors – drains); *4* – marl; *5* – maximum and minimum water level.

The subsided area increased step by step, until it included almost the whole territory over the mining plot No 27 (Fig. 1, Pos. *2*), which became totally waterlogged. In 1983 a partial drainage was carried out in the research area. As a result, the table of free water and its depth diminished and a large marshy area arose (Fig. 1, Pos. *6*; Fig. 4), around which a further stabilization of plant communities began.

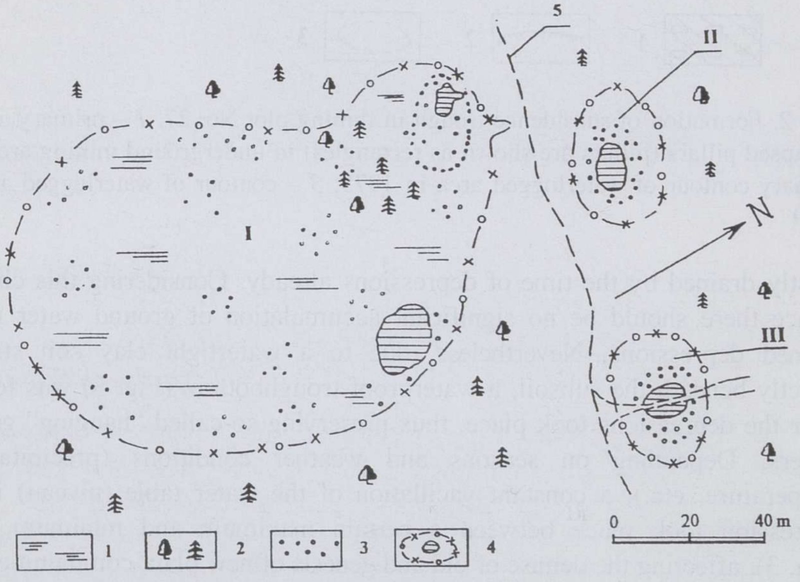

Fig. 4. Depressions on the mining plot No 27. I – lager marshy area with two water-bodies; II and III – small dysentrophic water-bodies with fluctuating water level; *1* – marshy area; *2* – swamp forest (stagnant waters); *3* – plant communities dominated by sedge, etc.; *4* – permanent water-bodies (see also Fig. 1, Pos. *9*) and the borders of the maximum water level in the periods of overflowing; *5* – track

At the present time the drainage is regulating the water level partially as well. In case of its malfunctioning the ground water will accumulate on the watertight stratum and the water level will constantly reach the maximum level of spring flood although there are no precipitations. Such situation occurred in 1999, for instance. On the contrary, during 1997, while the drainage system worked and there was little rain during the whole summer, the water level in marshy area dropped significantly and the ground water remained visible only in two deepest areas.

In the case of the closing of mine the current partial drainage through the trough bottom (through the medium of drill holes and joints in basic rocks) will stop and the natural ground water level probably be restored but this circumstance would not affect the ground water regime in depressions. Thus the closure of mines would not influence the already existing artificial bodies of water and environmental conditions would not undergone such drastic changes as during the occurrence of depressions. The alternation of stabilized plant communities will not proceed suddenly but rather as a result of a long-time natural process.

Chemical Composition of Waters

Among the chemical parameters that have been established during the past years are NO_2^-–N, PO_4^{3-}–P, SO_4^{2-}, and chemical oxygen demand (Table 1). Most pH values lie within the neutral area with only some different values (pH = 6.3 and 8.2). PO_4^{3-}–P occurs only as traces and chemical oxygen demand (COD_{Mn}) was high only in one sample taken from shallow water in marshy area (208 mg O_2/l), which is probably caused by deteriorating plant remains. In other places the COD_{Mn} value lays within 16–60 mg O_2/l.

Most fluctuating were the values of NO_2^-–N, the content of nitrate nitrogen reaching 0.02–0.90 mg/l. The highest NO_2^-–N values (0.6–0.9 mg/l) were registered in May 1996, but already by August the same value dropped to 0.02–0.07 mg/l. As a rule, rivers are considered to be polluted if the content of NO_2^-–N exceeds 1.2 mg/l (1,200 mg/m^3) and the content of PO_4^{3-}–P exceeds 0.03 mg/l (30 mg/m^3) [11]. Proceeding from these limits we can assume that the artificial bodies of water formed in the subsided areas due to ground water and precipitations do not contain nutrients in such a high concentration that they could be considered to be polluted.

Table 1. **Chemical Composition of Waters in the Study Area (1996–1998)**

Indicator	Value
pH	6.3–8.2
PO_4^{3-}, mg P/l	Traces
NO_3^-, mg N/l	0.02–0.9
Chemical oxygen demand (COD_{Mn}), mg O_2/l	16–59.2 (in the shallow water up to 208)
SO_4^{2-}, mg S/l	5–41.8

As a comparison it should be noted that in local lakes the content of NO_3^-–N is varying largely; during summer months it may even drop beneath the analytical detection limit (1 mg/m^3). Simultaneously some high NO_3^-–N concentrations have been established (especially in spring), which can be attributed to the influx of ground water with a high content of nitrogen. In most lakes the content of PO_4^{3-}–P varies less and its average value during many years totals 0.0077 mg/l (7.7 mg P /m^3) [12].

The highest content of sulfate ions in the water from subsided areas (41.8 mg/l) has been established in 1987 by EALH (unpublished data); later analyses have registered results that lie some two times lower than that (in 1996 5–30 mg SO_4^{2-}/l, respectively). This is a relatively low value, especially in comparison with the Kurtna Lakes, where some bodies of water have a high content of sulfates due to the influx of mining waters [13].

On the ground of those results we can declare that the minor bodies of water in the subsided area have been formed from ground water; among the nutrients necessary for the growth of plants their water contains average amounts of N and small amounts of phosphor. Its acidity (pH) is neutral.

Plant Community Development in the Deformed Areas

Changing environmental conditions also affect the development and alternation of plant communities. During the 1980's the impact of ground depressions on the state of forests was researched by Estonian Forestry Institute [9]. On the ground of those results the changes in water level depending on the original forest site type can be divided as following:

- In the subsided area only ground relief and general appearance of the forest change; the area itself will remain dry
- The subsided area is regularly overflooded
- The subsided area is permanently flooded

According to E. Kaar's data [14], before the occurrence of deformations in 1975, the research area was covered by a 20–40-year-old forest with site types of *Vaccinium myrtillus* and *Aegopodium* prevailing (Table 2).

The existence of a forest before ground deformations is also proved by yet extant treestumps (some dead and others broken) with a maximum height up to 2 metres.

The forest stand composition and plant communities before the occurrence of deformations (Table 2) were established using the old taxonomic descriptions mainly. At the present time forest is growing only on a narrow strip of the marshy area near the study plot No. I (Fig. 4), composed by young individuals of common birch, black alder, etc. (Table 3). The main new community there is birch swamp forest.

Table 2. **Original Plant Communities in the Subsided (Study) Area (by E. Kaar [14])**

Forest stand composition*	Site type	Community
Study plot I (Fig. 1)		
5Mä1Ku2Ks2Hb	Bilberry	*Vaccinium myrtillus*pine forest
10Mä	Bog whortleberry	*Vaccinium uliginosum*pine forest
Study plot II (Fig. 1)		
5Mä1Ku2Ks2Hb	Bilberry	*Vaccinium myrtillus* pine forest
Study plot III (Fig. 1)		
?Mä2Hb1Ks	Bilberry	*Vaccinium myrtillus* pine forest
6Ks5Hb	Goutweed	*Aegopodium* aspen forest
6Ks2Hb1Mä1Ku	Goutweed	*Aegopodium* birch forest
Study plot V (Fig. 1)		
No data	No data	No data
Study plot VI (Fig. 1)		
7Hb2Ks1Ku	Goutweed	*Aegopodium* aspen forest

* Mä – pine, Ku – spruce, Ks – birch, Hb – aspen.

Thus we can assume that the original plant community in the subsided area has been almost completely destroyed afterwards. During the last 15 years the development of vegetation has undergone a number of natural processes resulting in a vegetation type characteristic to swamps. The species composition of the swamp located in the area of the mining plot No. 27 indicates that a poor fen site type is currently prevailing there with considerable communities of bottle sedge, slender sedge and purple smallreed. In the same marshy area there are also two deeper bodies of water originating from depressions; in their side zone reeds, cat-tail and sedge are growing (Fig. 4).

Table 3. **Presence of the Tree- and Shrublayers in the Marshy Areas, % ('+' – Presence less than 10 %)**

Species	Presence
Trees	
Common birch (*Betula pubescens Her.*)	71
Black alder (*Alnus glutinosa CL.*) J.Gaertn.	10
Great sallow (*Salix caprea L.*)	10
Bird cherry (*Padus racemosa Lam*) Gil.	10
Shrubs	
Alder buckthorn (*Frangula alnus Mill.*)	80
Bird cherry (*Padus racemosa Lam.*) Gil	20
Black currant (*Ribes nigrum L.*)	+
Common sallow (*Salix cinerea L.*)	50
Willows (*Salix sp.*)	50

The resulting marshy area (Fig. 4) and almost all small water-bodies are surrounded by a strip of gray alder (*Alnus incana*) several metres wide, and some willow species, including great sallow (*Salix caprea*) and bay willow (*Salix pentadra*) forest that extends to the maximum water border during spring flood. Such species are characteristic for floodplain and minerotrophic mobile water swamp forests and thus in the border area of forest and depressions both nutrient and water regime conditions may be similar to these in swamp forests.

Among mosses *Calliergon cordifolium* was detected, which grows in moist areas. There were no sphagna, which indicates that at the present stage of subsided area development conditions for bog peat growth and development are unfavourable (water regime, alkaline air pollution in the form of oil shale fly ash, etc.).

Sinking water level in shallow bodies of water, which can reach almost the minimum during the dry period has especially favoured the growth and spread of sedges. In the plant communities in shallow bodies of water (study plots Nos. II, III and IV) bottle sedge is clearly predominant; in water cat-tail and in side zone opulent wood scirpus and bur reed can be seen. In those bodies of water a clear tendency of overgrowing can be observed as the sedges, especially the bottle sedge (*Carex rostrata*) grow not only in side zone but also in such water-bodies that are liable to run dry. Broad-leaved pondweed (*Potamogeton natans*) was abundantly detected in three plots (Nos. IV and V); by the end of summer it usually covers the whole water surface. More representative species found in the study area are given in Table 4.

All water-bodies formed in the depression area belong to the dysentrophic water-body site type where water contains abundant organic matter; the content of mineral matters is varying [15].

The further development of plant communities grown and stabilized in the area of depressions can proceed in many ways depending on the changes of environmental conditions. Like already said before, the closure of mines should not affect significantly the ground water regime and subsequently the plant communities.

The presently existing swamp can in the course of further development transfer to a swamp forest or further to a transitional bog [16], as indicated by the presence of a young swamp forest. We can assume that the presently lower study plots (Fig. 1, Nos. II–IV) can also change into a swamp forest as the environmental conditions prevailing there are more or less similar to these in larger marshy area. In the case of deeper study plots located in marshy area (V) the course of the further development can be deducted using the scheme of lake overgrowing by V. Sukachev [16]. According to this scheme, reed and carex will produce reed or carex peat and thus commence the overgrowing from borders to middle part.

Table 4. **More Representative Species in the Study Area, % (coverage by some sample quadrates 1 × 1 m, '0' – No species, '+' – Rare species)**

Species	Study plots (Fig. 1)				
	I	II	III	IV	V
Reed *Phragmites communis Trin.*	10–75	0…+	0…+	+...30	+...10
Purple smallreed *Calamagrostis canescens (Web.) Roth.*	+...40	+...20	0...+	+...30	+...10
Slender carex *Carex rostrata Stok.*	10–50	0...+	0...+	+...20	+...30
Bottle sedge *Carex lasiocarpa Ehrsh.*	+...80	+...85	+...30	+...40	10–95
Smooth horsetail *Equisetum limosum L.em.Roth.*	+...20	+	+	+...20	+
Comarum palustre L.	+...30	+	+	+	+
Cat-tail *Typha latifolia L.*	+...60	+...100	+...40	+...20	+...10
Broad-leaved pondweed *Potamogeton natans L.*	+...100	+	20–80	100	+
Conglomerate rush *Juncus conglomeratus L.*	+	+...20	+...20	+	+
Wood scirpus *Scirpus sylvaticus L.*	+	+	+	+	+...30
Simple bur reed *Sparganium simplex Hyds.*	+	+	+	+	+...95
Graceful sedge *Carex nigra (L.) Reichard*	+...20	+...20	+...20	+...20	+...60

It should also be noted that although the study areas are of little interest from the viewpoint of forest management, they still represent an interesting example of landscape diversity.

Conclusions

The research of changes in vegetation of the forest area of Estonian oil shale underground mining, where the deformations occurred more than 20 years ago, revealed the following results:

1. Ground deformations (depressions) will generate drastic changes in plant communities in the areas where the hydrological regime would rapidly change after the occurrence of depressions, largely as a result of local geological (natural) conditions. The development of new communities is subject to natural processes stabilizing in 15–20 years after the occurrence of the depressions.

2. Wetlands and artificial water-bodies emerging in subsided areas evolve from ground water and precipitations; in terms of trophic level they may be described as dysentrophic. The development of vegetation has undergone various processes, which have resulted in a new plant community characteristic to poor fen bog and dysentrophic water-bodies. In the course of further development a minerothropic stagnant water swamp forest or transitional bog forest may emerge here. In shallow bodies of water (depth up to 0.5 m) a clear tendency of overgrowing becomes evident, resulting in a development into a swamp forest. By deeper depressions (up to 1.5 metres) the development occurs according to the scheme of lake overgrowing.
3. Future closure of mines will not significantly influence the already existing water regime in artificial bodies of water and environmental conditions in subsided area; subsequent changes will not be as drastic as directly after the occurrence of depressions. The subsided areas are one of the examples of landscape diversity in the mining area.

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