Remote and ground-based observations of land cover restoration after forest reclamation within a brown coal basin

Oleksandr M. Masiuk1, Mykola M. Kharytonov2, Sergey A. Stankevich3

1 Oles Honchar Dnipro National University, Dnipro, Ukraine, almas63636@gmail.com
2 Dnipro State Agrarian and Economic University, Dnipro, Ukraine, kharytonov.m.m@dsau.dp.ua
3 Scientific Centre for Aerospace Research of the Earth, NAS of Ukraine, Kyiv, Ukraine, st@casre.kiev.ua

Abstract. The Semyonovsky - Golovkovsky brown - coal deposit is located within the boundaries of the Dnieper basin geological group and is located in the Alexandria mining region on the watershed of the Ingulets and Beshka rivers. Overburden rocks are loess - like, red - brown and glauconite-containing loams, kaolin and carbonaceous clays quartz, glauconite - containing and carbonaceous sands. The total area of reclaimed land was about 1006 hectares, of which 39 % was used for agriculture, 2 % was pasture and 59 % under forest reclamation. Geomorphologic assessment of the studied area was performed using Sentinel-1 satellite radar interferometry. Multispectral imagery of Sentinel-2 satellite system was used for remote assessment within the study area. We assessed the state of the *Robinia pseudocacia* plants growing under various forest conditions, in plantations created on the reclaimed landscapes of the Semenovsky - Golovkovsky brown coal basin. The processes of self-regulation and restoration of fertility on the reclaimed lands at the first stages of their biological development were slowed down. This significantly reduced the resistance of phytocenoses, both pure and mixed, to the conditions of the environment to which they were exposed. A comparison of the inventory stem wood of the black locust showed the superiority of monoculture plantations to mixed stands of pine - black locust and maple - black locust. The forest-forming process progresses with age. Remote assessment of the territories was conducted to assess the future prospects of biological conservation of reclaimed lands. The influence of the anthropogenic factor is observed throughout the section and is manifested in the man-made formation of the relief, reshaping of dumps, removal to the surface of overburden rocks. It is established that the height values can vary from 85 m to 213 m. 82.8 % of the surveyed area has not undergone significant changes in relief. About 15.5 % of the territory was under the influence of alluvial - diluvia processes. There have been corresponding changes in the share of vegetation according to vegetation cover fraction (VCF) over the past three years. The highest moisture content at the level of 0.2 - 0.3 relative units in 2015 was recorded in the territory occupying 78.4 %. Meanwhile, the shares of land cover with this level of humidity increased by almost 9% during the following 3 years to 2018. The highest density of vegetative cover was recorded in the North-Western part of the study area of forest reclamation. Thus, considering the potential suitability of the area for forest reclamation, we should note the important role of geomorphological, geological and water resources for the growth and development (formation) of plant communities

Key words: forest reclamation, land cover, remote sensing

Дистанційні та наземні спостереження відновлення земельного покрову після лісової рекультивації у буровугільному басейні

Олександр М. Масюк1, Микола М. Харитонов2, Сергій А. Станкевич3

1 Дніпровський Національний університет ім. Олеся Гончара, Дніпро, Україна, almas63636@gmail.com
2 Дніпровський державний аграрно - економічний університет, Дніпро, Україна, kharytonov.m.m@dsau.dp.ua
3 Науковий Центр Аерокосмічних досліджень Землі, НАН України, Київ, Україна, st@casre.kiev.ua

Анотація. Семеновсько-Головківське буровугільне родовище знаходиться в межах геологічної групи Дніпровського басейну і розташовано в Олександрійському районі на вододілі річок Інгулець і Бешка. Воно являє собою відпрацьовану кар'єру на денну поверхню якого винесені гірські породи надвугільної товщі. Розківшив породи представлені лосолідними, червоно-бурами і глауконітвміщуючими сулинками, каоліновими і вултитними глинами, глауконітовими і вултитними пісками. За- гальна площа рекультивації земель склала близько 1006 га, з них під сільськогосподарськими угіддями – 39 % території, пасовищами – 2 % і під лісою рекультивацією – 59 %. Геоморфологічну оцінку досліджуваної території було проведено із застосуванням супутникової радарної інтерферометрії Sentinel-1. Багатоспектральні зміни супутникової системи Senti-
nel-2 was used for distanced monitoring of the reclaimed territory. A significant change in the size of the lithostratigraphic zones was recorded, which led to a significant increase in the degree of the hydrogeologic regime. This is an important factor for the implementation of the reclamation project and has significantly improved soil quality compared to undisturbed soils. The duration required to attain a successful reclamation was about 10 years of reclamation. Overall, R. pseudoacacia has shown strong adaptation to poor soil conditions after reclamation and has markedly ameliorated soil succession in dumps (Yuan et al., 2018).

The reactions to mixture of ores and their change along a gradient of site conditions depend on the respective limiting factor and the species’ potential to overcome the limitation (Forrester, 2014). Complementarity in exploitation of water and mineral nutrients is most effective and growth accelerating on sites with limitation in water and mineral nutrients. Mixed stands of Scots pine and European beech have significantly higher structural heterogeneity than monocultures of Scots pine and European beech (Pretzsch et al., 2016). Comparison based on total biomass production may bring different results, as mixing tree species can change stem-crown allometry (Pretzsch, 2014; Liang et al., 2016; Vallet and Perot, 2016) and also tree ring width and wood density (Zeller, 2016). Tree species mixing can significantly modify individual tree morphology and reduce or improve wood quality (Pretzsch and Rais, 2016).

A successful reclamation programme must include a monitoring component to identify areas of successful reclamation, as well as areas where man-
agement problems exist or where reclamation practices are failing (Lein, 2001). Monitoring of the natural environment, especially areas degraded by mining activities, is connected with the constant need for precise and up-to-date land use/land cover maps (Szostak et al., 2015; Townsend et al., 2009). Novel techniques including geoinformation technologies such as those used in making land use and land cover change maps are used for characterizing the morphometry and determination of the spatial structure of vegetation on reclaimed post-mining areas (Chmielewski et al., 2014; Dudzińska - Nowak and Wężyk, 2013; Szostak et al., 2014; Wężyk et al., 2014). Remote sensing data are useful for the investigation and monitoring of vegetation change in open pit mining areas over a long period of time. This method is useful to identify areas where vegetation may be stressed, or where reclamation requires integrated approaches (Szostak and Nowicka, 2013; Maiti et al., 2019).

The aim of our research was to make a geospatial assessment of land cover after the extraction of brown coal and the technical stage of reclamation of disturbed areas.

**Materials and methods.** The Dnieper brown coal basin occupies an area the size of more 60 000 km². 12 brown coal areas are part of this basin. The surface of the basin is characterized as an elevated gently undulating plain, sometimes dissected by river valleys and a dense network of gullies and ravines.

Expressed dismembered relief causes the development of surface runoff. This is a factor in the formation of eroded lands with varying degrees of washout. This part of the area is affected by deep erosion. Artificial landforms in the basin are also observed together with natural geomorphological forms. These are quarry pits, trenches, overburden dumps, deformed surfaces, etc. A characteristic feature of the climate is quite a significant fluctuation in temperature and rainfall over the months.

Availability of soil productive moisture for plants is average. Approximately every fourth to fifth year is dry, due to insufficient rainfall in the spring and summer. Quite often there is a decrease (less than 50 % of the field moisture capacity) of moisture reserves, which coincides with the air drought – dry winds. Common species of forest stands are oak, ash, maple, elm, and linden).

The Semyonovsky-Golovkovsky brown-coal deposit area was estimated using the Sentinel-2 Multispectral Instrument (MSI), Landsat-8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) optical multispectral data. Standard preprocessing operations including radiometric calibration, atmospheric correction and cloud masking were applied to input multispectral images. The Landsat-8 OLI/TIRS 30 m spatial resolution imagery was used to calculate true (not radiant) temperature $T$ of land surface, while the Sentinel-2 MSI 10 m spatial resolution imagery produces the Normalized Water Index (NDWI) (Sakhatsky and Stankevich, 2007). Both $T$ and NDWI maps after co-registration was fused into land surface water content distribution (Zhang and Zhou, 2016). Normalized Difference Vegetation Index (NDVI) was computed to determine Vegeta-


Results and discussion. There is a wide variety in the spatial structure of phytocenoses in the studied plantations of black locust, depending on the diversity of forest growth conditions. The influence of the anthropogenic factor is observed throughout the coal basin and is manifested in the technogenic formation of relief, reshaping of dumps, uptake of overburden rocks to the day surface of the lignite deposit. Elevations alternate with depressions. This causes the diversity of the soil cover, both in fertility and moisture. Dynamics of forest mensuration indices of pure stands of black locust are shown in Fig. 1.

Eight-year plantings were located on the slope of the eastern exposure and differed in the lowest indices of forest inventory: height – 3.0 ± 0.034 m, diameter – 4.01 ± 0.06 cm, wood stock is 6.03 ± 0.06 m³/ha.

The virgin plantings of black locust at the age of 11 - 13 years reached a height of 6.12 ± 0.08 m and a diameter of 8.1 ± 0.10 cm. There was a differentiation of wood stocks of 25 - 28 m³/ha and fluctuations in the average growth from 1.92 to 2.55 m³. 15-year-old plantations of *Robinia pseudoacacia* in the ravine thalweg on loamy rocks in wet conditions of moisture were surrounded by steep slopes of the south-western and north-eastern exposures. The forest stand had an average height of 7.98 ± 0.10 m, an average diameter of 10.04 ± 0.15 cm, wood reserves – 44.03 ± 0.25 m³/ha. Black locust aged 20 years has a stock of stem wood 83.1 ± 0.40 m³/ha. Maximum forest growth effect of acacia on reclaimed lands was expressed in the average growth achieved at this age. The mono 25 - year - old *Robinia pseudoacacia* stands, which are in decline and are represented by loamy sediments, occupy the largest area. The range of moisture varies from moist to wet loams. The height of the stand was 11 - 12 m, diameter – 12 - 14 cm, wood reserves – 83 - 96 m³/ha, respectively. It should be noted that the average growth rates reached the maximum values at the age of 20 - 25 years – 3.84 – 4.15 m³, and the current in 15 - 20 years – 7.8 - 9.5 m³.

Some approaches have been applied in connection with the slow growth of forest crops on the dumps to intensify the growth processes. Use of methods of biological intensification of growth of tree cultures gave good results. One of them is the introduction of nitrogen fixing species into the forestry culture. Thus, plantations were created in which 40 % was occupied by Scots pine and 60 % by *Robinia pseudoacacia* (Fig. 2).

Plants with the composition of the stand 6R.p.4P.s. formed in the upper third of the waste of the Western exposure on loamy sediments. Wood reserves amounted to 12.07 ± 0.12 m³/ha. Black locust had a height of 4.05 ± 0.07 m, diameter – 6.06 ± 0.09 cm, pine – 3.03 ± 0.07m and 3.98 ± 0.09 cm respectively. It was found that with this ratio of tree species to 11 years of age, *Robinia pseudoacacia* was ahead of pine in terms of growth. The advantage of pure pine plantations was established on all parameters (altitude 33%, diameter by 50 % and stocks of wood at 100 %). Plants of *Robinia pseudoacacia* of natural origin penetrate with a decrease in the completeness of the monoculture of pine from the surrounding areas, ahead of the growth of the 11 - year - old pine (10P.s. + R.p.). In the future, with age (19 and 21 years),
Robinia pseudoacacia of natural origin is introduced into the monoculture of pine by 10 % (9P.s.1R.p.). However, it is significantly inferior to the growth rate of the main plant, especially in terms of wood reserves.

Mixed stands of the same age with different structure of the forest stand with the participation of Robinia pseudoacacia present another area of interest. Two sample areas had the same composition of 7 Black locusts + 3 Maples or Acer pseudoplatanus L. (A.p.) aged 10 years, but differing in geological conditions, which led to a change in the parameters of forest taxation (Fig. 3).

Maple at the age of 10 years occupies up to 30 % of such areas. Comparing the same structure of the forest stand phytocenosis (7R.p. + 3A.p.), growing in different conditions on washed and leveled areas, we can note that the wood reserves on the leveled areas were 22 % higher due to greater completeness.

Results of previous similar case studies comparing the same experimental pure and mixed-species plantations have shown that productivities were either similar or greater than the same species grown in monocultures (Piottto et al., 2003; Alice et al., 2004; Petit and Montagnini, 2004; Petit and Montagnini, 2006). Meantime, it was established that mixed - species plantations have greater potential advantages than monocultures (Mao et al., 2017). The greatest use of melioration in forest plantations is through the combination of a Nitrogen (N) - fixing and a non- N - fixing tree species (Kelty, 2006). N - fixing tree species may increase the supply of available N in the soil, benefiting both N - fixing and non- N - fixing trees. Strong facilitative effects of N - fixing species on the
growth of non-N-fixing species were found on a site with low soil N, but not on a site with high soil N (Bouillet et al., 2013). Trees and shrubs in the territory of a lignite deposit after the biological stage of reclamation were both in pure and in mixed condition. Thus, *Robinia pseudoacacia* monocultures on territories of reclaimed mines had higher values of height, diameter and productivity. These plantations at the age of 5–11 years exceeded at this stage the dynamics of growth and wood reserves of mixed plantations. The similar results have been obtained in case studies (Bouillet et al., 2013; Mao et al., 2017; Kelty et al., 2006; Pretzsch, 2014).

The highly dynamic process of the secondary forest succession has been shown on the tested areas of sulfur mines (Szostak et al., 2015).

Results of remote sensing of geomorphological features of the reclaimed area (terrain relief features formed in the post-reclaimed period). The studied area terrain elevations are shown in Fig. 4.

The influence of the anthropogenic factor is observed throughout the section and is manifested in the man-made formation of relief, reshaping of dumps, removal to the surface of overburden rocks. It is established that the height values can vary from 85 m to 213 m. The results of these changes in the microrelief for the last 3 years (from 2015 to 2018) are presented in Figure 5 and Table 1.

---

**Table 1.** Legend of terrain elevation change

| Code | Colour | Class          | Difference | Percent |
|------|--------|----------------|------------|---------|
| 0    |        | Unclassified   | no data    | 0.0000  |
| 1    |        | Strong Down    | <−0.30     | 0.1223  |
| 2    |        | Moderate Down  | −0.30 .. −0.15 | 0.7967  |
| 3    |        | Weak Down      | −0.15 .. −0.05 | 8.0757  |
| 4    |        | No Change      | −0.05 .. 0.05 | 82.7699 |
| 5    |        | Weak Rise      | 0.05 .. 0.15 | 7.3865  |
| 6    |        | Moderate Rise  | 0.15 .. 0.30 | 0.7891  |
| 7    |        | Strong Rise    | > 0.30     | 0.0597  |
According to the data obtained, 82.8% of the surveyed area has not undergone significant changes in terrain elevation. About 15.5% of the territory was under the influence of alluvial-diluvia processes.

Data on the distribution of land surface water content in the summer of 2015 and 2018 within the surveyed area are shown in Fig. 6 and Table 2. The logarithmic regression relationship between the \((\frac{(\text{W}^{\prime}+1)}{T})_f\) parameter and relative water content was restored therefor.

Elevations alternate with depressions, which causes the diversity of the soil cover, both in fertility and moisture.

The highest moisture content at the level of 0.2 - 0.3 relative units in 2015 was recorded in the territory occupying 78.4 %. Meanwhile, the shares of land cover with such humidity increased by almost 9% over the next 3 years.

VCF image differencing is successfully used to follow the long-term success of reclamation (Sarp,

Fig. 6. Water content distribution maps, Sentinel-2, Alexandria – Golovkovka

| Code | Colour | Value | Percent | Value | Percent |
|------|--------|-------|---------|-------|---------|
|      |        | 2015.08.09 | 2018.06.19 |        |         |
| 0    | no data | 0.0000 | 0.0000 |
| 1    | 0.0 – 0.1 | 0.0003 | 0.0 – 0.1 | 0.0014 |
| 2    | 0.1 – 0.2 | 1.3803 | 0.1 – 0.2 | 2.8939 |
| 3    | 0.2 – 0.3 | 78.3774 | 0.2 – 0.3 | 87.2895 |
| 4    | 0.3 – 0.4 | 18.1562 | 0.3 – 0.4 | 7.3259 |
| 5    | 0.4 – 0.5 | 0.3683 | 0.4 – 0.5 | 0.7078 |
| 6    | 0.5 – 0.6 | 0.2010 | 0.5 – 0.6 | 0.2217 |
| 7    | 0.6 – 0.7 | 0.2854 | 0.6 – 0.7 | 0.3207 |
| 8    | 0.7 – 0.8 | 0.9052 | 0.7 – 0.8 | 0.9199 |
| 9    | 0.8 – 0.9 | 0.3259 | 0.8 – 0.9 | 0.3192 |
The classic method for NDVI-based VCF calculating from Carlson & Ripley paper (Carlson and Ripley, 1997) was used:

\[
\text{VCF}(x, y) = \frac{(\text{NDVI}(x, y) - \text{NDVI}_0)/(\text{NDVI}_1 - \text{NDVI}_0))^2}{},
\]

where VCF\((x, y)\) is VCF value inside \((x, y)\) image element, NDVI\(_0\) and NDVI\(_1\) are NDVI thresholds values for vegetation-free and full vegetation cover terrain respectively.

Data on the state of vegetation cover in the summer of 2015 and 2018 in the surveyed area are shown in Fig. 7 and Table 3.

The VCF differentiation allows separation of vegetated areas from areas with little or no vegetative cover.
coverage. High VCF values are mostly indicated for reclaimed and vegetated areas. The highest density of vegetative cover was recorded in the North-Western part of the study area of forest reclamation. At the same time, vegetation cover fraction over the past three years decreased by codes 8-10 and increased by codes 1, 3, 4. Thus, considering the potential suitability of the area for forest reclamation, one should note the important role of geomorphological, geological and water resources for the growth and development (formation) of plant communities.

**Conclusion.** The processes of self-regulation and restoration of fertility on reclaimed lands at the first stages of their biological development were slowed down. This significantly reduced the resistance of phytocenoses, both pure and mixed, to the conditions of the environment provided to them. A comparison of the inventory stem wood of the black locust showed the superiority of monoculture plantations to mixed stands of pine-black locust and maple - black locust. Progression of the forest-forming process takes place with age. Remote assessment of the territories was conducted to assess the future prospects of biological conservation of reclaimed lands. The influence of the anthropogenic factor is observed throughout the section and is manifested in the man-made formation of relief, reshaping of dumps, removal to the surface of overburden rocks. It is established that the terrain’s height values can vary from 85 m to 213 m. 82.8 % of the surveyed area has not undergone significant changes in relief. About 15.5 % of the territory was under the influence of alluvial - diluvia processes. There have been corresponding changes in the share of vegetation using the VCF value codes over the past three years. The highest moisture content at the level of vegetation using the VCF value codes over the past three years decreased by codes 8-10 and increased by codes 1, 3, 4. Thus, considering the potential suitability of the area for forest reclamation, one should note the important role of geomorphological, geological and water resources for the growth and development (formation) of plant communities.

**References**

Alice, F., Montagnini, F., Montero, M., 2004. Productividad en plantaciones de especies nativas en La Estación Biológica La Selva, Sarapiquí, Heredia, Costa Rica. Agron. Costarricense 28 (2), 61–71.

Amichev, B.Y., Burger, J.A., Rodrigue, J.A., 2008. Carbon sequestration by forests and soils on mined land in the Midwestern and Appalachian coalfields of the U.S. Forec. Ecol. Manag. 256, 1949–1959.

Bouillet, J., Laclau, J., Goncalves, J.L.M., Voigtlaender, M., Gava, J.L., Leite, F.P., Hakamada, R., Mareschal, L., Mabiala, A., Tardy, F., Levillain, J., Deleporte, P., Epron, D., Nouvellon, Y., 2013. Eucalyptus and Acacia tree growth over entire rotation in single- and mixed-species plantations across five sites in Brazil and Congo. Forest Ecol. Manage. 301, 89–101.

Caravaca, F., Hernandez, M.T., Garcia, C., and Roldan, A., 2002. Improvement of rhizosphere aggregates stability of afforested semi-arid, plant species subjected to mycorrhizal inoculation and compost addition. Geoderma 108, 133-144.

Carlson, T.N., Ripley, D.A., 1997. On the relation between NDVI, fractional vegetation cover, and leaf area index. Remote Sensing of Environment. Vol 62, No 3: 241-252.

Chatterjee, A., Lal, R., Shrestha, R.K., Ussiri, D.A.N., 2009. Soil carbon pools of reclaimed mine soils under grass and forest land uses. Land Degrad. Dev. 20, 300–307.

Chmielewski, S., Chmielewski, T. and Tompalski, P., 2014. Land cover and landscape diversity analysis in the West Polesie Biosphere Reserve. International Agrophysics, 28(2), 153-162. DOI:10.2478/aph-2014-0003.

Cleveland, B., Kjelgren, R. Establishment of six tree species on deep-tilled minesoils during reclamation. Forest Ecology and Management. Volume 68, Issues 2–3, October 1994, 273-280. https://doi.org/10.1016/0378-1127(94)90051-5.

Dudzińska-Nowak and Wężyk, 2013 Dudzińska-Nowak, J. and Wężyk, P., 2014. Volumetric changes of a soft cliff coast 2008-2012 based on DTM from airborne laser scanning (Wolin Island, southern Baltic Sea). Journal of Coastal Research 04/2014, 70(SI), 59-64. DOI: 10.2112/SI70-011.1.

Forrester, D. I., 2014. The spatial and temporal dynamics of species interactions in mixed-species forests: From pattern to process. Forest Ecology and Management 312, 282-292.

Kelty, M.J., 2006. The role of species mixtures in plantation forestry. Forest Ecol. Manage. 233, 195–204.

Lein, J., 2001. Evaluating the utility of land satellite information for strip mine reclamation monitoring and assessment. Papers and Proceedings of the Applied Geography Conferences, 24, 1-8.

Liang, J., Crowther, T. W., Picard, N., Wiser, S., Zhou, M., Alberti, G., … and de-Miguel, S., 2016. Positive biodiversity-productivity relationship predominant in global forests. Science, 354(6309), aaf8957.

Likus-Cieśluk, J., Pietrzynkowski, M., 2017. Vegetation development and nutrients supply of trees in habitats with high sulfur concentration in reclaimed former sulfur mines Jeziorko (Southern Poland) Environ Sci Pollut Res Int. 2017; 24(25): 20556–20566. doi: 10.1007/s11356-017-9638-5.

Maiti, K.K., Bandyopadhyay, J., Chakravarty, D., Das, S.,
Mondal, S., 2019. Geospatial analysis for the assessment of mine land reclamation area: a case study of Noamundi Block, Jharkhand. Spatial Information Research. 1-13. DOI:10.1007/s41324-019-00270-4.

Mao, P., Tang, Q., Cao, B., Liu, J., Shao, H., Cao, Z., Hao, M., Zhu, Z. 2017. Eco-physiological adaptability in mixtures of Robinia pseudoacacia and Fraxinus velutina and coastal eco-engineering. Ecoengineering 106109 –115 http://dx.doi.org/10.1016/j.ecoleng.2017.05.021 0925.

Mendez, M.O., Maier, R.M., 2008. Phytostabilization of mine tailings in arid and semiarid environments: An emerging remediation technology. Environmental Health Perspectives 116(3), 278-283.

Piotto, D., Montagnini, F., Ugalde, L., Kanninen, M., 2003. Growth and effects of thinning of mixed and pure plantations with native trees in humid tropical Costa Rica. For. Ecol. Manage. 177, 427–439.

Petit, B., Montagnini, F., 2004. Growth equations and rotation ages of ten native tree species in mixed and pure plantations in the humid neotropics. For. Ecol. Manage. 199, 243–257.

Petit, B., Montagnini, F., 2006. Growth in pure and mixed plantations of tree species used in reforesting rural areas of the humid region of Costa Rica, Central America. Forest Ecology and Management 233 338–343.

Piotto, D., Montagnini, F., Ugalde, L., Kanninen, M., 2003. Performance of forest plantations in small and medium-sized farms in the Atlantic lowlands of Costa Rica. For. Ecol. Manage. 175, 195–204.

Pretzsch, H., Bravo-Oviedo, A., 2016. Mixing of Scots pine (Pinus sylvestris L.) and European beech (Fagus sylvatica L.) enhances structural heterogeneity, and the effect increases with water availability. Forest Ecology and Management 373: 149-166. https://doi.org/10.1016/j.foreco.2016.04.043.

Pretzsch, H., 2014. Canopy space filling and tree crown morphology in mixed-species stands compared with monocultures. Forest Ecology and Management 327:251-264.

Pretzsch, H., del Río, M., Ammer, C., Aydagic, A., Barbeito, I., Bielak, K., … & Fabrika, M., 2015. Growth and yield of mixed versus pure stands of Scots pine (Pinus sylvestris L.) and European beech (Fagus sylvatica L.) analysed along a productivity gradient through Europe. European Journal of Forest Research, 134(5), 927-947.

Sakhotsky, A.I., Stankievich, S.A., 2007. About possibilities of soil moisture estimation using satellite imagery optical bands for Ukraine territory. Reports of the NAS of Ukraine. No.11, 122-128.

Sarp, G., 2012. Determination of Vegetation Change Using Thematic Mapper Imagery in Afşin-Elbistan Lignite Basin; SE Turkey. Procedia Technology 1: 407-411.

Schaaf, W., Gast, M., Wilden, R., Huettl, R.F., 2000. Development of element cycles at post-mining sites.
soil and vegetation in opencast coal mine: A case study from *Robinia pseudoacacia* reclaimed forests, Pingshuo mine, China, Catena 165: 72-79. https://doi.org/10.1016/j.catena.2018.01.025

Zeller, L., 2016. Tree ring width and wood density in mixed versus pure stands of Scots pine and European beech, Master Thesis, MWW-MA 223, TUM, School of Forest Sciences and Resource Management, 39.

Zhang D., Zhou, G., 2016. Estimation of soil moisture from optical and thermal remote sensing: A review. Sensors. Vol.16. No.8. A.1308.29.

Zhang, X., Yan, G., Li, Q., Li, Z.-L., Wan, H., Guo, Z., 2006. Evaluating the fraction of vegetation cover based on NDVI spatial scale correction model. International Journal of Remote Sensing. Vol. 27. No.24: 5359-5372.

Zhao, Z.Q., Shahrour, I., Bai, Z.K., Fan, W.H., Feng, L.R., Li, H.F., 2013. Soils development in opencast coal mine spoils reclaimed for 1–13 years in the Western Loess Plateau of China. Eur. J. Soil Biol. 55, 40-46.

Zhao, Z.Q., Wang, H.Q., Bai, Z.K., Pan, Z.G., Wang, Y., 2015. Development of population structure and spatial distribution patterns of a restored forest during 17-year succession (1993–2010) in Pingshuo opencast mine spoil, China. Environ. Monit. Assess. 187, 1-13.

Zipper, C. E., 2000. Coal main reclamation, acid mine drainage, and the Clean Water Act. In R.I. Barnhisel et al. Reclamation of drastically disturbed lands. Agron. Monogr. 41. ASA, CSSA, and Madison, WI. 169-192.