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Woody artificial plantations as a significant factor of the sustainable development at mining & metallurgical area

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Abstract. The relevance of our research is determined by the need to find practical measures that will be aimed of the sustainable development formation and maintenance at mining and metallurgical areas by used of artificial woody plantation. The main objective of this work was on the standpoint of the ecosystem approach to consider the artificial woody plantations as a significant factor for sustainable development paradigm implementation at Kryvyi Rih mining and metallurgical district (Central Ukraine). During 2015-2020, by classical methods were studied the natural forest ecosystems and the artificial forest plantations, which are located in contrast ecological and environmental conditions. Numerous scientific papers about sustainable development have also served as materials for our work. At Kryvyi Rih mining and metallurgical district the leading characteristics of artificial woody plantations have a clear ecological and environmental conditionality. It is proved that in artificial woody plantations of this district tree species are in a state of stress. Therefore, these species lose stability due to the constant influence of adverse environmental factors of natural and anthropogenic genesis. The authors assume that the biogeochemical parameters of trees fallen can be considered one of the promising markers that determine the vitality / healthy of tree species and forecast the development of artificial woody plantations. It has been suggested that the artificial woody plantations at Kryvyi Rih mining and metallurgical area should acquire the status of one of the key factors that determine the sustainable development of this district and Ukraine as a whole. In practice, to achieve this goal, the following steps must be taken: (i) artificial woody plantation assessment, (ii) ecological and environment conditionality of artificial woody plantation current state ascertainment, (iii) sustainable model of artificial woody plantation development, (iv) sustainable management of artificial woody plantation, (v) sustainable development of artificial woody plantation. In the near future, it is recommended to optimize the Kryvyi Rih forest cover by 8-10%. The first step in streamlining and preliminary assessment of the artificial forest ecosystems sustainability is the use of biogeochemical indicators of the chemical circulation system relationship "Leaf precipitation - soil" as markers and predictors of the artificial forest current state in Kryvyi Rih District.

1 Introduction

Practices of the natural forest ecosystems and artificial forest plantations sustainable management are implemented in the World already over century. The international experience history of their service is changing as a result of growing interest to traditional paradigms forest resources policy. The greatest achievements are among the countries of the European Union [13]. Thus, currently in Europe the activities of many institutes are aimed at the most efficient forest use for both present and future generations. Ministerial Conference on the Protection of Forests in Europe is pan-European political tool for forest management [4, 26].

Since 1990, the cooperation of European countries has intensified their policies. These activities were aimed at: (i) consolidating funds for modern forest use, (ii) combating illegal logging, (iii) developing an approach to the assessment of ecosystem services and (iv) increasing attention to the social aspects of forestry and to the role of forests in a green economy [3, 5, 6, 8].

However, in most cases, current environmental activities are aimed primarily at sustainable development and to solving the problems of forest ecosystems and woody plantations. Meanwhile, forest stands can be very factors for sustainable development at industrial areas. This is most relevant for such areas where there

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is a strong anthropic impact on the environment, including mining and metallurgical areas [9, 12, 14, 17].

Last years the scientific community is actively searching for ways to implement the paradigm of sustainable development in practical measures. Scientists propose: (i) improving the optimal conditions for land use planning and conservation, (ii) developing strategic steps for sustainable development, (iii) calculating the amount of environmental compensation and (iv) community development planning [28, 30,31]. In our opinion, the change for approaches in achieving sustainable development in certain industrial areas (including mining and metallurgical areas) should be aimed at measures involving the use of natural forest ecosystems and artificial tree plantations [19, 21].

It should be noted that in many countries around the world (at the national / regional / local level) various institutions (scientific / public, state / municipal / private) are actively researching natural forest ecosystems and artificial woody plantations. In particular, the scientific field of these studies is: (i) assessment of the natural artificial forests resilience, (ii) elucidation of their cultural and aesthetic value, (iii) establishment of compensation mechanisms for damage. Also analyzed: (i) the state of forest ecosystems, as a complex of trees, shrubs, grasses, bacteria, fungi, protozoa, arthropods and other invertebrates, (ii) parameters of geochemical cycles of oxygen, carbon dioxide, water, minerals and dead organic matter. At the same time, researchers claim that in forest ecosystems the natural changes can never reach equilibrium, but is constantly changing in time and space [10, 11, 13, 23].

In general, natural forest ecosystems and artificial woody plantations have recently been well analyzed in numerous scientific publications. There are also numerous ones on various aspects of sustainable development. However, practical measures to implement sustainable development in a separate industrial area (for example, in the mining and metallurgical district) have in fact been left out of the attention of researchers.

The objective of this paper was to considered the artificial woody plantations as a significant factor for sustainable development paradigm implementation at Kryvyi Rih mining and metallurgical district.

2 Materials and methods

This study was conducted in the artificial woody plantations, which are located at Kryvyi Rih mining and metallurgical district (Central Ukraine). The study area is located between 47°53'54" and 48°8'52" north latitude and 33°19'52" and 33°33'38" west longitude (Figure 1).

During 2015-2020, we studied the natural forest ecosystems and the artificial forest plantations, which are located in contrast environmental conditions.

We studied all types of artificial woody plantations: (i) woody stands of city parks, (ii) woody stand of health protection zones, (iii) woody stands of city protection forest and (iv) woody stands of river protection forest. The natural forest ecosystems from of Gurivsky forest were used as control.

A forest woodland inventory was made a random sampling scheme. The 34 research plots (25*25 m) were established in natural forest ecosystems and in artificial woody plantations. Field data were collected through direct enumeration and measurement of all trees in every plot. In each plot, all woody stems of diameter at breast height (dbh) > 10 cm were recorded and: (i) their diameter at 1,3 m above ground (in two perpendicular directions by a caliper); (ii) their height (by a hypsometer) and (iii) their vitality were measured [16, 29].

For each research plot the following dendrometric parameters were computed: tree-density of the stand, basal area of the tree and volume of the tree [16, 29]. For each research plot the vitality of stand also was computed [1].

All data were submitted to descriptive statistics and analysis of variance (ANOVA). The statistical analysis was performed using the program SPSS for Windows. For all statistical analysis, significance was considered $P < 0{,}05$ [20].

Numerous scientific papers about sustainable development have also served as materials for our work. In their study, classical scientific methods were used: analysis and synthesis, induction and deduction, analogy and formalization, abstraction and concretization, classification and modeling.

3 Results and discussions

3.1 Current state of artificial woody plantations

The artificial woody plantations in the Kryvyi Rih mining and metallurgical district were planted in the 30-60s of the 20th century. In that historical period, afforestation was carried out as part of Soviet government state program to transform nature. For this purpose, significant financial and human resources were used.

In Kryvyi Rih district the artificial forests are characterized by significant variances in their structural and functional organization. It should also be noted that these artificial forests are located in areas with contrasting ecological & environmental condition.

Summing up the soil factors actions (fertility and moisture) and the air pollution actions, four ecological locations were identified: 1) environmentally friendly area (Background), 2) relative environmentally friendly area (Buffer 1), 3) relative environmentally not friendly area (Buffer 2) and 4) environmentally not friendly area (Impact).

Natural forest ecosystems of Gurivsky forest are located in environmentally friendly area. These ecosystems have a natural origin and are 110-160 years old (table 1). In their floristic composition, the dominant species are English oak, Norway maple and European ash. The natural origin of the Gurivsky forest ecosystem led to the presence of a full complete vertical structure. In this composition were detected Emergent, Canopy Understory Shrub and Herb layers. It was established that at Natural forest ecosystems of Gurivsky forest the values of stand density varied from 1100 to 1300 trees * ha^{-1}, stem heights were 17-19 m, stem

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diameters were from 19 to 21 cm, stand basal area were from 44 to 48 $m^{2*}ha^{-1}$, stand volume were from 500 to 550 $m^{3}*ha^{-1}$. It should be noted, that the vitality of the stand were very high and indicated to healthy forests of these ecosystems. In general, the characteristics of the Gurivsky forest were typical for the floodplain forests of Ukraine [15, 18, 25].

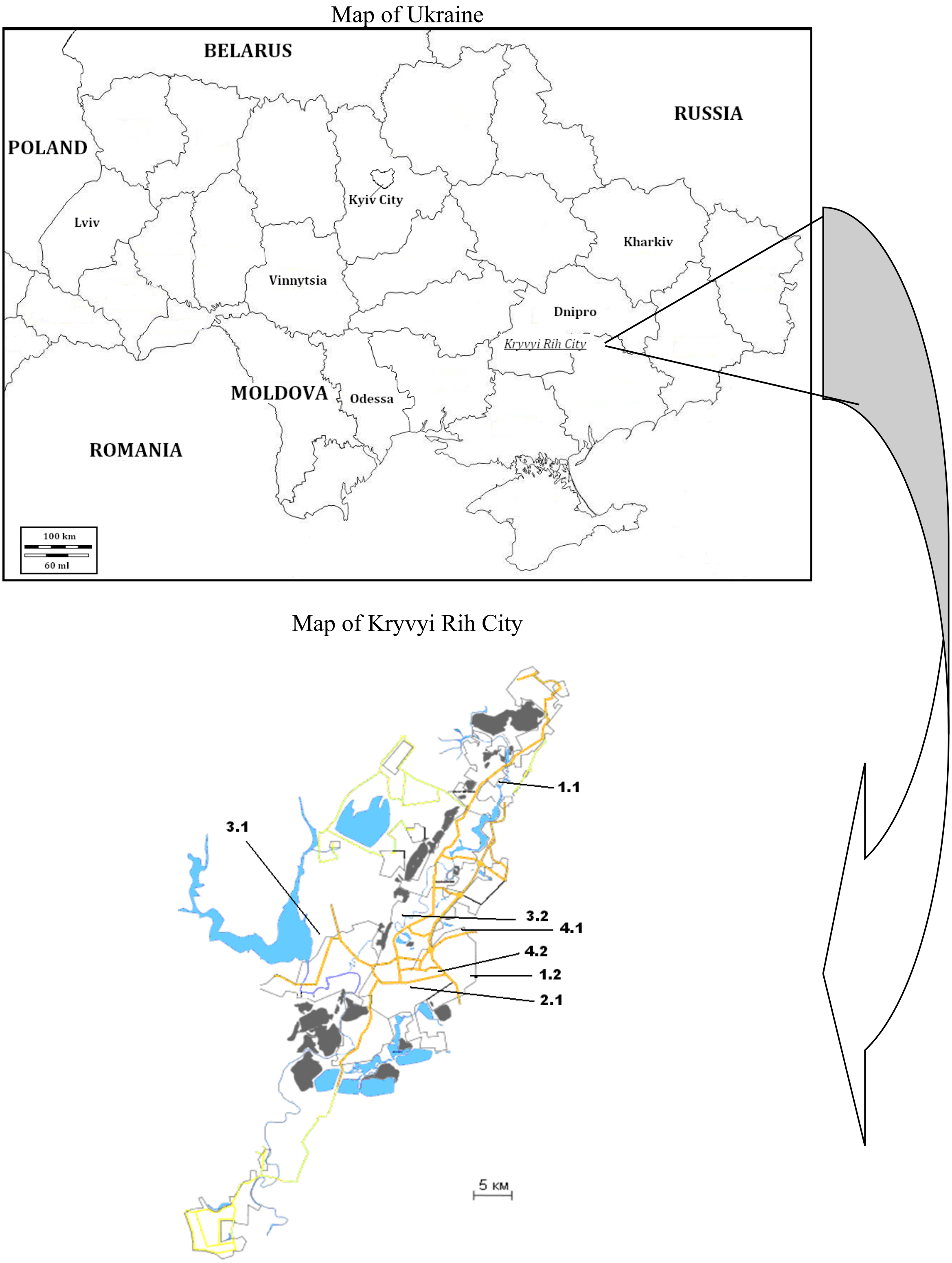

Fig 1. Location of study areas
1. – City parks (1.1 – Veseloternivsky arboretum, 1.2 – Dovgintsivsky arboretum);
2. – Health protection zones (2.1 – protection zones of PJSC "ArcelorMittal Kryvyi Rih");
3. – River protection forests (3.1 – Karachuny forest tract, 3.2 – Dubki forest tract);
4. – City protection forests (4.1 – Lisove forest tract, 4.2 – Sotsmisto forest tract)

Table 1. Characteristics of artificial woody plantations at Kryvyi Rih mining and metallurgical district.

Indexes	Location of forest sites			
	Background	Buffer 1	Buffer 2	Impact
Name of study areas				
Forest tract	Gurivsky natural forest	Veseloternivsky arboretum, partially Karachuny forest tract, Dubki forest tract	Dovgintsivsky arboretum, partially Karachuny forest tract, Lisove forest tract	Protection zones of PJSC "ArcelorMittal Kryvyi Rih", Sotsmisto forest tract
Ecological conditions of stand area				
Fertility and soil moisture	Fertile and sufficiently moist soils	Fertile and sufficiently moist soils	Relatively fertile and insufficiently moist soils	Relatively fertile and insufficiently moist soils
Levels of the air pollution	Very low	Low	Moderate	High
Biological stand parameters				
Origin of stand	Natural	Natural, artificial	Artificial	Artificial
Age of stand, years	150-170	50-120	40-80	50-90
Dominant species	English oak (*Quercus robur* L.) Norway maple (*Acer platanoides* L.) European ash (*Fraxinus excelsior* L.)	English oak (*Quercus robur* L.) European ash (*Fraxinus excelsior* L.), European white elm (*Ulmus laevis* L.) Ashleaf maple (*Acer negundo* L.)	English oak (*Quercus robur* L.) European ash (*Fraxinus excelsior* L.) Ashleaf maple (*Acer negundo* L.) Littleleaf linden (*Tilia cordata* L..)	English oak (*Quercus robur* L.) European ash (*Fraxinus excelsior* L.) Ashleaf maple (*Acer negundo* L.) Norway maple (*Acer platanoides* L.) Black cottonwood (*Populus nigra* L.)
Vertical structure of the stand				
Emergent layer	Available 100 %	Available 100 %	Available 100 %	Available 100 %
Canopy layer	Available 100 %	Available 100 %	Available 75 %	Available 100 %
Understory layer	Available 100 %	Available 75 %	Available 75 %	Available 75 %
Shrub layer	Available 100 %	Available 75 %	Available 25 %	Available 25 %
Herb layers	Available 100 %	Available 100 %	Available 75 %	Available 0 %
Dendrometric parameters of the stand				
Density, trees/ha	1100-1300	800-900	1400-1500	1400-1500
Height, m	17-19	15-17	12-14	10-12
Diameter, cm	19-21	24-26	16-18	14-16
Basal area, m^2/ha	44-48	34-38	30-34	26-32
Volume, m^3/ha	500-550	300-350	200-250	150-250
Vitality of the stand				
Levels of the vitality	High (healthy forests)	High (healthy forests)	Moderate (partially healthy forests)	Moderate (partially healthy forests)

Artificial woody plantations of the Veseloternivsky arboretum, river protection forests (Karachuny and Dubki forest tracts) are located in relative environmentally friendly area (Buffer 1). These plant communities grow on fertile and moist soils under low level of air pollution (table). In these woody plantations the dominant species are English oak, European ash, European white elm and Ashleaf maple. The age of these plantations is 50-120 years. It is important to note that the vertical structure of these plantations was not formed at all locations. On some forest sites understory and shrub layers were absent. In Buffer 1 area the dendrometric parameters of artificial woody plantations were slightly different from the control (F>Fcritical, $p<0,05$). Thus, the values of stand density varied from 800 to 900 trees $*ha^{-1}$, stem heights were 15-17 m, stem diameters were from 24 to 26 cm, stand basal area were from 34 to 38 $m^{2*}ha^{-1}$, stand volume were from 300 to 350 m^3*ha^{-1}. In relative environmentally friendly area the vitality of the stand was high and indicated to healthy forests of these woody plantations. In general, biological and dendrological characteristics of artificial woody plantations from Buffer 1 are typical for other artificial forests of Ukraine [15, 18, 25].

Artificial woody plantations of Dovgintsivsky arboretum and River protection forests (Karachuny forest tract (partially)) are located in relative environmentally not friendly area (Buffer 2). These plantations develop on relatively fertile soils with insufficient moisture under moderate level of air pollution (table). The age of the plantation varies from 40 to 80 years. English oak, Red oak, European ash, Ashleaf maple, Scots pine and Littleleaf linden are Dominant species. There is also an insufficiently formed vertical structure: trees of the emergent layer, with partially identified canopy and understory layers, shrub and herb layers is weakly expressed (table).

In these artificial woody plantation, the values of stand density varied were 1400-1500 trees $*ha^{-1}$, stem heights were 12-14 m, stem diameters were 16-18 cm, stand basal area were 30-34 $m^{2*}ha^{-1}$, stand volume were 200-250 m^3*ha^{-1}. These values differ significantly from the control measurements in the natural ecosystems of the Gurivsky forest (F>Fcritical, p<0,05). The vitality of the stand was not high and indicated to partially healthy forests of these woody plantations.

Health protection zones (protection zones of PJSC "ArcelorMittal Kryvyi Rih") and city protection forests (Lisove and Sotsmisto forest tracts) are located in environmentally not friendly area (Impact). These woody plantations develop mainly on relatively fertile soils with little moisture under high level of air pollution (table). The age of these plantations is 50-90 years. English oak, European ash, Ashleaf maple, Norway maple and Black cottonwood are dominant species (table).

In artificial woody plantation from environmentally not friendly area there is no complete vertical structure. Only emergent and canopy layers are present in all forest sites. While other layers (understory, shrubs and herb) are absent in forest sites. It was established that at these woody plantation the values of stand density varied from 1400 to 1500 trees $*ha^{-1}$, stem heights varied from 10 to 12 m, stem diameters varied from 14 to 16 cm, stand basal area varied from 26 to 32 $m^{2*}ha^{-1}$ and stand volume varied from 150 to 250 trees m^3*ha^{-1}. These values are very different from the control (F>Fcritical, p<0,05). The vitality of the stand was very low and indicated to partially healthy forests of these woody plantations.

In general, at Kryvyi Rih mining and metallurgical district the leading characteristics of artificial woody plantations have a clear ecological and environmental conditionality.

It is known that in all industrial regions, which are located in the steppe zone of Ukraine, tree species in artificial woody plantations grow and develop under the combined stress of moisture deficiency and anthropic pollution. In such negative ecological conditions, tree species are characterized by (i) inhibited growth (ii) suppressed physiological state, (iii) accelerated old aging processes and (iv) reduced environmental efficiency. Analysis of recent papers shows that the real vitality of the stand and healthy of trees in artificial woody plantations is unknown, due to their botanical features. That is why the development of rapid methods of early diagnosis of the vitality / healthy of tree species in artificial woody plantations in the steppes of Ukraine and the industrial area is becoming very important.

In our opinion, the biogeochemical parameters of trees fallen can be considered one of the promising markers that determine the vitality / healthy of tree species and forecast the development of artificial woody plantations [7].

At one time, even V.I. Vernadsky [27] taught that trees fallen leaves are “thin, the uppermost layer of soil, full of life”. But it is still unclear what chemical elements in fallen leaves can be considered the most informative for diagnosing vitality / healthy of tree species at artificial woody plantations.

Our research proves the reliable 29 correlation coefficients (from possible 70 ones) of the alkaline earth metals content in trees fallen leaves and the vitality of the stand from artificial woody plantations. In 15 cases these correlation coefficients confirm the presence of a direct relationship ($r^2 > 0$). That is, in the case of increasing values of alkaline earth metal content in fallen leaves, there is an increase level of the stand vitality.

In contrast, for the other 14 cases, an inverse correlation was observed ($r^2 < 0$). Based on the correlation strength assessment between the alkaline earth metals content in fallen leaves and stand vitality at the artificial woody plantations certain patterns have been established. At the same time various communications between the certain indicators were followed: (i) in 15 cases there was a weak connection ($0.3 < |r^2| < 0.5$), (ii) in 12 cases there was a medium connection ($0.5 < |r^2| < 0.7$), (iii) in 2 cases there was a strong connection ($0.7 < |r^2| < 0.9$). No cases of strong correlation were found within the calculation matrix ($|r^2| > 0.9$). This phenomenon requires additional reflection.

The obtained results confirm the hypothesis that the stand vitality of the emergent and canopy layers is the most sensitive to the alkaline earthmetals content in trees fallen leaves.

In general, at Kryvyi Rih mining and metallurgical district for 30-60 years numerous and large artificial woody plantations were created. At present, these plantations have reached their peak of development. Their leading biological and dendometric characteristics have a clear ecological conditionality. For woody plant species, soil moisture deficiency and atmospheric repetition pollution are significant environmental factors. In some cases, negative phenomena in artificial woody plantations are observed. At the same time, these plantations can become a "green framework" for future sustainable development Kryvyi Rih mining and metallurgical district.

3.2 Artificial woody plantations and sustainable development of the Kryvyi Rih district

For the last 40 years, the concept of sustainable development has been considered the only possible strategy for further interaction between man and his natural environment. Currently, there are more than 60 different definitions of the "sustainable development" concept. However, in our opinion, the most successful is the definition that was voiced in 1992 in Rio de Janeiro. According to him, “sustainable development of mankind” is understood as such a development that allows satisfying the needs of the present generation and does not jeopardize the ability of future generations to meet their needs.

In the practice of the sustainable development concept implementing, two main directions can be distinguished: resource-economic and sociophilosophical. In the first case, attention is focused on economics and ordering of natural resource consumption. The second direction involves the further development of the sustainable development concept, substantiation of the philosophical basis of this idea, as well as the search for ways and methods of forming an environmental ("ecological") culture for mankind.

Over the past 20-25 years, a significant number of recommendations for the implementation of sustainable development have been developed. Without diminishing the importance of all the aforementioned directions of sustainable development implementation ideas in modern realities, it should be noted that until now, the biosphere aspect of this concept has not been fully considered. Although it is generally accepted that the biosphere, as a phenomenon of our planet, forms unique conditions where only humanity can exist. At the same time, the existence of the biosphere and its stability are determined by natural forest ecosystems and artificial woody plantations.

In general, the concept of sustainable development is considered as the fundamental paradigm and the dominant vector for the further development of modern forestry. However, in the overwhelming majority of cases, the theoretical aspects of this concept development in relation to the forest were considered in scientific papers. The issues of sustainable development of forests and forestry are also actively discussed. While the applied aspects concerned exclusively the "greening" of forestry and grasslanding, optimization of land use systems, conservation of biodiversity, the study of ecological forest services, etc.

In our opinion, artificial woody plantations can be an important factor for the further sustainable development of the Kryvyi Rih area. In practice, to achieve this goal, the following steps must be taken: (i) artificial woody plantation assessment, (ii) ecological and environment conditionality of artificial woody plantation current state ascertainment, (iii) sustainable model of artificial woody plantation development, (iv) sustainable management of artificial woody plantation, (v) sustainable development of artificial woody plantation (Fig. 2).

Artificial woody plantation assessment intends consistent analyze of the plantation area and the plantation stand. Plantation area assessment has a purpose to study soil characteristics and to analyze the levels of soil and air pollution. Plantation stand assessment has a purpose to get a comprehensive understanding of stand with a vision of biology, dendrology and ecology. Moreover, special attention should be paid to the dendrometric characteristics of the stand and the viability of the stand. These parameters manifest the environmental prospects of the stand at natural forest ecosystems and artificial woody plantations. It should also be noted that the biogeochemical indicators of leaf litter are promising indicators of the forest stand.

Current state of artificial woody plantation is ecologically environmentally conditioned. Therefore, it is so important to identify this conditionality and also develop a model for this conditionality. Moreover, in this model, ecological markers and ecological predictors will be the "active center". In our understanding, ecological markers will manifest the current state of the stand, and ecological predictors will manifest the future state of the stand.

Sustainable model of artificial woody plantation should reflect the optimal floristic composition and spatial structure of future artificial woody plantations. We believe that by choosing adapted tree species and rationally placing tree species on the ground, it is possible to create very promising woody plantations. Such woody plantations will be maximally adapted to the climate, soil and environment of the area. Such tree plantations will be maximally adapted to the climate, soil and environment of the Kryvyi Rih area.

Sustainable management of artificial woody plantation has two directions. The first direction involves the improvement of already existing artificial woody plantations. The second direction involves the creation of new artificial tree plants. By our opinion, these two directions should be based on sustainable model of artificial woody plantation. In this case, the improved plantings and the created plantations will be as stable and efficient as possible.

In the leading countries of the world Issues of ensuring the stable development of natural forest ecosystems and artificial tree plantations are considered in conjunction with ensuring the balanced implementation of environmental and natural resource relations. In this case, the criteria and indicators of sustainable use of forests are a combination of simultaneous: 1) conservation of biological diversity; 2) maintaining the economic potential of forest ecosystems as a source of resources; 3) maintaining the viability of ecosystems that are affected by anthropogenic impacts, man-made pollution, changes in climatic conditions; 4) conservation and maintenance of soil and water resources on the territory of forest ecosystems; 5) ensuring the implementation of functionalities in the prevention of regional climate change in the region; 6) support and strengthening of long-term multiple socio-economic benefits from natural and artificial forests to meet the needs of society, strengthening the recreational and tourist potential of forests, as well as opportunities to meet cultural, social and spiritual needs in the process of forest use; 7) legal, organizational and economic framework for forest conservation and sustainable management in the relevant field. Ukraine is one of the least forested countries in Europe. At the same time, Ukraine has the smallest specific area of forests, both natural and artificial, per 1 ha of its territory compared to other European countries (only 0.178 ha per 1 ha).

In general, an important measure to achieve sustainable development in the Kryvyi Rih mining and metallurgical area is the streamlining of a few existing natural forest ecosystems and the creation of new artificial tree plantations. As is known, artificial tree plantations are able to improve the microclimate of certain areas due to the positive impact of trees on the environment. Due to the influence of tree plantations, the amount of precipitation increases by 5-25%, and the total river runoff increases by 15-20%. Such results are extremely relevant for water-deficient conditions. In addition, natural and artificial forests reduce levels of soil and groundwater pollution, prevent the spread of water and wind erosion. When creating artificial woody plantations at Kryvyi Rih area taking into account the levels of soil pollution by heavy metals and their biogeochemical features is very important [2, 7, 22, 24].

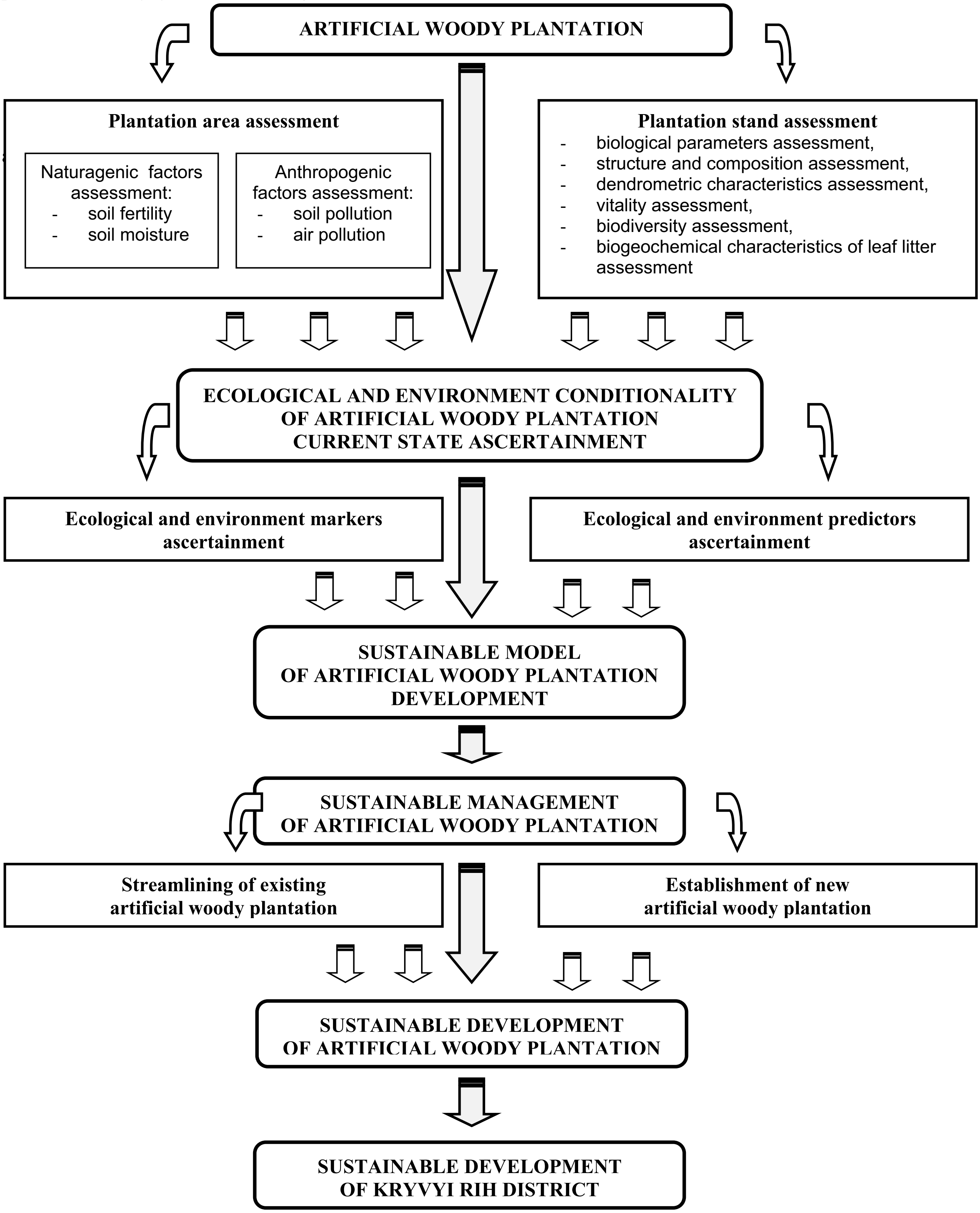

Fig. 2. Conceptual model of artificial woody plantations implementation in sustainable development at Kryvyi Rih district.

4 Conclusions

At Kryvyi Rih mining and metallurgical district for 30-60 years numerous and large artificial woody plantations were created. These plantations have reached their peak of development. Their leading characteristics have a clear ecological conditionality. For woody plant species, soil moisture deficiency and atmospheric repetition pollution are significant environmental factors. In some cases, negative phenomena in artificial woody plantations are observed. At the same time, these plantations can become a "green framework" for future sustainable development Kryvyi Rih mining and metallurgical district.

Artificial woody plantations can be an important factor for the further sustainable development of the Kryvyi Rih area. In practice, to achieve this goal, the following steps must be taken: (i) artificial woody plantation assessment, (ii) ecological and environment conditionality of artificial woody plantation current state ascertainment, (iii) sustainable model of artificial woody plantation development, (iv) sustainable management of artificial woody plantation, (v) sustainable development of artificial woody plantation.

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