Environmental Assessment of Relationships and Mutual Influences in the System "Protective Forest Plantations – Anthropogenic Landscapes"

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Abstract. Protective forest plantations (PFP) play an essential functional role in the operation of anthropogenic landscapes (AL). A study of processes in the system "PFP-AL" was conducted in the Boguslav agroforestry state, Kyiv region, Ukraine, to maintain sustainability. A method of ecological monitoring has been proposed to achieve environmental equilibrium stability. The calculations show the stable state of the ecosystem. A graphic-analytical method for quantitative assessment of the potential adverse effects of natural resource management has been proposed. It is shown that additional compensation of adverse effects is necessary, which can be performed by green structures.

1. Introduction

The technosphere in the structure of the biosphere is constantly changing and expanding. All of this leads to the transformation of natural landscapes into anthropogenic, characterized by a high technogenic load and excessive pollution of natural systems. It is known [1][2][3][4][5] that neighbouring landscapes have tended to decline the assimilative capacity of natural systems. The last one is a specific natural resource for self-healing and adaptation under the pressure of changes in its environment in evolutionary effects.

Studies have shown [6][7] that the protective forest plantations (PFP) are playing an essential functional role in the operation of anthropogenic landscapes (AL). Trees plantations create different types of autotrophic blocks of naturals and anthropogenic systems and have an inseparable influence on the biosphere. They from primary bio productivity, produce oxygen, absorb carbon dioxide, trap dust and soot, toxic substances, and take part in the biochemical cycles like the circulation of substances and energy. In addition, they are playing an essential role in the current processes of topsoil.

Forest ecosystems are essential components of natural system safe development and an integral part of ensuring the sustainability of socio-economic systems [8]. Therefore, to ensure a state’s environmental safety at different levels (regional, local), it is necessary to extend information about
forest ecosystems, which preserve ecological and stabilizing roles in nature and their assimilative potential.

We should form landscapes that are resistant to anthropogenic pressure. This forming requires the determination of areas with an optimal natural ratio and are altered by a farming activity because this is the main criterion [9] for assessing ecological conditions of anthropogenically altered landscapes (AAL). Studies have shown that PFP plays an essential functional role in the operation of AL.

It was found that information concerning the ecological and stabilizing role of PFP as natural systems is not available. Therefore, the determination of types and kinds of interrelations between abiotic and biotic components of the environment, and their mutual development and influence in the system "PFP-AL" for their environment-safe development, has become an actual problem nowadays. All of these require urgent attention and resolution according to the rate of growth of such systems.

2. Method
The study of all processes in the system "PFP-AL" was conducted in the Boguslav agroforestry state, Kyiv region, Ukraine. The primary task in forestry is the maintenance of the functioning of PFP at AAL according to the terms of the Conception of sustainable environmental development. The Boguslav district forests belong to the first group of forests that serve primarily protective functions – anti-erosion forests [10]. The forests of the first group performing soil protection and water safety, health-improving, sanitary and aesthetic functions. They occupy the entire area of the agroforestry fund, which is 4065.0 ha.

Each farming section on the territory of agroforestry corresponds to one of the three types – coniferous (915.4 ha or 24 %), hardwood (2698.3 ha or 70 %), and softwood (233.1 ha or 6 %). The sections aim to cultivate indigenous or specific target wood species according to forest types. For this, measures are being taken to ensure the most effective execution of protection, sanitation, water protection, and other natural functions of the forest.

The relationships have been studied inside the phytocenosis of the system "PFP – AL" for practical and theoretical improvement of existing protective forest management systems. The main task of the study is ensuring in the ecosystem the preservation of assimilative capacity and dynamic adaptation to different types of changes. The principal method of this study is conducting environmental monitoring by using environmental assessment of the potential on the territory PFP, which was carried out based on the forest management assessment for Boguslav agroforestry, concerning afforestation and methods of reforestation [11][12].

A practical-method of ecological monitoring of the condition is the method of dynamic researches PFP under the impact of environmental conditions change. We have developed and proposed environmental characterization by objective quantitative indicators: environmental equilibrium stability in regulated borders after anthropogenic changes and by the indicator of the ecological capacity of AL on the territory of agroforestry. Environmental equilibrium stability in regulated borders after anthropogenic changes AL was calculated using the formula.

\[ S = \sum_{i=1}^{n} \frac{E_a}{S}, \]  

(1)

where \( E_a \) – index of environmental accordance PFP to the natural state of AL (\( E_a = 0.9 \)).

Ecological capacity can be calculated based on the maximum amounts of pollutants that affect the ecosystem per unit of time and may be removed, accumulated, or transformed inside the ecosystem without significant violations of dynamic equilibrium. The ecological capacity of the system

\[ C_e = H S_a \sum_{i=1}^{3} X_{it} p_{PFP}, \]  

(2)

Where \( H \) – the farming capacity of the biosphere (1-2 Twh); \( S_a \) – the forested area of the agroforestry; \( X_{it} \) – environmental factors that caused by eco-stabilizing properties of PFP – oxygen-producing, carbon
dioxide absorbing, dust, and soot detention [6]; $pPFP$ – coefficient of absorption of primary pollutants by the biomass of PFP.

The exact value of coefficient $pPFP$ can be determined by the following formula:

$$Aa = Sfu \cdot pPFP,$$

(3)

Where $Aa$ – absorption amounts of main types of pollutants by biomass on the forested territory of Ukraine; $Sfu$ – the forested territory of Ukraine.

At first, the value of $Aa$ was calculated for the agroforestry area, and then, based on the primary data, the coefficient $pPFP$ for this area was found. Environmental equilibrium stability in regulated borders after anthropogenic changes $S = 0.0018$. The absorption amounts of main types of pollutants by biomass in agroforestry areas $tn = 22814.5$. Coefficient of absorption of primary pollutants by the PFP biomass $pPFP = 9.8$. The ecological capacity of the PFP ecosystem $Ce = 0.015$ GWh.

For a generalized assessment of environmental sustainability on the PFP territory, after calculating all indicators, a value of the sustainability coefficient of the PFP ecosystem was calculated as the multiplicity of exceeding its ecological capacity over the natural capacity on selected area:

$$Ks = Ce/Cn,$$

(4)

Where $Ce$ – ecological capacity of the ecosystem; $Cn$ – the natural capacity of the Boguslav agroforestry – the total volume of extraction by farming and destruction of local renewable resources (2.91 m).

Gradation of index $Ks$:

- $Ks \leq 1$ – exceeding the environmental capacity over the natural one on the selected area is not observed, and the situation is considered to be satisfactory;
- $1 < Ks \leq 2$ – a dangerous situation;
- $2 < Ks < 10$ – the situation is critical;
- $Ks \geq 10$ – the situation is extremely dangerous.

This research defined the ecological capacity in the magnitude of oxygen production, carbon dioxide absorption, and dust and soot detention. These indicators are among the most critical limiting factors developing mezoecosystem "PFP – AL."

3. Results and discussion

The calculations by equations (1), (2), (3), and (4) show that the coefficient of sustainability on the territory of agroforestry is $Ks = 0.005$. It testifies to large mezoecosystem reserves and shows that the natural systems are stable on their territory. To develop a scientifically grounded strategy of predicting and neutralizing threats to environmental safety, the quantitative assessment and ranking of the potential adverse effects of natural resource management become essential.

There are many models created [13] to evaluate possible threats on PFP and their environment by different types of impacts. We have developed and proposed a model that graphically displays the optimal balance on the territory in the system "PFP-AL." For its construction, it is necessary to combine graphs of the limiting ecological capacity of the territory mezoecosystem with its limiting environmental load. Let us suppose that for a mezoecosystem "PFP-AL" the optimal value of ecological capacity will be equal to $V$ (Figure 1). This means that we need to reduce human pressure on this territory by equal to the segment $FG$. 

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Figure. 1. Model of optimal territory balance of PFP: 
$P$ – limiting the ecological capacity of mezoecosystem territory; 
$W$ – limiting environmental load; 
$V$ – the optimal value of environmental capacity; 
$MC$ – mezoecosystem capacity; 
$MD$ – mezoecosystem distribution on environmental loading; 
$F$ – minimum point of optimum of environmental capacity; 
$G$ – maximum point of optimum of environmental capacity 
$FG$ – the amount of human pressure on the territory (author’s work)

If to continue reducing an existing anthropogenic impact (AI) on the territory AL and PFP, the environmental capacity of the area will increase to a value more considerable $FG$, which would require additional environmental support (like cultivation). Furthermore, this may exceed benefits from environmental protection activities in the form of partial environmental loading on the area (to the left of $V, MC > MD$). It means an inefficient distribution of resources in the form of unjustifiable reduction AI on the territory in favor of environmental activities. On the right side, on the contrary, the rate of environmental capacity is insufficient to meet the needs of mezoecosystem, and this can cause environmental rebooting of territory and even ecological disaster (Figure 1). In this case, the activity on the territory of PFP is directed only to obtain benefits and does not meet environmental needs in the area.

We can graphically prove, using this model, that, in equal measure, is ecologically unreasonably neither increasing nor decreasing AI on PFP. In turn, this allows us to evaluate all the potential environmental effects of natural resource management. The developed model is illustrated possible changes on the territory of mezoecosystem with possible ways of protective forest management development and shows the importance of preserving a balance between the environmental capacity of the territory and its limiting environmental load.

Human development causes the expansion of AL and the reduction of forest areas. This process causes a decrease in carbon dioxide sequestration and oxygen generation, leading to the greenhouse effect and degradation of outdoor and indoor air quality. The protection of present ecosystems is critical to mitigating the adverse effects. However, the additional compensation should be performed on territories—depleted by human activity, especially urbocenoses. We propose using the most effective solutions [14][15][16][17][18][19][20] – green structures (outdoor and indoor), – which can enrich the territories with different kinds of plants with increasing the functionality.

4. Conclusion
The conducted researches of functioning of the system "PFP-AL" showed that the system operates within its optimum conditions because the main quantitative parameters (environmental equilibrium stability in regulated borders after anthropogenic changes and ecological capacity of the territory) meet the requirements of sustainable forest management and sustainable development of the territory. The developed model is illustrated possible changes on the territory of mezoecosystem with possible ways of protective forest management development and shows the importance of preserving a balance between the environmental capacity of the territory and its limiting environmental load. The significance of ensuring PFP development on the territory of AL, like those that support an environmental assimilation capacity and are an integral part of a development by most of AL is shown. Additional compensation of adverse effects is necessary, which can be performed by green structures. Further researches can provide it. Now we are creating a new laboratory of heat-mass and gas exchange in green structures and indoor planting. It is equipped with a specially designed gas exchange camera and gas analyzers. It can provide quantitative data about carbon dioxide sequestration, the catching of different pollutants, and oxygen generation. An engineering method of calculation of “green structures” and indoor planting will be developed. It allows keeping enough indoor and outdoor air quality in different AL and compensating for the harmful effects of anthropogenic depletion of ecosystems.
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