Research paper

# Methodology for the assessment of damage and economic losses from harm to forest ecosystems as a result of armed aggression

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**Cherchyk, L.** 2022. Methodology for the assessment of damage and economic losses from harm to forest ecosystems as a result of armed aggression. – Forestry Studies | Metsanduslikud Uurimused 77, 2–20, ISSN 1406-9954. Journal homepage: http://mi.emu.ee/forestry.studies

**Abstract.** Significant changes in the environment have caused awareness of the strategic importance of forests as a factor in global environmental security, and socio-economic development of territories. Evidence of this are many international acts, including the provisions of the New EU Forest Strategy for 2030. However, in areas where hostilities are taking place, forests are being destroyed en masse, leading to systemic losses, the restoration of which will require large investments, efforts, and a long period of time. Therefore, it is important to improve the mechanisms for recovering compensation from the aggressor country, whose actions have led to losses from loss or damage to forest ecosystems. In this case, justification of the amount of compensation plays a significant role, and therefore there is a need to develop methodological approaches to their definition. Based on the summary of international practices, guidelines of international organizations, regulations of Ukraine, and scientific publications on the assessment and compensation of environmental damage, the author used a systematic approach that combines the assessment of damage from loss or damage to forest ecosystems and the cost of their restoration. The methodology involves taking into account the degree of damage in determining losses, lost profits, and costs of restoration of forest ecosystems in the context of forest ecosystem services – Provisioning Services, Regulating Services, Supporting Services, or other ecosystem maintenance services; Cultural Services, such as educational, aesthetic, and cultural heritage values, recreation, and tourism. The author proposes relevant methods for each component of the assessment and the relevant indicators. In determining the sets of indicators the author used those that can be calculated based on objective data, or that have an international practice of their calculation. The choice of data sources for the calculation of damage and losses from losses or damage to forest ecosystems and objects within them, caused to Ukraine as a result of hostilities, is stipulated.

**Key words:** forest ecosystems, ecosystem services, military actions, loss and damage assessment, restoration costs.

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## Introduction

Due to global climate change, and increasing anthropogenic pressure on ecosystems, the ecological role of forests is growing. Forests perform environmental and protective functions, including water protection, soil protection, anti-erosion,

DOI: 10.2478/fsmu-2022-0009



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absorption of carbon dioxide, and forming the ozone layer, accumulation of vapors. The importance of forests in ensuring the development of the green economy and social sphere is growing. The European Commission has published the New EU Forest Strategy for 2030 (European Commission, 2021). Its main priorities include protection, restoration, and sustainable forest management; the appliance of the principles of circular bioeconomics; ensuring the multifunctionality of EU forests; provision of alternative ecosystem services.

Ukraine has joined these processes, declaring its intention to implement the principles of sustainable development and the transition to sustainable forest management. But the military aggression of the Russian Federation against Ukraine on February 24th, 2022 makes it impossible to realize these intentions.

So far, the aggressor's military actions have led to the destruction of vast forests, including through mass felling of trees and forest fires, which have become catastrophic. Numerous fallen missiles, unexploded ordnance, and mines are in the forest area. The occupiers are looting natural resources, destroying natural ecosystems, and polluting the environment.

This is ecocide in its most severe form, which will have not only terrible consequences for the population of Ukraine, as it destroys the living environment of people, but Ukraine's economy, as forestry provides raw materials for a number of necessary economic activities, has high export potential, but also for the European continent, as forests perform critical regulatory functions, functions of maintaining ecosystems. As per modern approaches, these are forest ecosystem services, the restoration of which will require considerable investments, efforts, and a long period of time.

Therefore, the purpose of the study is to develop methodological approaches to assessing damage and economic losses from the harm to the forest ecosystems and objects within their borders caused to Ukraine as a result of the armed aggression of the Russian Federation (hereinafter referred to as the Methodology) to substantiate legal claims against the aggressor aimed at restoring forest ecosystems.

**Scientific sources review**

In the context of the study, the author elaborated and identified four groups of sources:

1) materials of international practices on compensation for environmental damage as a result of armed aggression;
2) guidance documents of international organizations on damage assessment and ecosystem services;
3) regulations of Ukraine on the assessment of natural resources and lands for various purposes and compensation for losses and damage;
4) scientific publications on the economic evaluation of ecosystem services.

**Approaches to assessing environmental damage as a result of armed aggression used to justify compensation in international practices**

To substantiate the claims for temporary loss of natural resources due to the Iraqi military invasion of Kuwait, the applicants used the Habitat Equivalency Analysis ("HEA") methodology to determine the nature and extent of compensation to cover losses in environmental services (EPL, 2022b). The loss budget was calculated as an environmental project aimed at replacing ecosystem services provided by irreversibly damaged natural resources. The claims for compensation for environmental damage after the Iraqi aggression were examined by the UN Compensation Commission (UNCC, 2022), established as a subsidiary body of the UN Security Council in 1991.

The UN Compensation Commission has recognized that there are no specific methods of assessing damage in international law. However, the court has to evaluate the damage and determine the appropriate compensation in case the amount of

damage caused and the reparation are duly justified. The amount of compensation includes the cost of restoration (EPL, 2022b).

In the case of Costa Rica and Nicaragua, the affected party used an "ecosystem approach", predicting losses when 50 years is needed to restore the affected area. Nicaraguan experts contrasted the assessment based on the theory of "recovery payments" (EPL, 2022a).

The court stated that the impairment or loss of the ability of the environment to provide goods and services, and the cost of the restoration of the damaged environment, were compensable under international law. Moreover, the evaluation of environmental damage should be viewed from an ecosystem perspective by making a general assessment of the deterioration or loss of environmental goods and services before restoration, rather than attributing value to specific categories of environmental goods and services and estimating recovery periods for each.

**Guiding documents of international organizations**

The Additional Protocol to the Geneva Conventions of 12 August 1949, concerning the Protection of Victims of International Armed Conflicts (Protocol I), of 8 June 1977, prohibits the use of methods or means of warfare that are intended to cause or will cause long-term and serious damage to the environment (Part III, Section I "Methods and means of warfare", Article 35 "Basic Rules", paragraph 3) (Geneva Conventions Protocol I, 1977).

The UN Declaration on Environment and Development (Rio Declaration on Environment and Development, 1992) foresees that "the environment and natural resources of people living in conditions of oppression, domination, and occupation must be protected... Therefore, states must respect international law, which ensures the protection of the environment during armed conflicts, and must cooperate, if necessary, in its further development."

However, Russia completely ignores the norms and rules of civilization, and its aggression should be classified as genocide and ecocide.

To determine the types of damage, the following provisions are taken into account:

- Convention on Civil Liability for Damage Resulting from Activities Dangerous to the Environment since June 21, 1993 (Lugano, Switzerland) (Council of Europe, 1993);
- OSCE Handbook of Best Practices in Conventional Ammunition. Organization for Security and Co-operation in Europe (OSCE, 2008);

In determining the methods and indicators for assessing forest ecosystem services, the following provisions were used:

- FAO Global Forest Resources Assessment 2020 main report (FAO, 2021);
- GEF Guidance Documents to Economic Valuation of Ecosystem Services in IW Projects (GEF IW:LEARN, 2019). Approaches to value determination are considered: Direct use-value, Indirect use-value, Non-Use values (Altruistic value, Bequest value, Existence value);
- Guidance Manual on Valuation and Accounting of Ecosystem Services for Small Island Developing States (UNEP, 2014). A reliable approach was used for capturing and accounting ecosystem services;
- Ramsar Technical Report No. 3 Guidance for valuing the benefits derived from wetland ecosystem services (De Groot *et al.*, 2006). Used approaches of function analysis (identification & quantification of services), methods and indicators. Valuation of services;
- Department for Environment, Food and Rural Affairs (An introductory guide to valuing ecosystem services (Defra, 2007). We agree with the position that "Ecosystem services contribute to economic welfare in two ways – through contributions to the

generation of income and wellbeing and through the prevention of damage that inflict costs on society. Both types of benefits should be accounted for in policy appraisal". The study takes into account the provisions on the rationale for the assessment of ecosystem services (*The Case for the Valuation of Ecosystem Services*), Chapter 4: Valuation of ecosystem services considers economic valuation techniques including the use of benefits transfer, and presents the Total Economic Value framework discussing how its use fits in with the valuation of ecosystem services; Annex 1: Valuation Methods);

- TEEB (2010); MEA (2005); CICES (Haines-Young & Potschin, 2012). A comprehensive assessment of the fundamental ecological and economic principles of measuring and valuing ecosystem services and biodiversity.

**Normative acts of Ukraine on the assessment of natural resources and lands for various purposes and compensation for losses and damage**

The methodology for assessing damage and economic losses from the harm to the forest ecosystems and objects within their borders caused to Ukraine as a result of the armed aggression takes into account certain provisions of the Forest Code of Ukraine (1994), Land Code of Ukraine (2022), Economic Code of Ukraine (2022), Civil Code of Ukraine (2022), Laws of Ukraine on Environmental Protection (1991) and other laws and regulations materials that may be used in whole or in part (with appropriate references) to determine damage.

In particular, in determining the types of damage and losses used and supplemented the list specified in the procedure for determining the damage and losses caused to Ukraine as a result of the armed aggression of the Russian Federation (Government of Ukraine, 2022).

The signs of loss of or damage to forest ecosystems used in the Methodology take into account the provisions of Art. 1 of the Law of Ukraine on state control over land use and protection (2003), No. 963-IV, edition from 27.05.2021, Resolutions of the Cabinet of Ministers of Ukraine "On approval of fees for calculating the amount of damage caused to forests" from July 23, 2008 N 665 (Government of Ukraine, 2008), and "On approval of fees for calculating the amount of damage caused by violation of the legislation on nature reserves" of July 24, 2013, No. 541(Government of Ukraine, 2013).

To determine the amount of pollution of forest lands, the provisions of the Methodology for determining the amount of damage caused by pollution and clogging of land resources due to violations of environmental legislation (Government of Ukraine, 2007).

To calculate the compensation for damage to land owners as a result of hostilities, the provisions of the Land Code of Ukraine (2022) (Section V, Chapter 24. Compensation to land owners and land users. Article 156. Grounds for compensation to land owners and land users), the Civil Code of Ukraine (2022), Chapter 3. Article 22. Compensation for damage and other methods of compensation for property damage).

When assessing the lost profit, the option of determining the net operating income is considered as specified in the Methodology for determining the amount of damage caused by the unauthorized occupation of land, misuse of land, damage to land, violation of the regime, regulations, and rules of their use (Government of Ukraine, 2020).

The provisions of the Land Code of Ukraine (2022), (Chapter 34, Article 201, item 3 in the wording of 01.01.2022) and the Methodology of normative monetary valuation of land plots (Government of Ukraine, 2021) was used to substantiate the costs of restoration.

**The results of research on the economic evaluation of ecosystem services**

The methodology is based on modern approaches to the assessment of forest ecosystem services according to their most common classification (Haines-Young & Potschin, 2012; Fisher *et al*., 2009; MEA, 2005; TEEB, 2010; Wallace, 2008; UK National Ecosystem Assessment, 2011).

Therefore, attention is focused on relevant sources, which set out methodological approaches to the evaluation of ecosystem services and direct indicators of the value of environmental goods and services.

In particular, the following classification of forest ecosystem services assessment was used: Provisioning Services; Regulating Services; Supporting Services or other ecosystem maintenance services; Cultural Services such as educational, aesthetic, and cultural heritage values, recreation, and tourism.

The results of research by a group of scientists were recognized by Costanza *et al.* (1997, 2014, 2017) who estimated the total value of forest goods and services consumed by humans during the year. The dynamics of the assessment show that the more profound the study of ecosystem services, the greater their value.

The publication of Costanza *et al.* (2017) traces the history of the issue, debate, and controversy that it caused. The authors also make recommendations for the future, pointing out the weakness of the main economic approaches to evaluation, growth, and development.

A review of methodological approaches to the assesment of ecosystem services showed their diversity, as the assessments addressed certain aspects in the context of the research topics.

In particular, Pagiola *et al*. (2004) proposed an assessment of the economic value of ecosystem conservation to examine the following aspects: the value of the overall flow of benefits from ecosystems; net benefits from interventions that change ecosystem conditions; distribution of costs and benefits of ecosystems; identifying potential sources of funding for conservation.

Kindu *et al*. (2016) conducted a study assessing changes in ecosystem services (ESVs) in response to the dynamics of land cover change (LULC) over four decades (1973–2012) using the example of the Munes-Shashemen landscape of the Ethiopian highlands. This study is valuable because, firstly, GIS was applied using LULC datasets from previous and current periods. Secondly, global value coefficients developed earlier, and modified conservative value coefficients were applied for the studied landscape.

Kindu *et al*. (2016) applied the maximum likelihood method in ArcGIS 10.5. ES coefficients were used to estimate the monetary value by applying the benefits transfer method published by Costanza *et al*. (2014).

This approach was also used by Mengist *et al*. (2022b). The same approach should be used to identify changes in landscapes before and after the hostilities in Ukraine.

Another study by Mengist *et al*. (2022a) argues that the value of forest ecosystem services (FES) varies depending on cultural, socio-economic, and environmental conditions. The authors propose to evaluate FES by studying the impact of social environment variables on the apparent variation in consumer value.

Grammatikopoulou & Vačkářová (2021) worked on the synopsis of forest valuation literature dating from 2000 to 2017. Their database aims to track the value of forests in Europe. The aim of the study was to identify the determinants of the value of forest ECs. The results were used in collecting supply and use forest ES accounts for the Czech Republic.

Ojea *et al*. (2016) recognize the role of climate change mitigation through forest sequestration and degradation (REDD) programs in mitigating climate change and point to the economic benefits of other forest ecosystem services. They conducted a global meta-analysis of primary forest

surveys published over the past 30 years, assessed the economic benefits of various forest ecosystem services in the target REDD countries, and discussed the implications of considering these economic indicators in REDD decision-making.

The author suggests using the results of the above studies to calculate the losses of regulatory and ecosystem maintenance services.

The problem of assessment of ecosystem services is also paramount in the work of many Ukrainian scientists, whose contribution is taken into account in the methodology. In particular, the proposals of Soloviy (2016), and Vasyliuk & Ilminska (2020) concerning the assessment of the major provision services of forest ecosystems according to the relevant indicators and the evaluation methods of ecosystem regulation and maintenance services.

As an alternative to assessing the lost material resources of the forest, scientific and practical recommendations developed by a group of scientists from the Research Institute of Forestry and Agroforestry, AHEM. Vysotsky, can be used. (Torosov *et al.*, 2019). The study identifies methodological tools and provides practical guidance on conducting a monetary assessment by types of forest resources, such as forest areas, enterprises, and regions of Ukraine. The suggestions of Furdychko *et al.* (2019) on the evaluation of forest ecosystem services based on remote sensing data were also considered.

**Initial prerequisites and clarification of the conceptual framework**

The provisions of the methodology consider that the importance of forests is to provide a continuous, highly efficient performance of environmental, economic, and social functions at the local, national and global levels. Forest should be viewed as a complex natural system, in which interconnected subsystems create a special environment and conditions for the life of various organisms, people, and performance of vital ecosystem services. As a result of the hostilities, damage to forests has brought upon a great loss for Ukraine and the world. The method takes into account the following consequences of hostilities:

- movement of heavy equipment and armed forces;
- bombing and shelling;
- fires as a consequence or because of arson;
- smoke and noise pollution;
- pollution with fuel and lubricants and other chemicals;
- accumulation of solid waste (including remnants of military equipment and ammunition);
- bodies of people and animals that have died;
- ultra- or infrasonic vibration waves;
- radioactive contamination;
- inability to perform forest service and other ecosystem maintenance services;
- impossibility of using the natural resources for production and providing living conditions for the population.

The methodology uses the following terms for damage and losses from harm to forest ecosystems and objects within their borders caused to Ukraine as a result of the armed aggression:

- losses – direct and indirect losses, expenses, and unearned income due to military aggression;
- damage – the lost or damaged forest ecosystems and objects within them or the cost of forest ecosystem services; losses due to the impossibility of timely implementation of planned forestry measures, which has led to or may lead to the deterioration of forest ecosystems;
- expenses for eliminating the consequences of hostilities – firefighting, soil washing, cleaning water bodies from garbage, removal of damaged equipment and ammunition; demining costs; reclamation of land damaged as a result of hostilities; arrangement and maintenance of engineering and tech-

nical structures, forest infrastructure;
- lost profits due to the inability to conduct business activities, severed business ties, and related activities.

**Research methodology**

The methodology for assessing the damage and losses from harm to forest ecosystems and objects within them caused to Ukraine as a result of the armed aggression takes into account the following components:

1) assessment of material losses of the forest ecosystem as a result of the destruction, damage due to hostilities, lack of opportunities for forest service and management, and inability to use natural resources for production and life of the population;
2) assessment of the costs for restoring damaged ecosystems to their prior state, at least their material resources;
3) assessment of losses related to forest regulatory and ecosystem maintenance services;
4) assessment of compensation for the loss of cultural, aesthetic, recreational, and landscape components of forest ecosystems.

The method includes the degree of damage: complete loss of resources; destruction of the forest ecosystem; resource degradation; deterioration of the forest ecosystem; postponing the possibility of implementing certain forest ecosystem services due to their condition or the level of destruction of forest infrastructure.

The assessment methods:

- based on the cost estimates of different types of land resources by regions of Ukraine according to the Resolution of the Cabinet of Ministers "On approval of the Methodology for determining the amount of damage caused by the unauthorized occupation of land, improper use of land" (Government of Ukraine, 2020);
- based on existing cost estimates of forest ecosystem services adopted in EU countries;
- based on a combination of several approaches to valuations, depending on the group of forest ecosystem services;
- based on technical and economic calculations of costs for forest ecosystem restoration.

The methodology justifies claims to the subjects of armed aggression for compensation for damage and losses caused to forest ecosystems and objects within their boundaries in order to sue them.

Data sources for calculating losses from the harm to the forest ecosystems and objects within their borders caused to Ukraine as a result of the armed aggression:

- results of field research conducted by relevant departments and commissions of forestry and other forest land owners;
- GIS data;
- results of independent commission surveys.

The methodology involves the primary data for the formation of loss statistics and applies a hierarchical approach established by the state forest management system (forestry; regional forestry and hunting departments; State Agency of Forest Resources of Ukraine), territorial organization of Ukraine for other owners of forest land. This involves the transfer and generation of data in the State Agency of Forest Resources of Ukraine.

Therefore, it is advisable to form a unified approach to the statistical reporting expansion or the separate report formation on the loss of forest ecosystem services with compulsory confirmation of the facts.

The main provisions of the Order are included in the "Method development of the assessment of damage and losses caused to Ukraine as a result of the armed aggression of the Russian Federation" approved by the resolution of the Cabinet of Ministers of Ukraine on March 20, 2022, No. 326 (Government of Ukraine, 2022).

## Results

### Assessment of material losses of the forest ecosystem as a result of their destruction, damage due to hostilities, lack of opportunities for forest service and management, and the inability to use natural resources for production and life of the population

Suggested methods:

- a component method, which provides post-resource detection of losses on the relevant indicators;
- a comparative method based on corresponding the values of individual similar indicators with each other. The most common are comparisons with normative indicators, comparisons with indicators of the state of similar intact ecosystems, comparison of actual and planned indicators of the state of forest ecosystems;
- the method of lost profits, which involves the calculation of the total income that could be obtained from the saved resource, territory, or object;
- method of direct calculation of costs incurred to prevent or reduce losses (firefighting, partial renewal of infrastructure, increased patrols, organization of stationary and dynamic patrols);
- balance sheet, which provides for the formation of material, raw material, and energy balances along the entire vertical of the forest sector of Ukraine.

The component (resource) approach to calculate the damage to the forest ecosystem and its natural objects is used if their self-restoration is impossible.

In particular, the main objects of assessment are disturbed soils; destroyed and damaged forest plantations (lists by the degree of maturity and predominant species of stands), natural undergrowth and samosas, seedlings, saplings, non-woody vegetation, fungi, berries, habitats of medicinal plants; destruction of wildlife, birds, and insects, damage or destruction of their dwellings and buildings, habitats and reproduction; destruction of or damage to forest infrastructure (Table 1).

For the calculations in Table 1, the formula is used:

$$C_{res} = \sum O_{res} \times T, \quad (1)$$

where $C_{res}$ – the total cost of losses of forest ecosystem services;

$O_{res}$ – the amount of resources;

T – fee for calculating the amount of damage.

These calculations are supplemented by an estimate of the lost profit that could have been obtained from the preserved resource, territory, or object; assessment of losses due to the lack of forest service and management; assessment of losses due to the lack of opportunities to provide living conditions for the population; an estimate of the costs incurred to prevent or reduce losses.

The assessment of lost profits that could be obtained from the preserved resource, territory, or object includes lost income from the sale of the main types of logging and processing activities; lost income from the sale of secondary forest resources (resin, stumps, bast and bark, wood greens, wood sap) and by-products of forest use (hay harvesting, cattle grazing, housing apiaries (beekeeping), harvesting wild fruits, nuts, mushrooms, berries, medicinal plants, forest litter collection, reed harvesting); lost income from tourism and recreational activities, hunting, sale of planting material (Table 2).

Table 1. Component (resource) approach to the calculation of damage to forest ecosystems and their natural objects.

| Resource type | UOM | Amount | Type of damage | The nature of the damage | Fee for calculating the amount of damage |
|---|---|---|---|---|---|
| Forest soils | 1000ha | | Disturbed soils<br><br>Removal of soil cover, pollution, and littering of their territories | Burning due to fire<br>Compaction, disturbance of soil structure and cover due to the movement of heavy machinery | *App.10.<br><br>**App. 10 |
| Forest plantations: lists by the degree of maturity and predominant species of stands | 1000ha or $m^3$ | | Destroyed, damaged trees:<br>- to the point of cessation of growth; - to the extent of non-cessation of growth | Fires<br>Bombing<br>Movement of heavy equipment, military units | *App. 1,2 |
| Wood resources | $m^3$ | | Felled trees | Aggressors + for defense purposes | *App. 1,2 |
| Forest undergrowth | 1000ha | | Destruction of and damage to forest crops, natural growth, self-seeding, seedlings, and saplings | Fires<br>Bombing<br>Movement of heavy equipment, military units | *App. 3 |
| Herbaceous vegetation | 1000ha | | Destruction or damage | Same as above | *App. 7 |
| Mycelium | 1000ha | | Destruction or damage | Same as above | |
| Medicinal plants | 1000ha | | Destruction or damage | Same as above | *App. 10 |
| Berries | 1000ha | | The same | Same as above | *App. 10 |
| Animals | Units | | Destruction of wildlife, damage to or destruction of their dwellings and buildings, habitats, and reproduction | Fires<br>Bombing<br>Movement of heavy equipment, military units.<br>Smoke, noise | **App. 7 |
| Birds | Units | | The same | Same as above | **App. 7 |
| Insects (bees) | Units | | Destruction of habitats and reproduction | Same as above | **App. 7 |
| Forest infrastructure | Units | | Destruction of or damage to information and security and other signs, drainage ditches, drainage, anti-erosion systems, roads, and other objects | Fires<br>Bombing<br>Movement of heavy equipment, military units. | *App. 6<br><br>*App. 8<br><br>**App. 12 |

Note: * Government of Ukraine, 2008; ** Government of Ukraine, 2013.

Table 2. An estimate of the lost profits that could have been derived from a saved resource, territory, or object.

| Indicators | Quantity | Price, tax, UAH | Amount, UAH |
|---|---|---|---|
| Revenues from the sale of the main types of logging and logging activities | | | |
| Revenues from the sale of products of processing of secondary forest resources and by-products of forest use | | | |
| Income from tourist and recreational activities | | | |
| Income from hunting | | | |
| Revenues from the sale of planting material | | | |
| Reporting of forestries for previous years | | | |

The formula used for the calculations in Table 2:

$$C_{lp} = \sum O_{res} \times P, \quad (2)$$

where $C_{lp}$ – the total lost profits that could have been gained from the preserved resource, territory, or object as a result of armed aggression;

$O_{res}$ – the amount of resources;

P – the sale price of the resource.

To calculate the damage to the forest ecosystem and its natural objects (Table 1) and assess the lost benefits that could be obtained from the preserved resource, territory, or object (Table 2), you can use the approaches proposed by Soloviy (2016), Vasyliuk & Ilminska (2020), Torosov *et al*. (2019).

The assessment of losses due to the lack of forest services and management includes forest losses due to the impossibility of forestry surveys, extermination work in pests and diseases, artificial reforestation, clearing of seedlings, new planting material, prevention of forest fires; deterioration of forests due to the impossibility of felling care, sanitary felling (Table 3).

Table 3. Estimation of losses due to lack of care options and forest management.

| Indicators | Quantity | Price, tax, UAH | Amount, UAH |
|---|---|---|---|
| Forest losses due to the impossibility of forest pathological examinations, ha | | | |
| Forest losses due to the impossibility of carrying out extermination work in the centers of pests and diseases by land methods, ha | | | |
| Deterioration of forests due to the impossibility of felling care, sanitary felling | | | |
| Forest losses due to the impossibility of artificial reforestation on fellings | | | |
| Forest losses due to the inability to prevent forest fires | | | |
| Losses due to the impossibility of growing seedlings, new planting material | | | |

The formula is used for the calculations in Table 3:

$$C_{lfs} = \sum O_{res} \times P, \quad (3)$$

where $C_{lfs}$ – the total cost of losses due to lack of forest care and management;

$O_{res}$ – the amount of lost resources;

P – fee or resource price to calculate the amount of damage.

Assessment of losses due to lack of opportunities to provide living conditions for the population include loss of forestry income due to the inability to harvest firewood, peat for the population living within/near the forest; loss of household income due to the impossibility of harvesting mushrooms, berries, medicinal plants by the population of the community living within/near the forest (Table 4).

The formula is used for the calculations in Table 4:

$$C_{lo} = \sum O_{res} \times P, \quad (4)$$

where $C_{lo}$ – the total cost of losses due to the lack of opportunities to use the natural resource potential to ensure the living conditions of the population due to armed aggression;

$O_{res}$ – resource volume;

P – the sale price of the resource.

Table 4. Estimation of losses due to the lack of opportunities to use natural resources to ensure the living conditions of the population.

| Indicators | Quantity | Price, tax, UAH | Amount, UAH |
|---|---|---|---|
| Loss of forestry income due to inability to harvest firewood for the population living within/near the forest, ha | | | |
| Loss of forestry income due to the impossibility of harvesting peat for the population living within/near the forest, ha | | | |
| Loss of household income due to inability to harvest mushrooms by the population living within/near the forest, ha | | | |
| Loss of household income due to the impossibility of harvesting berries by the population of the community living within/near the forest, ha | | | |
| Loss of household income due to the impossibility of harvesting medicinal plants by the population of the community living within/near the forest, ha | | | |

Estimation of costs incurred to prevent or reduce losses includes the cost of fighting fires, partial renewal of infrastructure, increased patrols of forests, organization and conduct of stationary and dynamic patrols. It is estimated on the basis of calculation (Table 5).

Table 5. Estimation of costs incurred to prevent or reduce losses.

| Indicators | Amount, UAH |
|---|---|
| Costs of fire fighting, ha | |
| The cost of partial infrastructure upgrades | |
| Expenditures on intensive patrol of forests | |
| Costs of organizing and conducting stationary and dynamic patrols | |

The comparative method is used in the case of forest damage, for the restoration of which no investment is required, as there is sufficient potential for self-restoration. In this case, the method of lost profits for the period of ecosystem self-restoration should be applied, using regulatory or similar indicators of intact ecosystems.

Thus, the assessment of losses of material components of the forest ecosystem due to their destruction, damage because of hostilities, lack of opportunities for forest services and management, and inability to use natural resources for production and providing living conditions for the population is carried out by the formula:

$$C_{PS} = C_{res} + C_{lp} + C_{lfs} + C_{lo} + C_{prev}, \quad (5)$$

where $C_{PS}$ – the total cost of losses of forest ecosystem services;

$C_{res}$ – the total cost of losses of material components of the forest ecosystem due to their destruction, damage because of hostilities (Formula 1);

$C_{lp}$ – the total lost benefit that could have been gained from the preserved resource, territory, or object without armed aggression (Formula 2);

$C_{lfs}$ – total losses due to lack of opportunities for forest services and management due to armed aggression (Formula 3);

$C_{lo}$ – the total cost of losses due to the inability to use natural resources to ensure the living conditions of the population (Formula 4);

$C_{prev}$ – the amount of costs incurred to prevent or reduce losses includes the cost of fighting fires, partial renewal of infrastructure, increased patrol of forests, organization, and conduct of stationary and dynamic patrols (direct account).

**Estimation of costs for restoration of disturbed ecosystems to the previous state**

Suggested methods:

- a calculation method, which provides a quantitative assessment of the cost of restoring damaged ecosystems. This takes into account the investment costs of one-time restoration of soils, damaged or destroyed plantations, forest infrastructure, etc., and operating costs incurred by forestry (another owner) during the entire recovery period. The annuity method must be applied to all costs;
- a normative approach based on the use of scientifically sound standards of raw materials, and energy, for the calculation of restoration costs (Table 6).

Table 6. Estimation of capital expenditures for the restoration of disturbed ecosystems.

| Indicators | Quantity | Price, tax, UAH | Amount, UAH |
|---|---|---|---|
| Expenditures for clearing lands damaged as a result of hostilities (pollution with fuel and lubricants and other chemicals, radiation, solid waste (including remnants of military equipment, ammunition); burial of bodies of people and animals that died), thousand hectares | | | |
| Expenditures for land reclamation, which were violated as a result of hostilities, thousand hectares | | | |
| Costs for planting forests, thousand hectares | | | |
| Costs for the restoration of planting material, thousand hectares | | | |
| Costs for the construction, arrangement, and maintenance of engineering structures, units for each type | | | |
| Costs for the renewal of forest infrastructure, units for each species | | | |
| Costs for the restoration of forest flora, units for each species or thousands of hectares | | | |
| Costs for the restoration of forest fauna, units for each species | | | |
| Costs for the restoration of mycelium, thousand hectares | | | |
| Costs for the restoration of forest protection strips, thousand hectares | | | |
| Demining costs, units | | | |
| Expenses for the implementation of hydraulic measures, including (if necessary) the clearing of rivers or other water bodies | | | |

Capital expenditures for the restoration of the pre-war level of activity of forestry and owners of forest lands and territorial communities are assessed separately.

**Assessment of losses of forest regulatory and ecosystem maintenance services**

Suggested methods:

- a coefficient method, which provides the application of correction factors for loss of useful properties or attractions, which allows correlating the actual situation with the normal, to measure the impact of destructive factors on the landscape or forest ecosystem;
- the expert method, which implies assessing the loss of useful properties or attractions with the involvement of experts (specialists), as the use of statistical methods is impossible. The assessment is based on a qualitative determination of the state of the forest ecosystem and its elements;
- indirect market valuation (preventive costs, opportunity cost or replacement cost, factor income).
- loss estimation based on the inability to implement regulatory and ecosystem maintenance services (Table 7).

Table 7. Assessment of losses of forest regulatory functions and ecosystem maintenance services.

| Source / Service | Indicator / Criterion | Gain | Approach to evaluation |
|---|---|---|---|
| Natural vegetation, the presence of moisture, and natural processes in terrestrial ecosystems of all types / Regulation of surface temperature and air | Protection of soil with vegetation, transpiration, and evaporation from the surface of reservoirs, soil; preservation of soil structure | Maintaining stable climatic conditions, microclimate, providing comfortable living conditions for people, agricultural activities; protection against natural disasters | Due to possible losses or compensatory measures (due to loss of crops, the need for air conditioning of living space and storage facilities) |
| Natural vegetation, moisture, and natural processes in terrestrial ecosystems of all types / Regulation of moisture cycle (regulation of local precipitation, humidity) | Processes of transpiration, evaporation from the surface of water bodies, soil, plants. Water-holding capacity of vegetation | Preservation of fresh water sources. Maintaining stable climatic conditions, and microclimate, providing comfortable living conditions for people, and agricultural activities; protection against natural disasters | The cost of fresh water used for drinking, industrial water supply. The cost of moisture control can also be estimated according to possible losses or compensatory measures: due as crop loss or the need for artificial irrigation |
| Natural and artificially formed woody vegetation / Regulation of air flows (reduction of wind force and speed, peak gusts) | Shielding of air flows by forests and artificial plantings | Maintaining stable climatic conditions, microclimate, providing comfortable living conditions for people, agricultural activities; protection against natural disasters | The cost of temperature control can be estimated through possible losses or compensatory measures: due to crop loss, destruction of residential, domestic and industrial premises, as well as other ecosystems |
| Natural vegetation in ecosystems of all types / Regulation of air composition and quality | The ability of vegetation to affect the concentration of atmospheric gases, and pollutants in the air, accumulate them in organic matter, and neutralize pollutants | Maintaining a stable composition of atmospheric air provides comfortable living conditions for people and agricultural activities | Estimating the cost of temperature control due to possible losses or compensatory measures: due to deteriorating health, treatment costs, and reduced life expectancy |

| Source / Service | Indicator / Criterion | Gain | Approach to evaluation |
|---|---|---|---|
| Terrestrial ecosystems of all types, as well as artificial plantations with closed vegetation / Replenishment of groundwater | Infiltration of precipitation (including snow retention), their cleaning, and transportation to soil horizons | Water supply, increase in yield | The cost of water consumed from groundwater horizons, and surface water originating from underground sources. When groundwater has healing and health properties, evaluate the equivalent of the health effect |
| Natural vegetation in terrestrial ecosystems of all types. Artificial plantings (forest strips, reclaimed lands, buffer strips, fallows) / Soil formation | Presence of soil organisms and natural grassy vegetation, rhizosphere. Reduction of vegetation strength and power in surface runoff, reduction of wind speed | Soil fertility, and the possibility of growing crops | The cost of products grown using soils |
| Natural vegetation in terrestrial ecosystems of all types / Protection of soils from erosion | The presence of natural vegetation protects soils from drying out, wind and water erosion, and ultraviolet light; affecting the level of the albedo of the earth's surface | Soil fertility, the possibility of growing agricultural crops. No costs for the use of fertilizers and the cost of surface water quality | The cost of products grown using soils. Biodiversity conservation |
| Coastal ecosystems of watercourses and reservoirs / Protection against natural disasters, mitigation of adverse climatic conditions. Shore protection | Natural properties of coastal vegetation to resist the kinetic processes of shoreline abrasion | Protection of settlements and agricultural lands from the destructive effects of floods | It is possible to estimate the cost of shore protection through possible losses or compensatory measures: due to the loss of crops, destruction of residential, domestic, industrial premises, and other ecosystems |
| Vegetation / Primary productivity of ecosystems and greenhouse gas deposits | The cycle of matter and energy, the formation of primary biomass through photosynthesis. Removal of greenhouse gases from the atmosphere and accumulation in biomass of living plants (wood) and their dead parts | Formation of stable climatic conditions. Avoiding the effects of droughts, rapid climate fluctuations, and natural disasters | Calculation of the value of greenhouse gas emission allowances. The damage from climate change caused by greenhouse gas emissions should also be taken into account. |
| Ecosystems of all types / Biodiversity | Natural processes in ecosystems | Formation of genetic and species diversity of living organisms; creation of permanent interspecific groups; formation of natural balance in ecosystems with the highest bio-productivity and resistance to fluctuations in environmental conditions | The basis for the future economic development of the community and improvement of people's living standards |

Note: Soloviy, 2016; Vasyliuk & Ilminska, 2020.

**Assessment of compensation for the loss of cultural, aesthetic, recreational, and landscape components of forest ecosystems**

Compensation for the loss of cultural, aesthetic, recreational, and landscape components of forest ecosystems (fourth component) can be estimated using the above methods, as well as methods of travel costs, hedonic pricing, and conditional assessment (Table 8).

Table 8. Compensation for loss of cultural, aesthetic, recreational, landscape components of forest ecosystems and related indicators.

| Source / Service | Indicator / Criterion | Gain | Price, tax, UAH |
|---|---|---|---|
| Natural landscapes of biodiversity, processes, and phenomena in ecosystems / Recreation and spiritual enrichment services | Health properties and sensory information: attractive landscapes, favorable climatic conditions, microclimate, phenology, clean air, no negative anthropogenic impacts | Opportunities for physical recreation, medical or psychological rehabilitation. Opportunities for aesthetic pleasure, spiritual enrichment, spiritual practices | Equivalent to the health effect (including avoidance of medical expenses and time spent on treatment). The equivalent of the cost you are willing to pay for transportation to and from natural areas. Economic benefits of communities, organizations, and households |
| Natural ecosystems of all types / Services of cognition (scientific, educational, upbringing) | Possibility of the scientific study of biodiversity and natural processes | Production of scientific knowledge (in particular for the needs of medicine, and agriculture) | Profit from the introduction of scientific knowledge (in particular for the needs of medicine, and agriculture). Economic benefits from the improvement of methods of agriculture, medicine, and protection of the population. Economic benefits of communities, organizations, households |
| Natural landscapes / Environment for recreation, tourism, rural green tourism, ecotourism | Health properties, and sensory information: attractive landscapes, favorable climatic conditions, microclimate, phenology, clean air, no negative anthropogenic impacts | Opportunities for physical recreation, medical or psychological rehabilitation Opportunities for aesthetic pleasure, spiritual enrichment, spiritual practices | Equivalent health effect. Economic benefit of communities, organizations, households |

Note: Soloviy, 2016; Vasyliuk & Ilminska, 2020.

The total assessment of damage and losses from the harm to the forest ecosystems and objects within their borders caused to Ukraine as a result of the armed aggression (for all components) is determined by the formula:

$$C = C_{RS} + C_{REST} + C_{REG} + C_{COM,} \qquad (6)$$

where C – total cost of damage and losses from the harm to the forest ecosystems and objects within their borders caused to Ukraine as a result of the armed aggression;

$C_{RS}$ – total cost of losses of forest ecosystem services (first component);

$C_{REST}$ – total costs for restoration of disturbed ecosystems to the previous state (second component);

$C_{REG}$ – total cost of losses of forest regulatory and ecosystem maintenance services (third component);

$C_{COM}$ – the amount of compensation for the loss of cultural, aesthetic, recreational, and landscape components of forest ecosystems (fourth component).

In our opinion, this approach allows the assessment of the damage and losses from the harm to the forest ecosystems and objects within their borders caused to Ukraine as a result of the armed aggression and allows to move to the formation of appropriate targeted funds to compensate for the costs and losses.

## Conclusions

Significant environmental changes have caused awareness of the strategic importance of forests as a factor in global environmental security, and socio-economic development of territories. Evidence of this are many international acts, including the provisions of the New EU Forest Strategy for 2030 (European Commission, 2021). However, in areas where hostilities are taking place, forests are being destroyed en masse, leading to systemic losses, the restoration of which will require vast investments, efforts, and a long time.

Therefore, it is essential to improve the mechanisms for collecting compensation from the aggressor country, whose actions have led to losses from loss or damage to forest ecosystems. In this case, the validity of the compensation amounts plays a significant role. Thus, there is a need to develop methodological approaches to their definition.

When developing a methodology for assessing the damage and economic losses from the harm to the forest ecosystems and objects within their borders caused by armed aggression, it is important to choose the right methodological approach, evidence-based sources of information about the damage, and data processing methods.

The study of materials of international practices, guiding documents of international organizations, regulations of Ukraine, and scientific publications on the assessment of and compensation for environmental damage shows that they differ significantly depending on the objectives of the study, scope of activities, and departmental priorities. It is established that the main approaches to such assessment are resource, productive, systemic, ecosystem, of the global accounting value of ecosystem services, direct use-value, indirect use-value, non-use values, and the value of forest ecosystem services. Within each approach, it is offered to apply certain assessment methods.

Based on the generalization of these materials, the author used a systematic approach, which allowed to combine the assessment of damage from loss or damage to forest ecosystems and the cost of their restoration.

The methodology involves taking into account the degree of damage in determining losses, lost profits, and costs of restoration of forest ecosystems in the context of forest ecosystem services – provisioning services, regulating services, supporting services, or other ecosystem maintenance services; cultural services, such as educational, aesthetic, and cultural heritage values, recreation, and tourism.

The author proposes appropriate methodologies for each evaluation component and relevant indicators. When determining sets of indicators, those are used that can be calculated on the basis of objective data, or there is an international practice for their calculation.

**Acknowledgments.** The study was conducted within the expert group of the state institution Institute of Market and Economic and Environmental Research of the National Academy of Sciences of Ukraine in response to a letter from the Ministry of Environmental Protection and Natural Resources of Ukraine No. 25 / 5-21 / 3803-22 dated 09.03.2022 and research work "Natural asset management based on blue growth" (No. 0122U000738).

Approbation of the research results took place at the meeting of the Scientific Council of the Institute on April 14, 2022, and the International Scientific and Practical Conference "International Economic Relations. Sustainable development of Ukraine in the context of globalization and European economic integration: problems, prospects, efficiency" on May 31, 2022. The author is grateful for the critical remarks, suggestions that improved the argumentation of the author's ideas, and support.

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*Received June 28, 2022, accepted September 23, 2022*