

Analytical Hierarchy Method for Evaluating the Environmental Sustainability in the Context of Ecosystem Services Enhancing: A Case Study of the Biosphere Reserve, Ukraine

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Abstract – The ability of natural systems to provide services is critical to the sustainability of the environment. The increasing environmental pressures necessitate the creation of conditions conducive to the preservation and sustainability of natural ecosystems. A review of similar studies reveals that when evaluating ecosystem services, more consideration should be given to evaluating ecosystem stability. The Ukrainian Biosphere Reserve was chosen as the study polygon due to its importance as a conservation area and the diversity of natural ecosystems. The Analytical Hierarchy Method, in this case, provides a very straightforward way to analyze such complicated systems. The first step is to identify and value the services offered by the Biosphere Reserve's wetland, forest, and aquatic ecosystems. Then, four criteria (C1–C4) and impacts (P1–Pn) that directly affect the ecological sustainability of a certain ecosystem within each criterion were identified. The overall weight of each impact on specific ecosystem sustainability was computed and estimated to reach the main goal (G). The integrated ecological stability evaluation index (CEI) was then calculated using the overall weight values. Wetland and forest ecosystem indices were calculated to be 0.63 and 0.64, indicating that these systems are moderately stable. The stability index for aquatic ecosystems is 0.75, indicating that the system is ecologically stable. As a result, it is critical to focus on reducing negative factors affecting wetlands and forest ecosystems, such as sylvatization and/or recreational activities, to strengthen ecosystem stability and the ability to provide services.

Keywords – Ecosystem stability; hierarchy structure; natural ecosystem; pairwise comparison matrix.

Nomenclature

BR	Biosphere reserve
AHM	Analytical hierarchy method

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1. INTRODUCTION

Today's threats, such as the exhaustion of resources, decreasing the ecological sustainability of natural ecosystems, and decreasing their ability to self-recover, require the development and application of mechanisms for management by ecosystem services (ES) [1], [2].

Ecosystem services, defined as all valuable resources and benefits that man can get from nature, satisfy fundamental human needs within a living environment, so the quality of our lives directly depends on them [3], [4]. According to the UN document 'Millennium Ecosystem Assessment,' ecosystem services are considered as 'direct and indirect ecosystem contributions to human well-being' [5].

Understanding how significant ES are for biodiversity conservation and supporting natural environmental processes requires knowledge of them [6]–[9]. On the other hand, ES research is equally essential when deciding to conserve natural ecosystems and their components for supporting economic opportunities [10] and providing a human habitat [11]–[13], [3].

During recent decades, ES are not considered as 'gifts of nature' but as values that should be preserved and developed. Simultaneously, a one-sided focus on service provision was compromised in favor of a more complex estimation [14], [15].

Human services can be classified into three categories according to the CICES general classification developed by Haines-Young and Potschin [16]–[18]. The first category, *cultural*, includes human-ecosystem connections on physical, intellectual, and mental levels. Biomass, drinking and processing water, fiber, woody materials, and so on are all included in the *provisioning* category. The third category, *regulating and services*, includes soil formation, pest and disease control, climate change, and other similar activities.

The greatest threat to today's community and the economy is the degradation of ecosystems and, as a result, the loss of their services [20]. At this point, assessing threats to natural ecosystems (forests, wetlands, etc.) is critical to ensure their ecological sustainability in light of the ecosystem services they provide to society. Fig. 1 shows the standard procedure for such ES assessment at the national level.

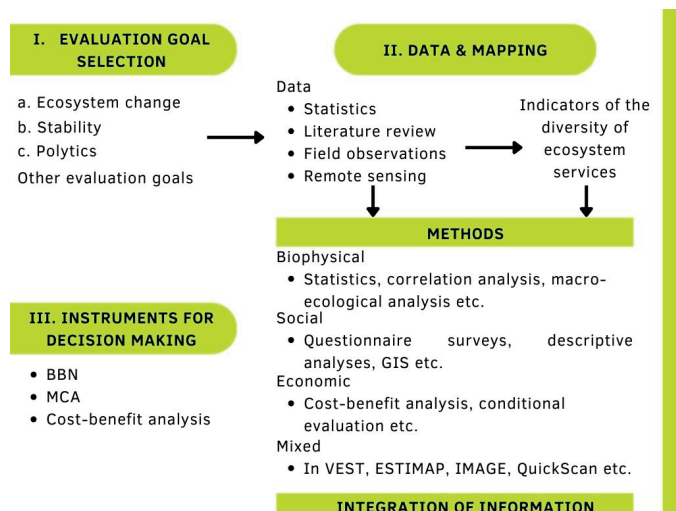


Fig. 1. Common procedure for such ES evaluation at the national level [21].

However, it is necessary to distinguish between ‘ecosystem functions’ and ‘ecosystem services’. Table 1 summarizes the major distinctions stated by several authors.

TABLE 1. ECOSYSTEMS FUNCTIONS AND SERVICES, EXTRACTED FROM THE LITERATURE REVIEW AND THEIR DESCRIPTIONS

Author, source	Ecosystem function, ecological function	Ecosystem services
Ehrlich P., Ehrlich A., 1981 [22]	A set of ecosystem processes.	Ecosystem functions, which are used by society.
Daily G., <i>et al.</i> , 1997 [23]	–	Conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life.
Costanza R., <i>et al.</i> , 1997 [24]	Ecosystem functions refer variously to the habitat, biological or system properties or processes of ecosystems.	Ecosystem goods (such as food) and services (such as waste assimilation) represent the benefits human populations derive, directly or indirectly, from ecosystem functions.
de Groot R., <i>et al.</i> , 2002 [25]	The capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly.	Observed ecosystem functions are reconceptualized as ‘ecosystem goods or services’ when human values are implied.
Wallace K., 2007 [26]	Ecosystem function is treated here as a synonym of ecosystem processes which are the complex interactions (events, reactions or operations) among biotic and abiotic elements of ecosystems that lead to a definite result.	The benefits people obtain from ecosystems which include food, water, timber, cultural values, etc., and are the outcomes sought through ecosystem management.
Fisher B., <i>et al.</i> , 2009 [27]	Processes consumed or utilized by humanity either directly or indirectly. The functions become services if there are humans that benefit from them.	The aspects of ecosystems utilized (actively or passively) to produce human well-being.
Haines-Young R., Potschin M., 2012 [17]	Ecosystem ability or potential to provide services, conditioned by its structural properties and processes, supported by it.	The contributions that ecosystems make to human well-being). These services are final in that they are the outputs of ecosystems (whether natural, semi-natural or artificial) that most directly affect the well-being of people.
TEEB, 2010 [28]	Subset of the interactions between ecosystem structure and processes that underpin the capacity of an ecosystem to provide goods and services.	The direct and indirect contributions of ecosystems to human well-being.
Zahvoyska L., Soloviy I. [29]	Material, energy, and information processes occur in the ecosystem due to its composition, structure, and dynamics (spatial and temporal).	Ecosystems' contribution to human well-being has been classified as economical.

Note: symbol (–) means that the author has not considered the corresponding functions or services

Given the aforementioned, losses of ecosystem functions of natural systems may be irreversible at the current rate of environmental degradation, resulting in ecological-economic losses and posing a real threat to partial or total loss of ecosystem services.

As a result, the current study aims to investigate and define the main factors influencing the destabilization of natural ecosystems in ‘Shatskyi’ BR, which will aid in minimizing and/or avoiding the loss of ecosystems' primary ecological functions. BR natural complexes' ability to provide ecosystem services will also improve.

A definition of influence factors on wetlands, forest, and aquatic ecosystems, specifically:

- support of biogeochemical cycles;

- stabilization of climate parameters;
 - formation of a stable hydrological regime;
 - soils productivity and erosion protection;
 - ecologically safe waste management;
 - monitoring of separate species and groups of agricultural and aesthetic importance etc.
- Providing stability to the ecosystem functions mentioned above will increase the productivity of essential ecosystem services, specifically:
- biomass provision;
 - BR microclimate formation;
 - stable water supply;
 - soil fertility support;
 - natural control of forestry pests';
 - biodiversity protection and biotope stability provision.

2. STUDY AREA & DEFINING OF ECOSYSTEMS SERVICES

The 'Shatskyi' BR is a nature preserve in Ukrainian West Polesie that joined the Transboundary BR 'West Polesie' in 2012. (Poland – Ukraine – Belarus). It sets itself apart from others by combining various natural complexes within a single territory. (Fig. 2).

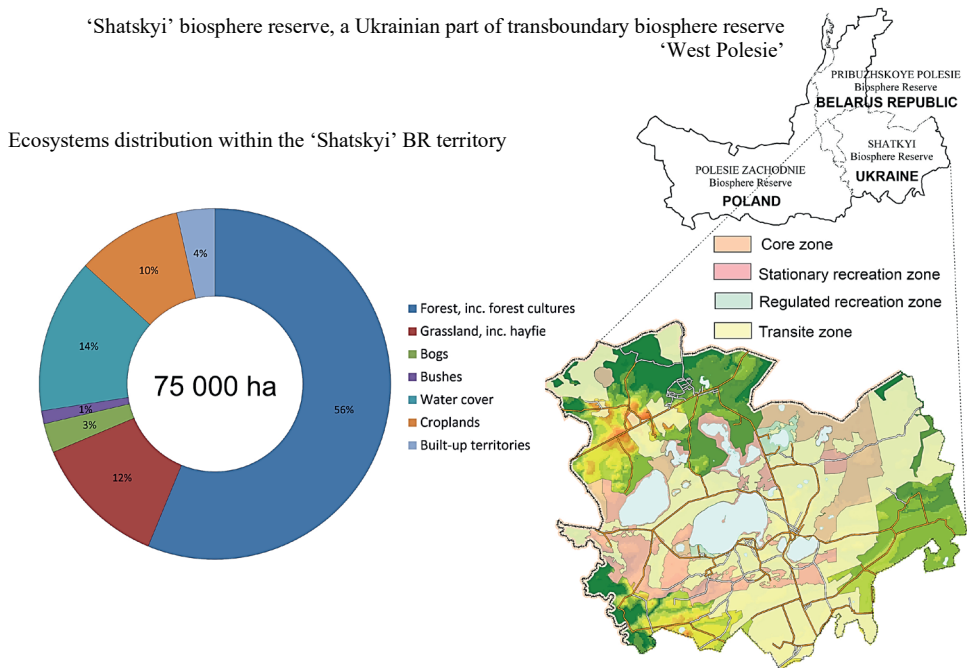


Fig. 2. The study area depicts the distribution of ecosystems within the 'Shatskyi' BR in Ukraine.

Polesie has historically been both a forest and a very humid region. The bogs in this area have a significant impact on the microclimate of the entire region. This area influences the feeling of climate because it is a large wet 'sponge' in the heart of Europe: it is not too hot and not too dry in the summer, and it is not too cold and not too windy in the winter. Despite the region's poor sandy soils, it does not rank last in terms of yield due to adequate moisture.

Polesie has vast areas of bogs and wetlands, which can store a large amount of water throughout the hot season. BR wetlands were designated as an IBA (Important Bird Area) by the Ramsar Convention in 1995, indicating their global importance as a waterfowl habitat. Natural vegetation stabilizes the soil surface and saves it from eroding.

A careless approach to environmental sustainability, on the other hand, could be disastrous for the entire region. Annual peat extraction, peat extraction from ecosystems, draining of bogs and wetlands for agricultural or forestry purposes, and vegetation loss all contribute to Polesie's soil insecurity. Such actions have resulted in desertification in the region. The other effect of climate change is the loss of many natural ecosystems due to snowless winters and long periods without rainfall, combined with a lack of moisture in wetlands and within wetlands. All of these disastrous outcomes are the result of the loss of a single ecosystem service: the preservation of the territories' wetlands hydrological regime.

As a result, early evaluation of ecosystem stability and environmental sustainability is critical to provide ecosystem services.

2.1. Forest ecosystem

The BR forests are relatively evenly distributed, but their large solid massifs are concentrated on the outskirts of the territory. The most common is a pine (*Pinus sylvestris* L.) forest with different levels of moisture and a mix of hanging birch (*Betula pendula* Roth.), oak (*Quercus robur* L.), and blueberries (*Vaccinium myrtillus* L.) in the forest cover. Hanging birch forests occupy 17.9 % of the forest area, while black alder (*Alnus glutinosa* (L.) Gaerth.) forests about 21.3 % (58.2 % - a total area occupied by forest).

When discussing forest ecosystem functions, we should emphasize their ability to accumulate and maintain the cycle of substances, produce and store energy, and regulate and protect basic physical characteristics of the environment under the influence of external factors such as climate change. Deforestation and transformation to agricultural ecosystems change metabolic processes in the atmosphere, vegetation, and soils, affecting carbon balance at the local and global levels [30]. Among the major factors influencing forests' ability to deposit carbon is the age and composition of phytocenosis, as well as the age and composition of forest resources [31]. At the appropriate level, a stable ecosystem performing its functions can provide ecosystem services (Fig. 3).

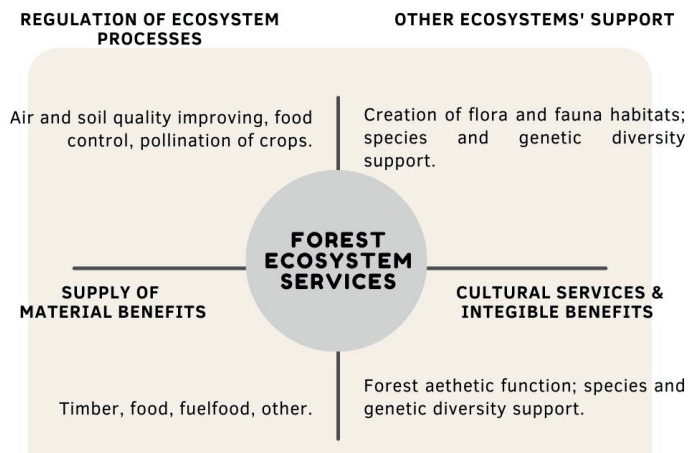


Fig. 3. Forest ecosystem services provided by BR.

Within the BR boundaries, forests have high health, cultural, and aesthetic value. The most commonly used for this purpose are the stationary and regulated recreation zone forests (Fig. 2), which total 13 658.5 hectares.

2.2. Wetlands ecosystem

The types and vegetation cover of BR wetlands vary. Eutrophic bogs prevail, with mesotrophic bogs occupying slightly smaller areas and oligotrophic bogs exceedingly rare. Many eutrophic bogs have been drained, and some have been transformed into peat meadows.

The loss of biological diversity is one of the most serious global environmental issues today. Wetland species are the most vulnerable to BR because of significant fluctuations in lake water levels and drying of specific habitats, causing them to lose necessary habitats, reproduction, and wintering. As a result, preservation and recovery efforts are prioritized for these groups.

The most valuable geosystems in BR landscape areas and waterways are water-lake, coastal water, and wetland. Despite significant anthropogenic effects (drainage reclamation, mining, etc.) on BR's natural geosystems, only aquatic and coastal-water groups have undergone extensive changes with insignificant changes in phytocenotic structure.

Identifying the factors influencing the core ecological functions of wetland ecosystems and ensuring the environmental sustainability of their functioning will allow us to improve the ecosystem benefits they provide (Fig. 4).

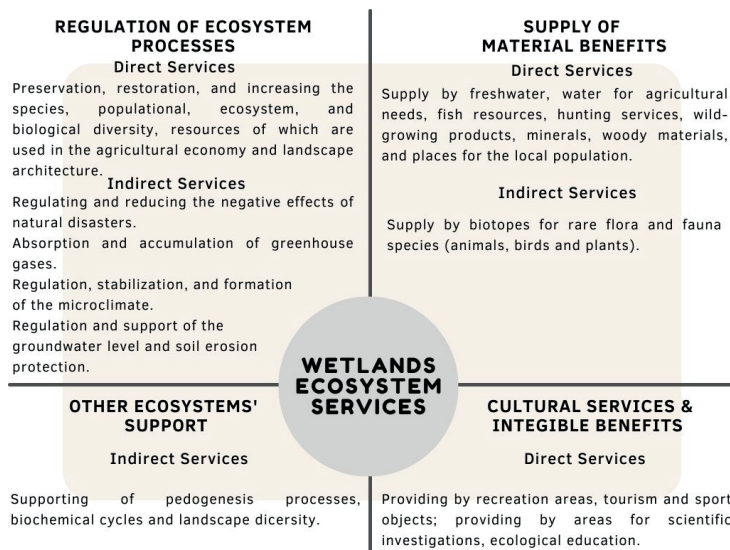


Fig. 4. Wetland's ecosystem services provided by BR.

2.3. Aquatic ecosystem

The presence of many lakes and an undeveloped river network represented by the rivers Prypiat and Western Bug and their tributaries distinguishes surface waters. The BR is traversed by rivers and streams with continuous watercourses totaling over 114 kilometers. The lake complex of the territory consists of 31 lakes, the majority of which are karst in origin, covering an area of approximately 5928 hectares.

Many lakes, canals, and other bodies of water encourage the growth of wetlands, coastal waters, and aquatic plants, all of which are extremely important and, in some cases, unique, and thus must be protected. These complexes are vital to the functioning of lake ecosystems because they serve as breeding grounds for fish, waterfowl, and other species.

Managing the ecological sustainability of aquatic ecosystems by reducing the impact of negative factors on them will help to provide essential ecosystem services (Fig. 5), the most important of which is a stable water supply.

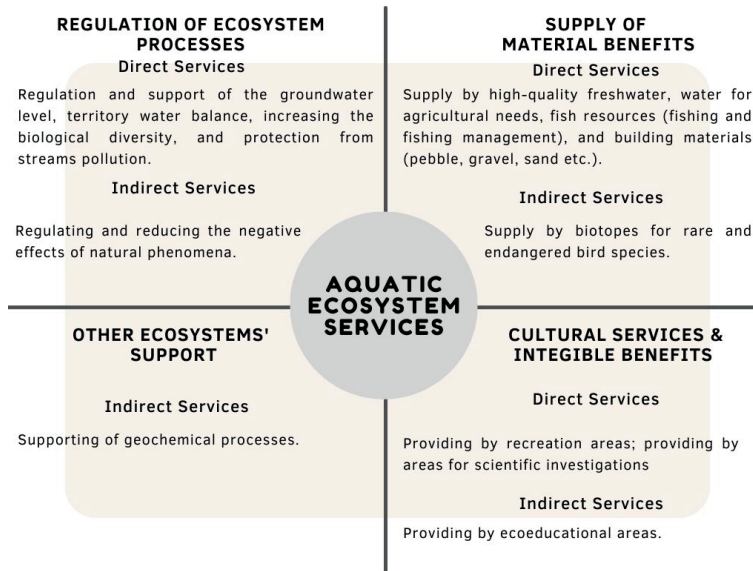


Fig. 5. Aquatic ecosystem services provided by BR.

3. METHOD DESCRIPTION AND APPLICATION

3.1. Hierarchy analysis methodology

The AHM was created by Tomas Saaty as a mathematical tool for a system approach to solving complex decision-making problems [32]. Through the basic steps depicted in Fig. 6, the AHM allows for the clear and rational structure of a complex decision-making problem.

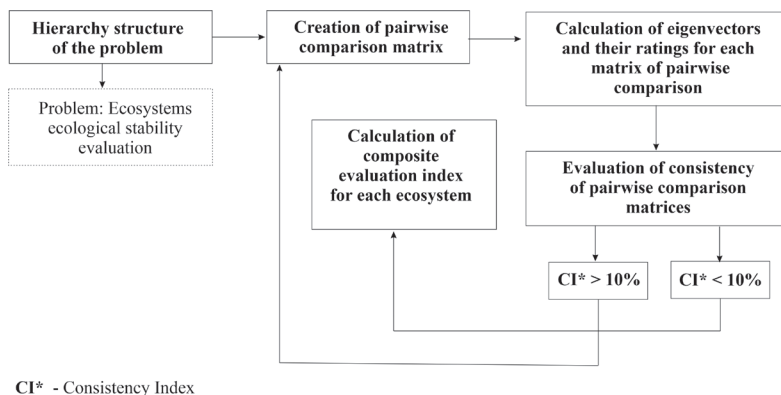


Fig. 6. Stages of AHM realization.

3.2. AHM realization

Analyzing the decision-making problem with AHM begins with creating a problem hierarchy that includes the goal, criteria, impacts, and other elements that influence the choice. A set of components exists in every system, including ecological systems (biotic and abiotic influence). As a result, when selecting parameters that affect ecosystem stability, it is critical to consider their importance in achieving the overall goal. It should be noted that the set of defined ES provided by each chosen system serves as the foundation for the formation of other elements. Each hierarchy element may represent a different aspect of a problem. The *goal* (*G*) is to evaluate ecosystems' ecological sustainability, which contains a set of *criteria* (*C*) (in our instance, elements of influence on ecosystems) that are rated over the *impacts* (*P*) on ecosystems' stability.

Depending on the essence of one or another impact (Table 2), a set of criteria (*C1–C4*) was created following our goal (*G*), allowing us to get the impacts *P1–Pn*, where *n* is the number of impacts on wetlands ecosystem (Fig. 7), forest (Fig. 8) and aquatic ecosystems (Fig. 9).

Using a pairwise comparison technique, the next stage involves determining relative weights, which have a relative relevance or favor of elements in the created hierarchy structure.

Following the creation of the goal hierarchy, the pairwise comparison matrices must be filled using the relative importance table [32].

This part of AHM technique will be demonstrated on the example of wetlands ecosystems. The outcomes for forest and aquatic ecosystems are provided below. First, the factors assessing the impact of each criterion on the ecological sustainability of wetland ecosystems determine the value of each criterion.

TABLE 2. GENERAL DESCRIPTION OF IMPACTS WITHIN EACH CRITERION

Criteria	Impact	Description
Natural impact (C1)	Climate changes	Impact of global warming, change (reduction) in precipitation, decrease in lake ice cover, formation of the lake complex's local microclimate.
	Sylvatization (reforestation)	The process of formation or restoration of natural vegetation cover (forest) in areas of meadows and wetlands.
	Natural phenomena	A set of natural phenomena (thunderstorm, storm, snowstorm, hail, tornado, and drought).
	Fires	Bottom fires (caused by the burning of forest litter, mosses and lichens, and grass cover), upper (forest fires), and subsurface fires (typical of most wetlands).
	Forest pests and diseases	Pine forest diseases and pests that cause damage and dryness.
Anthropogenic impact (C2)	Land use structure	Impact on wetlands in the form of sylvatization of agricultural lands or, conversely, plowing of the territory (destruction of wetlands).
	Melioration (drainage)	To date, the drainage system practically does not perform its functions, resulting in the re-wetting of territory (restoration of wetlands).
	Recreation activity	Recreation has a negative impact on natural complexes in the following ways: degradation of vegetation due to trampling, disease, and tree felling for construction; densification of buildings and reduction of territories under natural vegetation within recreational complexes; deterioration of the quality of surface and underground waters by domestic sewage; contamination of adjacent territories (including forest) with solid household waste.

	Infrastructure development	Infrastructure development includes: motor vehicles, road communications (growing territory fragmentation); recreational construction and the creation of artificial reservoirs.
	Poaching	Unlawful extraction of natural resources includes unauthorized fishing, unlawful hunting, collecting plants from the Red Book, and illicit sand and gravel mining.
	Unauthorized felling	Unlawful deforestation has a negative impact on reforestation and forest plantation formation processes.
Function value (C4)	Water regulation	All three ecosystems have a water-regulating function (forest ecosystems – reduce maximum moisture consumption under the forest canopy; wetlands – water absorption and flood prevention, water purification; aquatic ecosystems – affect a significant amount of evaporation and precipitation).
	Biological diversity conservation	The function of sustaining biological diversity is common to all ecosystem types (forest, water, and wetlands) and plays an essential role in supporting the stability of ecosystems and the biosphere as a whole.
	Climate development	Climate formation is a function shared by all ecosystems: forest (forming a microclimate beneath the canopy of the forest); aquatic (evaporation from the surface of bodies of water); wetlands (carbon deposition, moisture retention).
Socio-economic (C3)	Policies and regulations	The need to follow a set of rules (legislation) and policies (doing a specific kind of activity) in order to ensure the economic and social part, ethical practice, and the functioning of natural ecosystems.
	Inconsistency of population professional level with the needs of the region	Inconsistencies in the volume (large degree of unemployment) and structure of personnel professional and qualification training to the real needs of the regional labor market.
	Population environmental awareness	Environmental consciousness is manifested in a person's total knowledge and personal attitude toward the environment, readiness to take actions that allow the environment to be preserved, or readiness to refrain from actions that cause damage to the natural environment, and willingness to support or not support environmental policy.
	Economic development level	Making the appropriate political, economic, and social circumstances for structural transformation of society (combating unemployment and population migration). The attempt to look for appropriate ways to use the region's growth (cross-border scenario, tourism development) to benefit the larger population. Coordination of decision-making processes relating to the transformation of the region's economy (raising the population's educational and qualification level, fostering local entrepreneurship).
	Loss of professional skills	Population loss of professional skills owing to unemployment, which frequently leads to unlawful extraction of natural resources (poaching, uncontrolled logging).

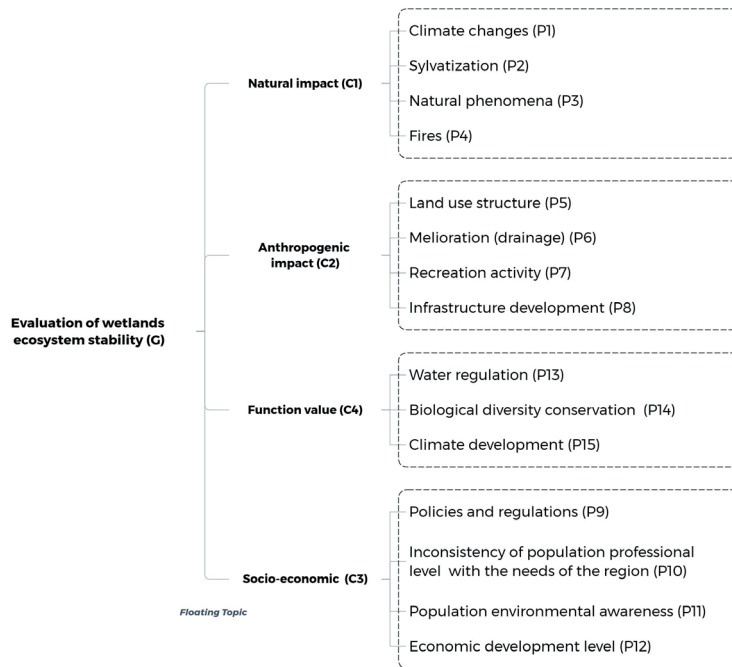


Fig. 7. Impacts on wetlands ecosystem stability of the BR.

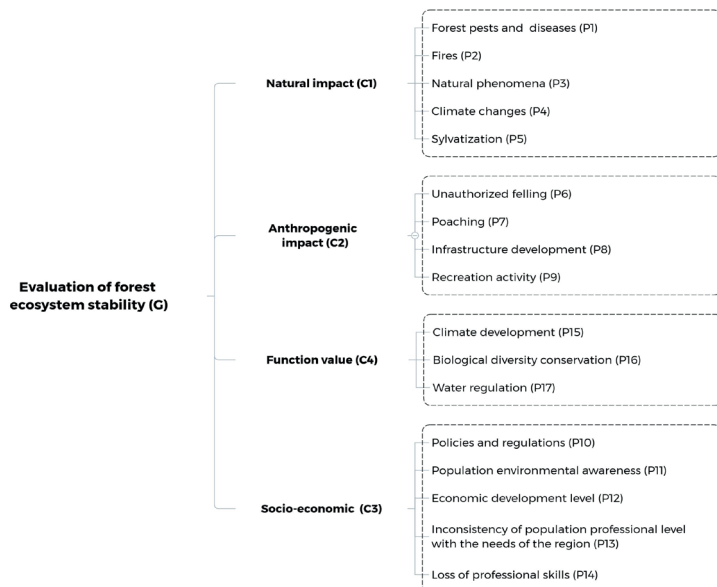


Fig. 8. Impacts on forest ecosystem stability of the BR.

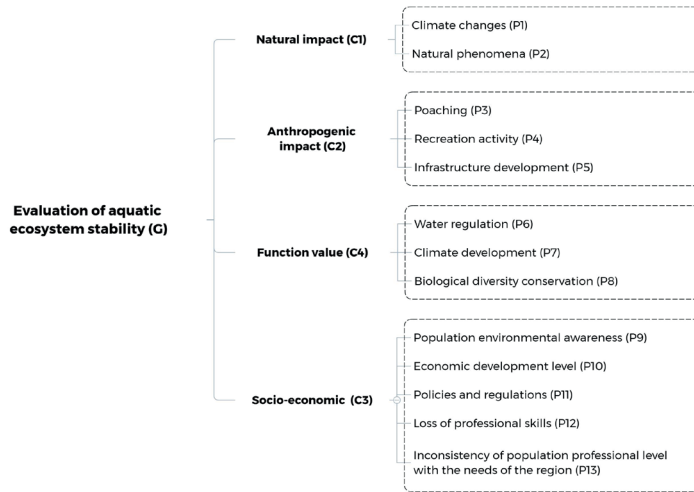


Fig. 9. Impacts on aquatic ecosystem stability of the BR.

According to a matrix ($G-C$) of pairwise comparisons of criteria that directly impact the achievement of the main goal for wetlands ecosystem, we have received the following priority of four evaluation criteria (Natural impact ($C1$), Anthropogenic impact ($C2$), Socio-economic ($C3$), and Function value ($C4$)) for the overall goal: $W_{C1} = 0.4717$, $W_{C2} = 0.1218$, $W_{C3} = 0.0911$, $W_{C4} = 0.3154$. The consistency ratio of the comparison between the four indices is less than 10 %. The maximum eigenvalue of the matrix is $\lambda_{\max} = 4.9615$, the consistency of expert judgments is equal to $CI = 0.0524$, and the relative consistency is $RC = 5.82 \% < 10 \%$.

The next step involves the definition of the most significant criterion among the ‘Natural impact’ ($C1$), ‘Anthropogenic impact’ ($C2$), ‘Socio-economic’ ($C3$), and ‘Functional value’ ($C4$) (see Table 3).

TABLE 3. SUMMARY TABLE OF NORMALIZED MATRICES

C1-P		C2-P		C3-P		C4-P	
$C1 = 0.4717$	W	$C2 = 0.1218$	W	$C3 = 0.0911$	W	$C4 = 0.3154$	W
$P1$	0.3342	$P5$	0.6173	$P9$	0.0819	$P13$	0.4665
$P2$	0.4651	$P6$	0.1328	$P10$	0.4819	$P14$	0.4330
$P3$	0.1068	$P7$	0.0705	$P11$	0.2631	$P15$	0.1005
$P4$	0.0940	$P8$	0.1794	$P12$	0.1731		
$\lambda_{\max} = 4.1210$		$\lambda_{\max} = 4.0830$		$\lambda_{\max} = 4.1653$		$\lambda_{\max} = 3.0055$	
$CI = 0.0403$		$CI = 0.0277$		$CI = 0.0548$		$CI = 0.0028$	
$RC = 4.48 \% < 10 \%$		$RC = 3.07 \% < 10 \%$		$RC = 6.09 \% < 10 \%$		$RC = 0.48 \% < 10 \%$	

Note: the consistency ratio of the comparison between the indices is less than 10 %.

Table 4 displays the penultimate stage, following the development of the goal hierarchy and the construction of pairwise comparison matrices. It includes the calculation of the global weights that show each evaluation index weight W_{cpi} (index weight per criterion P_i) for the overall goal for BR ecosystems.

TABLE 4. THE OVERALL WEIGHT OF THE EVALUATION INDEX OF BR ECOSYSTEM STABILITY

Wetland ecosystem		Forest ecosystem		Aquatic ecosystem	
The indices	The overall weight, W_{CP_i}	The indices	The overall weight, W_{CP_i}	The indices	The overall weight, W_{CP_i}
P_1	0.1576	P_1	0.2919	P_1	0.0506
P_2	0.2194	P_2	0.0465	P_2	0.0072
P_3	0.0504	P_3	0.0975	P_3	0.3052
P_4	0.0443	P_4	0.1121	P_4	0.0574
P_5	0.0752	P_5	0.0397	P_5	0.1081
P_6	0.0162	P_6	0.0788	P_6	0.0127
P_7	0.0086	P_7	0.0130	P_7	0.0618
P_8	0.0219	P_8	0.0327	P_8	0.0310
P_9	0.0075	P_9	0.0068	P_9	0.0121
P_{10}	0.0439	P_{10}	0.0028	P_{10}	0.0061
P_{11}	0.0240	P_{11}	0.0059	P_{11}	0.2572
P_{12}	0.0158	P_{12}	0.0274	P_{12}	0.0579
P_{13}	0.1471	P_{13}	0.0116	P_{13}	0.0326
P_{14}	0.1366	P_{14}	0.0099		
P_{15}	0.0317	P_{15}	0.1299		
		P_{16}	0.0244		
		P_{17}	0.0690		
$CI = 0.1256$		$CI = 0.2008$		$CI = 0.0962$	
$GCI = 0.0283$		$GCI = 0.0351$		$GCI = 0.0141$	
$GCR = 0.0071$		$GCR = 0.0088$		$GCR = 0.0035$	

To obtain the stability evaluation results a composite index method was used [33]. It enables an overall evaluation to be reflected by integrating multiple variables, indices, or indicators obtained through other methods.

Calculating a composite evaluation index (CEI):

$$CEI = \frac{1}{5} \sum_{i=1}^n W_{cpi} \times W_i, n = 1, 2, 3, \dots, 17, \quad (1)$$

where W_{cpi} – index weight per criterion P_i , W_i - weight evaluation of individual index.

Calculating a weight evaluation of individual index:

$$W_i = R_i \times V, V = (5, 4, 3, 2, 1)^T, \quad (2)$$

where R_i is membership degree of vector V for any of the indices per criterion P_i .

Table 5 demonstrates the results of the evaluation index score vector (W_{CP_i}) calculations for all BR ecosystems.

Such ranking describes the ecosystem's balance ability when its environment is interfered with by external environment changes. Very good indicates that the ecosystem is highly stable and resistant to external environmental change. Very poor demonstrates that the ecosystem is unstable and that the consequences of external ecological change are severe.

TABLE 5. CALCULATED EVALUATION INDICES SCORE VECTORS (W_i) FOR BR ECOSYSTEMS

Wetland Ecosystem		Forest Ecosystem		Water Ecosystem	
Index, P	Evaluation index score vector, W_i	Index, P	Evaluation index score vector, W_i	Index, P	Evaluation index score vector, W_i
$P1$	$W_1 = 2.6$	$P1$	$W_1 = 2.7$	$P1$	$W_1 = 3.9$
$P2$	$W_2 = 2.3$	$P2$	$W_2 = 3.0$	$P2$	$W_2 = 3.6$
$P3$	$W_3 = 3.1$	$P3$	$W_3 = 3.1$	$P3$	$W_3 = 3.3$
$P4$	$W_4 = 3.3$	$P4$	$W_4 = 3.1$	$P4$	$W_4 = 3.0$
$P5$	$W_5 = 3.1$	$P5$	$W_5 = 4.3$	$P5$	$W_5 = 3.1$
$P6$	$W_6 = 3.3$	$P6$	$W_6 = 2.2$	$P6$	$W_6 = 3.0$
$P7$	$W_7 = 4.4$	$P7$	$W_7 = 3.1$	$P7$	$W_7 = 2.6$
$P8$	$W_8 = 3.0$	$P8$	$W_8 = 3.0$	$P8$	$W_8 = 3.4$
$P9$	$W_9 = 3.8$	$P9$	$W_9 = 3.3$	$P9$	$W_9 = 3.6$
$P10$	$W_{10} = 2.5$	$P10$	$W_{10} = 2.6$	$P10$	$W_{10} = 2.7$
$P11$	$W_{11} = 3.2$	$P11$	$W_{11} = 3.2$	$P11$	$W_{11} = 4.7$
$P12$	$W_{12} = 3.7$	$P12$	$W_{12} = 2.9$	$P12$	$W_{12} = 4.7$
$P13$	$W_{13} = 4.0$	$P13$	$W_{13} = 3.0$	$P13$	$W_{13} = 4.5$
$P14$	$W_{14} = 4.2$	$P14$	$W_{14} = 2.9$		
$P15$	$W_{15} = 4.1$	$P15$	$W_{15} = 4.1$		
		$P16$	$W_{16} = 4.2$		
		$P17$	$W_{17} = 4.2$		

4. DISCUSSION AND CONCLUSIONS

4.1. Results of AHM application

By analyzing the results of pairwise comparison matrices, we can outline the main criteria for each ecosystem that directly impact the achievement of the main goal. For wetlands and forest ecosystems such criteria are Natural impact ($C1$) and Functional value ($C4$). Anthropogenic impact ($C2$) and Socio-economic ($C3$) are the main criteria that impact the achievement of sustainability of aquatic ecosystems.

Calculating the global weights (see Table 4) helps us to identify the most influential indices in each ecosystem. The impact of such indices can be either good or harmful, depending on their ability to stabilize a given system. Water regulation ($P13$) and ecological diversity protection ($P14$) are two roles of wetlands stabilization. This ecosystem is being destabilized by sylvatization ($P2$) and the effects of climate change ($P1$). Forest pests and diseases ($P1$), as well as climate change ($P4$), are the most harmful influences on the ecosystem of forests. The most substantial stabilizing impact is provided by the climatic development function ($P15$). Poaching ($P3$) has a harmful effect on aquatic ecosystems. Noncompliance with policies and regulations ($P11$) also has a negative impact on the aquatic ecology.

For defining ecological sustainability, the CEI data is analyzed using the following ranges. CEI from 0.85 to 1 describes an extremely stable system, whereas CEI from 0.7 to 0.85 describes a highly stable system. The CEI of a moderately stable system ranges from 0.55 to 0.7, whereas that of a stable system ranges from 0.4 to 0.55. $CEI < 0.4$ describes an unstable ecosystem.

The stability of BR wetlands is 0.63, indicating moderate ecosystem stability, according to the CEI value. Furthermore, the 'Functional value' (CEI $C4$) value is 0.82, which is greater than the composite value of the target layer and has little effect on wetlands destabilization. The value for CEI $C1$ 'Natural impacts,' which includes 'Climate changes' and

'Sylvatization,' is 0.52, which is significantly higher than the composite value and influences the ecological sustainability of ecosystems.

Some endemic species that can only thrive in specific wetlands are harmed by significant expansion of the sylvatization process (wetland overgrowth). Most fish and amphibians can only exist at certain periods of their life cycles in aquatic and wetland habitats. Wetland environments are vital for birds, especially migrating waterfowl. The Secretariat of the Ramsar Convention emphasizes the importance of biodiversity in wetlands. Their ability to provide services such as water filtering and purification, carbon sequestration and storage, coastal erosion prevention, construction material manufacture, and so on will distinguish them. As a result, great effort must be made to regulate sylvatization inside the Biosphere Reserve zone in order to guarantee wetlands' biological survival.

The *CEI* of the forest ecosystem is 0.64, indicating moderate stability. The composite index for 'Functional value' is 0.83, which is much greater than the target layer value and is not environmentally damaging. Both the 'Natural impacts' and 'Socio-economic impacts' *CEI* scores are 0.59, indicating that forest ecosystems are being destabilized. 'Anthropogenic impacts' have the biggest negative impact on the forest environment, with a *CEI* C2 of 0.51. To achieve the primary goal, logging and poaching must be decreased, and stronger laws for forest recreation must be implemented. Creating the conditions for improved indicators of forest ecosystem stability will enable forests to perform greater ecosystem services, particularly those connected to climate formation and water regulation.

A *CEI* of 0.75 indicates the aquatic ecosystem is highly stable. 'Natural impacts' has a *CEI* of 0.77, which is somewhat higher than the composite value of the target layer. As a result, they have little impact on aquatic ecosystem instability. With a *CEI* of 0.30, 'Anthropogenic impacts' have the largest impact on ecosystem instability in aquatic systems. Recreational activities, infrastructure development, and poaching are among them. As a result, it is necessary to pay particular attention to limiting the negative impact of recreational activities within water bodies and establishing more appropriate fishing rules within the Shatskyi Biosphere Reserve lakes in order to ensure the higher ecological viability of aquatic ecosystems. Creating more suitable conditions would aid in the provision of ES by the aquatic ecosystem, notably in terms of climate formation and safe drinking water for the local population.

4.2. Conclusions

Despite inconsistencies in the definition and evaluation of ecosystem services, the civilized world considers the current degradation of natural ecosystems and the loss of their services to be one of the most serious threats to human survival. As a result, efforts are being made to develop a framework for evaluating the environmental sustainability of natural ecosystems to quantify the ecosystem services that they may provide.

Because of the combination of multiple ecosystems (wetlands, forest and aquatic) within the same region, the Biosphere's natural habitat is unique. These ecosystems' ecological sustainability was assessed using the analytical hierarchy method. This method highlights those elements that sustain or destabilize a certain ecosystem by producing matrices of pairwise comparisons of a number of factors that affect ecosystems. According to the study's results, the aquatic ecosystem is currently the most stable, as measured by the *CEI* indicator. Of course, this is a benefit to the BR, since this ecosystem has been a leader in delivering ecosystem services (recreation, sport fishing, and water supply to the local population) in this region for the final beneficiary for about twenty years. According to the *CEI* indicator, wetlands and forest ecosystems are moderately stable. However, their supply of ecosystem services, which are crucial for both end users and ecosystems, is equally important.

The complexity of natural ecosystems, because of the many factors and impacts, justifies the use of AHM since it can provide a relatively simple technique for evaluating the stability of such systems while accounting for the greatest number of parameters. Other approaches for analyzing such complex systems are time and energy expensive, and can only be used in the case of an extremely detailed study of one specific ecosystem or its components.

In the future, the study will try to use the approach of AHM to analyze the territory (region) in terms of additional problems. Today, the primary directions for the Bioserve management are the assessment of the region's recreational potential and the analysis of the possibility of rational land and forest management using a wider range of criteria (influences).

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