IMPROVEMENT OF ECONOMIC MECHANISM OF RATIONAL USE OF FOREST RESOURCES USING DISCRETE MATHEMATICS METHOD

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Abstract. This article proposes a balanced approach to the management of forest resources in Ukraine, based on a mathematical model developed using discrete mathematics. The algorithm of our study involved the following stages: 1) delineation of the spectrum of factors that characterize the ecological, economic, social processes of using forestry lands; 2) development of an economic system for the use of forest resources, with the simultaneous scientifically based establishment of interrelationships between the elements of the system; 3) calculation of the matrix of coefficients of pair correlations, which substantiate the relationships between the elements of the economic mechanism of the rational use of forest resources; 4) optimization of the economic graph of the use of forest resources, by distinguishing the key and secondary elements of the system; 5) economic and mathematical modeling of the rational use of forest resources. In order to apply the obtained calculations at the applied level in rational use of forest resources, we proposed appropriate strategic directions for the use of forest resources depending on the degree of impact on the environment. On the basis of the proposed management approaches of rational use of forest resources, we have developed mathematical models that allow to analyse the effectiveness of applying one or another strategy. The adequacy of the developed regression equations is confirmed by the coefficient of determination, Fisher (F) and Durbin-Watson (DW) tests. The developed mathematical models allow tracking the change of modeling indicators depending on the factor criteria and establishing their regularity. The article analyzes the use of forestry land in Ukraine based on two management approaches: an ecocentric approach and a balanced approach. The results show that the ecocentric approach can minimize the ecological situation in the short term but may negatively affect the development of the economy of nature use in Ukraine. The balanced approach, on the other hand, is the most adaptive for sustainable development. To ensure the balanced use of forest resources, the article outlines several conditions, including the regulation of market mechanisms, reduction of the anthropogenic impact, improvement of the ecological situation, and development of state programs. Fulfilling these conditions is mandatory to ensure the maximization of economic benefits from the use of forestry land with the formation of a favourable environment and the promotion of solutions to social problems of the population. The proposed approach can have positive consequences in regions where the level of forest production is low and the use of forest resources is unprofitable.

Keywords: economic mechanism; rational use; forest resources; discrete mathematics; graphs.

Introduction

Forests play a critical role in sustaining the ecological health, social well-being, and economic prosperity of communities around the world. However, managing forests for multiple uses, including timber production, conservation, and recreation, is a complex and challenging task that requires effective economic mechanisms for resource allocation [1-4].

The current economic mechanisms for managing forest resources often fail to account for the complexities of forest ecosystems and the diverse interests of stakeholders. As a result, inefficient use of forest resources can lead to environmental degradation, social conflicts, and economic inefficiencies.

To address this problem, this article proposes the use of discrete mathematics as a method to improve the economic mechanism of rational use of forest resources. Discrete mathematics involves using mathematical models and algorithms to analyse and optimize resource allocation, taking into account multiple criteria and constraints.

The issue of ecological and economic use of natural resources was highlighted in the publications by such economists as Hanif S., Lateef M., Hussain K., Hyder S., Usman B., Zaman K. [5], Batool R., Sharif A., Islam T., Zaman K., Shoukry A. M., Sharkawy M. A. [6], Aeknarajindawat N., Suteerachai B., Suksod P. [7] and others [8].

Modern theoretical and methodological provisions regarding the rational use and protection of land resources were formed in the scientific works of Afshan S., Yaqoob T. [9], Ahmad F., Draz M. U., Chang W. Y., Yang S. C., Su, L. [10], Danish, Baloch, M. A., Mahmood, N., Zhang, J. W. [11] and others [15].

The application of discrete mathematics to forest resource management can help ensure that forest resources are used in a way that maximizes economic benefits while minimizing negative environmental and social impacts. By providing a more accurate and comprehensive understanding of the trade-offs between different forest uses, this approach can help promote sustainable forest management practices and enhance the well-being of forest-dependent communities.

Overall, this research has the potential to solve the problem of inefficient and unsustainable use of forest resources by offering a more effective and comprehensive economic mechanism for forest resource management.

Materials and methods

The problem of managing forest resources for multiple uses is complex and challenging. Forests provide valuable ecosystem services such as carbon sequestration, biodiversity conservation, and watershed protection, as well as raw materials for various industries. Moreover, forests are also important sources of income and livelihood for forest-dependent communities. However, balancing the competing demands for forest resources requires effective economic mechanisms for resource allocation.

The current economic mechanisms for forest resource management are often insufficient for several reasons. First, the traditional approach to forest management is based on a sectoral and siloed approach that does not take into account the complex interactions and interdependencies among different forest uses. Second, these mechanisms often prioritize short-term economic gains over long-term sustainability, resulting in the overexploitation of forest resources and environmental degradation. Third, the current mechanisms often fail to consider the diverse interests and values of stakeholders, leading to social conflicts and unsustainable resource use.

To address these limitations, this article proposes the use of discrete mathematics as a method to improve the economic mechanism of rational use of forest resources. Discrete mathematics involves using mathematical models and algorithms to analyze and optimize resource allocation, taking into account multiple criteria and constraints.

The application of discrete mathematics to forest resource management can help ensure that forest resources are used in a way that maximizes economic benefits while minimizing negative environmental and social impacts. By providing a more accurate and comprehensive understanding of the trade-offs between different forest uses, this approach can help promote sustainable forest management practices and enhance the well-being of forest-dependent communities.

The use of discrete mathematics can also help address some of the challenges associated with traditional forest management approaches. For example, it can provide a more integrated and systemic approach to forest management, taking into account the complex interactions among different forest uses. It can also help promote a long-term perspective on forest management by optimizing resource use over time.

Overall, the proposed solution of using discrete mathematics as a method to improve the economic mechanism of rational use of forest resources has the potential to promote sustainable forest management practices and enhance the well-being of forest-dependent communities.

We proposed to improve the economic mechanism of rational use of natural resources, including forestry land, on the basis of the section of discrete mathematics – the theory of "graphs" that studies the properties of graphs, which in turn allow us to present the relationships between various objects in the field of nature management (outlined as a result of the research, analytical calculations), in particular, connections between forestry production, cash flows, fiscal payments, sources of financing, average wages of workers in the field of forestry, etc.

Therefore, it is most expedient to describe the specified relationships between objects in the field of forest use in the form of a corresponding "graph" (network) – a set of vertices (objects) connected to each other by "edges" (lines). In the mathematical sense, "graph" can be represented in the form of formula (1) [12; 13].

$$G = (V, E) \tag{1}$$

where V – set of points called vertices;
E – set of edges.

According to the theoretical and methodological foundations of the theory of "graphs", economic and mathematical modelling of rational use of forestry land, it is necessary to foresee a set of defined vertices that are interconnected in a certain way.

Thus, as a result of the study, it is expected to develop a "graph", which is an economic mechanism for rational use of forestry land, which is formed from vertices or elements (financial and economic mechanism, social phenomena, etc.) and a complex of analytical ties (edges) that characterize dependence between the graph elements and can have a (+) or (–) sign [14].

The algorithm of our research involves the following stages:

1. Delineation of the spectrum of factors that characterize the ecological, economic, social processes of the use of forestry lands;
2. The development of an economic system for the use of forestry land in Ukraine, with the simultaneous scientifically based establishment of interrelationships between the elements of the system;
3. Optimization of the economic graph of forestry land use, by distinguishing the key and secondary elements of the system.

Results and discussion

Based on the first point of the proposed research algorithm, we determined the future peaks of the economic mechanism (graph) of the use of forestry land in Ukraine (Table 1).

In order to facilitate the development of graphs in the development of the economic mechanism of the use of forestry land, we proposed the corresponding abbreviations of the names of structural elements (vertices) that affect the use of forest resources (Table 1).

Table 1

Vertices of the economic mechanism (graph) of forest land use in Ukraine

No	Name of the vertices	Brief description of the impact on the use of forest resources	Legend
1	Area of the territory	Determines the composition and volume of forest resources in geospatial terms	AT
2	Environmental situation in the region	Describes the ecological consequences of deforestation	ESR
3	Area of forestry land	Characterizes the potential of forest use	AFL
4	Number of forestry enterprises included in the structure of the State Forestry Agency of Ukraine	Characterizes the potential of forestry	NFE
5	Structure of forestry lands of Ukraine	Characterizes the possibilities of forest use	SFL
6	Value of forest resources	Determines the cost of forest resources	VFR
7	Volume of forestry products	Characterizes the intensity of use of forestry land	VFP
8	Current costs of atmospheric air protection and climate change problems	Identifies some needs in forest resources	CCP
9	Amount of mineral fertilizers applied per unit area of agricultural land	Allows to assess the degree of afforestation effect of forests on the microclimatic conditions of growing agricultural crops	AMF
10	Yield of agricultural crops		YAC
11	Aggregate demand for forest resources of Ukraine	Determines the real demand for forest resources of Ukraine	ADFR
12	Normative and legislative provision of forestry management	Characterizes the structural rules and norms of forest use in Ukraine	NLPFM

Table 1 (continued)

No	Name of the vertices	Brief description of the impact on the use of forest resources	Legend
13	Population structure in Ukraine (rural) in conditions of decentralization of power	Characterizes the level of forest security of the population in Ukraine	PS
14	Volume of forestry machinery	Characterizes the technical capabilities of forestry	VFM
15	Capital expenditure on forestry	-	CE
16	Average salary of employees in the forestry sector of the economy	Characterizes material costs for labor in forestry	AS
17	Area of basic forest management	Characterizes costs of forest management	ABFM
18	Protection of the forest from fire	Determines material costs for forest fire protection measures	PFF
19	Combating forest pests and diseases	Characterized by financial costs for measures to combat forest pests and diseases	CFPD
20	Soil and typological examination	Characterizes costs of justified and typological examinations	STE
21	Design and research works	Characterizes costs of design and research work	DRW
22	Monitoring of forestry lands	Characterizes costs of forest monitoring	MFL
23	Harvested commercial wood	Determines the volume of commercial wood from forest use	HCW
24	Realized wood	Total volume of wood is sold by forestry enterprises	RW
25	Conducting forest certification	Determines costs of forest certification	CFC
26	Sale price of agricultural products	Determines the mathematical relationship between the amount of loss of tree cover and the sale prices of agricultural products	SPAP
27	Volume of household forest use	Characterizes the demand for forest resources from the population	VHFU
28	Area of afforestation impact on agricultural land	Determines the degree of ecological impact of forests on adjacent agricultural lands	AAIAL
29	Forest reproduction area	Characterizes the level of use of forest resources in the context of sustainable development	FRA
30	Logging formation and improvement of forests	Characterizes the level of economic development of forestry land	LFIF
31	Total area of felling	Determines the level of use of forestry land	TAF
32	Volume of harvesting of liquid wood	Determines the volume of liquid wood from forest use	VHLW
33	Inventory and assessment of forestry lands	Characterizes costs of forest inventory and assessment	IAFL
34	Payment norms for special use of forest resources (except wood from felling for main use)	Rent payments from special use of forest resources	PNSU
35	Payment norms for special use of forest resources (wood from felling for main use)	-	PNSU/ MU
36	Financial assistance from international partners (organizations) for implementation of sustainable development goals	Economic incentives for the balanced development of the forest sector	FAF
37	Capital investments in forestry and logging	It characterizes the directions of development of the forest industry of Ukraine	CIFL
38	Aggregate supply of forest resources in Ukraine	It characterizes the economic potential of using forest resources	ASFR

On the basis of the proposed vertices, a graph of the economic mechanism of the use of forestry land in Ukraine was developed, presented in Fig. 1. It is worth emphasizing that in the structure of the economic mechanism of forest use in Ukraine, we have highlighted relevant subsystems (blocks), such as market mechanisms, forestry, forest production process, a complex of restrictions and parameters of forest use, market regulatory mechanisms, which in our opinion fully characterize supply and demand as the main elements of market relations for forest resources in Ukraine.

For further mathematical modelling of the rational use and protection of forestry lands in Ukraine, it is necessary to present the graph of the economic mechanism developed by us in the form of an adjacency matrix (Fig.1, Table 2). According to the theoretical principles, the adjacency matrix of the graph *G* of the economic mechanism of the rational use of forestry land, with a finite number of vertices *n* (numbered by numbers from 1 to *n*) is a square matrix *A* of size *n*, in which the value of the element a_{ij} is equal to the number of edges from the *i* vertex of the graph in *j* vertex [15].

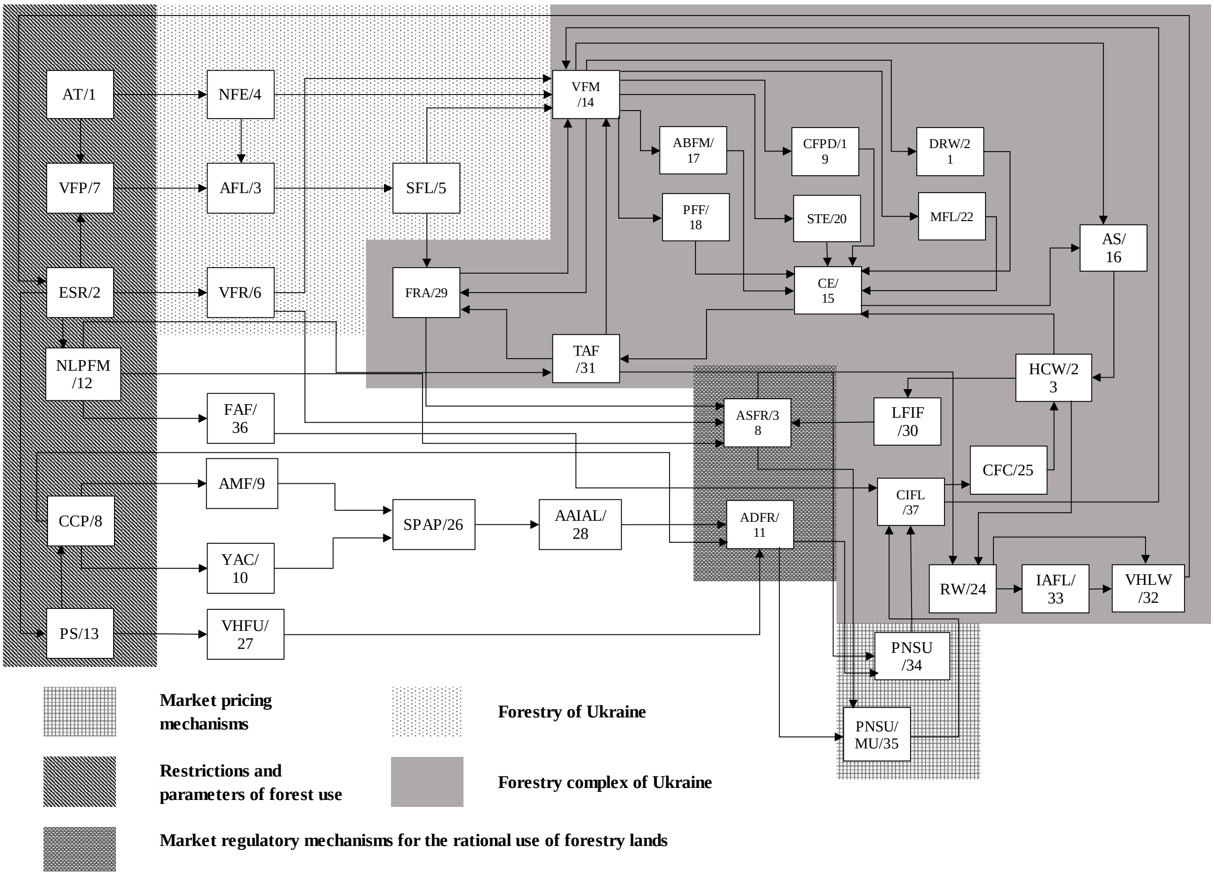

Fig. 1. **Economic mechanism (graph) of the use of forestry lands of Ukraine**

We developed a matrix of adjacency of the vertices of the economic mechanism (graph) of the use of forestry land in Ukraine, the elements of which are indicated in the form of values 1, 0, -1 using the rule: an element of the adjacency matrix of oriented graph is defined as follows: it is equal to 1” or -1 depending on the nature of the influence, if the vertex V_i is the beginning of the “edge” E_i; is equal to 0, if the “edge” does not go from the vertex V_i to the vertex V_j, i.e. it is not incident [14; 15].

The scientific-methodological approach proposed by us makes it possible to create a complete scientifically-based system that combines the existing organizational, social, economic, ecological elements of the use of forestry land in Ukraine. Based on the developed matrix, there is an opportunity to develop an applied mathematical model for the purpose of forecasting and determining the optimal scenario of rational use and protection of forestry lands in Ukraine.

At the same time, before mathematical modelling of the rational use and protection of forestry land in Ukraine, we consider it necessary to optimize the structure of the proposed graph (economic model of forest use) by highlighting key relationships and structural objects. As a result of performing such actions, we obtained an optimized ("drawn") graph of the economic model of the use of forestry land in Ukraine.

On the basis of the calculated matrix of pairwise correlation coefficients, which substantiate the relationships between the elements of the economic mechanism of the rational use of forestry land in Ukraine, we modified and improved the previously optimized graph, which enables us in further research to propose applied mathematical models in order to implement effective solutions and positive development of the national forest management system in conditions of decentralization of power.

In order to apply the obtained calculations at the applied level in the process of rational use of forestry land in Ukraine, appropriate strategic directions for the use of forest resources are proposed depending on the degree of impact on the environment: Strategy I. Eco-centric approach; Strategy II. A balanced approach; Strategy III. Technocentric approach.

Mathematical models have been developed on the basis of the proposed management approaches for rational use of forestry land, which allow for the analysis of the effectiveness of the application of one or another strategy (Table 2).

Table 2

Mathematical models of forest land use in Ukraine

Management approach	Mathematical model	Durbin-Watson (DW) test	Coefficient of determination (R^2)	Fisher's F-test
Strategy I. Ecocentric approach – modeling indicator Y – ecological situation in the region	$F = 7931.7978 - 0.6692 \times AFL + 0.0008 \times CCP + 0.3627 \times SPAP - 20.2765 \times CE + 0.0002 \times VFR + 0.1423 \times P - 0.0335 \times AS - 0.3214 \times ASFR + 0.1293 \times VHLW \rightarrow \min$	2.295	0.989	29.33
Strategy II. A balanced approach – modeling indicator Y – aggregate demand for forest resources of Ukraine	$F = -8751.1467 + 0.0992 \times PS + 0.000014 \times VFR + 0.0006 \times ASFR + 0.0943 \times P + 11.8532 \times K + 0.0101 \times AS - 0.00003 \times CCP - 0.0228 \times SPAP + 0.6543 \times AFL + 0.1246 \times ESR$ $\begin{cases} CIFL \rightarrow \max; \\ -2840.8073 - 0.0008 \times VFR + 0.0008 \times CCP + 0.3496 \times PS \rightarrow \min; \\ ADFR \sim ASFR; \end{cases}$ $\begin{cases} -86317.9478 + 1.4912 \times VFR + 8.2889 \times AFL + 0.0021 \times VFR + 2.2052 \times P \rightarrow \max. \end{cases}$	2.663	0.906	3.83
Strategy III. Technocentric approach – modeling indicator – total supply of forest resources in Ukraine	$F = 3027817.3925 + 0.0005 \times VFR + 9.1112 \times ADFR + 0.6862 \times AS + 3.9648 \times P - 253.6946 \times CE - 46.3908 \times AT - 1.0945 \times ESR - 93.1691 \times AFL + 0.0009 \times CCP - 3.6843 \times PS + 0.4643 \times HCW \rightarrow \max$	2.814	0.999	976.49

As a result of the analysis of the use of forestry land in Ukraine based on an ecocentric approach (strategy I), the following results were obtained: with an annual increase of 10% of the key indicators of the proposed model (in particular, the area of land for forestry, current costs for atmospheric air protection and solutions problems of climate change, rent for the special use of forest resources), the ecological situation in the region will be minimized (favourable) in the short term (within four years). At the same time, the volume of liquid wood harvesting, the total supply of forest resources, the value of forest resources in Ukraine must remain unchanged, which will negatively affect the development of the economy of nature use in Ukraine, and the amount of income to the budgets of territorial communities from rent for special use of forest resources will also decrease. The application of this approach can have positive consequences in regions where the level of forest production is low, in particular, the use of forest resources is unprofitable (Donetska, Zaporizka, Luhanska, Mykolaivska, Odeska, Kharkivska, Khersonska, Dnipropetrovska, Lvivska, Volynska oblast).

The most adaptive, from the point of view of sustainable development, is the 2nd strategic approach. In the process of developing a mathematical model for this management approach, linear and power multiple regressions were calculated.

To ensure balanced use of forest resources based on the proposed mathematical model, it is mandatory to fulfil the conditions outlined in the form of a system of equations (presented above in Table 2), which ensure maximization of economic benefits from the use of forestry land with the formation of a favourable environment and the promotion of solutions to social problems of the population.

The balanced approach proposed in the process of scientific research assumes the fulfilment of the following conditions:

- Regulation of market mechanisms in the process of using forestry lands:

1. Ensuring an increase in the amount of income from the payment of rent payments for special use of forest resources in the amount of 86% to the local budgets of territorial communities by improving the financial and economic mechanism of the use of forestry land, creating a system for monitoring the quality and volume of forest land use with the use of geo-information and blockchain technologies;
2. Improving the pricing mechanism of forest resources and increasing the value of forest products by 58%;
3. Changeling part of forestry profits to finance measures to combat cancer in the population of Ukraine.

- Reduction of anthropogenic impact (of the rural population) on forest resources by regulating (reducing) tariffs for gas supply for the population (the level of anthropogenic load should decrease by 2% in the forecast period);
- An increase in the amount of financing of current costs for the protection of atmospheric air and solving climate change problems to 0.1% in the forecast period due to the attraction of capital investments in forestry and logging;
- Improvement of the ecological situation in the region (by 0.4% every year) due to the improvement of forest conservation technologies, minimization of losses of forest resources due to forest fires;
- Development of state programs to increase the area of forestry land on lands unsuitable for agricultural production;
- Improvement of the regulatory framework regarding the introduction of the institute of public control over compliance with ecological requirements of forest use;
- Ensuring a balance between the total volume of the demand for forest resources and the total supply;
- Increasing the labour productivity of workers in the field of forestry, which will make it possible to reduce the wage costs by 0.05%.

Conclusions

1. The ecocentric approach to the use of forestry land in Ukraine (strategy I) can minimize the ecological situation in the short term but may negatively affect the development of the economy of nature use in Ukraine.
2. The 2nd strategic approach is the most adaptive for sustainable development, and a mathematical model was developed for this management approach using linear and power multiple regressions. The balanced approach to the management of forest resources in Ukraine involves the regulation of market mechanisms, reduction of the anthropogenic impact, improvement of the ecological situation, and development of state programs. Fulfilling the conditions outlined in the system of equations is mandatory to ensure balanced use of forest resources based on the proposed mathematical model.
3. Regulation of market mechanisms should ensure an increase in the amount of income from the payment of rent payments for special use of forest resources in the amount of 86% to the local budgets of territorial communities, improve the pricing mechanism of forest resources, and channel part of forestry profits to finance measures to combat cancer in the population of Ukraine.
4. Tariffs for gas supply for the population should be regulated to reduce the anthropogenic impact on forest resources, and the amount of financing of current costs for the protection of atmospheric air and solving climate change problems should be increased.
5. The ecological situation in the region can be improved by improving the forest conservation technologies, minimizing losses of forest resources due to forest fires, and increasing the area of forestry land on lands unsuitable for agricultural production.
6. The regulatory framework should be improved regarding the introduction of the institute of public control over compliance with ecological requirements of forest use, and a balance should be ensured between the total volume of the demand for forest resources and the total supply.

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Author contributions

Conceptualization, Ivan Openko; methodology, Ivan Openko and Ruslan Tykhenko; software, Oleksandr Shevchenko; validation, Anatoliy Rokochinskiy and Pavlo Volk; formal analysis, Oleksandr Shevchenko, Oleksandr Chumachenko, Yevheniia Kryvoviaz; investigation, Ivan Openko and Yanina Stepchuk; data curation, Ivan Openko, Yanina Stepchuk and Oleg Tsvyakh; writing original draft preparation, Ivan Openko and Yanina Stepchuk; writing – review and editing, Ivan Openko and Ruslan Tykhenko; visualization, Yanina Stepchuk, Ivan Zhyla, Oleksandr Chumachenko, Yevheniia Kryvoviaz; project administration, Ivan Openko; funding acquisition, Oleg Tsvyakh, Anatoliy Rokochinskiy and Pavlo Volk, Ivan Zhyla, Oleksandr Chumachenko, Yevheniia Kryvoviaz. All authors have read and agreed to the published version of the manuscript.

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