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RESEARCH ARTICLE

Protecting Our Planet: The Vital Role of Carbon Sequestration in Combating Threats to Environmental Sustainability

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ABSTRACT

This research study aimed to examine the impacts of eutrophication, human footprints, and economic growth on environmental sustainability through the underlying mechanism of biodiversity loss and the moderating role of carbon sequestration in the relationship between loss of biodiversity and environmental sustainability. A total of 553 farmers from different regions of Indonesia participated in the study, and the data collected was analyzed using SmartPLS software. The findings revealed a significant negative impact of eutrophication and human footprints on environmental sustainability through biodiversity loss. The moderating role of carbon sequestration was found to be significant in the relationship between biodiversity and environmental sustainability. These findings provide valuable insights into the complex relationship between biodiversity and environmental sustainability and highlight the importance of considering the role of carbon sequestration in promoting sustainable development and environmental conservation.

INTRODUCTION

Environmental sustainability has become a pressing issue in the modern era, as human activities have caused extensive damage to the natural environment (Saputra and Dhianty, 2022). Biodiversity is essential for maintaining ecosystem stability and functioning, providing ecosystem services that support human well-being, such as air and water purification, pollination, and nutrient cycling (Moranta et al., 2022). However, biodiversity loss significantly impacts environmental sustainability, leading to decreased resilience and increased vulnerability to environmental stressors (Gong et al., 2022). At the same time, the loss of biodiversity has severe consequences for ecosystem functioning, as it reduces the ability of ecosystems to provide essential services, such as carbon sequestration, nutrient cycling, and water purification. One of the major factors contributing to the loss of biodiversity is eutrophication. This process occurs when excess nutrients (usually from agricultural or industrial sources) enter water bodies, leading to the death of aquatic animals and, ultimately, a loss of biodiversity (Kumar et al., 2023).

Besides, the human footprint on the environment has resulted in the depletion of natural resources, increased pollution, and an alarming loss of biodiversity (Hua et al., 2022). Human footprints, such as land use changes, industrialization, and urbanization, have also contributed to biodiversity loss (Mu et al., 2022). Additionally, the demand for natural resources and economic growth has led to deforestation, pollution, and the degradation of natural habitats, leading to a decline in species richness and diversity (Ahmed et al., 2022). The research states the need for empirical evidence that examines the complex relationships between eutrophication, human footprints, and economic growth on environmental sustainability and how these factors contribute to biodiversity loss. This could involve examining the environmental stressors contributing to biodiversity loss and investigating the mechanisms underlying the relationship between biodiversity and environmental sustainability (Habibullah et al., 2022; Morand, 2020).

Additionally, the study aims to investigate the moderating role of carbon sequestration in the relationship between biodiversity and environmental sustainability. There needs to be more research that comprehensively explores these relationships, and empirical evidence is needed to inform policymakers and stakeholders on effective strategies for promoting environmental sustainability (Green and Keenan, 2022). Therefore, there is a need for further research that investigates the relationships between these factors and identifies potential solutions to mitigate the negative impacts of human activities on biodiversity and the environment. On the other hand, "carbon sequestration, the process of removing carbon dioxide from the atmosphere and storing it in carbon sinks such as forests and oceans, has been proposed as a potential mechanism to mitigate the negative impacts of environmental stressors on biodiversity and environmental sustainability" (Wei et al., 2022, p. 338). Carbon sequestration reduces the amount of carbon dioxide in the atmosphere, contributing to climate change and providing multiple co-benefits, such as supporting biodiversity conservation and ecosystem restoration (Janzen et al., 2022).

Therefore, the current research aims to explore the complex relationship between environmental stressors, biodiversity loss, carbon sequestration, and environmental sustainability in a developing nation context. Indonesia is one of the most biodiverse countries in the world, with high levels of species endemism and rich ecosystems such as tropical forests, coral reefs, and mangroves (Rahmawasiah et al., 2022). However, Indonesia also faces significant environmental challenges, including deforestation, marine pollution, land degradation, and climate change (Basuki et al., 2022). Additionally, industries like agriculture, mining, and manufacturing, which have significant environmental impacts, have driven the Indonesian economy's rapid growth in recent years (Triyono et al., 2022). At the same time, Indonesia is committed to achieving the Sustainable Development Goals (SDGs) and has set targets for reducing greenhouse gas emissions, conserving biodiversity, and improving environmental sustainability (Elia et al., 2020). Therefore, a contextual gap for the study could be related to the need to understand the impacts of eutrophication, human footprints, and economic growth on environmental sustainability in the Indonesian context and how these impacts are related to biodiversity loss and the role of carbon sequestration. Additionally, the study could explore the policy implications and opportunities for addressing these challenges in Indonesia, such as by implementing ecosystem-based approaches, green technologies, and sustainable land use practices.

Furthermore, the current study is grounded in the ecosystem services concept. The ecosystem services theory posits that ecosystems provide many benefits to humans. The loss of biodiversity and ecosystem functioning can result in the degradation of these ecosystem services, negatively impacting human well-being and sustainability (Huynh et al., 2022). Based on these theoretical foundations, the current study aims;

- To investigate the relationship between eutrophication, human footprints, economic growth, loss of biodiversity, and environmental sustainability.
- To examine the moderating role of carbon sequestration in the relationship between biodiversity and environmental sustainability.
- To identify the underlying mechanisms through which loss of biodiversity impacts environmental sustainability. • To assess the relative contributions of eutrophication, human footprints, economic growth, and biodiversity loss to environmental sustainability degradation.
- To explore policy implications for promoting

environmental sustainability through biodiversity conservation and carbon sequestration.
- To recommend future research directions for improving environmental sustainability in the face of global challenges such as climate change, pollution, and loss of biodiversity.

LITERATURE REVIEW AND THEORETICAL FOUNDATION

Ecosystem services theory

The concept of ecosystem services provides a theoretical foundation for understanding the impacts of eutrophication, human footprints, and economic growth on environmental sustainability and the underlying mechanisms of biodiversity loss. This concept recognizes that ecosystems provide a range of goods and services essential for human well-being, including provisioning, regulating, cultural, and supporting services (**?** , 2019). The loss of biodiversity is a critical issue for the sustainability of ecosystem services, as it can negatively impact all four categories of services (Gong et al., 2022). Eutrophication and human footprints, such as deforestation and pollution, are two key drivers of biodiversity loss (Meerhoff et al., 2022). While often seen as a positive force for development, economic growth can also negatively impact biodiversity and ecosystem services (Jamil, 2022).

Additionally, the moderating role of carbon sequestration in the relationship between biodiversity and environmental sustainability is an area of research that requires further investigation. Hence, the ecosystem services theory provides the theoretical foundation for understanding the impacts of eutrophication, human footprints, and economic growth on environmental sustainability through biodiversity loss (Brück et al., 2022). The role of carbon sequestration in moderating the relationship between biodiversity and environmental sustainability is an important area of research that can inform policy and management decisions aimed at preserving ecosystem services for future generations.

Eutrophication, human footprints, and economic growth on environmental sustainability

"Eutrophication is a process that occurs when excessive nutrients such as nitrogen and phosphorus enter a water body, leading to an overgrowth of algae and other aquatic plants" (Zhou et al., 2022, p. 216). This phenomenon significantly impacts environmental sustainability, affecting both the ecosystem and human health. One of the primary effects of eutrophication is the depletion of oxygen levels in the water body, leading to the death of fish and other aquatic organisms (Kumar et al., 2023). The overgrowth of algae blocks sunlight, preventing the growth of submerged aquatic plants, which are crucial to providing oxygen to the water (Bell et al., 2014). This ultimately results in the collapse of the aquatic ecosystem, causing a reduction in biodiversity and the loss of important ecosystem services. In addition, algal blooms can make water bodies unpleasant and unsafe for recreational activities, such as swimming and boating, leading to decreased tourism revenue (Meerhoff et al., 2022). Moreover, releasing greenhouse gases, particularly carbon dioxide and methane, is a byproduct of eutrophication, leading to further environmental problems. Overall, eutrophication poses a significant threat to environmental sustainability, affecting both the ecosystem and human health.

Human footprints, or the impact of human activities on the environment, are a significant concern regarding environmental sustainability. The negative impact of human activities on the environment has been well documented, and it is important to understand how these footprints affect environmental sustainability (Smigaj et al., 2023). One of the most significant impacts of human footprints on environmental sustainability is the depletion of natural resources. Human activities such as mining, deforestation, and overfishing have depleted many natural resources (Qu et al., 2022; Saravanan et al., 2022). When resources are depleted, it becomes more difficult for ecosystems to function correctly, which can lead to a decline in biodiversity and ecosystem services (Mu et al., 2022). Furthermore, economic growth and environmental sustainability are two important factors that are often seen as being in opposition to each other. Economic growth involves increased production and consumption of goods and services, which can lead to greater prosperity and higher living standards (Wang et al. 2022). However, this growth can also negatively impact the environment through pollution, deforestation, and the depletion of natural resources (Mujtaba et al., 2022). Thus, based on the ecosystem service theory and literature supporting it with logical arguments, it is hypothesized that:

H1: There is a negative impact of a) eutrophication, b) human footprints, and c) economic growth on environmental sustainability.

Eutrophication, human footprints, economic growth, and loss of biodiversity

When nutrient levels in the water are high, algae and other aquatic plants can grow uncontrollably. As they die, they sink to the bottom of the body of water and decompose, using up oxygen in the process (Meerhoff et al., 2022). As a result, many species of fish, crustaceans, and other aquatic animals may die off, reducing biodiversity in the area. Eutrophication can also change the composition of aquatic plant and animal communities. For example, some species of algae may thrive under conditions of high nutrient levels, while others may be unable to compete (Kumar et al., 2023). This can result in a shift in the types of plants, and animals in the ecosystem, potentially leading to a decrease in overall biodiversity. Another way in which eutrophication can lead to the loss of biodiversity is through the creation of "dead zones" in bodies of water (Zhou et al., 2022). Hence, it is important to manage nutrient inputs to bodies of water to minimize the risk of eutrophication and protect aquatic biodiversity.

Human footprints have had a significant impact on the loss of biodiversity. The human population has grown exponentially, and as a result, there has been an increase in the demand for food, shelter, and resources (Kapferer and Valette-Florence, 2019). Human activities such as deforestation, urbanization, industrialization, and pollution have resulted in habitat destruction and fragmentation, leading to biodiversity loss. Deforestation is one of the significant contributors to biodiversity loss (Reydon et al., 2020). Forests are the habitats for various animal and plant species, and deforestation destroys these habitats. Wildlife is forced to migrate when forests are cleared for agriculture or urbanization, leading to biodiversity loss. Simultaneously, economic growth and development have undoubtedly brought numerous benefits to human society, such as increased wealth, improved living standards, and access to better healthcare and education (Permatasari et al., 2022). However, this growth has also led to significant negative impacts on the natural world, particularly on biodiversity (Ahmed et al., 2022). Hence, it is postulated that:

H2: There is a positive impact of a) eutrophication, b) human footprints, and c) economic growth on biodiversity loss.

Loss of biodiversity and environmental sustainability

Environmental sustainability is the ability of natural systems to continue providing the resources necessary to support life on Earth without being degraded or depleted (Van Schoubroeck et al., 2023). Loss of biodiversity can significantly impact environmental sustainability, disrupting the balance of natural systems and leading to a cascade of negative effects (Gong et al., 2022). Research shows that biodiversity loss can lead to reduced ecosystem services. Ecosystem services are the benefits humans receive from natural ecosystems, such as clean air and water, food, and medicinal plants. When biodiversity declines, ecosystems become less resilient and unable to provide these services, which can significantly impact human health and well-being (Saputra and Dhianty, 2022). Loss of biodiversity can also lead to the collapse of entire ecosystems. When one species is lost, it can have a ripple effect throughout the ecosystem, disrupting the food web and leading to the extinction of other species. This can ultimately lead to the collapse of the entire ecosystem, which can have catastrophic consequences for both the environment and human societies that rely on these ecosystems (Koval et al., 2021).

Additionally, loss of biodiversity can lead to increased vulnerability to climate change. When biodiversity is lost, this capacity is diminished, making ecosystems more vulnerable to the impacts of climate change, such as rising temperatures and sea levels, resulting in the destruction of environmental sustainability (Haryani, 2021). Hence, based on the above arguments and ecosystem services theory, it is hypothesized that:

H3: The loss of biodiversity has a negative impact on environmental sustainability.

Mediatory role of loss of biodiversity

Biodiversity loss, eutrophication, human footprints, and economic growth are interconnected and can directly impact sustainable growth. The current study postulates that biodiversity loss can mediate the relationship between eutrophication, human footprints, and economic growth with sustainable growth. The loss of biodiversity can be seen as a symptom of these interrelated issues. The loss of species diversity can lead to declining ecosystem services essential for human well-being, including providing clean water and air, nutrient cycling, and climate regulation (Mujtaba et al., 2022). Therefore, the loss of biodiversity can negatively affect sustainable growth. Research shows that eutrophication can cause biodiversity loss by creating anoxic conditions that make it difficult for many aquatic species to survive (Meerhoff et al., 2022). This loss of biodiversity can harm sustainable growth as it can reduce the resilience of ecosystems to future environmental changes.

Moreover, human footprints on the environment can also cause biodiversity loss. For example, overfishing can also cause the depletion of fish populations, impacting the entire food chain and ecosystem (Maire et al., 2021). This loss of biodiversity can negatively affect sustainable growth by reducing ecosystems' capacity to provide services necessary for human well-being. Economic growth can also have a significant impact on biodiversity loss. For example, expanding agricultural lands and urbanization can cause habitat loss and biodiversity loss (Wang et al., 2022). By lowering ecosystems' ability to provide crucial goods and services for human well-being, the loss of biodiversity resulting from these connected problems may harm sustainable growth. Therefore, it is vital to consider biodiversity loss when considering sustainable growth and implementing measures to protect biodiversity and ecosystems.

H4: The loss of biodiversity mediates the association of a) eutrophication, b) human footprints, and c) economic growth with environmental sustainability.

Moderating role of Carbon sequestration

Carbon sequestration is critical in the relationship between biodiversity and environmental sustainability. Carbon sequestration is important to environmental sustainability because it helps mitigate climate change's impacts by reducing greenhouse gas emissions (Green and Keenan, 2022). The process involves capturing and storing atmospheric carbon dioxide from plants, soils, and other natural systems (Arehart et al., 2021; Bangash et al., 2021). Biodiverse ecosystems can better capture and store carbon because they contain a greater variety of plant species, each with unique characteristics that enable them to capture and store carbon differently (Bai and Cotrufo, 2022). Additionally, biodiversity can improve the productivity of ecosystems, leading to more significant carbon sequestration. This is because different species of plants can work together to increase nutrient cycling, soil health, and other ecosystem functions that contribute to carbon storage (Janzen et al., 2022). Hence, carbon sequestration is critical in the relationship between biodiversity and environmental sustainability. To achieve environmental sustainability, it is necessary to implement a range of strategies that promote both biodiversity and carbon sequestration, as well as policies that support the conservation of biodiversity and the reduction of greenhouse gas emissions. Based on this realization, it is postulated that:

H5: Carbon sequestration moderates the association between the loss of biodiversity and environmental sustainability such that the negative impact of biodiversity on environmental sustainability is reduced in the case of a higher level of carbon sequestration.

Theoretical work of the study

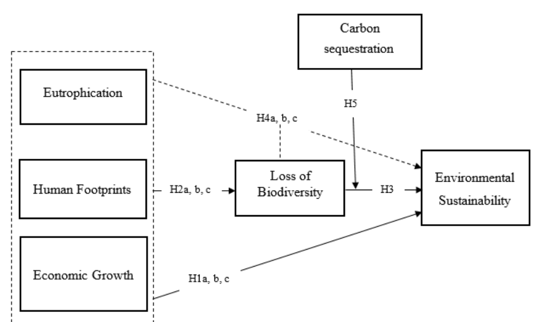

Figure 1: Theoretical farmwork of the study

Figure 1 presents the theoretical framework of the study, rooted in the premise that the loss of biodiversity is a key driver of environmental degradation, which is influenced by various factors, including eutrophication, human activities, and economic growth. By exploring these relationships, the study aims to provide insights into the complex dynamics of environmental sustainability and inform policy and management strategies for mitigating the negative impacts of human activities on the natural environment.

RESEARCH METHODS

To examine the impacts of eutrophication, human footprints, and economic growth on environmental sustainability via an underlying mechanism of biodiversity loss with the moderating role of carbon sequestration, the current study was conducted among farmers in different regions of Indonesia. For that purpose, a quantitative research design was applied, using a survey questionnaire to gather data and analyze the relationship between the variables in the research topic. Besides, the authors identified and contacted the farmers from different regions of Indonesia affected by eutrophication, human footprints, and economic growth in their environment using a random sampling technique. They were asked to participate in a survey. The survey questionnaire was designed to gather information on the impacts of eutrophication, human footprints, and economic growth on environmental sustainability, the loss of biodiversity, and the moderating role of carbon sequestration. The questionnaire was divided into two sections: (a) demographic information and (b) items linked to all study constructs. The data was collected between the 15th of June 2022 and the 5th of August 2022. At the same time, the research was conducted following ethical principles and guidelines. Informed consent was obtained from all participants, and their confidentiality and anonymity were ensured. The institutional ethics committee also approved the research. Finally, statistical software analyzed the quantitative data collected from the survey questionnaire. Descriptive statistics, such as frequencies, percentages, and means, were calculated to describe the data. Inferential statistics, such as correlation and regression analyses, were conducted to test the hypotheses and examine the relationships between the variables.

Demographic characteristics

The study surveyed 523 farmers from different regions in Indonesia, and the results showed that 62% of the farmers were male and 38% were female. The age distribution of the farmers was as follows: 18-35 years old: 12%; 36-50 years old: 28%; 51-65 years old: 40%; over 65 years old: 20%. Regarding education, the farmers with primary school or below were 15%; those with secondary school were 45%; and those with college or university degrees were 40%. Besides, most of the farms had ownership or were working for small farms (less than 10 hectares): 50%; medium farms (10–50 hectares): 35%; and large farms (over 50 hectares): 15%. Whereas, in terms of farming experience, 10% of farmers had less than 5 years of experience, 20% with 5-10 years of experience, and 35% each with 11-20 years and over 20 years of experience. Overall, the sample of farmers in the study was predominantly male, with the majority over 50 and have completed secondary school education. Half of the farmers surveyed had small farms, while a significant portion had over 20 years of farming experience.

Study measures

Eutrophication was measured with a 6-item scale adapted from Bell et al. (2014). Whereas human footprints were measured with five items adapted from the previous studies, as presented in Table 1. Simultaneously, economic growth was measured with five items adapted from Liobikienė and Butkus (2019). At the same time, we used a six-item scale from Morand (2020) to measure biodiversity loss. Additionally, environmental sustainability was measured with five items extracted from Song et al. (2019). Finally, we adapted seven items from Arehart et al. (2021) to measure carbon sequestration. All the items were measured on a 5-point Likert scale and are given in Table 1.

DATA ANALYSIS AND RESULTS

Measurement model

We used SmartPLS v.4 software to examine the causal relationships between independent and dependent variables by analyzing environmental sustainability factors using partially square structural equation modelling. In the initial stage, we evaluated the study measures' descriptive statistics, which showed that all skewness and kurtosis values were within the acceptable range of +1 to -1 and +2 to -2, respectively, indicating normal distribution. We then conducted a simulation analysis to determine the impact of the demographic characteristics of the study respondents on the dependent construct.

Table 1: Factor loadings, reliability, and validity

Constructs/items	FL	AVE	CR	CA
Eutrophication		0.579	0.892	0.
EUT1: The accumulation of nutrients such as nitrogen and phosphorus in water bodies is harmful.	0.736			
EUT2: The growth of harmful algal blooms and low oxygen levels in water bodies is a serious environmental issue.	0.750			
EUT3: Human activities such as agriculture, urban development, and sewage treatment can contribute to eutrophication.	0.797			
EUT4: I believe that individual actions, such as reducing fertilizer use and properly disposing of household chemicals, can help prevent eutrophication.	0.758			
EUT5: I am aware of the economic costs associated with eutrophication, such as lost recreational opportunities and decreased property values.	0.769			
EUT6: It is important to take measures to prevent or reduce eutrophication in water bodies.	0.755			
Human Footprints		0.594	0.880	0.754
HF1: Human activities are responsible for significant environmental impacts.	0.788			
HF2: The footprint of human activities extends beyond local areas to impact global ecosystems.	0.755			
HF3: Human activities, such as transportation and energy production, contribute significantly to greenhouse gas emissions and climate change.	0.802			
HF4: Land use changes, such as deforestation and urbanization, have significant impacts on biodiversity and ecosystem services.	0.771			
HF5: Human activities, such as agriculture and industry, contribute to water pollution and scarcity.	0.736			
Economic growth		0.586	0.876	0.759
EG1: Economic growth can have negative impacts on the environment, such as increased resource consumption and pollution	0.788			
EG2: Economic growth is important for creating job opportunities.	0.773			
EG3: Economic growth is important for increasing the standard of living for individuals and communities.	0.841			
EG4: Economic growth is important for generating tax revenue that can be used for public services and infrastructure.	0.717			
EG5: Economic growth is important for promoting technological innovation and competitiveness.	0.700			
Loss of biodiversity		0.645	0.916	0.743
LOBD1: I believe that biodiversity loss is a serious environmental issue.	0.792			
LOBD2: I think that human activities, such as habitat destruction and climate change, are major causes of biodiversity loss.	0.814			
LOBD3: I am aware of the negative impacts of biodiversity loss on ecosystem services, such as pollination and carbon storage.	0.774			
LOBD4: I think that protecting endangered species and their habitats is important for preserving biodiversity.	0.826			
LOBD5: I believe that individuals and organizations can take action to help prevent biodiversity loss, such as supporting conservation efforts and reducing their ecological footprint.	0.829			
LOBD6: I am concerned about the loss of biodiversity and its impact on the environment.	0.783			
Environmental sustainability		0.624	0.892	0.749
ES1: I make an effort to reduce my energy consumption and carbon footprint.	0.754			
ES2: I am willing to pay more for environmentally friendly products and services.	0.845			
ES3: I support conservation efforts to protect natural habitats and ecosystems.	0.794			
ES4: I am aware of the environmental impact of my daily activities.	0.797			
ES5: I believe it is important to consider the long-term consequences of our actions on the environment.	0.757			
Carbon Sequestration		0.563	0.900	0.798
CS1: I am aware of the importance of carbon sequestration in mitigating climate change.	0.707			
CS2: I believe that increasing carbon sequestration is an important strategy for reducing greenhouse gas emissions.	0.741			
CS3: I think that restoring natural habitats such as forests and wetlands can be an effective way to increase carbon sequestration.	0.720			
CS4: I am aware of the benefits of agroforestry and other sustainable land use practices for carbon sequestration.	0.765			
CS5: I think that governments should invest in programs that promote carbon sequestration.	0.757			
CS6: I believe that individuals and businesses should take action to reduce their carbon footprint and support carbon sequestration efforts.	0.760			
CS7: I think that carbon sequestration should be integrated into international climate change agreements.	0.798			

Note: FL= Factor Loadings AVE=Average Variance Extracted; CR=Composite Reliability; CA= Cronbach's Alpha.

The findings revealed that respondents' education significantly influenced their perceptions of environmental sustainability under various factors. Therefore, we controlled for this variable in further analysis. In the third stage, we calculated the psychometric properties of the variables to ensure their validity and normality. We considered four criteria: "factor loadings, Cronbach alpha composite reliability, and average variance extracted." Our results indicated that all study items had factor loadings above 0.70, meeting the threshold value (Sarstedt et al., 2017). We also found that the Cronbach alpha and composite reliability values were above 0.70, indicating robust measures (Hair et al., 2019). Furthermore, the AVE values were above 0.70. Table 1 presents all results in detail.

To address the potential issue of multicollinearity between the constructs under study, we evaluated their discriminant validity. This was done by calculating the heterotrait-monotrait (HTMT) ratio, which measures construct similarity. The HTMT values, as shown in Table 2, were below the recommended threshold of 0.85 (Henseler et al., 2015), reflecting no multicollinearity issues.

Table 2: Heterotrait-monotrait ratio

Constructs	Mean	Std	1	2	3	4	5	6
Eutrophication	3.91	1.02	0.760					
Human Footprints	3.97	1.09	0.406	0.770				
Economic Growth	4.06	0.90	0.422	0.601	0.765			
Loss of Biodiversity	4.12	0.87	0.460	0.511	0.406	0.803		
Environmental Sustainability	3.87	1.12	0.538	0.590	0.510	0.457	0.789	
Carbon Sequestration	4.00	1.05	0.613	0.490	0.619	0.529	0.605	0.750

Note: The square roots of AVEs of the constructs are shown in bold in diagonal.

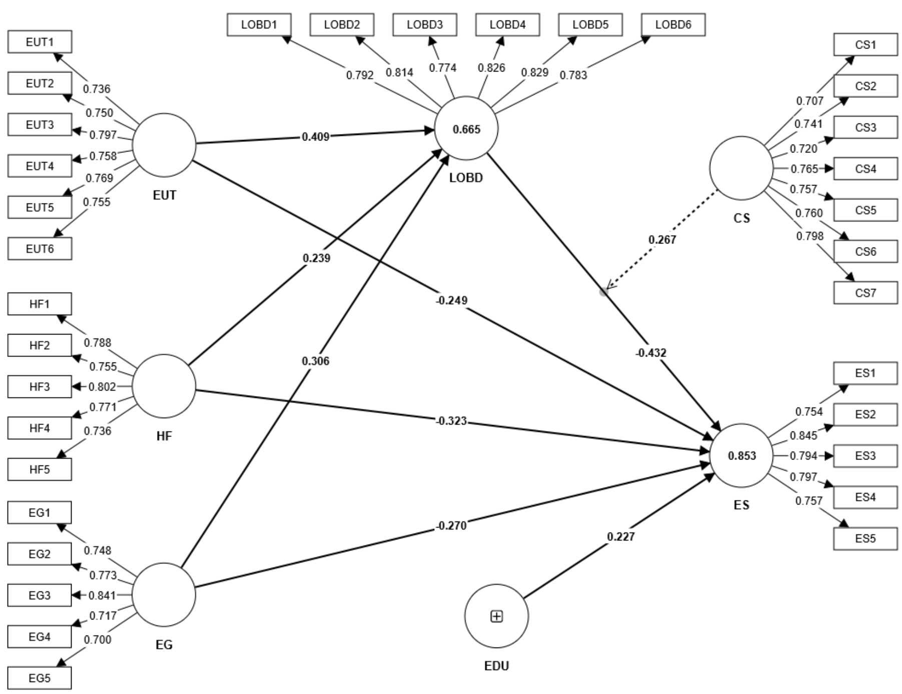

Figure 2: Full Measurement Model

Structural model

The study utilized structural equation modelling in SmartPLS v.4 to examine the causal relationships presented in the hypotheses. The overall fitness of the model was evaluated using the coefficient of determination (R2), which showed a variance of 85.3% and 66.5% for environmental sustainability and loss of biodiversity, respectively. The findings indicated significant direct and indirect associations among the study variables.

Hypotheses testing

The direct hypotheses showed that eutrophication (β = -0.249**, t = 3.902), human footprints (β = -0.323***, t = 4.870), and economic growth (β = -0.270**, t = 3.569) had a negative impact on environmental sustainability. At the same time, eutrophication (β = 0.409***, t = 5.856), human footprints (ß = 0.239**, t = 3.679), and economic growth (β = 0.306***, t = 4.192) had a positive impact on the loss of biodiversity. Simultaneously, this biodiversity loss negatively influenced environmental sustainability (β = -0.432***, t = 6.477). These results supported hypotheses H1 a, b, and c; H2 a, b, and c; and H3. Additionally, the study supported the mediation hypotheses H4 a, b, and c and showed that eutrophication (β = 0.161**, t = 2.931), human footprints (β = 0.178**, t = 3.126), and economic growth (β = 0.117**, t = 2.231) indirectly influenced environmental sustainability through the mediatory role of loss of biodiversity. The results are presented in Table 3.

In addition, we utilized the product indicator method in the PLS-SEM v.4 software to create an interaction term, CS*LOBD, to investigate if carbon sequestration plays a role in mitigating the relationship between loss of biodiversity and environmental sustainability. Our analysis showed that the interaction term reduced the negative impact of biodiversity loss on environmental sustainability. These findings highlight the importance of carbon sequestration in promoting environmental sustainability and mitigating the adverse effects of various social, environmental, and economic factors. The moderation results, presented in Figure 2 and Table 3, support our study's acceptance of hypothesis H5.

Table 3: Hypothesis testing results

	Hypotheses	Std. Beta	*t*-value	*p*-values	Supported
H1a	EUT→ES	-0.249	3.902	0.005	Yes
H1b	HF→ES	-0.323	4.870	0.000	Yes
H1c	EG→ES	-0.270	3.569	0.001	Yes
H2a	EUT→LOBD	0.409	5.856	0.000	Yes
H2b	HF→LOBD	0.239	3.679	0.005	Yes
H2c	EG→LOBD	0.306	4.192	0.000	Yes
H3	LOBD→ES	-0.432	6.477	0.000	Yes
H4a	EUT→LOBD →ES	-0.161	2.931	0.009	Yes
H4b	HF→LOBD→ES	-0.178	3.126	0.007	Yes
H4c	EG→LOBD→ES	-0.117	2.231	0.011	Yes
H5	CS* LOBD→EA	0.267	4.378	0.003	Yes

Where: EUT= Eutrophication; HF= Human Footprints; EG= Economic Growth; LOBD= Loss of Biodiversity; ES= Environmental Sustainability; CS= Carbon Sequestration

DISCUSSION AND CONCLUSION

Environmental sustainability is crucial for maintaining the quality of life on the planet and preserving the Earth's natural resources (Koval et al., 2021). One of the key factors affecting environmental sustainability is the loss of biodiversity, which is associated with negative impacts such as decreased ecosystem resilience and reduced ecosystem services (Valatin et al., 2022). Carbon sequestration is important to mitigate biodiversity loss and promote environmental sustainability. This research aims to investigate the impacts of eutrophication, human footprints, and economic growth on environmental sustainability and to explore the moderating role of carbon sequestration in the relationship between biodiversity and environmental sustainability.

Results showed that eutrophication, human footprints, and economic growth had a significant positive effect on biodiversity loss and a negative effect on environmental sustainability. The study further suggests that eutrophication, human footprints, and economic growth are significant factors contributing to Indonesia's negative impact on environmental sustainability. In Indonesia, eutrophication is a major problem, particularly in coastal areas with high levels of agricultural activities and wastewater discharge (Rahmawasiah et al., 2022). This excessive nutrient loading is primarily due to the overuse of chemical fertilizers in agriculture and untreated sewage discharge (Nugroho et al., 2022). The study suggests that excessive nutrient loading in the water negatively impacts the environment and reduces its sustainability. Likewise, human footprints contribute to the depletion of natural resources, the loss of biodiversity, and increased pollution levels. In Indonesia, these activities are prevalent, particularly in urban areas with a high demand for infrastructure and industrial development.

Moreover, economic growth refers to the increased production of goods and services in a country (Wei et al., 2022). In Indonesia, economic growth is a priority for the government, and economic activity has significantly increased in recent years. However, this economic growth has come at a cost to the environment, with the depletion of natural resources and increased pollution levels. The study suggests that economic growth significantly negatively affects environmental sustainability in Indonesia, particularly in regions where economic activities are concentrated. Economic growth has been linked to environmental sustainability in several ways. For example, economic growth can lead to increased technological advancements, promoting more efficient resource use and reducing pollution levels (Mujtaba et al., 2022). However, economic growth can also lead to increased production, consumption, and waste generation, negatively impacting the environment. One of the major concerns with economic growth is the degradation of natural resources and the loss of biodiversity.

The result also shows that carbon sequestration can promote biodiversity by providing habitat for various species, supporting ecosystem services such as pollination and nutrient cycling, and enhancing the resilience of ecosystems. Carbon sequestration can also help mitigate the effects of climate change by reducing greenhouse gas emissions, which can help prevent biodiversity loss due to climate change (Arehart et al., 2021; Green and Keenan, 2022). The moderating role of carbon sequestration in the relationship between biodiversity and environmental sustainability is crucial. Carbon sequestration can help mitigate biodiversity loss's negative impacts, promoting environmental sustainability. The relationship between biodiversity and environmental sustainability is complex, and carbon sequestration is essential for maintaining a healthy environment.

Theoretical implications

This research has several theoretical implications for the field of environmental sustainability. Firstly, the research highlights the interconnectedness of different environmental issues. Eutrophication, human footprints, economic growth, and loss of biodiversity are all factors that can impact environmental sustainability. The research recognizes that these factors are not independent but interconnected and that addressing one issue can have positive or negative consequences on others. Secondly, the research emphasizes the critical role of biodiversity in environmental sustainability. Biodiversity provides several ecosystem services, including carbon sequestration, soil fertility, and pest control (Habibullah et al., 2022). Loss of biodiversity can lead to a decline in these services, negatively impacting the environment and human well-being (Gong et al., 2022). Thirdly, the research underscores the importance of carbon sequestration in promoting environmental sustainability. Carbon sequestration involves capturing and storing atmospheric carbon dioxide (Janzen et al., 2022). Carbon sequestration can help mitigate the impacts of climate change by reducing greenhouse gas emissions. Finally, the research highlights the moderating role of carbon sequestration in the relationship between biodiversity and environmental sustainability. Carbon sequestration can help maintain biodiversity by reducing the negative impacts of climate change on ecosystems.

Practical implications

The research has some practical implications. Human activities such as deforestation, mining, and urbanization contribute to biodiversity loss and eutrophication. These activities also cause the emission of greenhouse gases and environmental degradation. Therefore, policies should be implemented to reduce human footprints by promoting sustainable practices, such as afforestation and the conservation of natural habitats. In addition, economic growth is essential for development, but it should not come at the expense of the environment. Sustainable economic growth can be achieved by promoting renewable energy, reducing waste, and promoting sustainable production and consumption. Moreover, eutrophication and the loss of biodiversity are major threats to ecosystems. Therefore, the restoration of degraded ecosystems should be prioritized to restore the ecosystem services that support human well-being. This can be achieved by restoring natural habitats like wetlands, forests, and grasslands. Besides, carbon sequestration is a critical mechanism in the fight against climate change. Promoting carbon sequestration can be achieved by afforestation and reforestation, promoting the use of clean energy, and reducing emissions from various sources. At the same time, agriculture significantly contributes to eutrophication and biodiversity loss. Therefore, sustainable practices such as conservation agriculture, agroforestry, and integrated crop-livestock systems should be promoted. These practices promote biodiversity conservation and soil health and reduce greenhouse gas emissions. Finally, biodiversity is essential for ecosystem services such as pollination, nutrient cycling, and soil formation. Therefore, biodiversity conservation should be promoted by protecting natural habitats, sustainable land use practices, and sustainable tourism.

Limitations and future research directions

The research that has been conducted aligns with an important and complex study area with a range of limitations and potential future research directions. One of the main limitations of this research topic is the availability and reliability of data. Data on biodiversity loss, carbon sequestration, eutrophication, human footprints, and economic growth must often be completed, consistently, or available. Therefore, it can be challenging to accurately measure and analyze the relationships between these variables. Future research should focus on improving data collection and analysis methods to address the data limitations. This can be achieved by developing new data collection techniques, standardized data reporting frameworks, and improved statistical methods. The impacts of eutrophication, human footprints, and economic growth on environmental sustainability can vary significantly depending on the location, ecosystem, and social and economic context. Thus, the results of any research conducted in one particular area may need to be more generalizable to other regions. Future research should explore these contracts and their associations across cultures and socioeconomic contexts to address the context-dependency limitation. This can help identify the most effective strategies for promoting sustainability in different regions. This topic requires expertise from various disciplines, including ecology, environmental science, economics, and sociology. Integration of these disciplines can be challenging, and interdisciplinary communication and collaboration are essential. Future research should focus on integrating the expertise of different disciplines to provide a more comprehensive understanding of the complex relationships between biodiversity, carbon sequestration, and environmental sustainability. This can be achieved through interdisciplinary collaboration, shared research frameworks, and the development of common terminology and methods. Finally, future research should focus on identifying practical policy implications that can promote environmental sustainability while considering economic growth and human well-being. This can help inform policy decisions and promote sustainable development practices.

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