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Impact of 50% Depletion Rate on Forest Resource Biomass: A Computational Approach

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Abstract
This study investigates the impact of anthropogenic activities on forest resource biomass through a computational modeling approach. In this study, we analyze the effects of urbanization, deforestation, and agricultural expansion on biomass density across diverse forest ecosystems. Our model integrates socio-economic factors, such as human population density and population pressure to simulate the degradation of forest resources over time. Results indicate a significant negative correlation between human activities and biomass productivity, particularly in regions subjected to intensive agricultural practices and urban sprawl. The findings highlight critical thresholds beyond which forest ecosystems experience irreversible biomass loss, emphasizing the need for sustainable land management strategies. By forecasting potential future scenarios based on current trends, this research provides a framework for policymakers to mitigate the adverse effects of anthropogenic activities on forest biomass, promoting conservation and restoration efforts. The study underscores the importance of computational approaches in understanding complex ecological interactions and guiding sustainable development initiatives.

Keywords: Industrialization, Forest Resources Biomass, Population Density, Population Pressure

Introduction

Forests are vital components of the Earth's biosphere, providing essential ecosystem services such as carbon sequestration, biodiversity support, and soil stabilization (Mohammed 2014). However, anthropogenic activities—including deforestation, land-use change, and urban expansion pose significant threats to forest ecosystems (Eguiguren et al. 2019). These human-induced changes not only alter the structure and composition of forests but also have profound impacts on forest resource biomass, which is crucial for maintaining ecological balance and mitigating climate change (Ekaka-a 2009). Forest biomass, encompassing both the living and dead organic matter within a forest, serves as a key indicator of ecosystem health and productivity. The loss of forest biomass due to anthropogenic activities can lead to diminished carbon storage capacity, reduced biodiversity, and increased vulnerability to environmental stressors, (Mbakwe, 1996). Understanding and quantifying these impacts are essential for devising effective conservation strategies and promoting sustainable land management practices (Eke, 2025). Traditional methods of assessing forest biomass involve ground-based surveys and remote sensing techniques. While ground-based surveys provide detailed information, they are often limited by scale and logistical constraints. Remote sensing offers a broader perspective but may lack the resolution needed for precise biomass assessments. To bridge these gaps, computational approaches that integrate remote sensing data, geographic information systems (GIS), and advanced analytical techniques have emerged as powerful tools for evaluating the impacts of anthropogenic activities on forest biomass (Aliyu et al. 2014).

This study adopts a computational approach to systematically analyze the effects of human-induced changes on forest resource biomass. By leveraging satellite remote sensing data, GIS, and machine learning algorithms, we aim to

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develop a comprehensive model that can assess and predict biomass alterations across different regions and temporal scales. This approach allows for the integration of diverse data sources, enhancing the accuracy and scalability of biomass assessments. Our objectives are threefold: first, to quantify the extent and intensity of biomass loss associated with various anthropogenic activities; second, to identify the driving factors behind these changes; and third, to project future biomass trends under different land-use scenarios. Through this study, we seek to provide valuable insights for policymakers, conservationists, and researchers, supporting informed decision-making and effective management strategies for forest conservation and sustainable development (IUCN, 1992).

1. Materials and Methods

From Ramdhani et al., (2015),

$$\frac{dB}{dt} = S\left(1 - \frac{B}{L}\right)B - S_0B - \beta_2NB - S_1IB - \beta_3B^2I \quad (1)$$

$$\frac{dN}{dt} = r\left(1 - \frac{N}{K}\right)N - r_0N + \beta_1NB \quad (2)$$

$$\frac{dP}{dt} = \lambda N - \lambda_0P - \theta I \quad (3)$$

$$\frac{dI}{dt} = \pi\theta P + \pi_1S_1IB - \theta_0I \quad (4)$$

With the following constraints conditions:

$$B(0) > 0, N(0) > 0, P(0) > 0, I(0) > 0 \text{ and } 0 < \pi \leq 1, 0 < \pi_1 \leq 1$$

Where the notations:

$B(t)$ = the density of forestry resource biomass at time t
$N(t)$ = the density of population dependent on the resource at time t
$P(t)$ = the density of population pressure at time t
$I(t)$ = the density of industrialization at time t
S = the intrinsic growth rate coefficient of the forest resources biomass
S_0 = the coefficient of natural depletion rate of resource biomass S_1
= the coefficient of the depletion rate of biomass density caused by industrialization
r = the intrinsic growth rate of the population density
r_0 = the coefficient of natural depletion rate of population
L = the carrying capacity of the forestry resources biomass
K = the carrying capacity of the population density
β_1 = the growth rate of cumulative density of human population effect of resources
β_2 = corresponding depletion rate coefficient of the resource biomass density due to population
β_3 = the depletion rate coefficient of forestry resources biomass due to crowding by industrialisation
λ = the growth coefficient of population pressure
λ_0 = the natural depletion rate coefficient of population pressure
θ = depletion rate coefficient of population pressure due to industrialisation
θ_0 = coefficient of control rate of industrialisation which is applied by government
π = growth rate of industrialisation effect of population pressure
π_1S_1 = growth rate of industrialisation due to forestry resource.

Results

Here, key results from our analyses and numerical simulations are presented as follows:
Table 1 as well as Figure 1 summarize the solution trajectory of the Impact of experimental time for the interaction between forest resource biomass, human population density, population pressure and industrialization, when all the parameter values are fixed for the time interval of $t \in 0(1)25$ months.

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Table 1: Impact of experimental time for the interaction between forest resource biomass, human population density, population pressure and industrialization, when all the parameter values are fixed for the time interval of $t \in 0(1)25$ months.

Time, t (month)	N1	N2	N3	N4
0	1.0000	1.0000	1.0000	1.0000
1.0000	9.5736	2.1157	1.2095	0.4366
2.0000	7.0728	3.4008	3.3726	0.2041
3.0000	3.7447	4.1844	4.7828	0.1059
4.0000	1.9659	4.4796	5.3807	0.0679
5.0000	1.2419	4.5639	5.5731	0.0540
6.0000	0.9567	4.5826	5.6248	0.0489
7.0000	0.8453	4.5845	5.6357	0.0470
8.0000	0.8049	4.5833	5.6365	0.0463
9.0000	0.7928	4.5823	5.6358	0.0460
10.0000	0.7907	4.5817	5.6346	0.0459
11.0000	0.7912	4.5815	5.6306	0.0458
12.0000	0.7919	4.5815	5.6347	0.0458
13.0000	0.7924	4.5815	5.6358	0.0458
14.0000	0.7926	4.5815	5.6363	0.0458
15.0000	0.7926	4.5815	5.6366	0.0458
16.0000	0.7927	4.5815	5.6315	0.0458
17.0000	0.7927	4.5815	5.6355	0.0458
18.0000	0.7927	4.5815	5.6365	0.0458
19.0000	0.7926	4.5815	5.6391	0.0458
20.0000	0.7926	4.5815	5.6375	0.0458
21.0000	0.7927	4.5815	5.6331	0.0458
22.0000	0.7927	4.5815	5.6360	0.0458
23.0000	0.7926	4.5815	5.6381	0.0458
24.0000	0.7927	4.5815	5.6359	0.0458
25.0000	0.7927	4.5815	5.6346	0.0458

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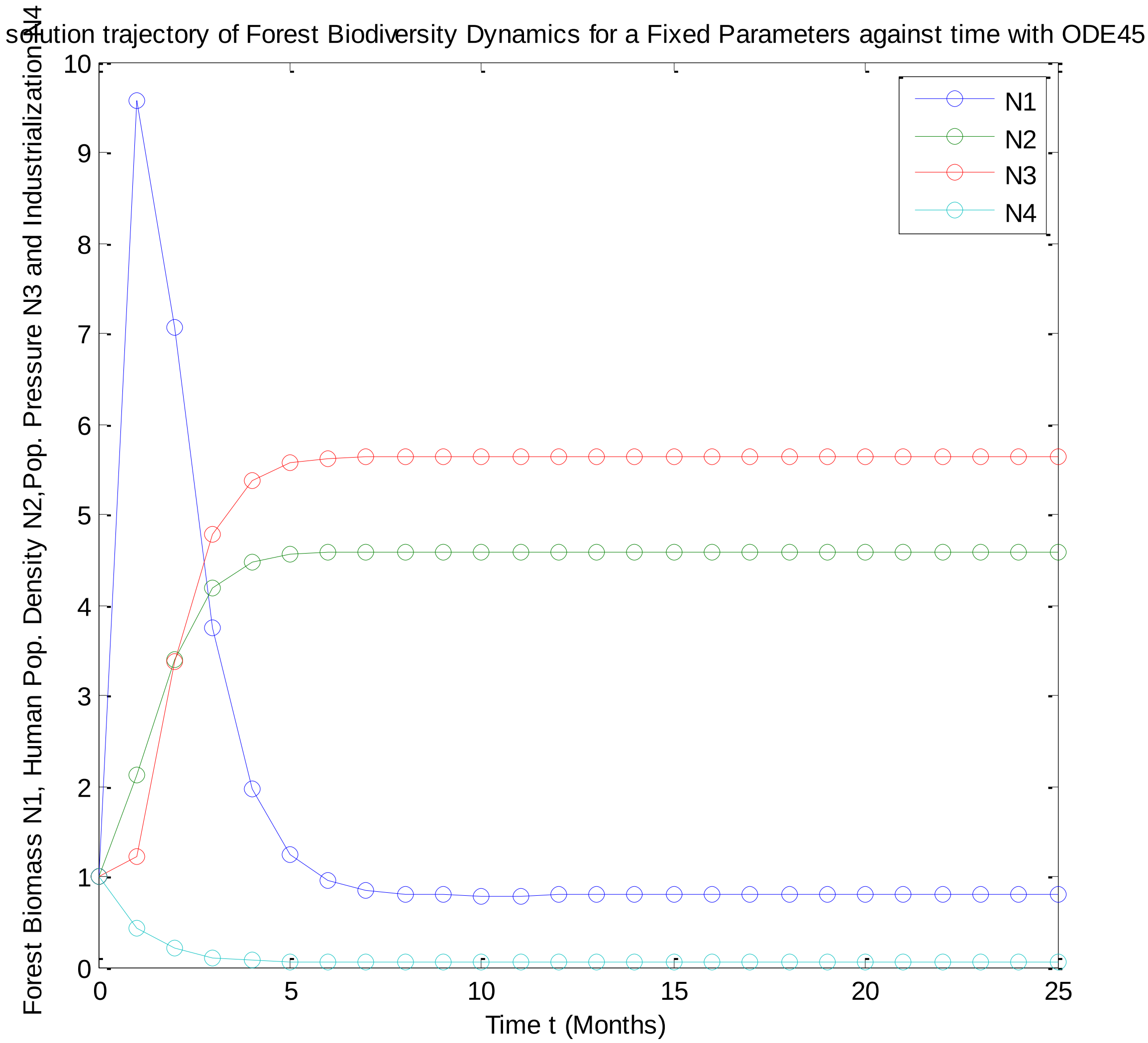

Figure 1: Solution Trajectory of the Impact of experimental time for the interaction between forest resource biomass, human population density, population pressure and industrialization, when all the parameter values are fixed for the time interval of $t2 \in 0(1)25$ months.

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Table 2 as well as Figure 2 summarize solution trajectory of the Impact of 50% Variation of Depletion rate Coefficient of Forest Biomass.

Table 2: Impact of 50% Variation of Depletion rate Coefficient of Forest Biomass

Time,t(month)	N1	N11	EBD(%)	N2	N21	N3	N31	N4	N41
0	0.0010	0.0010	0	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010
0.0010	0.0096	0.0133	0.0387	0.0021	0.0022	0.0012	0.0012	0.0004	0.0005
0.0020	0.0071	0.0147	0.1079	0.0034	0.0036	0.0034	0.0035	0.0002	0.0002
0.0030	0.0037	0.0145	0.2883	0.0042	0.0046	0.0048	0.0051	0.0001	0.0001
0.0040	0.0020	0.0144	0.6318	0.0045	0.0050	0.0054	0.0059	0.0001	0.0001
0.0050	0.0012	0.0144	1.0618	0.0046	0.0051	0.0056	0.0062	0.0001	0.0001
0.0060	0.0010	0.0145	1.4140	0.0046	0.0052	0.0056	0.0063	0.0000	0.0001
0.0070	0.0008	0.0145	1.6183	0.0046	0.0052	0.0056	0.0063	0.0000	0.0001
0.0080	0.0008	0.0146	1.7084	0.0046	0.0052	0.0056	0.0064	0.0000	0.0001
0.0090	0.0008	0.0146	1.7374	0.0046	0.0052	0.0056	0.0064	0.0000	0.0001
0.0100	0.0008	0.0146	1.7423	0.0046	0.0052	0.0056	0.0064	0.0000	0.0001
0.0110	0.0008	0.0146	1.7419	0.0046	0.0052	0.0056	0.0064	0.0000	0.0001
0.0120	0.0008	0.0146	1.7412	0.0046	0.0052	0.0056	0.0064	0.0000	0.0001
0.0130	0.0008	0.0146	1.7391	0.0046	0.0052	0.0056	0.0064	0.0000	0.0001
0.0140	0.0008	0.0146	1.7385	0.0046	0.0052	0.0056	0.0064	0.0000	0.0001
0.0150	0.0008	0.0146	1.7394	0.0046	0.0052	0.0056	0.0064	0.0000	0.0001
0.0160	0.0008	0.0146	1.7390	0.0046	0.0052	0.0056	0.0064	0.0000	0.0001
0.0170	0.0008	0.0146	1.7382	0.0046	0.0052	0.0056	0.0064	0.0000	0.0001
0.0180	0.0008	0.0146	1.7389	0.0046	0.0052	0.0056	0.0064	0.0000	0.0001
0.0190	0.0008	0.0146	1.7394	0.0046	0.0052	0.0056	0.0064	0.0000	0.0001
0.0200	0.0008	0.0146	1.7385	0.0046	0.0052	0.0056	0.0064	0.0000	0.0001
0.0210	0.0008	0.0146	1.7384	0.0046	0.0052	0.0056	0.0064	0.0000	0.0001
0.0220	0.0008	0.0146	1.7395	0.0046	0.0052	0.0056	0.0064	0.0000	0.0001
0.0230	0.0008	0.0146	1.7388	0.0046	0.0052	0.0056	0.0064	0.0000	0.0001
0.0240	0.0008	0.0146	1.7383	0.0046	0.0052	0.0056	0.0064	0.0000	0.0001
0.0250	0.0008	0.0146	1.7390	0.0046	0.0052	0.0056	0.0064	0.0000	0.0001

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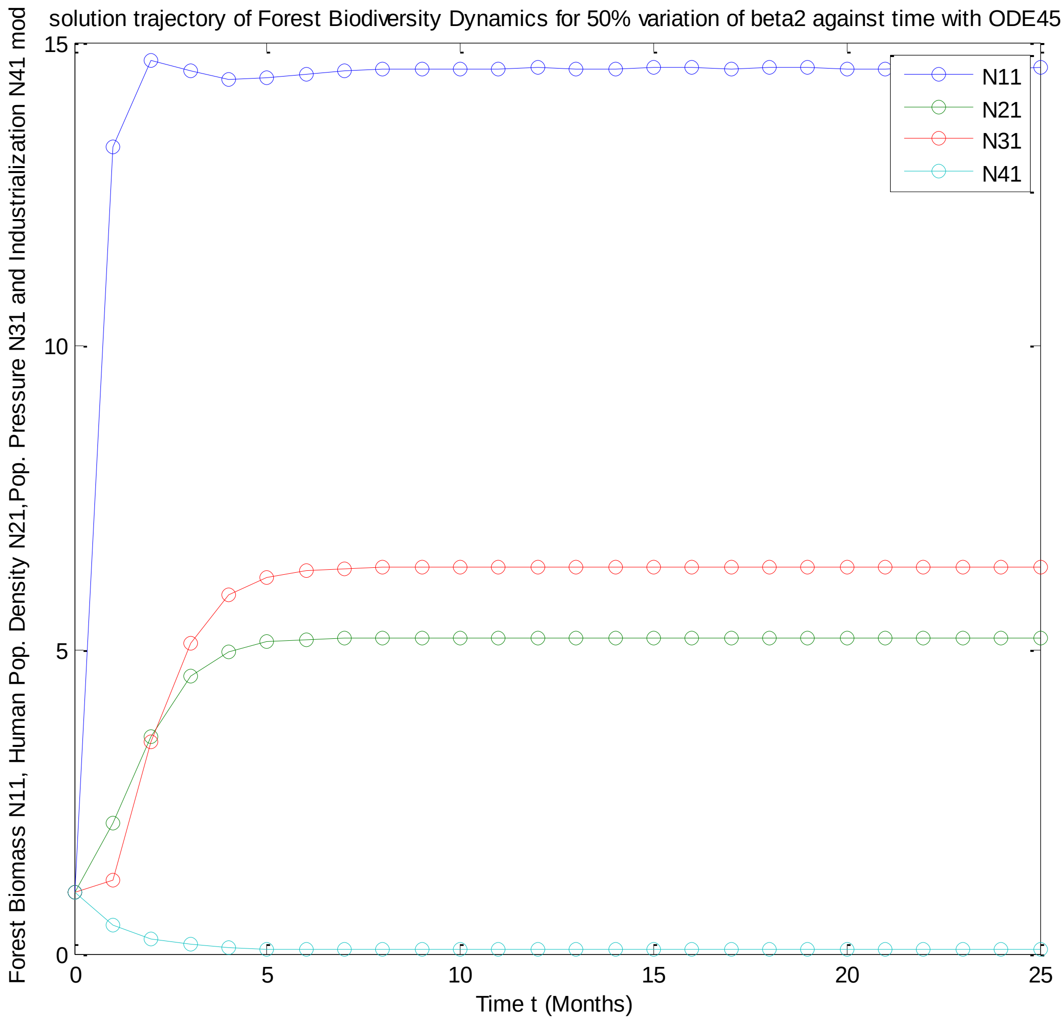

Figure 2: Solution Trajectory of the Impact of 50% Variation of Depletion rate Coefficient of Forest Biomass

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Discussion

Under this section, key results that were obtained from the numerical simulation are being analysed and results discussed for the various cases. In studying the Impact of experimental time for the interaction between forest resource biomass, human population density, population pressure and industrialization, when all the parameter values are fixed for the time interval of $t \in 0(1)25$ months. Four (4) coordinates were examined namely N1 being the forest resource biomass for fixed values, N2 being the human population density for fixed parameter values, N3 being the population pressure for fixed parameter values and N4 being the industrialization for fixed parameter values. From the numerical result obtained, we observed that on the base day of our experimental time, here called the initial condition; all the parameter values were fixed for the time interval of $t \in 0(1)25$ months, the initial values of the interacting variables; forest resource biomass N1, human population density, N2, population pressure, N3 and industrialization, N4, here called the initial conditions on the base day were recorded as 1.0000, 1.0000, 1.0000 and 1.0000. It was observed that the forest resource biomass, N1, decreased steadily from 9.5736 to 0.7907 for the first ten (10) months, after which it slight increased from 0.7912 in the eleventh month to 0.7926 in the fifteenth month. The value fluctuated between 0.7926 and 0.7927 till the twenty fifth month; indicating a convergence. On the other hand, the human population density, N2, increased steadily for the first seven (7) months, from 2.1157 to 4.5845 then for the next three months, it dropped slightly from 4.5833 on the eighth month to 4.5815 on the eleventh month where it stagnated till the twenty fifth month. This indicates that there were no new human arrivals into the area under study, hence, the stability of the population density. The population pressure, N3, increased steadily for the first eight (8) months; from 1.2095 to 5.6365. It declined for another three (3) months; from 5.6258 to 5.6306, it rose again for another three (3) months; from 5.6347 to 5.6363 in the sixteenth month. This trend of increasing for three months and dropping for one month continued; an indication that the forest resources tried to manage the rising population at intervals. Finally on this table, the impact of industrialization steadily decreased for ten (10) months; from 0.4366 to 0.0459 before stabilizing for the rest of the remaining fifteen (15) months at 0.0458. This gives a picture of the fact that at the time of constructing the industry, the forest resource was greatly impacted upon; and once the construction was over, the impact was minimized. This trend is clearly seen on Figure 1.

In studying the impact of 50% Variation of Depletion rate Coefficient of Forest Biomass, eight (8) coordinates were examined namely N1 being the forest resource biomass for fixed values, N11 being the modified forest resource biomass, N2 being the human population density for fixed parameter values, N21 being the modified population density, N3 being the population pressure for fixed parameter values, N31 being the modified population pressure and N4 being the industrialization for fixed parameter values, and N41 being the modified industrialization. We observed that the initial values of the interacting variables; forest resource biomass N1, human population density, N2, population pressure, N3 and industrialization, N4, here called the initial conditions on the base day were recorded as 1.0000, 1.0000, 1.0000 and 1.0000. From the result obtained in Table 4.2 as well as figure 4.2, on the Impact of 50% Variation of Depletion rate Coefficient of Forest Biomass, there was a biodiversity gain. When the depletion rate coefficient on the forest biomass was reduced by half (50%), there was a significant increase on the modified forest resource biomass, N11; which increased from 13.2739 for the first month to 14.5767 in the twenty fifth (25^{th}) month. After the first month, the modified forest resource biomass increased from 13.2739 to 14.7056 in the second month. Increase in the modified forest resource biomass were equally recorded from the fifth to the ninth months, eleventh to the twelfth months, fifteenth, eighteenth, nineteenth, twenty – second as well as the twenty fifth months. The increase was however not sustained for the third, fourth, thirteenth, fourteenth, sixteenth, seventeenth, twentieth, twenty – first, twenty – third as well as the twenty fourth months. In the same way, the modified population density N21 increased from the first to the fifteenth month; with a value of 2.1568 to 5.2079, after which it converged to 5.2080. The modified population pressure N31 increased steadily from 1.2112 in the first month to 6.3662 in the fifteenth month where it converged till the twenty fifth month. The modified industrialization recorded a steady decline from 0.4565 for the first month to 0.0719 in the twelfth month; where it also converged till the twenty-fifth month. This means that, when the impact on the forest resource biomass is reduced, the impact of industrialization will diminish. In other words, when the effect of industrialization is reduced, the forest resource biomass, the population density as well as the

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population pressure will increase. This trend is clearly seen on Figure 2. In summary, when the depletion rate coefficient of the forest resource biomass was reduced by half (50%), the forest resources biomass improved greatly, the human population density rose significantly; this also triggered the population pressure.

Conclusion

The computational approach applied in this study provides a data-driven understanding of the impacts of anthropogenic activities on forest resource biomass. We have effectively quantified and analyzed the changes in forest biomass resulting from human-induced activities. Our findings demonstrate that anthropogenic activities have significantly contributed to the decline in forest biomass. The extent and intensity of biomass loss vary depending on the specific type of activity. Deforestation and urban expansion emerge as the most critical factors driving biomass reduction. The use of Mat lab ODE45 numerical scheme has proven to be robust in predicting biomass loss and projecting future trends. Our projections indicate that without effective intervention, the trend of biomass loss is likely to continue, exacerbating environmental and climatic challenges.

Recommendations

1. In terms of policy implications, our result underscores the necessity for targeted conservation strategies and sustainable land management practices. Effective policy measures should focus on mitigating deforestation, promoting reforestation, and enhancing land-use planning to minimize adverse impacts on forest biomass. Additionally, the integration of socio-economic data into biomass assessments provides valuable insights into the driving forces behind these changes, facilitating more informed decision-making.
2. The computational approach demonstrated in this study offers a scalable and detailed framework for monitoring forest resources and assessing the impact of human activities. It provides valuable tools for policymakers, conservationists, and researchers, enabling them to make data-driven decisions and implement effective strategies for forest conservation and sustainable development.
3. Finally, addressing the challenges posed by anthropogenic activities on forest biomass requires a collaborative effort that combines advanced computational techniques with actionable policy measures. By leveraging the insights gained from this study, stakeholders can work towards preserving forest ecosystems, enhancing their resilience, and ensuring the continued provision of essential ecosystem services.

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