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Impact of Additive and Non-Additive Random Environmental Perturbation in Modelling Anthropogenic Activities on Forest Biodiversity

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Abstract
Anthropogenic activities considerably impact forest biodiversity. Disturbances such as deforestation, habitat fragmentation and climate change, significantly impact forest biodiversity. However, due to the inclusion of a low additive environmental perturbation on the coefficient of the depletion rate of forest resource biomass due to crowding by industrialization, the interacting variables which were fully randomized saturates to a converging value for human population density. In this scenario, grey areas for biodiversity loss due to the depletions of the forest resource biomass were captured. By providing a comprehensive understanding of the impacts of human activities on forest ecosystems, our computational approach aims to inform sustainable management practices and enhance conservation strategies. Ultimately, this study contributes to the ongoing efforts to mitigate the adverse effects of anthropogenic activities on forest biodiversity, ensuring the preservation of these vital ecosystems for future generations. In conclusion, the integration of modelling, numerical prediction, and mitigation strategies through a computational approach offers a promising pathway for addressing the challenges of anthropogenic impacts on forest biodiversity. As we move forward, continued advancements in computational techniques and collaborative efforts among stakeholders will be essential for safeguarding these vital ecosystems for future generations. The detailed results and discussions of our findings are fully presented in this study

Keywords: Anthropogenic Activities, Forest Biodiversity, Environment, perturbation, Climate Change

Introduction

Forests are one of the most bio diverse ecosystems on the planet, providing habitat for a vast array of plant and animal species (Mohammed 2014). However, these ecosystems are facing unprecedented threats from anthropogenic activities, which are significantly impacting forest biodiversity (Eke 2025). This introduction provides an overview of the impact of human-induced disturbances on forest ecosystems, highlighting the importance of preserving biodiversity and the need for sustainable forest management. Forests are crucial ecosystems that support a wide range of plant and animal species (Mmom 2007). They provide essential ecosystem services including: carbon sequestration (the process of capturing and storing atmospheric carbon dioxide; either naturally or through human intervention. This helps mitigate climate change by reducing the amount of carbon dioxide in the atmosphere). Water regulation (forests play a critical role in maintaining water cycles, ensuring the availability of fresh water resources). Other areas include soil conservation and biodiversity (Shivanna, 2022; Ekaka-a, 2009). According to Wuver and Attuquayefio (2006), some of the most significant anthropogenic activities affecting forests include: deforestation, habitat fragmentation, climate change, and overexploitation. Some of the consequences of these anthropogenic activities on forest biodiversity include: loss of ecosystem services such as carbon sequestration, water regulation, species decline and decreased resilience (Dubey & Narayanan, 2010). It is also important to adopt sustainable forest management practices; which includes: protected areas, such as parks and wild life reserves to safeguard biodiversity, sustainable harvesting, reforestation and afforestation (creating a forest where it never existed before), and community engagement (Mmom &Arokoyu, 2009). It is a natural phenomenon that as the population in an area grows, this growth will trigger the population pressure, and these will in turn impact on the forest resources biomass of the area (Agarawal et al. 2010).But a scenario where the forest resources biomass goes through some form of environmental perturbation (Akpodee & Ekaka-a, 2019; IUCN 1992).what will be the effect on the forest? We shall examine the subject matter using a predator prey model (Kar, 2003).

Mathematical formulation

Ramdhani et al. (2015), stated the following equations, which were adopted by Eke (2025):

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

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

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

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

For additive random noise intensity inclusion on the depletion rate coefficient of the forest resources biomass due to crowding by industrialization, we redefine the model as follows:

$$\frac{dB}{dt} = S\left(1 - \frac{B}{L}\right)B - S_0B - \beta_2NB - S_1IB - (\beta_3 + rni * rand(1))B^2I \quad (1a)$$

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

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

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

With the following constraints conditions:

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

For non additive random noise intensity inclusion on the depletion rate coefficient of the forest resources biomass due to crowding by industrialization, we redefine the model as follows:

$$\frac{dB}{dt} = S\left(1 - \frac{B}{L}\right)B - S_0B - \beta_2NB - S_1IB - (\beta_3 - rni * rand(1))B^2I \quad (1b)$$

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

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

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

With the following constraints:

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

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

$\beta_1 =$ the growth rate of cumulative density of human population effect of resources

$\beta_2 =$ corresponding depletion rate coefficient of the resource biomass density due to population

$\beta_3 =$ the depletion rate coefficient of forestry resources biomass due to crowding by industrialisation

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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
$\pi_1 S_1$ = growth rate of industrialisation due to forestry resource.

rni = random noise intensity
In order to circumvent this endemic problem, we explore the application of a numerical simulation as a strategy by using a Matlab numerical scheme called ordinary differential equation of order 45 (ODE 45).

Results
The results and discussion will be given in the next section:

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

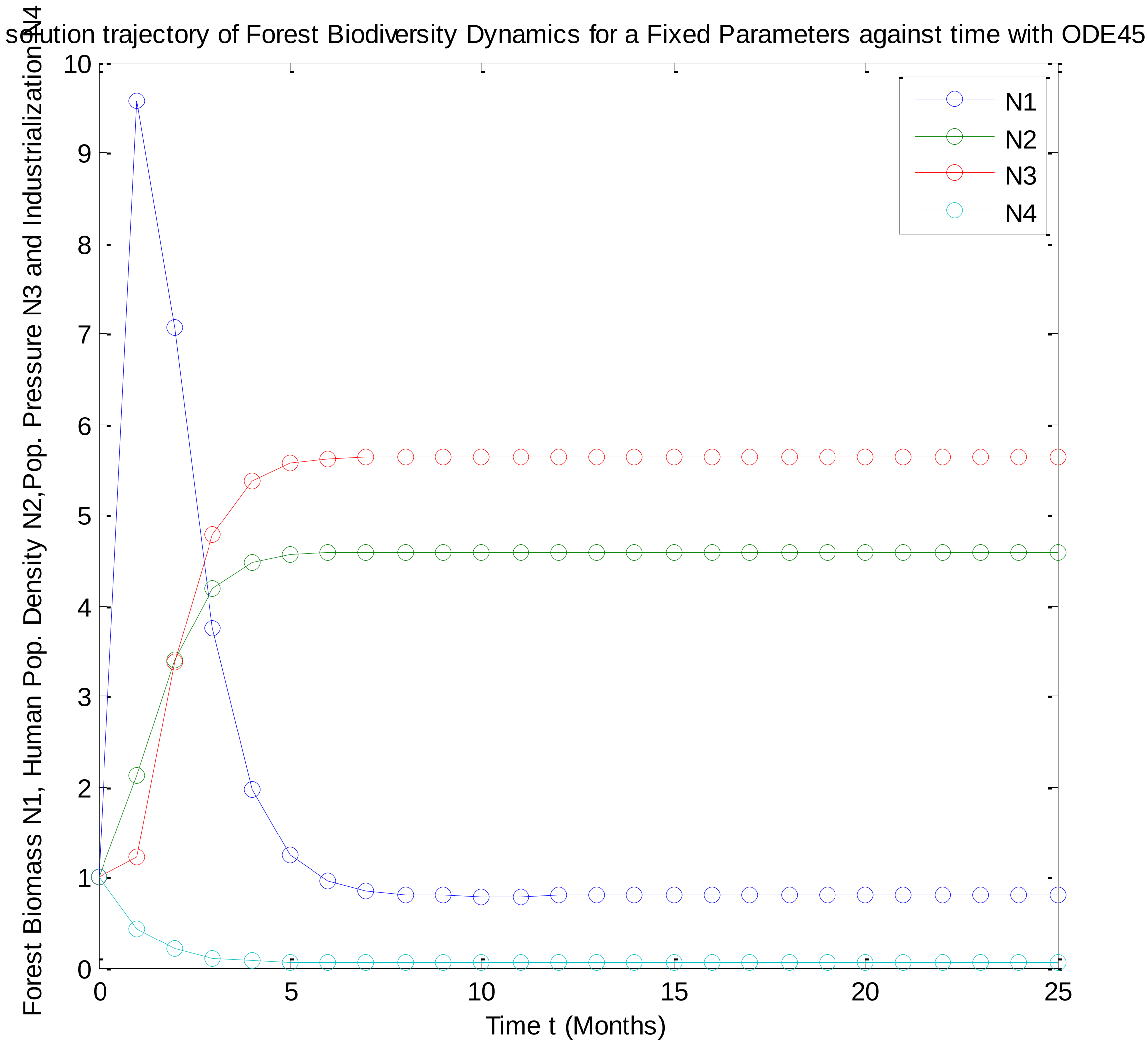

Figure 1: Solution Trajectory of the Impact of Experimental Time for the Interaction Between Forest Resource Biomass, Human Population Density, Population Pressure and Industrialization, When all the Parameter Values are Fixed for the Time Interval of $t2 \in 0(1)25$ Months.

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Table 2Scenario 1 of the Impact of the Inclusion of a low Additive Random Environmental Perturbation Value $rni = 0.04$ of the Coefficient of the Depletion rate of Forestry Resources Biomass due to Crowding by Industrialization for a Time Interval $t \in 0\ (1) 25$.

Time,t(month)	N1	N22	EBD(%)	N2	N23	N3	N24	N4	N25
0	1.0000	1.0000	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.0000	9.5736	9.5058	0.7074*	2.1157	2.1149	1.2095	1.2095	0.4366	0.4362
2.0000	7.0728	7.0569	0.2246*	3.4008	3.3996	3.3726	3.3717	0.2041	0.2039
3.0000	3.7447	3.7472	0.0658	4.1844	4.1836	4.7828	4.7820	0.1059	0.1058
4.0000	1.9659	1.9660	0.0056	4.4796	4.4793	5.3807	5.3804	0.0679	0.0678
5.0000	1.2419	1.2409	0.0798*	4.5639	4.5637	5.5731	5.5729	0.0540	0.0539
6.0000	0.9567	0.9564	0.0289*	4.5826	4.5825	5.6248	5.6247	0.0489	0.0489
7.0000	0.8453	0.8448	0.0606*	4.5845	4.5845	5.6357	5.6358	0.0470	0.0470
8.0000	0.8049	0.8046	0.0428*	4.5833	4.5833	5.6365	5.6389	0.0463	0.0463
9.0000	0.7928	0.7925	0.0377*	4.5823	4.5822	5.6358	5.6366	0.0460	0.0460
10.0000	0.7907	0.7901	0.0723*	4.5817	4.5817	5.6346	5.6355	0.0459	0.0459
11.0000	0.7912	0.7905	0.0867*	4.5815	4.5815	5.6306	5.6343	0.0458	0.0458
12.0000	0.7919	0.7913	0.0725*	4.5815	4.5814	5.6347	5.6317	0.0458	0.0458
13.0000	0.7924	0.7919	0.0545*	4.5815	4.5814	5.6358	5.6288	0.0458	0.0458
14.0000	0.7926	0.7920	0.0710*	4.5815	4.5814	5.6363	5.6352	0.0458	0.0458
15.0000	0.7926	0.7921	0.0743*	4.5815	4.5815	5.6366	5.6353	0.0458	0.0458
16.0000	0.7927	0.7920	0.0800*	4.5815	4.5815	5.6315	5.6348	0.0458	0.0458
17.0000	0.7927	0.7924	0.0357*	4.5815	4.5815	5.6355	5.6335	0.0458	0.0458
18.0000	0.7927	0.7921	0.0693*	4.5815	4.5815	5.6365	5.6359	0.0458	0.0458
19.0000	0.7926	0.7921	0.0708*	4.5815	4.5815	5.6391	5.6383	0.0458	0.0458
20.0000	0.7926	0.7917	0.1258*	4.5815	4.5814	5.6375	5.6396	0.0458	0.0458
21.0000	0.7927	0.7920	0.0831*	4.5815	4.5814	5.6331	5.6354	0.0458	0.0458
22.0000	0.7927	0.7921	0.0684*	4.5815	4.5815	5.6360	5.6343	0.0458	0.0458
23.0000	0.7926	0.7924	0.0288*	4.5815	4.5815	5.6381	5.6364	0.0458	0.0458
24.0000	0.7927	0.7922	0.0582*	4.5815	4.5815	5.6359	5.6388	0.0458	0.0458
25.0000	0.7927	0.7921	0.0738*	4.5815	4.5815	5.6346	5.6340	0.0458	0.0458

*** indicates areas of biodiversity loss**

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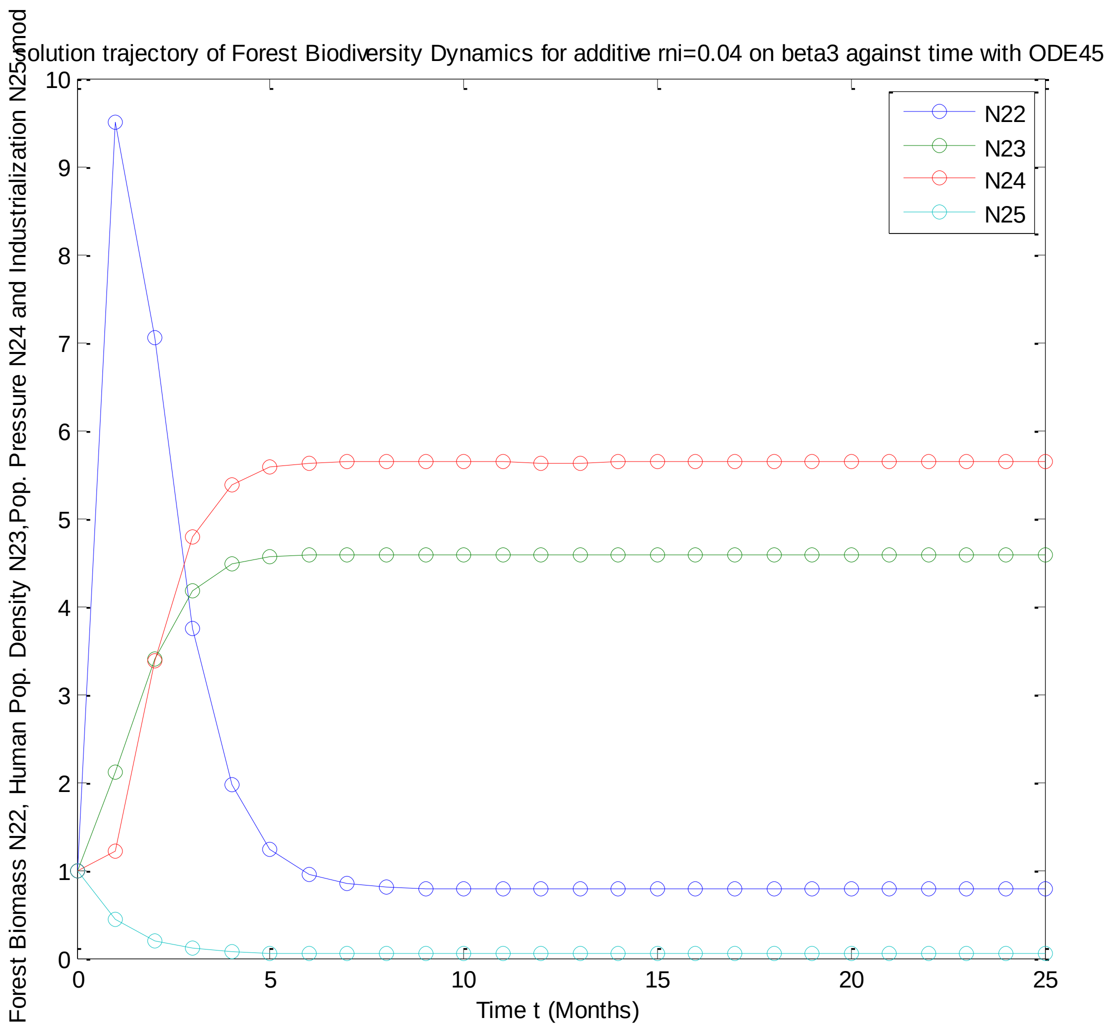

Figure 2: Solution Trajectory of the Impact of the Inclusion of a low Additive Random Environmental Perturbation Value $rni = 0.04$ of the Coefficient of the Depletion Rate of Forestry Resources Biomass due to Crowding by Industrialization for a Time Interval $t \in 0\ (1) 25$.

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Table 3:Scenario 1 of the Impact of the Inclusion of a low non Additive Random Environmental Perturbation Value $rni = 0.04$ of the Coefficient of the Depletion Rate of Forestry Resources Biomass due to Crowding by Industrialization for a Time Interval $t \in 0\ (1) 25$.

Time,t(month)	N1	N32	EBD(%)	N2	N33	N3	N34	N4	N35
0	1.0000	1.0000	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.0000	9.5736	9.6462	0.7583	2.1157	2.1166	1.2095	1.2095	0.4366	0.4371
2.0000	7.0728	7.0747	0.0273	3.4008	3.4023	3.3726	3.3737	0.2041	0.2045
3.0000	3.7447	3.7436	0.0284*	4.1844	4.1851	4.7828	4.7834	0.1059	0.1060
4.0000	1.9659	1.9659	0.0003*	4.4796	4.4798	5.3807	5.3809	0.0679	0.0679
5.0000	1.2419	1.2424	0.0411	4.5639	4.5640	5.5731	5.5732	0.0540	0.0540
6.0000	0.9567	0.9572	0.0465	4.5826	4.5827	5.6248	5.6249	0.0489	0.0489
7.0000	0.8453	0.8458	0.0592	4.5845	4.5845	5.6357	5.6358	0.0470	0.0470
8.0000	0.8049	0.8056	0.0830	4.5833	4.5834	5.6365	5.6369	0.0463	0.0463
9.0000	0.7928	0.7932	0.0553	4.5823	4.5823	5.6358	5.6376	0.0460	0.0460
10.0000	0.7907	0.7909	0.0312	4.5817	4.5817	5.6346	5.6368	0.0459	0.0459
11.0000	0.7912	0.7918	0.0852	4.5815	4.5815	5.6306	5.6352	0.0458	0.0458
12.0000	0.7919	0.7930	0.1419	4.5815	4.5815	5.6347	5.6332	0.0458	0.0458
13.0000	0.7924	0.7929	0.0744	4.5815	4.5815	5.6358	5.6331	0.0458	0.0458
14.0000	0.7926	0.7930	0.0594	4.5815	4.5815	5.6363	5.6359	0.0458	0.0458
15.0000	0.7926	0.7934	0.0946	4.5815	4.5815	5.6366	5.6364	0.0458	0.0458
16.0000	0.7927	0.7933	0.0751	4.5815	4.5815	5.6315	5.6351	0.0458	0.0458
17.0000	0.7927	0.7934	0.0882	4.5815	4.5815	5.6355	5.6329	0.0458	0.0458
18.0000	0.7927	0.7934	0.0950	4.5815	4.5815	5.6365	5.6334	0.0458	0.0458
19.0000	0.7926	0.7931	0.0596	4.5815	4.5815	5.6391	5.6362	0.0458	0.0458
20.0000	0.7926	0.7930	0.0402	4.5815	4.5815	5.6375	5.6366	0.0458	0.0458
21.0000	0.7927	0.7931	0.0601	4.5815	4.5815	5.6331	5.6353	0.0458	0.0458
22.0000	0.7927	0.7931	0.0513	4.5815	4.5815	5.6360	5.6328	0.0458	0.0458
23.0000	0.7926	0.7931	0.0553	4.5815	4.5815	5.6381	5.6340	0.0458	0.0458
24.0000	0.7927	0.7931	0.0601	4.5815	4.5815	5.6359	5.6364	0.0458	0.0458
25.0000	0.7927	0.7932	0.0633	4.5815	4.5815	5.6346	5.6350	0.0458	0.0458

*** indicates areas of biodiversity loss**

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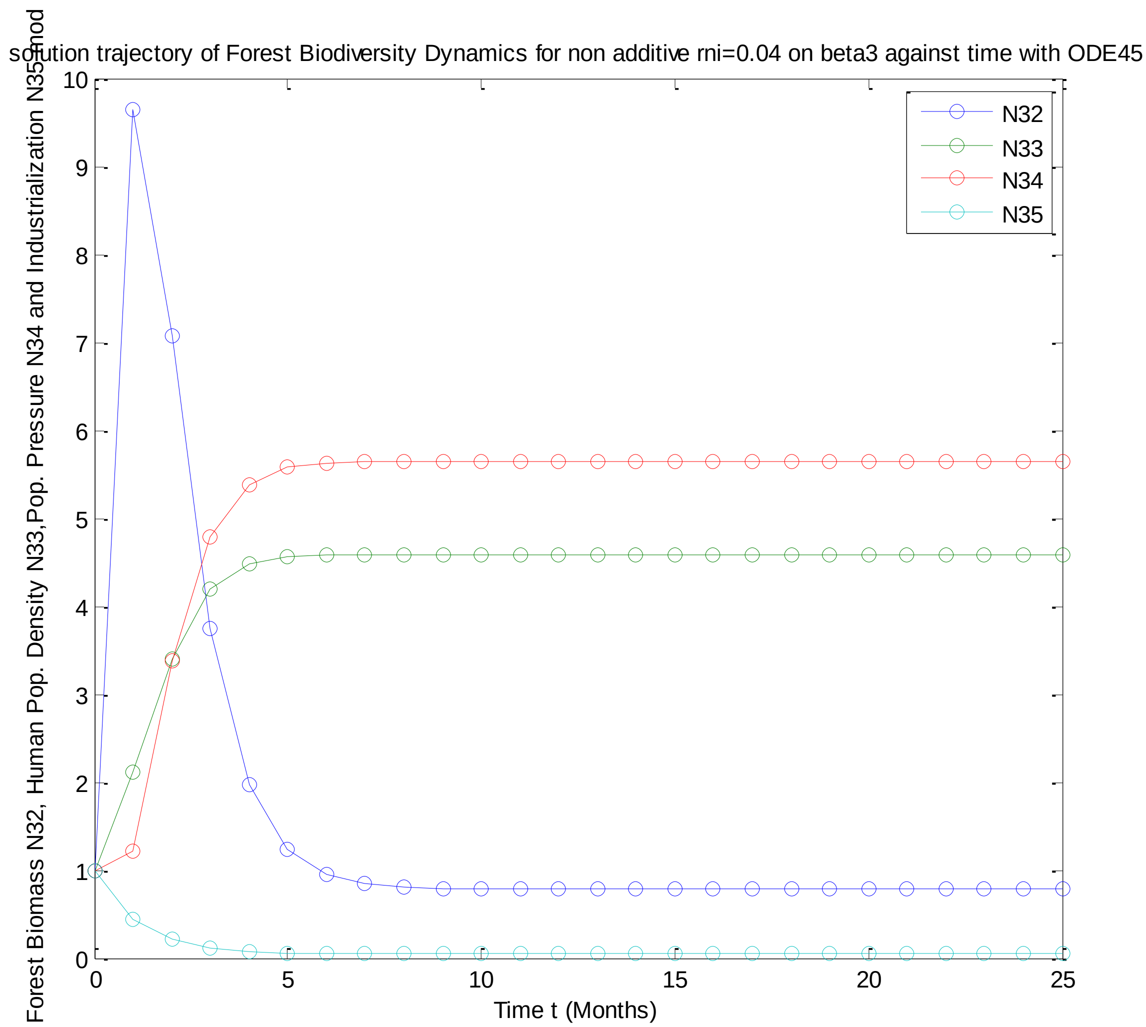

Figure 3: Solution Trajectory of the Impact of the Inclusion of a low non Additive Random Environmental Perturbation Value $rni = 0.04$ of the Coefficient of the Depletion Rate of Forestry Resources Biomass due to Crowding by Industrialization for a Time Interval $t \in 0\ (1)25$.

Discussion

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, as shown in Figure 1. 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 0.7907for 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

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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.

Scenario 1 of the Impact of the Inclusion of a low Additive Random Environmental Perturbation Value $\boldsymbol{rni = 0.04}$ of the Coefficient of the Depletion Rate of Forestry Resources Biomass due to Crowding by Industrialization for a Time Interval$\boldsymbol{t \in 0\ (1)25}$ as shown in Figure 2.

The Impact of the inclusion of a low additive random environmental perturbation value $rni = 0.04$ of the coefficient of the depletion rate coefficient of forestry resources biomass due to crowding by industrialization for a time interval$t \in 0\ (1)25$.Eight (8) coordinates were examined namely: N1 being the forest resource biomass for fixed values, N22 being the modified forest resource biomass, N2 being the human population density for fixed parameter values, N23 being the modified population density, N3 being the population pressure for fixed parameter values, N24 being the modified population pressure and N4 being the industrialization for fixed parameter values, and N25 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 are recorded as 1.0000, 1.0000, 1.0000 and 1.0000. The inclusion of a low additive random environmental perturbation of the coefficient of the depletion rate of forestry resources biomass due to crowding by industrialization, recorded a massive biodiversity loss on the modified forest resources biomass. However there was a steady rise in the modified human population density, which translated to a rise in the modified population pressure. This was not the case for the modified industrialization which recorded a decline.

Scenario 1 of the Impact of the Inclusion of a low non Additive Random Environmental Perturbation Value $\boldsymbol{rni = 0.04}$ of the Coefficient of the Depletion Rate coefficient of Forestry Resources Biomass due to Crowding by Industrialization for a Time Interval $\boldsymbol{t \in 0\ (1)25}$, as shown in Figure 3.

In studying the Impact of the inclusion of a low non additive random environmental perturbation value $rni = 0.04$ of the coefficient of the depletion rate of forestry resources biomass due to crowding by industrialization for a time interval $t \in 0\ (1)25$, eight (8) coordinates were examined namely: N1 being the forest resource biomass for fixed values, N32 being the modified forest resource biomass, N2 being the human population density for fixed parameter values, N33 being the modified population density, N3 being the population pressure for fixed parameter values, N34 being the modified population pressure and N4 being the industrialization for fixed parameter values, and N35 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 are recorded as 1.0000, 1.0000, 1.0000 and 1.0000. A biodiversity loss was recorded for the third and fourth months, while the remaining twenty – three months recorded a biodiversity gain. The modified forest resources biomass recorded a decline in the first ten months. The fourteenth, sixteenth, nineteenth and twentieth months also recorded a decline, while an increase was recorded for the eleventh, twelfth, thirteenth, fifteenth and seventeenth months. The modified human population density recorded a steady rise for the first seven months; this trend was reversed to a decline which converged to 4.5815 through the remaining fifteen months. The modified industrialization declined steadily from 0.4371 to 0.0458 between the first through the eleventh months where it converged till the twenty – fifth month. This is an indication that the inclusion of a low non additive random environmental perturbation value $rni = 0.04$ of the coefficient of the depletion rate of forestry resources biomass due to crowding by industrialization has an adverse effect on the modified forest resource biomass but enhanced the effect on the modified human population density as well as the modified population pressure.

Conclusion

Environmental perturbation which refers to disturbances or disruptions on the natural environment can be caused by various factors including humans (anthropogenic activities). These perturbations affect ecosystems leading to changes in population dynamics, species composition, deforestation, pollution, and industrialization. The inclusion of a low additive environmental perturbation resulted in a massive biodiversity loss; while the inclusion of a non additive random environmental perturbation resulted in a biodiversity gain. It is therefore very important to note that the inclusion of an additive environmental perturbation has adverse effect on the forest biodiversity. This additive environmental perturbation could be of various degrees; ranging from low, mild and severe. The higher the value, the more adverse the effect will be.

Recommendations

1. Effective policy measures should focus on mitigating deforestation, promoting reforestation, and enhancing land-use planning to minimize adverse impacts on forest biomass.
2. 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.
3. 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.
4. Addressing the challenges posed by anthropogenic activities on forest biomass requires a collaborative effort that combines advanced computational techniques with actionable policy measures.
5. 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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