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SIMULATION MODELING OF BIODIVERSITY

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ABSTRACT

In the discipline of entomology, the crop science policy of minimizing plant disease effect in order to obtain improved yield between the interacting plant species is a long standing theoretical and experimental idea. In this present analysis, we have applied the method of ODE 45 numerical simulations to obtain novel results that we have not seen elsewhere which are in tandem with the above policy. We would expect these observations to provide further insight on how to select the disease condition variation that will enhance and sustain biodiversity gain and avoid the introduction of a disease condition variation that will likely predict biodiversity loss. The full results of this study are presented and discussed quantitatively only in the context of two dissimilar carrying capacities scenario.

Introduction:

The growth of two plant species over time especially in the context of two plant species that compete for a limited resource in a harsh climate such as the arctic (Ekaka-a 2009) can be quantitatively analyzed by constructing a continual dynamical system of nonlinear first order differential equation that captures the key factors that either enhance or inhibit the growth of the two plant species over time. Such as two intrinsic growth rate that enhance the growth of the two plant species over time, two intra-competition coefficient that inhibit the growth of the two plant species over time, two inter-competition coefficient that inhibit the growth of the two

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Plant species over time in the scenario of competition, the inclusion of plant disease factors that inhibit the growth of the two plant species over time and the choice of equal initial condition that can be used to study the effect of plant disease condition on two competing plant species.

Ford, Lump and Ekaka-a (2010) constructed a deterministic modeling of two plant species interactions in a harsh climate using the ordinary differential equations of order 45 (ODE 45) numerical method. They observed that by extending the length of the growing season, their proposed model can be used to manipulate the environment and to draw simple conclusions on the climate change effect on the two interacting plant species in the arctic region.

Campbell and Madden (1990) reviewed the principles and methods involved in the monitoring of epidemics of plant diseases and they described the knowledge of the possible applications of epidemiology.

Nafo and Ekaka-a (2013) considered the interaction between two legumes such as cowpea and groundnut that depends on the mathematical modeling tool that uses a system of continuous non linear first order ordinary differential equations. A feedback control that was used to stabilize an unstable steady state solution was developed.

Thebault and Loreau (2005) considered the relationship between biodiversity and the functioning of the ecosystem in food web using an ecosystem simple model analysis. Observation was made that the interactions of the trophic have a stronger impact on the relationship.

Neville, Lump and Ekaka-a (2010) studied the plant species interactions mathematical modeling in a harsh climate. Summer and winter season models were used.to provide new insight into the known behavior of the interactions of plant species.

Cardinale, Duffy, Gonzalet, Hooper, Pernings, Venail, Nanwani, Mace, Tilman, Wardle, Kinzig, Daily, Loreau, Grace, Larigauderie, Srivastava and

Naeem (2012) reviewed the research of two decades on how the loss of biodiversity influences ecosystem functioning and its impact on goods and services. It was observed that the loss of biodiversity decreases the functioning of ecosystem stability through time. The impact of biodiversity is non-linear and saturating in any single ecosystem process such that the charges increases as biodiversity loss increases.

Plank (1963) described new methods of epidemiological analysis that was mainly based on the relation between the amount of inoculum and the disease it produces likewise the infection rates.. He used control-by-sanitation, resistant varieties method to conduct the analysis. The result reduced either the infection rate or the inoculum or both.

Barbetti, You, Li, Ma x and Sivasithamparam (2018) studied the management of root diseases of pastures legumes using the cultural strategies control and soil fertility method that resulted to the legumes overall growth improvement.

Amusa, Adegbote, Mohammed and Balyehru (2003) considered different diseases associated with Yam and its management strategies. Observation was made that the most widely spread of all the field diseases was anthracnose while yam mosaic virus and dry rot causes severe losses in yam. The management strategies applied were use of crop rotation, fallowing, planting of healthy materialand and the use of resistant cultivars.

Atsu and Ekaka-a (2017) examined modeling intervention with respect to Biodiversity loss using computationally numerical scheme. They observed that a shorter length of the growing season predicts a biodiversity loss and an increased length of the growing season predicts a biodiversity gain.

James (1974) considered the assessment of plant disease and losses. The measurement of disease-loss appraisal was used to determine the loss of economic due to different amount of diseases.

Walker (1983) considered losses of crops such that the effects of pests, diseases and weeds on agricultural production was monitored. The use of information about crop losses was adopted as it helps the prevention of pest and disease attack on crops to be achieved.

Materials and Methods

Assumptions

1. The growth of the first and second plant species is enhanced by their intrinsic growth rate which is defined as the difference between the birth rate and the death rate of the plant species.
2. The growth of the first and second plant species is inhibited by their intra-competition coefficient that is due to the self interaction between individual plant species.
3. The growth of the plant species also is inhibited by the inter-competition coefficient that is due to the interactions between the plant species.
4. The growth of the plant species is inhibited by the effect of the plant disease on the plant species.

Mathematical Formulations

Following Ekaka a (2009), we have considered the following system of continuous nonlinear first order differential equation.

$$\frac{dx(t)}{dt} = \alpha_1 x - \beta_1 x^2 - r_1 xy - k_1 x^2 y \quad (1)$$

$$\frac{dy(t)}{dt} = \alpha_2 y - \beta_2 y^2 - r_2 xy - k_2 xy^2 \quad (2)$$

Having the initial data $x(0) > 0$ and $y(0) > 0$

For the purpose of clarity, the variables for these model equations are defined as follows:

x represents first plant species.

y represents second plant species.

α_1 represents the intrinsic growth rate (the difference between the birth rate and the death rate) of the first plant species.

α_2 represents the intrinsic growth rate (the difference between the birth rate and the death rate) of the second plant species.

β_1 represents the intra competition coefficient due to the interaction of the first population with itself to inhibit its growth.

β_2 represents the intra competition coefficient due to the interaction of the second plant species with itself to inhibit its growth.

r_1 represents the inter competition coefficient due to the interaction of the second population to inhibit the growth of the first population.
r_2 represents the inter competition coefficient due to the interaction of the first population to inhibit the growth of the second population
k_1 represents disease condition affecting first plant species
k_2 represents disease condition affecting second plant species.
Following Ekaka-a (2009), we have considered the following parameter values:
$\alpha_1 = 0.168, \alpha_2 = 0.002, \beta_1 = 0.0020339, \beta_2 = 0.000015, r_1 = 0.0005, r_2 = 0.00002, k_1 = 0.1, k_2 = 0.1.$

Notations
In this study, the meaning of each notation is specified as follows;
LGS represents length of growing season
PB1 (old) column represents the data values of the first plant biomass when all the model parameters values are fixed.
PB1 (new) column represents the data values of the first plant biomass when parameter values of k_1 changes and all other model parameter values fixed.
EBG1(%) column represents the estimated biodiversity gain of the first plant species in percentage.
PB2 (old) column represents the data values of the second plant biomass when all the model parameter values are fixed.
PB2 (new) column represents the data values of the second plant biomass where all the other model parameters are fixed except k_2.
EBG2(%) column represents the estimated biodiversity gain of the second plant species in percentage.
EBL1(%) column represents the estimated biodiversity loss in percentage of the first plant species.
EBL2(%) column represents the estimated biodiversity loss in percentage of the second plant species.
g/A represents grams per area plant cover

Method of Analysis

The key method of analyzing the proposed problem in these work is defined as follows:

$$EBG1(\%) = [\frac{PB1\text{ (new)} - PB1\text{ (old)}}{PB1\text{ (old)}}](100)$$

$$EBG2(\%) = [\frac{PB2\text{ (new)} - PB2\text{ (old)}}{PB2\text{ (old)}}](100)$$

$$EBL1(\%) = [1 - \frac{PB1\text{ (new)}}{PB1\text{ (old)}}][100]$$

$$EBL2(\%) = [1 - \frac{PB2\text{ (new)}}{PB2\text{ (old)}}](100)$$

Results

On the application of the above mentioned method, we have obtained the following results in the context of two dissimilar carrying capacities as displayed in Table 1 – Table 5.

Table 1 Decreasing the effect of equal plant disease condition on the yields of two plant species and its implication on biodiversity: $k_1 = k_2 = 0.001$.

LGS	PB1(old) g/A	PB1(new) g/A	EBG1(%)	PB2(old) g/A	PB2(new) g/A	EBG2(%)
1	0.2500	0.2500	0.00	0.2500	0.2500	0.00
31	9.3404	25.3006	170.87	0.0776	0.2524	225.26
61	43.9908	74.4583	69.26	0.0115	0.1781	1448.70
91	66.8711	77.3732	15.70	0.0039	0.1281	3184.62
121	73.8448	78.5682	6.40	0.0022	0.0997	4431.82
151	76.5762	79.2670	3.51	0.0015	0.0816	5340.00
181	78.1319	79.8064	2.14	0.0011	0.0691	6181.82
211	78.9867	80.1536	1.48	0.0009	0.0599	6555.56
241	79.6353	80.4323	1.00	0.0007	0.0529	7457.14
271	80.0099	80.6512	0.80	0.0006	0.0474	7800.00
301	80.3494	80.8865	0.67	0.0006	0.0430	7066.67
331	80.5177	80.9724	0.56	0.0005	0.0394	7780.00
361	80.8200	81.1233	0.38	0.0004	0.0363	8975.00
391	80.9341	81.2181	0.35	0.0004	0.0337	8325.00
421	81.0992	81.3860	0.35	0.0004	0.0315	7775.00

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Table 2 Decreasing the effect of equal plant disease condition on the yields of two plant species and its implication on biodiversity: $k_1 = k_2 = 0.005$

LGS	PB1(old) g/A	PB1(new) g/A	EBG1(%)	PB2(old) g/A	PB2(new) g/A	EBG2(%)
1	0.2500	0.2500	0.00	0.2500	0.2500	0.00
31	9.3404	22.2554	138.27	0.0776	0.2163	178.74
61	43.9908	65.1294	48.05	0.0115	0.0849	638.26
91	66.8711	73.3936	9.75	0.0039	0.0455	1066.67
121	73.8448	76.4153	3.48	0.0022	0.0304	1281.82
151	76.5762	78.0159	1.88	0.0015	0.0228	1420.00
181	78.1319	78.8968	0.98	0.0011	0.0182	1554.55
211	78.9867	79.5484	0.71	0.0009	0.0151	1577.78
241	79.6353	79.9565	0.40	0.0007	0.0129	1742.86
271	80.0099	80.3510	0.43	0.0006	0.0113	1783.33
301	80.3494	80.5169	0.21	0.0006	0.0101	1583.33
331	80.5177	80.7695	0.31	0.0005	0.0091	1720.00
361	80.8200	80.9058	0.11	0.0004	0.0083	1975.00
391	80.9341	81.1116	0.22	0.0004	0.0076	1800.00
421	81.0992	81.1498	0.06	0.0004	0.0070	1650.00

Table 3 Decreasing the effect of equal plant disease condition on the yields of two plant species and its implication on biodiversity: $k_1 = k_2 = 0.0995$

LGS	PB1(old) g/A	PB1(new) g/A	EBG1(%)	PB2(old) g/A	PB2(new) g/A	EBG2(%)
1	0.2500	0.2500	0.00	0.250000	0.250000	0.00
31	9.3404	9.3596	0.21	0.077573	0.077758	0.24
61	43.9908	44.0302	0.09	0.011541	0.011580	0.34
91	66.8711	66.8838	0.02	0.003916	0.003932	0.41
121	73.8448	73.8494	0.01	0.002164	0.002174	0.46
151	76.5762	76.5777	0.002	0.001471	0.001378	**6.32**
181	78.1319	78.1327	0.001	0.001109	0.001115	0.54
211	78.9867	78.9873	0.001	0.000889	0.000893	0.45
241	79.6353	79.6348	**0.001**	0.000742	0.000746	0.54
271	80.0099	80.0103	0.0005	0.000637	0.000640	0.47
301	80.3494	80.3503	0.001	0.000558	0.000561	0.54

331	80.5177	80.5187	0.001	0.000497	0.000500	0.60
361	80.8200	80.8196	**0.0005**	0.000449	0.000451	0.45
391	80.9341	80.9339	**0.0002**	0.000409	0.000411	0.49
421	81.0992	81.1001	0.001	0.000376	0.000438	16.49

Table 4 Increasing the effect of equal plant disease condition on the yields of two plant species and its implication on biodiversity: $k_1 = k_2 = 0.101$

LGS	PB1(old) g/A	PB1(new) g/A	EBL1(%)	PB2(old) g/A	PB2(new) g/A	EBL2(%)
1	0.2500	0.2500	0.00	0.250000	0.250000	0.00
31	9.3404	9.3024	0.41	0.077573	0.077213	0.46
61	43.9908	43.9126	0.18	0.011541	0.011463	0.68
91	66.8711	66.8458	0.04	0.003916	0.003884	0.82
121	73.8448	73.8355	0.01	0.002164	0.002145	0.88
151	76.5762	76.5734	0.004	0.001471	0.001457	0.95
181	78.1319	78.1301	0.002	0.001109	0.001109	0.00
211	78.9867	78.9855	0.002	0.000889	0.000881	0.90
241	79.6353	79.6361	0.001	0.000742	0.000735	0.94
271	80.0099	80.0093	0.001	0.000637	0.000631	0.94
301	80.3494	80.3475	0.002	0.000558	0.000553	0.90
331	80.5177	80.5159	0.002	0.000497	0.000493	0.80
361	80.8200	80.8207	0.001	0.000449	0.000444	1.11
391	80.9341	80.9345	0.0005	0.000409	0.000405	0.98
421	81.0992	81.0972	0.002	0.000376	0.000372	1.06

Table 5 Increasing the effect of equal plant disease condition on the yields of two plant species and its implication on biodiversity: $k_1 = k_2 = 0.11$

LGS	PB1(old) g/A	PB1(new) g/A	EBL1(%)	PB2(old) g/A	PB2(new) g/A	EBL2(%)
1	0.2500	0.2500	0.00	0.250000	0.250000	0.00
31	9.3404	8.9814	3.84	0.077573	0.074160	4.40
61	43.9908	43.2388	1.71	0.011541	0.010820	6.25
91	66.8711	66.6264	0.37	0.003916	0.003617	7.64
121	73.8448	73.7561	0.12	0.002164	0.001986	8.23

151	76.5762	76.5562	0.03	0.001471	0.001346	8.50
181	78.1319	78.1054	0.03	0.001109	0.001014	8.57
211	78.9867	78.9762	0.01	0.000889	0.000812	8.66
241	79.6353	79.6333	0.003	0.000742	0.000677	8.76
271	80.0099	79.9870	0.03	0.000637	0.000581	8.79
301	80.3494	80.3337	0.02	0.000558	0.000509	8.78
331	80.5177	80.5666	**0.06**	0.000497	0.000453	8.85
361	80.8200	80.8516	**0.04**	0.000449	0.000409	8.91
391	80.9341	80.9290	0.01	0.000409	0.000372	9.05
421	81.0992	81.0643	0.04	0.000376	0.000342	9.04

Discussions of Results

In Table 1, we have observed that the first plant species has shown an evidence of 0.35% biodiversity gain whereas the second plant species has shown an evidence of 7775% biodiversity gain in the context of two dissimilar carrying capacities.

From Table 2, we have similarly observed that the effective biodiversity gain for the first plant species is 0.06% and the second plant species is 1650% biodiversity gain in the context of two dissimilar carrying capacities.

From Table 3, the estimated biodiversity gain shows an evidence of 0.001% and 16.49% for the first and second plant species respectively in the context of two dissimilar carrying capacities.

In Table 4, we have observed that the first plant species has shown an evidence of biodiversity loss of 0.002% whereas the second plant species has shown an evidence of 1.06% biodiversity loss in the context of two dissimilar carrying capacities.

In Table 5, similarly, we have observed that the estimated biodiversity loss has shown an evidence of 0.04% and 9.04% in the first and second plant species respectively in the context of two dissimilar carrying capacities.

Conclusion

We have used the method of ODE 45 numerical simulation to obtain the following;

1. By decreasing the disease factor on the two interacting plant species that compete for a limited resource in a harsh climate ecosystem setting, we have found a dominant biodiversity gain which continues to decrease in magnitude up to the lower limit of the bifurcation interval and thereafter changes to a relatively biodiversity gain scenario.
2. By increasing the disease factor on the two interacting plant species that compete for a limited resource in a harsh climate ecosystem, we have found a relatively biodiversity loss to an extend.

Considering the fact that the intrinsic growth rate parameter values $\alpha_1 = 0.168$ and $\alpha_2 = 0,002$ are not known exactly, it will be a good idea to study the effect of including a random noise fluctuation in a semi stochastic sense and its implication on the prediction of either biodiversity loss or biodiversity gain numerically. This open problem which we did not consider in this study will be the subject of our next research investigation.

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