Faculty of Bioengineering

LBRTI2102: Process-based modelling in bioscience engineering

Project Report - Predator-prey model of cattle and grassland in Enugu, Nigeria

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1.0 Introduction

Livestock grazing is one of the major sources of food and livelihood in Nigeria. Almost half of the total protein demand depends solely on beef compared to other sources. Like other developing countries, agriculture and livestock farming contribute to 70% of the total occupation in Nigeria (Duru, 2022). However, there is a spatial variability of cattle production in Nigeria. Almost 97% of total cattle are produced in northern Nigeria. The southern part of the country on the other hand provides a huge market for cattle as this region has not been recognized for commercial cattle production. (National Open University of Nigeria, 2004a). Therefore, cattle nomadism plays a significant role in transporting these cattle from north to south, particularly with the increasing depletion of arable grassland for these cattle in the north.

1.1 Background of the study

Nigeria has this centuries-old culture of seasonal cattle migration by a group of pastoral nomads, popularly known as Fulani herdsmen, an ethnic community culturally segregated from other Nigerians. Currently, almost seven million Fulani are living within grassland savannas in the Sahel and semi-arid part of west Africa, among which half of them are in the northern part of Nigeria. During the beginning of the dry season, the northern part of the country gets unproductive due to excessive heat and drought. On the other hand, the southern part remains productive because of its proximity to the Atlantic ocean and rainforests in the coastal belts. In search of grassland, fallow fields, and surface water, the Fulani community drives their cattle from the drier northern regions to wetter southern regions. They stay in the south until the drought subsides and farmers start farming after the seasonal break. In a nomad group, around 10 to 20 families, each controlling 20 to 40 head of cattle, travel an average distance of 180 miles in search of arable pasture. This journey is recognized as a slow journey that takes five to six months as nomads take intermittent rests in favorable places for food and shelter (Lambrecht, 1976).

Although this nomadism has been practiced peacefully in Nigeria for centuries and is well known for its symbiotic relationship with farmers, several deadly conflicts have arisen with local farmers in the south in recent eras. During the period of 2010 to 2016, casualties increased to 3000%, reporting 2500 deaths in 2016 by conflicts between cattle headers and local farmers (Eke, 2020) because these cattle herders tend to stay for a longer time than usual, resulting in the destruction of the crops of local farmers by their cattle. Severe climatic pressure (low rainfall, drought, etc.) in the northern region creating resource scarcity during the dry season also indirectly forces them to stay long in the south. Usually, their environmental impacts (southward migration) are compensated by grassland regrowth during the rainy season when cattle headers migrate back to the north. However, excessive grazing beyond the carrying capacity of the environment for a shorter period creates irreversible environmental burdens, soil degradation, and crop damage. It is therefore crucial to estimate the grazing duration within the carrying capacity of the environment in order to take necessary steps to protect southern lands from overgrazing.

By considering resource availability, cattle population dynamics, and other factors, a model would help to estimate the maximum duration of sustainable grazing and the number of cattle that a system can accommodate to avoid overgrazing. It is based on this premise that this study aims to create a model to estimate the carrying capacity of one of the favorite destinations of the cattle herders, and how long it will take to finish the arable grassland in this location by considering their biomass, population dynamics, environmental variables, grazing capacity and exchange of energy within the system. This will help policymakers and planners to implement sustainable resource management by taking intervention before the complete depletion of the grassland in this location.

1.2 Literature Review

Nature is governed by complex interactions between species and biogeochemical cycling. It is difficult to detect these subtle interactions but sometimes it is necessary to understand the environmental functioning. Mathematical modeling opens a new door to translating natural processes into mathematical equations (Obaid, 2013). This quantitative understanding helps us to create a simulation by examining the key parameters, variables, interrelations, and spatial and temporal dynamics of the system. In the field of biosciences engineering, mathematical modeling has been practically useful to understand the dynamics of both natural and man-made systems. Models are also used for making realistic predictions by setting up some relevant parameters despite predefined uncertainties and errors. One of the popular ecological models is the predator-prey model introduced by Alfred J Lotka in 1910, which helps us to understand the population dynamics in a system where one community plays as a predator and the other the community prey. Usually, the predator increases when the prey is abundant at the beginning and decreases when the prey number declines. Prey on the other hand tries to escape from predation by speed, camouflage, sight, hearing, etc. If the predator population declines, the prey's population exceeds the carrying capacity in the system, and eventually, the prey also dies in the absence of food. Therefore, predators and prey evolve together in a complex biological system through their evolutionary force. Many studies have been using this predator-prey model simulation by adapting it according to their desired systems.

In a study, Hsieh & Hsiao (2008) considered a predator-prey model with infectious disease in both populations, as the contagious disease spreads from one species to another and found more complex dynamics. Another study also modified the predator–prey model by using logistic growth in the prey population as infected prey are more vulnerable to predation. Vulnerable prey can easily be hunted which helps the predators to survive, and also by killing the last infected individual, the disease can die out which can otherwise be endemic (Hethcote et al., 2004). In 1997, Wang & Chen adapted the predator-prey model in their study as all the predators do not possess an equal likelihood of attacking the prey. Immature predators are raised by their parents and therefore do not attack the prey until a certain age (Wang & Chen, 1997). In assessing the impact of overexploitation of a system, Martin & Ruan (2001) used predator-prey models by considering the maximum sustainable yields (MSY), which indicates that overexploitation of resources beyond the system's carrying capacity leads to a loss in productivity. This study took into consideration how much harvesting is possible without dangerously altering the harvested population which lies between 40% to 60% of carrying capacity in most population growth modeling (Martin & Ruan, 2001).

Predator-prey model has not only been used in ecological or disease modeling, but several studies have also adapted it for grassland and livestock modeling (Cameroni & Fort, 2017; Fort, 2020; Fort et al., 2017). Cameroni & Fort (2017) developed a predator-prey grassland livestock (PPGL) model by adapting the Lotka-Volterra predator-prey model, using two variables: grass growth rate and individual lightweight of the animal. The PPGL model also translated the non-linear interaction between the variables (weight variation, reproduction, forage ability, consumption rate, carrying capacity, etc.). Also, in estimating the optimal range of food production in a system, Fort et al. (2017) presented two examples based on predator-prey dynamics and the Lotka-Volterra equation for food production optimization in an agroecosystem and more recently, a study that used PPGL for spring forage stash modeling as an extension of the conventional predator-prey model (Pereira Machín & Cameroni, 2022).

The Lotka-Volterra model explains the interaction between or within different species and their living environment, taking into account their temporal variability. This model provides the motivation for developing a predator-prey model for grassland depletion in the southern part of Nigeria due to seasonal grazing.

1.3 Aim and Objectives

The aim of this model is to examine the temporal relationship between the grassland and the cattle in Enugu State (South-eastern Nigeria) and to estimate the carrying capacity of the system. To achieve this aim, the following objectives will be applied.

- Estimate the total grassland coverage of the study area
- Understand the complexity of the prey and predator biology (growth, consumption, biomass, etc.) to estimate model parameters
- Model the system to show the relationship between the two organisms in the ecosystem

1.4 Study Area

The two locations that are of primary focus in this study are Kaduna in Kaduna State, Northern Nigeria, and Enugu in Enugu State, South-eastern Nigeria, where Kaduna is the origin location and Enugu is the destination. Kaduna was selected as the origin because it represents more than 30% of the cattle herders' population in Nigeria and is known as the state with the highest cattle production rate in the country. The state is covered by the Sudan savanna vegetation, characterized by scattered short trees and shrubs. Temperature is generally hot and dry during the dry seasons and humid during the short rainy seasons. Enugu was selected as the destination location because of the abundance of savannah grassland in the area and its proximity to the north compared to other southern states. It is also known as the state with the best water source in the country, and a favorable location for cattle herders. Situated on the green hills of the Enugu plateau, the destination is known to have a transition between derived savannah predominantly made up of the *Andropogon* grass species and rainforest vegetation (Akanazu, 2016). The climate is generally humid, and its humidity is highest between March and November during the rainy season.

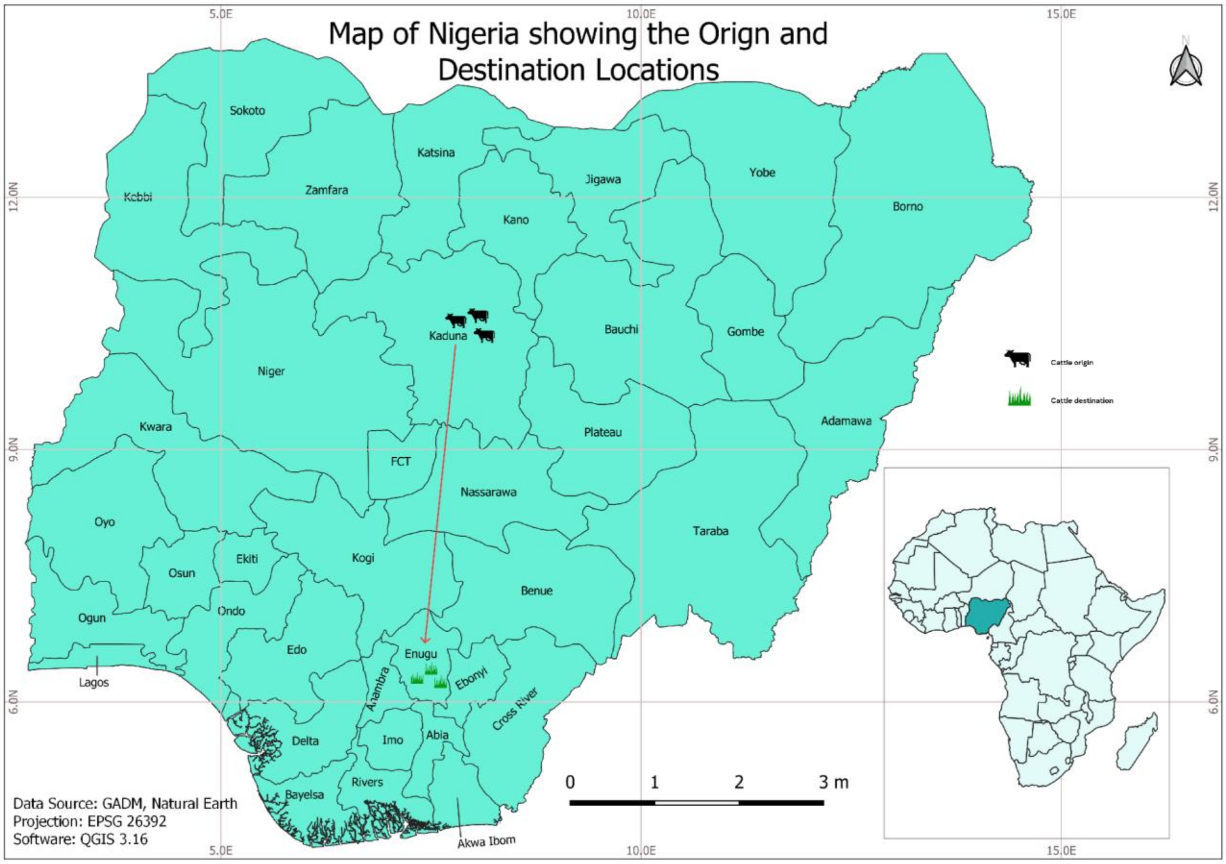

Figure 1 - Map of Nigeria showing the origin and destination location

1.5 Methodology

To forecast and anticipate the behavior of a complex system, natural characteristics are translated into a mathematical model. In our case, we used a logistic growth model to understand the complex system between cattle and grassland grazing in Nigeria. From the literature review, we are convinced that for estimating grassland depletion we can use predator-prey-based models to examine the temporal interaction between the two communities of species within the system. For the parameterization of the data used in this model, different variables were used from empirical literature that reflects possible situations in the field.

1.5.1 Assumptions of the model

Mathematical models cannot fully translate complex natural phenomena. Therefore, all models are based on some assumptions beyond which the model is not applicable. For simplification, this model is based on the following assumptions:

1. The cattle live only on foraged grass, with no hay or any other cow food. The grass is also considered a single representative species (Andropogon spp.) rather than a complex mixture in the field.

2. Only the height of the grass is considered for available grass biomass, and the grass is evenly distributed throughout the pasture.

3. Only the linear tendency of weight gain on grass consumption rate was considered.

4. The cattle population is homogenous in physical characteristics. All cows are assumed to have the same weight, growth rate, and consumption rate.

5. Not all headers move from the origin to the destination, only a percentage of them move towards the destination in search of pastures.

6. The male population is 7 times more than the female population.

1.5.2 The model applied

The model applied in this study is the predator-prey model. Predator-prey models are increasingly used to explain the interaction between two species in a given system. In a system, the result of the interaction between the prey and the predator can be explained by losses of prey populations by predation and the biomass gain of predator population by eating the prey. In this case, the cattle were considered the predator and the grasses as the prey. Therefore, Lotka-Volterra simple equation can be used to translate the field situation thus:

$dx/dt = ax - bxy$ ………………………………………………………………………. (1)

$dy/dt = cxy - dy$ ……………………………………………………………………...(2)

where *dx/dt* and *dy/dt* represent the evolution of grass biomass and the evolution of cow biomass over time. In the absence of cows, the grassland will grow exponentially and result in *+ax*, predation over time would reduce the per capita grass growth rate by *'b'* which is proportional to the total prey and predator population *(-bxy)*. On the other hand, when there is no prey, the predator population would be exponentially decreased to *-dy*, over time cow's growth rate would be per capita growth due to grass consumption multiplied with the total population of the system. In that closed system, *bxy* is the loss of energy from the prey and *cxy* is the energy gain as predator biomass.

Lotka-Volterra equation is developed for the predator and unlimited prey. However, this classical equation has several limitations such as unrealistic assumptions, structurally unstable solutions, and problems with saturation effects. To avoid these problems Cameroni & Fort (2017) developed a realistic equation that used a non-linear response function to explain the grassland dynamics in a predator-prey system considering weight variation, reproduction, forage ability, consumption rate, carrying capacity, etc. This equation was translated to represent the interaction over time, between the grassland and cattle community in the destination ecosystem of the study.

dx/dt = r*x*(1-x/k) -((c*s*x**2*y**0.75)/(H**2+x**2))...................................(3)

dy/dt = b*y**0.75*((c*x**2/(H**2+x**2))-l) ....(4)

Where *r* is the pasture growth rate, *c* is the grass intake rate, *s* is the stocking rate, *H* represents half saturation grass intake, *k* is the carrying capacity, *b* is grass conversion efficiency, and *I* is the minimum grass requirement.

1.5.3 System Model Interaction

The general model of the system is the predator-prey system with limited capacity where the cattle is the predator, and the grassland is the prey. The grassland coverage in the ecosystem is limited as not all areas are covered in grassland and the cattle population does not leave the ecosystem as they are restricted to only the resources within the system. The interaction in the system can be expressed using the figure below.

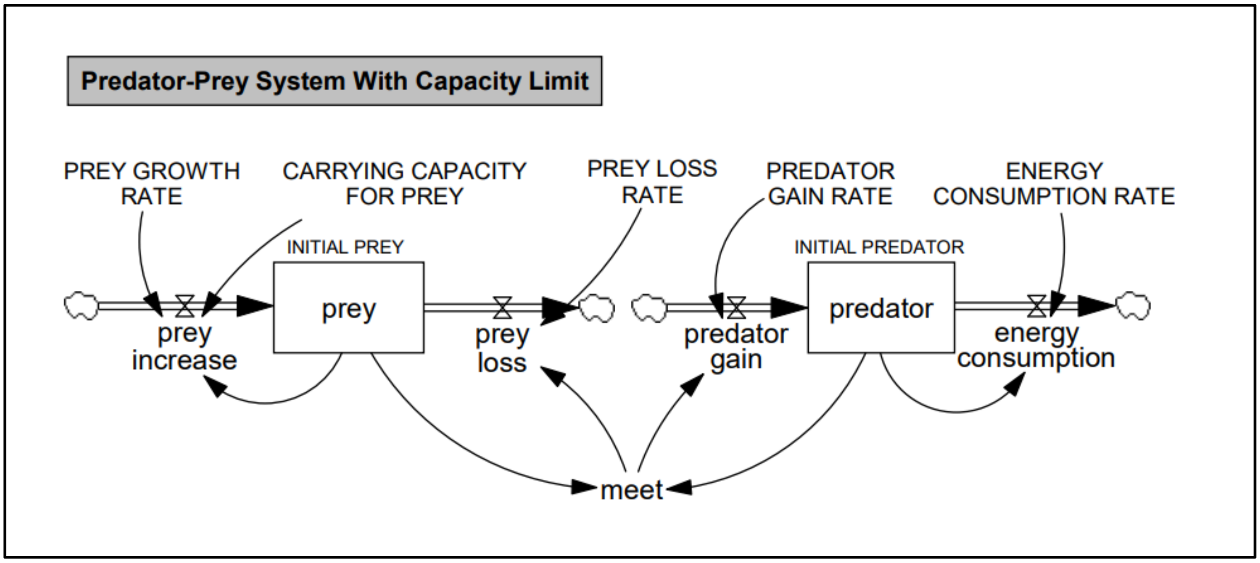

Figure 2 – System model interaction between predator and prey. (Source: Hanert, 2022)

Another system model interaction that could be applied to this system is the predator with two populations of prey interaction particularly as an alternative prey population was introduced into the model to examine the changed condition of the system when there is another prey. The second prey introduced into the model shares similar characteristics with the initial prey only with the exclusion of growth rate, so this variable was excluded from the model. It is also important to note that the second prey was introduced only at a specific period into the system to see the effect of its presence in the model.

1.5.4 Parameterization of the model

For the model simulation, eight parameters were estimated that represented the variables in the system - r (prey growth rate), c (prey loss), H (half saturation grass intake), b (predator energy conversion rate), l (predator biomass), s (predator stocking rate), kmax and kmin (maximum and minimum carry capacity of the system), and CC (deviation average of the NPP). These eight parameters were estimated from empirical data sources, however, some of these parameters were modified to reflect the condition of the system based on the information obtained from these secondary data sources such as published journals, research articles, websites, and blogs.

1.5.4.1 Prey growth rate (r): This is the maximum growth rate of the grasses per day. It was estimated that grasses of the Andropogon species grow up to 0.02cm per day (Dieter, 1972), thus, this parameter was not adjusted for the model because the grass specie in the ecosystem is of similar characteristics.

1.5.4.2 Prey biomass - predator grass intake (c): This variable represents the prey loss rate as a result of the predator intake of the prey biomass, measured per animal unit of weight (/day/kg) calculated from the daily energy requirement of cattle. To estimate this parameter, the energy maintenance requirement and liveweight of the cattle were considered which results in the daily energy requirement (DER) in Mcal per kg of metabolic live weight expressed in this equation:

DER = 0.107 + 0.141 ADG (Cameroni & Hugo, 2017)

The average daily gain of body mass (ADGmax) of the cattle refers to the maximum weight the animal will achieve when it consumes the prey, which was substituted in the equation above, divided by the dry matter content (DM) of the grassland. Thus, the equation can be rewritten as

c = (0.107 + 0.141 ADGmax) / (pastureEnergy.kgDMcm) (Cameroni & Hugo, 2017)

ADG max was empirically estimated at 0.660kg per animal per day at 91 days per season however for this model, 365 days per season was used since it is assumed that the herders are fully nomadic, and the cattle are on the grazing field throughout the year. The pasture energy represents the grass density which was estimated at 2414.57km^2 for the study area (Enugu) and the foliage weight of the grass species was 0.577kg/m^2 (Dieter, 1972). To convert the metabolized energy and the grass from kg of DM to cm, the conversion factor applied by Cameroni & Hugo (2017) was adopted which was expressed as 180kg DM.cm^{-1} thus, c = 7.2 x 10^{-4} cm.kg metabolic liveweight.day^{-1} was obtained.

1.5.4.3 Half saturation grass intake (H): This parameter represents the height of the grass at which half of the daily intake requirement of grass of the cattle is met. Generally, it is estimated that cattle consume 2% of their body weight daily (Cameroni & Hugo, 2017), and since we have earlier estimated that the maximum predator grass intake (c) is 0.0007, H will be the height at which c/2, that is, 0.00035. Ideally, this parameter is calculated by using the Holling III response function to model the intake behavior of animals in different grass heights to describe the physical limits for large herbivores grazing when the height is low (de Boer, 2012). With the initial height of the grass at 5cm (average height for Andropogon spp.) and c at 0.0007cm where the animal takes up to 2% of its body weight all things being equal, the estimated height of the grass at which they will take half of their daily requirement (c/2 - 0.00035cm).

1.5.4.4 Predator energy conversion rate (b): This relates to the efficiency of grass intake to energy and metabolized energy to liveweight gain of the animals. This usually varies between 16% (for high fiber feeds) and 60% (for grasses and new shoots). Based on empirical evidence, this parameter was kept at 81 kg metabolic live weight cm-1 because we assumed that the pastures have high fiber content with an estimated average value of 0.25kg (Cameroni & Hugo, 2017).

1.5.4.5 Predator biomass (I): This is the grass requirement for animal maintenance, that is, the grass height at which the animal maintains its liveweight. This parameter was calculated using the formula below;

I_m (H) = c xm^2 / (H^2 + xm^2) where H is the half-saturation grass intake and x is the initial grass height (5cm). Substituting them in the formula, the predator biomass was estimated at 5.3×10^{-4}.

1.5.4.6 Predator stocking rate (s): The stocking rate allows the herder to maximize production by adding cattle to the herd. In this model, this parameter was used to reflect the predator growth rate in the ecosystem. With an assumption that the cattle population has females which are 7 times less than the female population, this variable was estimated using the gestation period of cattle (283 days), the time period under observation for the ecosystem (1200 days), and the time-lapse it takes to wean the young calf (6-7 months). Thus, the stocking rate was calculated at 1 predator head addition for the cycle of grazing.

1.5.4.7 The maximum and minimum carrying capacity of the system (kmax, kmin): K is the carrying capacity of the system which remains constant in most of the modeling. However, in reality, the pasture carrying capacity is influenced by the diurnal cycle and seasonal variations. Cameroni & Fort, (2017) derived an equation from Net Primary Production (NPP) dataset where K fluctuated between Kmax and Kmin over time. Maximum growth of Andropogon grass species was found at 121cm in the pasture. To estimate the lower limit, we estimated that below 5.45cm it would be hard for large grazing herbivores to consume the grasses.

$$K(t) = ((kmax-kmin)/2 * \cos((2*\pi*t)/365) + (kmax + kmin)/2)* CC$$

1.5.4.8 Deviation average of the NPP (CC): CC used in the k(t) equation above is the percent of deviation from the average NPP value which can be interpreted as a climatic condition that influences the pasture carrying capacity. For normal pasture growth, CC=1 is used, where CC>1 represents excessive forage supply and CC<1 denotes drought conditions (Dieguez-Cameroni & Terra, 2014). CC =1 was used considering normal pasture growth in the destination region which was logical as the abundance of arable grassland was the triggering force of this migration.

Table 1: Parameters used for the simulation of the model

Parameters	**Symbol**	**Units**	**Data source**
Prey growth rate	r	day^{-1}	(Bartaburu, 2011).
Predator grass intake (prey biomass)	c	cm·kg metabolic live $weight^{-1}·day^{-1}$	calculated
Half-saturation grass intake	H	cm	calculated
Predator energy conversion rate	b	kg metabolic $liveweight·cm^{-1}$	(Cameroni & Fort, 2017)
Predator biomass	l	cm·kg metabolic $liveweight^{-1}·day^{-1}$	(Cameroni & Fort, 2017)

Predator stocking rate (growth rate)	S	unitless	(Cameroni & Fort, 2017)
Minimum and maximum carrying capacity of the system	Kmin & Kmax	cm	https://www.gardenia.net/plant/andropogon-gerardii
Climatic condition influencing grass growth	CC	unitless	(Dieguez-Cameroni & Terra, 2014)

2.0 Results

As expected, there were oscillations in the predator-prey relationship graph in figure 3a below. The grass and the cow increased in the first 100 days, however, the grass declined when it reached its maximum because of the continued grazing and maintained this decline until 200 days. At this point, there was also a very slight decline in the cattle biomass but as the grasses began regenerating the cattle biomass increased again. When the grass got to its peak at 500 days, the cow biomass also increased greatly but when it got to its peak at 600 days, the grass declined. The grass remained low at this level until 1000 days, and this made the cow biomass decline because of the reduced grazing opportunity. Due to the decrease in the cow biomass because of reduced grass, the grass had the opportunity to regenerate and increase in biomass because of the limited number of cows feeding on it, so it grew to its peak at 1200 days. During this time, the cow biomass also began to increase too because of the presence of grass biomass for grazing.

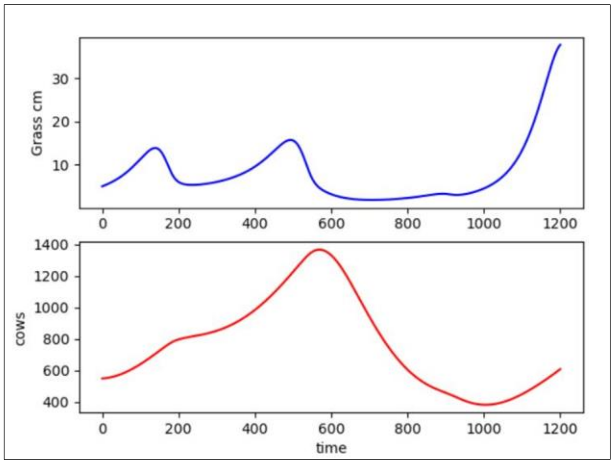

Figure 3a – cattle and grass evolution with time

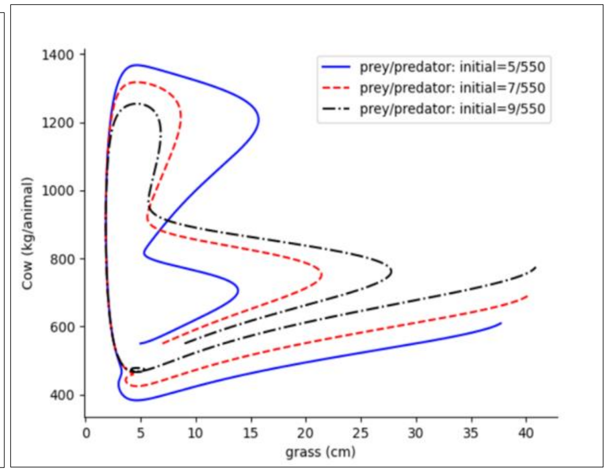

Figure 3b – state trajectory of the system

The state trajectory diagram (figure 3b) above shows the simulation of the system using three initial conditions for the prey. The relationship between the prey and the predator depends on the prey's initial condition such that when the initial condition of the prey is increased, the predator also increases. However, another effect of the increased initial condition of the prey is in its regrowth rate since higher initial conditions result in increased prey quantity in the system when the predator declines.

Because mathematical models can also be used to aid decision-making as they provide quantitative results for the observed phenomena, the number of cattle biomasses in this model was modified to examine the rate at which the grassland will be depleted completely with the presence of cows to know the maximum number of cattle that should be allowed into the grazing area based on its carrying capacity.

First, the cattle biomass was multiplied by 100 to change the initial value to 55000. A sharp decline in grass biomass was observed which stayed at 0 for up to 600 days. This means that when 55000 biomasses of cattle are introduced into the area, the grassland will be depleted immediately and will remain depleted for that number of days. Also, the cattle biomass was decreasing gradually because of the limited resources for that amount of cattle until it biomass dropped to 0. At this point, the grasses began to regenerate because of the absence of cattle in the field as seen in figure 4 below.

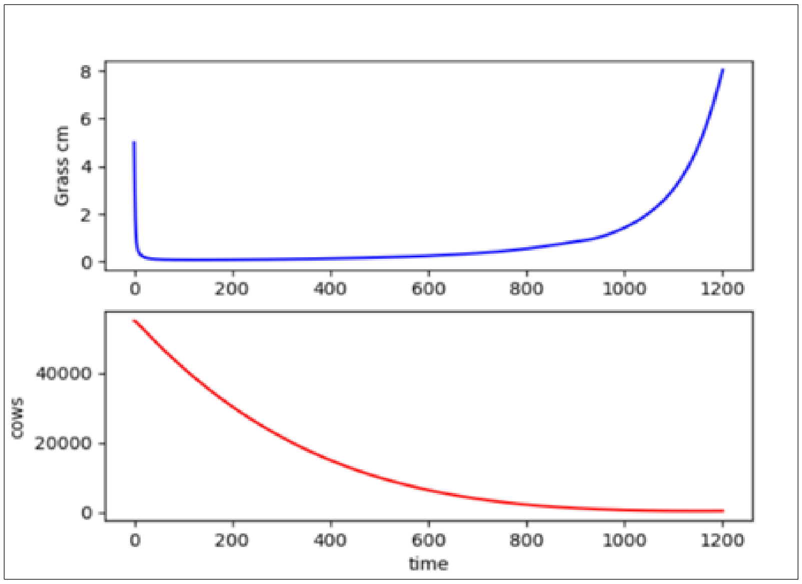

Figure 4 – cattle and grass evolution with time at 55000 cattle biomasses

Since introducing 55000 biomass of cattle was pushing the grazing field to its limit, introducing the cattle biomass gradually was then considered. The initial biomass of cattle was adjusted to 5500, and it was observed that the grass declined gradually but also remained at a very low level for up to 300 days before a slight increase. The cattle biomass also decreased steadily from inception and reached the lowest possible biomass at 600 days. During this period, the grass began regenerating and reached its peak at 800 days which also triggered the increase in cattle biomass. However, this growth was not sustained for long as the grass declined immediately after the cattle increased. See figure 5 below

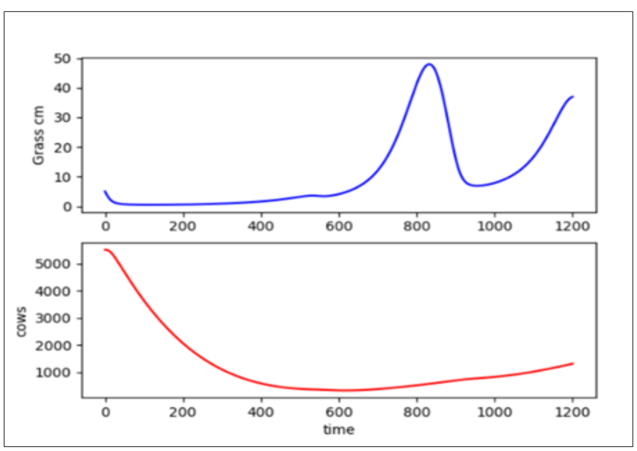

Figure 5 – cattle and grass evolution with time at 5500 cattle biomasses

When the cattle biomass was increased to 16500, the duration at which the grass stayed depleted increased compared to when the cow biomass was 5500 but shorter than when the cow biomass was 55000 (see figures 4, 5, and 6). The grass began regenerating after 400 days but the cattle biomass remained low even when the grass biomass increased to about 13 cm in 900 days, the cow biomass did not increase. This could probably be because the cow biomass was greatly reduced such that even with the presence of grass, they were unable to experience an increase. A slight increase in the cattle biomass was however observed after 1000 days but this increase is not significant compared to the increase in grass biomass which grew up to 50cm because of the prolonged redundancy of the cattle population.

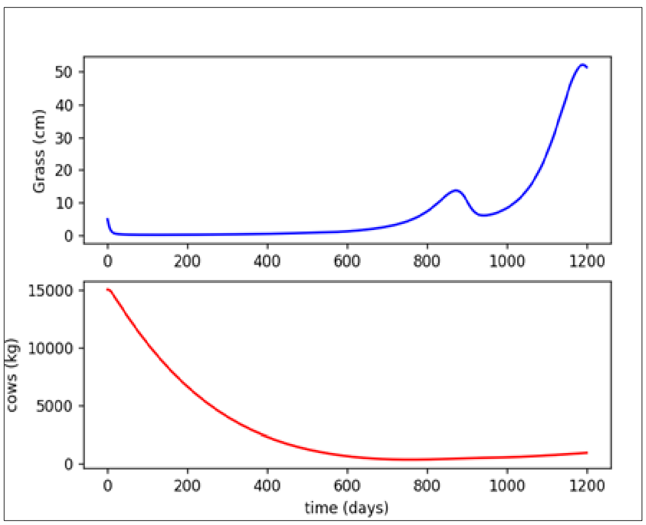

Figure 6 – cattle and grass evolution with time at 16500 cattle biomasses

To make the model a bit complex, another prey for the cattle was introduced in the form of hay after a specific period. It was assumed that after the cattle must have foraged the grassland for some time, the herders might prepare hay for them for sustenance as the grassland is depleting so the hay was introduced as an alternative source of food for the cattle. To introduce the hay, it is logical to assume the cattle reduced their consumption of fresh grass by half as they have hay alternatives for sustenance which can feel them for longer periods.

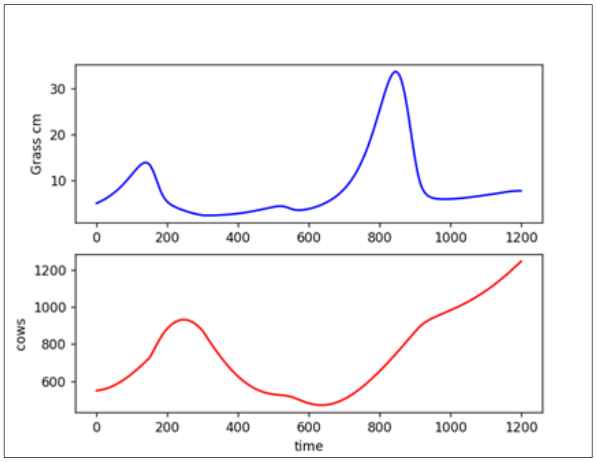

Figure 7a – cattle and grass evolution with hay at 150-300 days

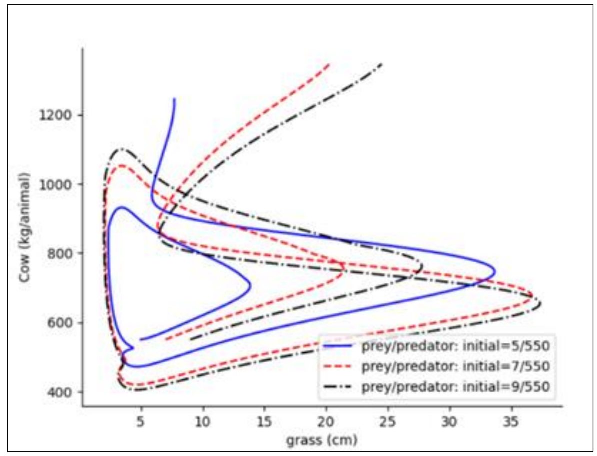

Figure 7b – state trajectory of the system

Initially, the hay was introduced between 150 and 300 days after the intake of fresh grass from the field was halved. The effect of the hay was not significantly noticed, but it was observed that the cow biomass did not decrease immediately the grasses declined because they were sustained by the hay.

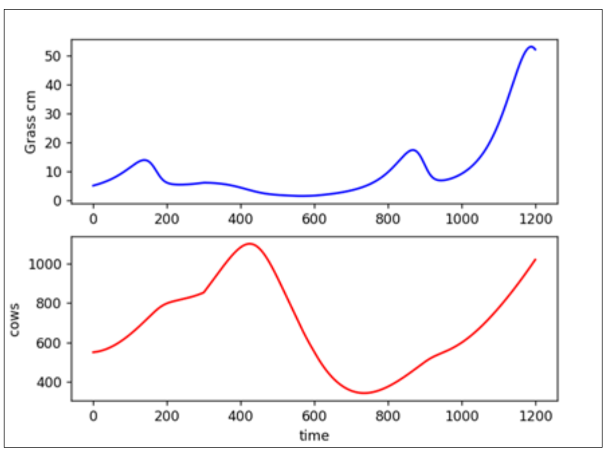

Figure 8a – cattle and grass evolution with hay at 300-600 days

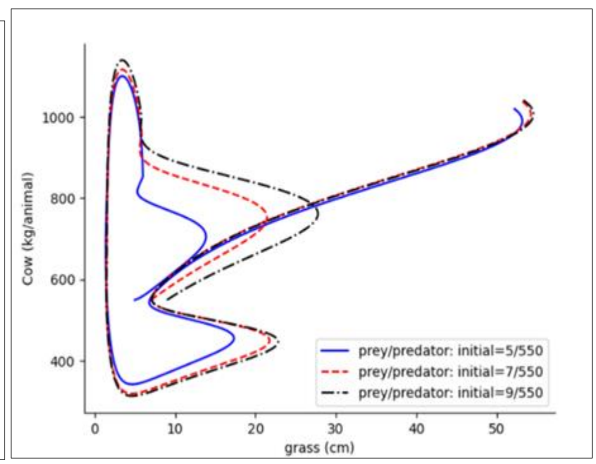

Figure 8b – state trajectory of the system

The time of introducing the hay was also modified following the period when the grass started declining in the field between 300 to 600 days. When hay was introduced, the cattle biomass increased significantly even though the grass biomass was depleting and remained very low for a long period. This is because even with the absence of grass, the cattle had alternative feed to rely on for sustenance and only declined approximately 200 days after the grass remained low in the field. This decline shows that with the absence of grasses, only hay as a source of feed cannot sustain the cattle population for long.

2.1 Validation of the model and sensitivity analysis

The validation of the model performance was not possible because of the unavailability of datasets to validate the model, so a sensitivity analysis was carried out on the parameters to see how sensitive they are in the model when they are changed slightly. The parameters modified were the grass growth rate (r), the stocking rate (S) which is a representation of the population increase, the grass conversion efficiency (b) which represents the conversion of prey intake (grass) to predator biomass (cattle), and the grass requirement for animal maintenance (I_m) which is the difference between the total intake and the intake rate.

2.1.1 Grass growth rate (r)

The initial grass growth rate was 0.02 (2% per day) for the model but for the sensitivity analysis, it was modified to 0.03 (3% per day). It was observed that the cattle biomass increased throughout the observed period with a little decreasing point that did not last for long and increased as soon as the grass biomass increased. There were also observed oscillations in the grass growth rate but what is important to note here is that the grass biomass increased sharply compared to the growth rate of 2% per day and even when it declined, it did not stay declined for long as it grew almost immediately because of the increased growth rate.

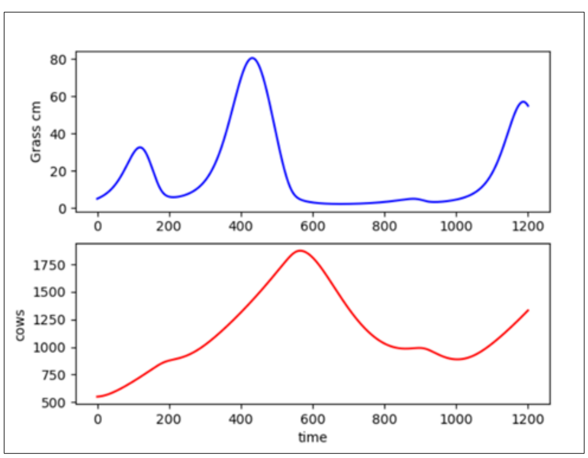

Figure 9a – cattle and grass evolution with r at 0.03

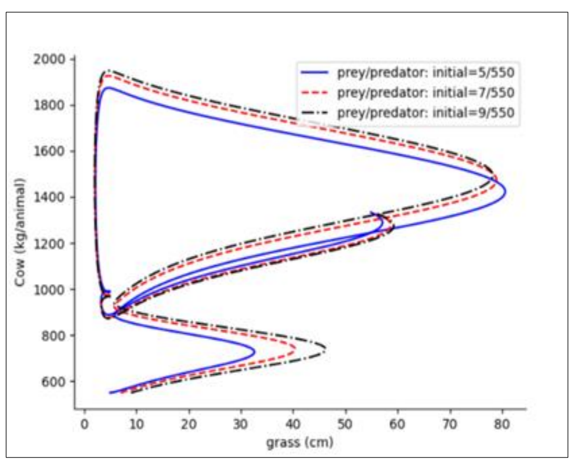

Figure 9b – state trajectory of the system

The growth rate was also modified to 1% growth per day (0.01), and it was observed that the grass biomass decreased gradually with the introduction of cow biomass. The cow biomass also declined sharply until its minimum at 600 days, then, the grass biomass began to increase. As the grass biomass began to increase, the cow biomass also increased gradually however, the grass declined shortly after because they were not allowed to attain full biomass before the cow consumption.

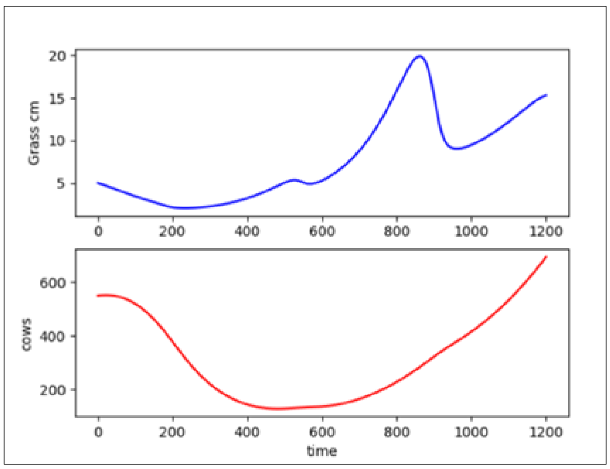

Figure 10a – cattle and grass evolution with r at 0.01

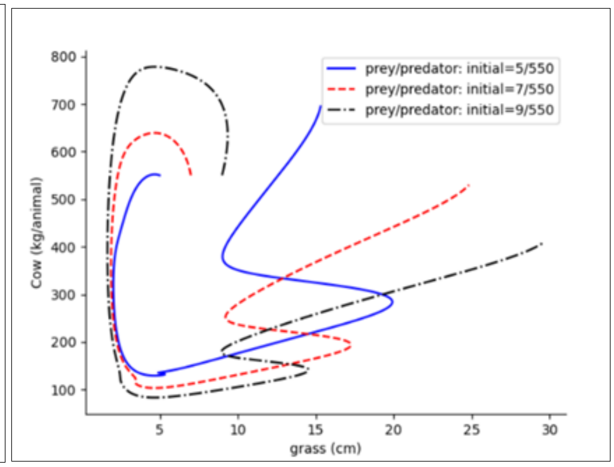

Figure 10b – state trajectory of the system

2.1.2 Stocking rate (S)

The stocking rate represents the rate at which the cattle heads will be increased in the field. To test the sensitivity of this parameter, the initial condition of this parameter was adjusted to 1.05 and a slight change from the original condition of the system was observed as the height of the grass at the start of the relationship reduced and the cattle biomass increased. When this parameter was increased between 1.01 to 1.04, no observable change was seen in the system until it was changed to 1.05.

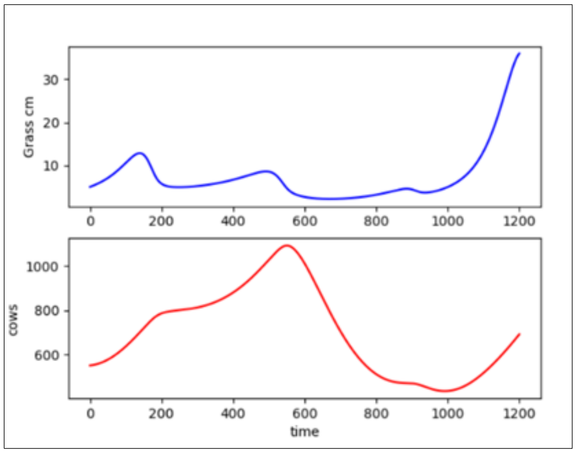

Figure 11a – cattle and grass evolution with S at 1.05

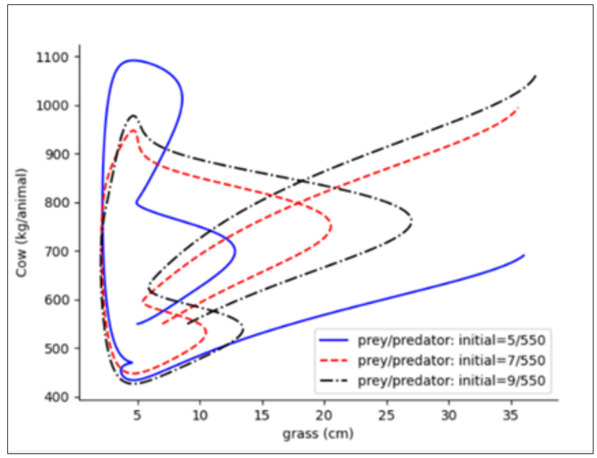

Figure 11b – state trajectory of the system

This parameter was later reduced to 0.9 and a significant change was observed between the initial condition as the grass increased because of the reduced rate of cattle biomass in the system.

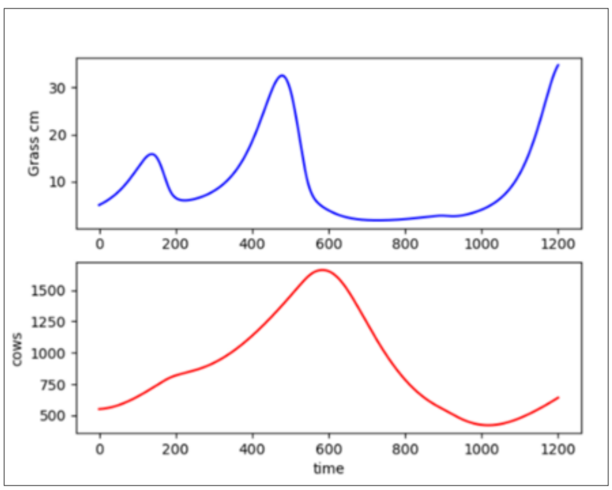

Figure 12a – cattle and grass evolution with S at 0.09

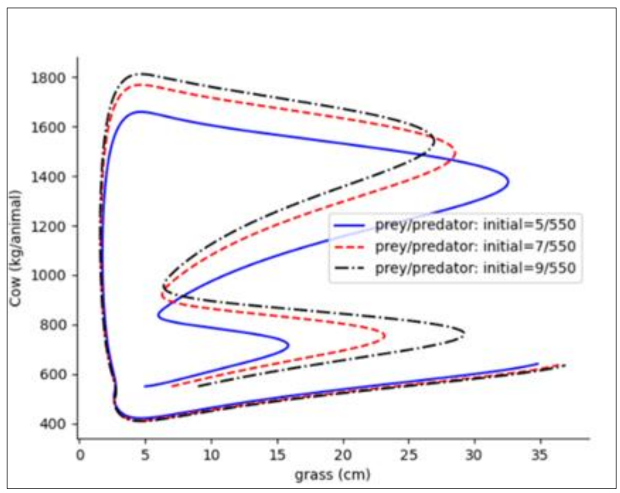

Figure 12b – state trajectory of the system

2.1.3 Predator conversion rate (b)

The initial value of this parameter (81) was adjusted to 85. By adding 5 units to this parameter, no observable change was noticed between the initial condition of the system and the current with the increase in the predator conversion rate as the grass biomass and cattle biomass remained the same, showing similar oscillations as with the initial condition. This parameter is not sensitive in the model as a slight change does not affect the overall performance of the model.

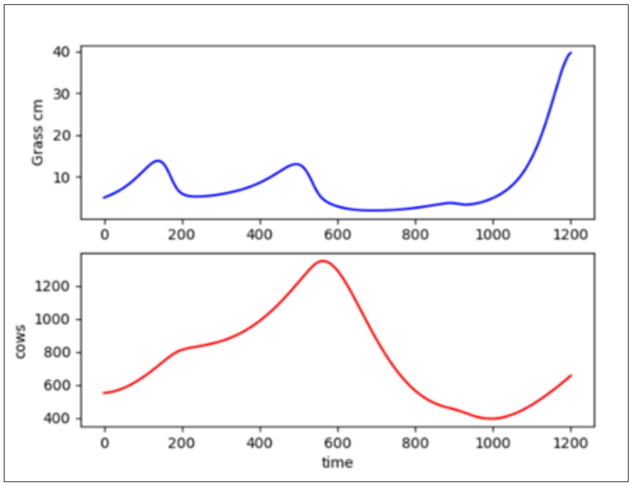

Figure 13a – cattle and grass evolution with b at 85

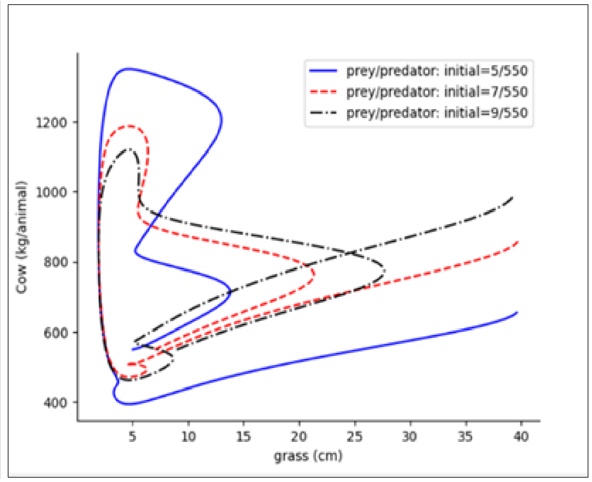

Figure 13b – state trajectory of the system

2.1.4 Predator Biomass (I)

The initial parameter of the predator biomass at 0.00053 was reduced to 0.00051 in figure 14 below. An identifiable change was observed in the grass and cattle biomass as the grass decreased compared to the initial condition of the system. When this parameter was increased to 0.00058 keeping other variables constant, the grass growth rate increased more than its initial condition. Also, while the cattle biomass decreased gradually when the parameter was increased, the decline was faster when the parameter was reduced to 0.00051 compared to 0.00058. This is because the more the biomass of the cattle, the longer it takes to shed off even with the minimum grass or prey for sustenance.

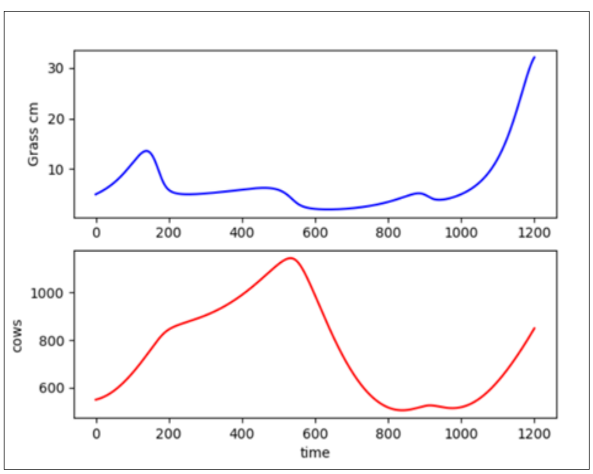

Figure 14a – cattle and grass evolution I at 0.00051

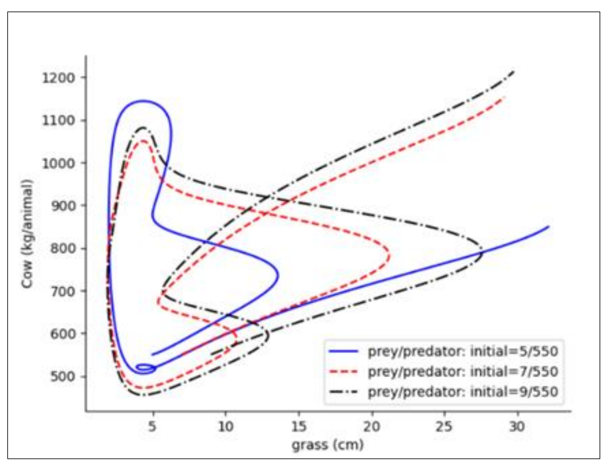

Figure 14b – state trajectory of the system

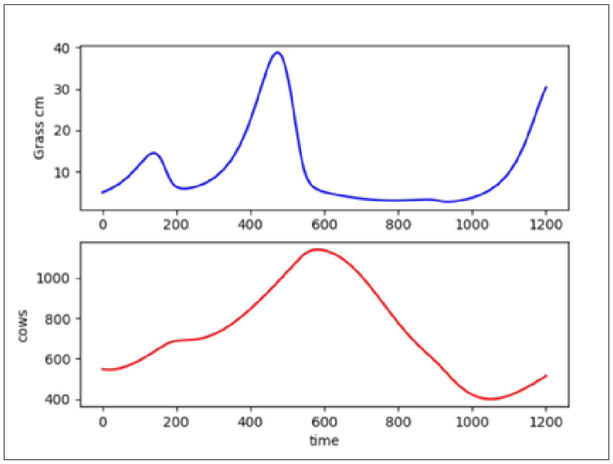

Figure 15a – cattle and grass evolution I at 0.00051

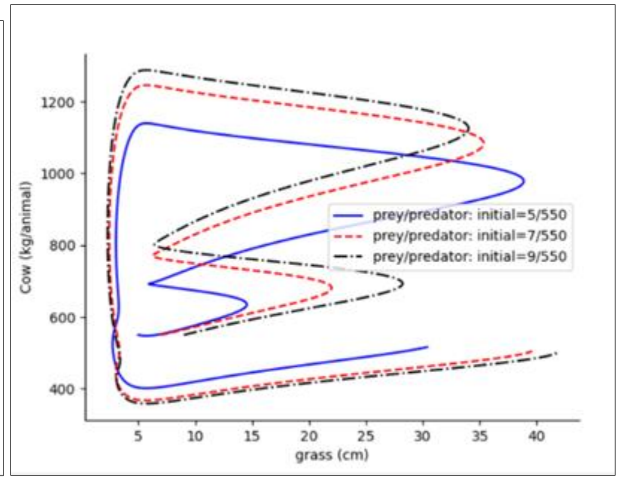

Figure 15b – state trajectory of the system

2.2 Criticism of the model

The major lapse of the model was the estimation of accurate parameters that can reflect the true condition of the system because of the unavailability of quantitative data. This can introduce a considerable number of biases into the model since some variables were estimated based on empirical findings particularly as these empirical datasets were obtained under different research conditions even though the ecosystems and models show similar characteristics as our model. Also, one assumption that may introduce possible bias in this model is the presence of the female cattle population within the herd. Generally, in Nigeria, female cattle are not reared by nomadic pastoralism as they are kept for their milk and to reproduce, but it was logical to assume that they are 7 times lesser than the male population in this model, to show the possible dynamics of time evolution when other animals are introduced into the system.

The assumption that all cattle have the same weight and consume the same amount of grass daily is not a true reflection of a realistic ecosystem thus, it is only necessary that in adopting this model, an in-depth study of the ecosystem and the biology of the organisms be carried out to reduce the estimation of parameters which may impair the model performance.

3.0 Discussion and Conclusion

This model portrayed the relationship between cattle and grassland in a defined rangeland ecosystem in Enugu Nigeria. From the model interaction, the grass biomass decreased with continued grazing from the cattle population, and the cattle biomass increased with the consumption of the grasses. When the grasses depleted because of overgrazing as the cattle biomass surpassed the system capacity, the cattle biomass also depleted because of the absence of grass to feed on. The introduction of alternative prey in the form of hay for the predator population reversed this effect as the cattle biomass was sustained for longer periods even with the absence of grass for grazing in the ecosystem, and the grass regrowth rate was faster because the cattle consumption of the grass was reduced.

The maximum carrying capacity for predators in the ecosystem based on the grassland coverage was estimated at 5500 of predator biomass because it was at this rate that the grass depletion stayed low for the shortest amount of time before regeneration. Also, the time period at which the grassland would be depleted completely such that the destination ecosystem and the origin ecosystem would be at equilibrium was observed at 600 days when the grassland was the lowest. This condition may trigger the migration of the herders to other favorable locations where they can access pasture since the condition of the destination is similar to their origin which triggered their migration initially. However, if they choose to remain in the ecosystem, they could possibly suffer a loss of their cattle biomass before the grass regenerates, that is why the alternative option of providing hay and not surpassing the carrying capacity of the system must be considered if they are to maximize the ecosystem for the cattle development.

This model was not validated because of the unavailability of datasets but the sensitivity analysis of the model parameters revealed that the most sensitive variable was the predator biomass and the prey growth rate such that a unit (or less) increase of these parameters showed significant changes in the system.

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