Research Paper

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Deforestation and Sustainability of the Forest Cover: a Lotka-Volterra Perspective

Economics

KEYWORDS : Deforestation, Lotka-Volterra Model, Forest Institutions, Carrying Capacity.

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ABSTRACT

The destruction of the forest cover is a serious global issue as it poses a threat to the life supporting ability of the earth we live in. Our planners in India have laid down action plans to curb this unscrupulous manmade menace through Institutions like FCA and NFP that banned the felling of trees, and added support is available from Economic Liberalization. This is a predator-prey situation where humans are predating the preys that are the defenseless mute trees. Their objective is gathering wood – a material which is consumed for multiple purposes, from fuels to a variety of commercial applications. The author has viewed this problem from a Lotka-Volterra(LV) standpoint. Proposing an augmented LV equation it has been demonstrated through examples that total sustainability of the forest cover is a reality under judicious management.

Introduction

Globally, deforestation has been a long standing subject of concern for biologists and environmentalists. This is a process of conversion of forests to non-forests. It induces a degradation that reduces the forest quality: the density and structure of trees, the ecological services, the biomass of plants and animals, and of the biodiversity as a whole It incapacitates the ability of the forest to act as a repository of biodiversity - a protector against soil erosion and a promoter of carbon storage.

The terms Deforestation and Forest Degradation are often used interchangeably - being a pheno- menon caused by human activities like over-grazing and over-exploitation apart from natural calamities. The forest - a vital component of the eco-system - covers about 30% of the land area. If used sustainably, forests could serve as crucial safety-nets in times of economic stringencies for the forest dwellers, providing them with shelter, food and fuel while catering to their daily needs. Studies reveal that deforestation results mainly from unscrupulous human activities who are careless about the consequences of their deleterious action.

The Indian policy makers have been active on this matter and to arrest the wanton deforestation the National Forest Policy (1988) specified that 1/3 of the geographical area of India should be brought under forest cover by the end of the Eleventh Plan period. To implement this, two major Institutions – the Forest Conservation Act (FCA,1980) and the National Forest Policy (NFP,1988) were enforced, banning the felling of trees.

The Economic Liberalization (EL,1991) has a significant role to play in generating alternative employment for the rural masses in developing countries. It leads to an inflow of Foreign Direct Investment (FDI) through which multinational companies bring in assets like skill, technology, management know-how and information on market. Thus, it is assuring enough that conjunction of all the above can help to mitigate forest destruction by discouraging this activity and attracting the fellers to alternative occupation.

Patil et. al (2013) studied the Impact of Economic Institutions on the Consumption of Forest Products in India together with two Forest Institutions, and the EL and the GNP. The results of their analysis show a reduction in the domestic supply of forest products.

Sallam et. al (2013) studied the balance between Population, Natural Resources and Sustainability through a variant of the Lotka-Voterra Equations and Supply and Demand model. They claim that their theoretical test signified its potential for monitoring sustainability and also guide decision makers in improving the sustainability plans.

Objective of Our Study

The intent of the present study is to revisit and analyze the problem of deforestation which is created by the unscrupulous action of men. It is our endeavour to demonstrate how Liberalization, by providing alternative job opportunities, and the FCA and NFP by imposing ban on deforestation, can arrest the process of rampant destruction of forests.

The Modelling

The deforestation problem has much in common with the Predator-Prey model due to Lotka and Volterra. It is tempting to base our analysis on the Lotka -Volterra (LV) prototype, augmenting the original formulation when necessary.

The LV formulation (1925-26) was created to examine the problem of struggle for existence between two biological players only– a predator (say, wolf) and a prey (say, a rabbit). The wolf kills the rabbit for food, while the rabbit eats vegetables which is abundant. The wolf dies when rabbit's flesh is unavailable, and the rabbit dies only when it is killed by the wolf. The argument is as follows :

Growth rate of rabbit = Birth rate due to food – Death rate due to predation.

And,

Growth rate of wolf = Birth rate due to food – Death rate due to starvation.

Mathematically put, the above two statements are tantamount to :

$x' = ax - bxy$ .....(1) and

$y' = dyx - cy$ ... ... (2),

where (') = d/dt

In the above two equations:

x = Population of rabbits, y = Population of wolves, a = Birth rate of rabbits per capita, b = Predation death rate of rabbits per capita per wolf, d = Birth rate of wolves per capita per rabbit and c = Per capita starvation death rate of wolves. The a,b,c,d values are all positive.

Equations (1) and (2) are non-linear first order differential equations whose closed form solutions cannot be obtained readily, if not at all. However, numerical solutions for particular cases can be found without difficulty. The solutions often show periodic fluctuations of the populations (non-harmonic) and have been studied by many authors. The fluctuations vanish when x=c/d

and y=a/b are set as the prey-predator initial populations. The literature is replete with the application of the seminal LV model .

Our present problem has two species in a forest ecosystem - Trees (x, preys) and Humans (y, predators) who fell them down for fuel or commercial purposes.

The Lotka – Volterra equations have been used in economic theory for long; their initial application is perhaps due to R. Goodwin (Desai,1995). It is worthwhile now to employ them in the analysis of our problem.

To make Equations (1) and (2) apply, some augmentation and conceptual adjustments or modi-fications will be necessary.

In these adjustments the constants a and b retain their original biological meanings explained earlier. But the predator constants c and d shall be given a different interpretation. c would now mean per capita natural disappearance rate of the Humans (in place of death) due to emigration or loss of motivation in forest extraction when they find that the resource they depend upon is becoming scarce. And d shall mean growth in predator ranks due to new participants from outside.

Note at this stage that in the absence of predation the tree population grows exponentially:

$x' = ax$ ...(3)

or, $x=\exp(at)$. ... (4)

The outcome of equation (4) is unrealistic as it is boundless. Verhulst (12) had studied this and introduced the concept of Carrying Capacity (CC) by incorporating a logistic relation in equation (4) as suggested in the following well known equation:

$x' = ax[1- x/K]$ . ... (5) , where K is the carrying capacity.

A typical resulting population growth with K = 500, is shown in Fig.1.

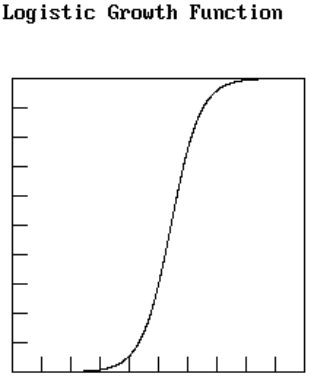

Fig.1 Population Growth (Vershulz)

Clearly the growth figure is kept bounded by a maximum value K. Also, the initial growth pattern evolves gradually from zero and its rate vanishes with time after reaching a maximum.

It will be appropriate now to consider analytically a few cases with examples such as those adduced below:

First Example

Let us commence with an example of a small forest (4000 sq.m, ≈1 acre) containing 1000 samples of a fast growing variety of trees. 500 men come to this forest to fell the trees. We assume the following data for analysis:

We choose the constants of equation (1) and equation(2) as:

Initial population of trees = 1000.

Initial population of men = 500.

a=1 per tree; b= 0.01 per tree per man (tree feller)

c=0.5 per man (tree feller); d= 0.01 per man per tree. These a,b,c,d values are considered as *intrinsic* and fixed.

The LV equations, as already mentioned, are analytically intractable in general. However, for particular cases, they can be handled at ease by the Runge-Kutta (RK) group of formulations numerically.

Fig.2 shows the numerical solution results:

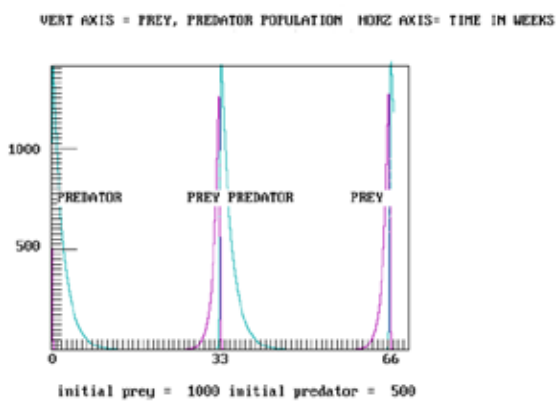

Fig.2 Population Dynamics

It is interesting to note that the trees practically disappear in about 8 days' time while the men vanish after 13 weeks. Next the trees begin to appear after 26 weeks and the men join gradually after 32 weeks. Note that the forest remains barren for 25 weeks and this continues cyclically of which two are shown.

There is a difference between the first and the following cycles which start with nearly zero participants with predators joining after 6 weeks after the reappearance of trees. This lag gives a boost to tree population where the maximum of 1190 is reached.

This status of the forest is nearly that of a desert; it cannot be tolerated by an environmentalist who would consider it as a doom.

It is time that some augmentation be made to the LV prototype to make further study convenient.

Owing to the alternative livelihood options opened up by Liberalization, a larger fraction of the predators migrate out of the system. A control parameter q is introduced as a multiplier to c to handle this larger exodus. Also, control parameter p is introduced as a multiplier to d to give the controlling action due to the Forest Institutions. New members, this time, are not free to join the predator ranks from outside. Verhult's logistic relation is also included to make the model more practical. The augmented LV equations now appear as :

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x'=ax[1-x/K] –bxy ... ... (6) modifying only the first term, and

y' = pdyx –qcy … … (7) , where

p £ 1 is a parameter introduced by the Institutions representing control and q ≥ 1 is a parameter introduced by Liberalization; due to more lucrative options open, larger emigration of the humans will result. Obviously, q > 1. The effect of *intrinsic* values a. c and d are now controllable.

Second Example

Liberalization (EL) and Carrying Capacity included
Maintaining the data set of the First Example the following are also assumed:

K=(Carrying Capacity for Trees) = 1200 and p = 1, q = 14

Using equations (6) and (7) the results of simulation are shown in Fig.3 :

Initial Prey = 1000
Initial Predator = 500
Final Prey = 699
Final Predator = 41

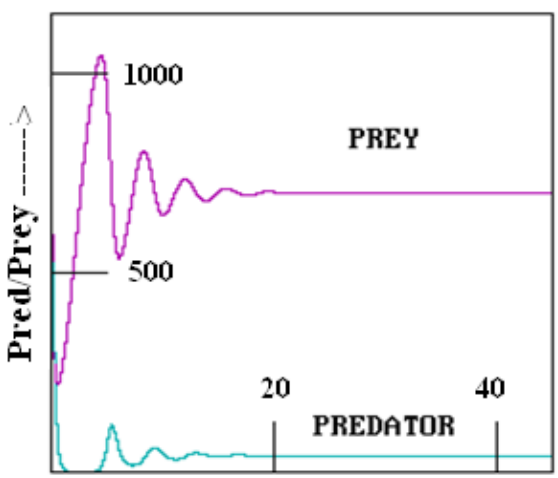

Fig.3 Population Dynamics

Fig.3 shows unique damped oscillations in the population time history – nearly harmonic for the preys and anharmonic for the predators, with a period of 5 weeks approx. Predator peaks lag by about 1 week. Fluctuations in predator population are resulting from variable motivation. After about 20 weeks, the fluctuations disappear and a steady state is reached. This is stability leading to forest saving.

The effect of Liberalization (EL) is thus positive, indeed.

Third Example.

Liberalization, Institutions and Carrying Capacity included.

Maintaining the other data of the Second Example, we choose p = 0.7 to represent the control exerted by FCA and NFP.

Numerical solution with the data set is shown in Fig.4

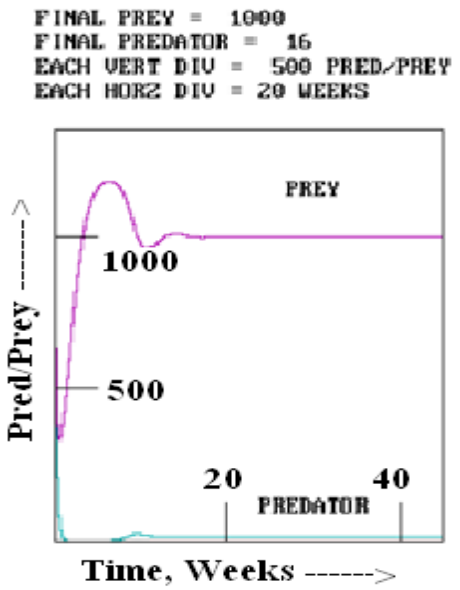

Fig.4 Population Dynamics

Fig. 4 has some striking features. The oscillations in the prey populations are very highly damped which die down in about 2 cycles (20 weeks). These fluctuations look close to harmonic with a peak value of about 1184.The steady state value is amazing - it is 1000 ! That means the original tree population is restored within 20 weeks and maintained thence forth. This is sustainability and forest conservation. The implication is that with FCA and NFP in force together with the promise of EL, forest conservation and sustainability can be a reality.

The predator population dynamics is far from harmonic which also reaches a steady state value - of 16 in about 20 weeks and is maintained thence. The drastic fall in predator population is worthy of note. It highlights the effects of FCA, NFP and EL. The choice of parameters p and q, however, holds the key to management.

Conclusion
The forest cover is very important in maintaining the life supporting ability of this planet of which the humans are not the only inhabitants. Biologists and environmentalists over the past few decades have been advocating the importance of sustainability of the forest cover. NFP stipulated that 1/3 of the geographical area of India is to be brought under the forest cover (which stood at 23.81% of its geographical area in 2011) by the Third Plan period. Needless to reiterate that achieving this target is a monumental task .

The LV model has been most important for the biologists since the first quarter of the 20th century. In this paper, the author has augmented these equations suitably in the light of FCA, NFP, EL and CC. The results of the cases considered in the examples are enlightening and establish a possibility of protection and sustainable maintenance of the forest cover. It is hoped that our policy makers for environmental protection shall benefit from these findings and review their action plans as needed in the future.

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