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Eradication of Karuvelam Using a Bioeconomic Model

B. Amudhambigai[#1], A.Neeraja[*2], R. Roseleen Nithiya[#3]

[#]*Department of Mathematics, Sri Sarada College for Women*
Salem, TamilNadu,India.

[1]rbamudha@yahoo.co.in,[2]neeru572010@gmail.com,[3]roseleennithiya25@gmail.com

***Abstract*: This project gives the effects of karuvelam at Attayampatti village situated in Salem District, TamilNadu. A bio economic model is used to eradicate the Karuvelam trees. This model is divided into two components as ecology and economics. Numerical simulation and scenario analysis are obtained to eradicate them and finally a simple fuzzy logic based Mamdani model is used to view the proportionality between the growth of karuvelam trees and the ground water level.**

***Keywords*— Mathematical Modelling, Numerical Simulation, Scenario analysis, Fuzzy Logic, Fuzzy Rules.**

I. INTRODUCTION

The Karuvelam tree, or *Prosopis juliflora* as it is known biologically, is a species native to West Africa and was brought to TamilNadu in 1960s as fuel wood. Slowly, these started drifting into dams and rivers, causing problems. Karuvelam is a major threat to water conservation. The ground water level has depleted since the Karuvelam trees rapidly absorb the ground water thereby causing ground water scarcity. Here, our aim is to control its growth and increase the ground water level.

Vikram Dayal [11] studied the effect of *Prosopis juliflora* an exotic tree on diverse agents in Ranthambore National Park, situated in Rajasthan, India using Lotka-Volterra Equations. The effects of *Prosopis juliflora* on the users has been modelled by drawing on mathematical ecology by Gurney and Nisbet [3]. The bio economic model that studies the economics of developing country protected areas and the usage of different modelling approaches was studied by Chopra and Adhikari [2]. The most common fuzzy methodology is Mamdani's fuzzy inference method which was built using fuzzy set theory. This method was proposed in 1975 by Ebrahim Mamdani [9] as an attempt to control a steam engine and boiler combination. Fuzzy Mamdani Model on Air Pollution was studied by Amudhambigai and Neeraja [1]. After getting various details, Fuzzy Mamdani model is used to find the conclusion.

The area taken for study is Attayampatti town panchayat, Salem. Attayampatti is the town panchayat, with population of about 14 thousand. It is the second most populous town panchayat in Salem district. There are 3649 households. Total geographical area of Attayampatti town panchayat is 2.4 km^2. Out of 240 hectares, 4.36 hectares are under karuvelam.

People planted karuvelam for fuel wood. Apart from the purpose of planting them for fuel wood, they served the additional purpose of protecting the agricultural lands from goats. Now this shrub has proliferated like a virus in Attayampatti.

2. Preliminaries

Definition 2.1 [4]

Carrying capacity is defined as the environment's maximal load. Carrying capacity was originally used to determine the number of animals that could graze on a segment of land without destroying it.

Definition 2.2 [5]

A **functional response** in ecology is the intake rate of a consumer as a function of food density. It is associated with the numerical response, which is the reproduction rate of a consumer as a function of food density. Functional responses are generally classified into three types, which are called **Holling's type I, II, and III**.

Definition 2.3 [5]

Holling's Type II functional response is characterized by a decelerating intake rate, which follows from the assumption that the consumer is limited by its capacity to process food. Type II functional response is often modelled by a rectangular hyperbola.

Definition 2.4 [9]

A function that occurs as the result of the division of two exponential functions is called a **logistic function**. Logistic function is also known as the logistic curve.

Definition 2.5 [6]

The **Lotka-Volterra equations,** also known as the predator-prey equations are a pair of first-order, nonlinear, differential equations frequently used to describe the dynamics of biological systems in which two species interact, one as a predator and the other as prey. The populations change through time according to the pair of equations.

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$$\frac{dx}{dt} = \alpha x - \beta xy \quad ; \frac{dy}{dt} = \delta xy - \gamma y$$

where, x is the number of prey; y is the number of some predator; $\frac{dx}{dt}$ and $\frac{dy}{dt}$ represents the growth rates of the two populations over time; t represents time and $\alpha, \beta, \gamma, \delta$ are positive real parameters describing the interaction of the two species.

Definition 2.6 [11]

A fuzzy set is a pair (U, m) where U is a set and m: U → [0, 1].

Definition 2.7 [11]

A membership function (MF) for a fuzzy set A on the universe of discourse X is defined as μ_A: X → [0, 1]. This value, quantifies the grade of membership of the element in X to the fuzzy set A.

Definition 2.8 [7]

A fuzzy number A = (a, b, c) is said to be a triangular fuzzy number if its membership function is given by

$$\mu_A(x) = \begin{cases} 0 & x \le a \\ \frac{x-a}{b-a} & a \le x \le b \\ \frac{c-x}{c-b} & b \le x \le c \\ 0 & c \le x \end{cases}$$

3. Eradication of Karuvelam Using a Bio - Economic Model

In this section, a bio economic model is used to eradicate the growth of the Karuvelam trees. Numerical simulation is obtained to eradicate the Karuvelam trees. Since there is considerable uncertainty about the ecology-economy interactions, alternative scenarios are also examined.

3.1 Model Overview and Equations

The study was undertaken at Attayampatti village situated in Salem District, TamilNadu, India. The entire area is divided as the area covered by 'Karuvelam' and remaining areas. If land under Karuvelam can be cleared, then the area moves into the category 'other area' (Area without Karuvelam). It is observed that out of 40 trees in an area one is Karuvelam.

Both 'Karuvelam' and trees on 'other area' produce wood. In addition, Karuvelam also produces pods, which are eaten by goats. Cattle compete for grass that grows in 'other area'. Cattle and goats are assumed to follow a logistic growth function, with carrying capacity determined by the availability of feed.

We can divide the model into two components, ecology and economics. The ecology component of the model is discussed now.

3.2 Ecology

The effect of Karuvelam on the users of village, lake and river has been modelled by drawing on mathematical ecology. To study the effect of Karuvelam on Attayampatti, a weed control model is used.

TABLE I

Karuvelam and Attayampatti area composition

Variable	Symbol	Values (Attayampatti)
Total Area	A	240 ha
Area under Karuvelam	A_K	4.36364 ha
Rate of growth of Karuvelam per unit area	r_K	1.85657
Cost of Nutrients	CNu	Rs. 50,000 (app)
Cost for maintaining the ground water	CG_W	Rs.1,00,000(app)
Rate of pod growth per unit area	g_K	700-1000
No. of goats surviving on Karuvelam	X	250
Parameters for estimating goat and cattle carrying capacity	K	0.34
Initial carrying cost	K_k	Rs. 5,00,000(app)
Fraction of area under karuvelam	f_{KC}	0.04/4.6364
Number of factors	N	4
Goats that browse in land has not been invaded by karuvelam	X_4	150
Goats that browse in land that has been invaded by karuvelam	X_5	250
Number of cattle	M	60
Price of cattle	p_c	Rs. 25,000
Price of milk	p_M	Rs.34
Price of wood	p_W	Rs. 15
Production of wood in Karuvelam area	w_k	120 kg
Production of wood in other area	w	80 kg
Fraction of cattle that	m_F	30/60 (total

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were milk bearing		cattle = 60)
Milk yield per milk bearing cattle	m_c	8 litres
Price of goat	p_G	Rs. 5000
Cattle removal fraction	O_c	20/60
Goat removal fraction	O_G	200/250

The area of Attayampatti (A_A) consists of area under Karuvelam (A_K), and the other area (A) as given in (3.1)

$$A_A = A_K + A \quad (3.1)$$

The characteristics of Karuvelam in terms of spread, effects and control are discussed. This influenced the assumptions used in the following equations related to it. The spread of Karuvelam is assumed to follow a logistic function. When Karuvelam is cleared in the land, it moves from the category A_K to the category A.

However, this is only partially successful as the tree will again grow back. Hence, we use the following formula (3.2) to reduce the growth of Karuvelam with respect to the various parameters: ir_K - the intrinsic rate of growth of Karuvelam; A_k -area under Karuvelam; N-the cost of nutrients; k_K -the initial carrying cost of land; f_{KC} -the fraction of area under Karuvelam is cleared; t- time and G-the cost of maintaining ground water level.

$$\frac{dA_k}{dt} = ir_k A_k \left[1 - \frac{A_K}{k_K - (CNu + CG_w)}\right] - 0.9 A_k f_{kc} \quad (3.2)$$

where, $ir_K A_K$ is the rate of growth of Karuvelam for the total land A_K ;

$k_K - (CNu + CG_w)$ is the carrying cost of area occupied by Karuvelam at a point in time.

The intrinsic rate of growth of Karuvelam ir_K given in (3.3) is equal to a base rate of growth and an additional rate of growth that depends on the abundance of goats surviving in the Karuvelam area.

$$ir_K = 0.025 + (0.025 \text{ x } X / A_k g_k k) \quad (3.3)$$

where, X is the stock of goats surviving on Karuvelam area; g_K is the rate of growth per unit area; k is the parameters for estimating goat and cattle carrying capacity; $A_K g_K$ k is the carrying capacity of goats surviving on karuvelam.

For Attayampatti village,

$ir_K = 0.025 + (0.025 \text{ x } 250 / (4.36364)(800)(0.34)) = 0.0303$

$$\frac{dA_K}{dt} = ir_k A_k \left[1 - \frac{A_k}{K_k - (N + CG_w)}\right] - 0.9 A_k f_{kc}$$

Thus we have from Table 1

$$\frac{dA_K}{dt} = (0.0303)(4.36364)\left[1 - \frac{4.36364}{5,00,000 - 1,50,000}\right] - (0.9)(4.36364)\left(\frac{0.04}{4.36364}\right)$$

and hence

$$\frac{dA_K}{dt} = 0.0950 \quad (3.4)$$

Equation (3.4) gives the rate of change in the growth of Karuvelam trees in the area taken for study. It can be seen that, there is a significant decrease in the growth rate of Karuvelam. This was accomplished due to the significant increase in the growth of pods and increase in the number of cattles that feed on Karuvelam. Thus, larger the rate of growth of pods per unit area and larger the number of cattles in the area covered by Karuvelam, lesser the growth of Karuvelam in that area. This rate of growth can be calculated using the Lotka – Volterra Model.

3.3 The Effects of the Growth of Karuvelam

It is stated in the report of the newspaper "The Hindu" that cattle tied to the Karuvelam trees suffer from problems such as infertility and giving birth to offspring with physic.al deformities.

I. Hence the increase in the number of cattle, number of birds and the amount of ground water level interrupted by the growth of Karuvelam trees is as follows:

$$\frac{dC}{dt} = nA_k ; \frac{dB}{dt} = nA_k ; \frac{dG_w}{dt} = nA_k \quad (3.5)$$

where, C refers Cattle, B refers Birds and G_w refers Ground Water Level and n is the number of parameters which causes the reduction in the amount of Cattle, Birds and Ground Water Level by the Karuvelam trees.

3.3.1 The effect of Karuvelam on the growth of other trees:

The differential equation (3.6) shows how the growth of other trees is affected by the growth of Karuvelam.

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$\frac{dY}{dt}$ = growth of other trees – death of other trees = $[R_k\ R_r\ Y]-[U\ Y]$ (3.6)

Where, R_k is the number of Karuvelam trees removed; R_r is the coefficient of rate of rainfall; Y is the number of other trees; U is the number of other trees grazed by animals. There are six categories of ingestion that causes the death of trees in an area: X_1 - herbivores that graze the other trees; X_2 - wild herbivores that browse the other trees; X_3 - cattle; X_4 - Goats that browse in land that has not been invaded by Karuvelam; X_5 - Goats that browse in land that has been invaded by Karuvelam.

The destruction of other trees is high, availability of nutrients and other basic essential needs are low, which is directly proportional to its abundance. Hence no other plants or shrubs would grow next to the Karuvelam trees.

3.3.2 Effects of Karuvelam in Lakes and River

The availability of water in lakes, ponds and river is proportional to the difference between the amount of rainfall and the growth of Karuvelam in that area as shown in (3.8)

$\frac{dW}{dt}$ = standard water level – scarcity of water level

$= [W\ R_1\ Y] - [R_2\ W]$ (3.8)

Where, W is the standard water level in lakes and ponds; R_1 is the coefficient of removal of Karuvelam trees; R_2 is the coefficient of growth of Karuvelam trees; Y is the number of other trees. Thus, the Karuvelam trees are harmful to the ecology as they turn the land dry by sucking too much of ground water besides poisoning them.

3.4 Economics

The benefits of the categories of villagers over the period of time simulated is given by

$\int B_i\ e^{-\rho t\ dt}$, i=C, G, W and ρ is the discount rate

The cattle owner gets benefits from selling (1) the cattle offtake (removal of cattle from stock for sale) and (2) milk from the cattle.

I. The benefits to the cattle owner, B_C, are given by:

$$\int B_C\ e^{-\rho t}\ dt; \text{where } B_C = p_M m_F m_c m + P_C O_C m$$

Here p_M is the price of milk; m is the number of cattle; m_F is the fraction of cattle that are milk bearing; m_C is the milk yield per milk-bearing cattle; P_c is the price of cattle & O_C is the off take fraction of cattle. From Table 1,

p_M = Rs. 34, $m_F = \frac{30}{60}$, m = 60, m_C = 8 litres, p_C = Rs. 25,000, $O_C = \frac{20}{60}$, $\rho = 12\%$

$$B_C = (34)\left(\frac{30}{60}\right)(60)(8) + (25{,}000)\left(\frac{20}{60}\right)(60) = 5{,}08{,}160$$

$$\int B_C e^{-\rho t} dt = 508160 \int e^{-12t} dt$$

Hence depending on various time factors the cattle owner is benefited by removing the Karuvelam trees.

II. The goat owner gets benefits from selling goats. Revenues from selling goats are taken as a measure of benefits to the goat owner as shown in (3.9)

$$B_G = P_G\ O_G\ (X_4 + X_5) \quad (3.9)$$

Where, O_G is the goat removal fraction; P_G is the price of goat; X_4 is goats that browse in land has not been invaded by Karuvelam & X_5 is goats that browse in land has been invaded by Karuvelam

From the data table 1,

P_G = Rs.5000, $O_G = \frac{200}{250}$, X_4 = 150, X_5 = 250

B_G = 16,00,000, $\rho = 30\%$

$$\int B_G\ e^{-\rho t} dt = 160000 \int e^{-30t}\ dt$$

III. The wood gatherer is assumed to gather wood equal to the growth of wood stock. The model abstracts from the possibility that too much extraction could affect the stock of wood. Revenues from sale of this wood are taken as a measure of the benefits to the wood gatherer and it is given in (3.10)

$$B_W = P_W\ (wA + w_k\ A_k) \quad (3.10)$$

Where, w and w_K are the productivity of wood in land under non-Karuvelam and Karuvelam.

From the data table 1

P_w = Rs. 15, w = 80 kg, w_K = 120 kg; B_W = 290618.17 and ρ = 1%

$$\int B_w e^{-\rho t} dt = 290618.17 \int e^{-t} dt$$

Thus, the increase in the profit on the removal of Karuvelam trees for cattle owners proves the need for eradication of the trees.

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4. Application of Various Scenarios in Fuzzy Mamdani Model

In this section four scenarios are given to show the depletion of water in the study area by applying the Fuzzy Mamdani model. Thus, after giving the rules in the rule editor if the number of trees in an area is entered in the input, the level of water and the amount of nitrogen is given as output based on the data given. In this model, the antecedent (if – part of the rule) and the consequent (then-part of the rule) are fuzzy propositions:

$$R_i : \text{if x is } A_i \text{ then y is } B_i,\ i = 1,2,\ldots,K.$$

Here A_i and B_i are linguistic terms represented by fuzzy sets and K denotes the number of rules in the model.

4.1 Scenarios:

Scenario 1: If Karuvelam trees are removed then water level in lakes, tanks and ponds will be increased.

Scenario 2: If Karuvelam trees are not removed then the benefits of cattle and goat owner will be maximized

Scenario 3: If Karuvelam trees are not removed then water level will be decreased.

Scenario 4: If Karuvelam trees are removed then the benefits of cattle and goat owner will be minimized.

Fuzzy Mamdani model is applied to all the scenarios as follows:

The membership function is given based on the number of trees and the level of water in tanks and ponds and the amount of Nitrogen in the soil. Though there are many nutrients, Nitrogen is a Macronutrient and plays a vital role in enriching the soil. The membership function for these factors is given below.

TABLE III

Range of each Factors

Range	No. of Karuvelam Trees	Level of Water (tmc)	Amount of nitrogen (mg)
Low	0-50	0-20	0-25
Medium	50-150	20-50	25-50
High	>150	>50	50-75

Fuzzy Rules: The fuzzy rules are

1. If (No. of Karuvelam trees is Low) then (Level of Water is High) and (Amount of Nitrogen is High).
2. If (No. of Karuvelam Trees is Medium) then (Level of Water is Medium) and (Amount of Nitrogen is Medium).
3. If (No. of Karuvelam Trees is High) then (Level of Water is Low) and (Amount of Nitrogen is Low). The FIS editor for the input and output variables are given below:

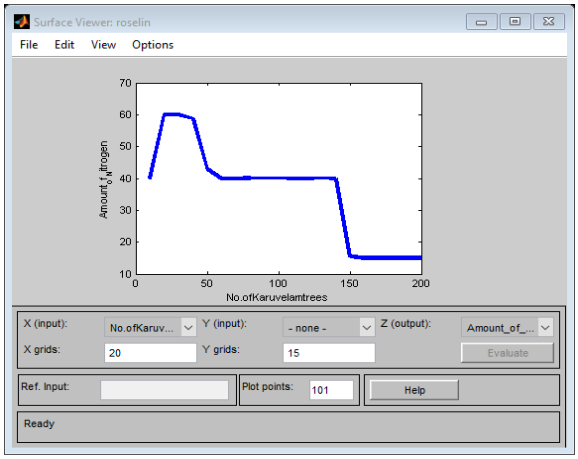
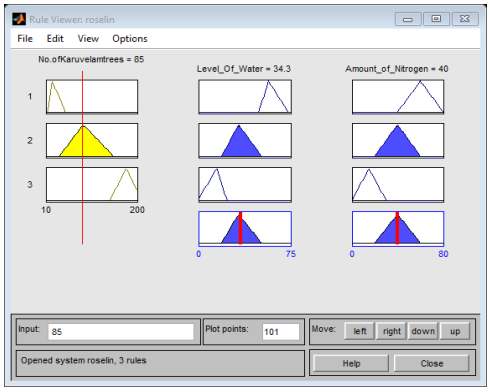


Fig. 1 A FIS editor for input and output variables

Thus, if the Number of Karuvelam trees are entered in the input column, the water level and the amount of Nitrogen can be found out using the Fuzzy editor as shown in Fig.2



Range: Medium

Fig. 2 Level of water and nitrogen when range is medium

5. Conclusion

The government must take necessary steps in the eradication of seemai karuvelam. So far only 15% of the trees had been removed and they are still abundant in number.

The rapid invasion of karuvelam trees in Attayampatti village has depleted the level of water in lakes and river and also the ground water level. Hence the only lasting solution is to dig out the trees and roots entirely, using machines. The Agriculture and Horticulture departments are taking several measures to identify trees

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that harm the ecosystem and destroy them. Also, it is the responsibility of every citizen to destroy atleast one Karuvelam, thereby preventing the earth from many hazardous effects.

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