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COMPARISON OF EMPIRICAL AND SIMULATED PREY-PREDATOR MODELS IN BIOLOGICAL CONTROL TECHNIQUE

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***Abstract*—This study is performed to compare the empirical model and simulated model concerning with the equilibrium of prey-predator correlation in biological control technique particularly in palm-oil farm ecosystem. Owl or its scientific name tyto alba is popular used as the population controller for pest especially rat or its scientific name rattus tiomanicus in palm-oil farm in Malaysia. To serve this intent, an empirical model is developed to compare with a simulated model. The testing carried out results that the empirical model used is less suitable than the simulated model to prove the equilibrium of prey-predator correlation in biological control technique.**

Future work will be discussed on perceiving the long-term effects concerned rat and owl population with palm-oil crops.

Keywords—biological control; equilibrium; prey-predator; empirical model; simulated model.

I. INTRODUCTION

Rat is known as the main pest of palm-oil. The rat species identified in destroying palm-oil fruit is the species of rattus tiomanicus. This rat lives on soil and nests in piles of old fronds cut out of the trees. The rat population in palm-oil farm can reach from 200 to 600 per hectare should it is ignored without proper control [16]]. The rat lifespan is from 10 to 22 months. The sexual maturity of a rat is 4 months. A female rat is capable to reproduce from 5 to 10 for every 3 to 4 months [11,15].

The breeding of rats is handled in many ways by palm-oil farmers. The popular way is to lure using poisonous palm-oil fruit to kill the rats. The popular pesticides used in Malaysia are from the types of rodenticide brodifacoun which also causes the death of predator birds due to poisoning [3, 4]. This method implies that it is less convenient as the pesticide used is very strong and able to kill untargeted animals. The biological control technique is an alternative to the usage of poisoning technique in controlling pests for commercial crops. It is a safer way to sustain soil nutrient aside from saving predator bird population and untargeted animal population in palm-oil farm ecosystem [18].

The owl meant as the predator to rat in the model developed is from the species of tyle alba or barn-owl. The selection of this owl type as the predator is due to its longevity with diet of 98% rats [2,3, 6, 14, 17]. The estimation of rat nutrition by a pair of owls and an owlet is 1300 rats yearly [2]. *Tyto alba* is a mediumsized owl, length of body is 38 cm or 16 inches, opening of wing is at 106 cm and has long and gripping legs [7].

II. EMPIRICAL PREY-PREDATOR MODEL

The empirical model has ever been used in research is by [5]. As Tn represents rat population and Bn represents owl population on time n, the formula to represent the correlation of prey-predator is as follows:

$$\Delta T_n = aT_n - bT_nB_n \qquad (2.1)$$

$$\Delta B_n = cT_nB_n - \mathrm{dB_n} \qquad (2.2)$$

Assumption:

T_n increases exponentially on unavailability of B_n;

B_n decreases exponentially on availability of T_n;

b, the constant is far smaller than a; and c is far smaller than d.

In this study, the constants of *a*, *b*, *c* and *d* on the above-mentioned formula are regarded as the birth rate and death rate of prey-predator.

The rat death rate in this research is assumed only due to the kill by owl. Other causes are not taken into account in this model. The same case applies to owl population. The death of owl happens when the food supply specifically rat deteriorates. This study determines *a* = 0.25, *b* = 0.001, *c* = 0.0001 and *d* = 0.17.

Subsequently, the calculation is made on values of *n*0, *n*1, *n*2, …, *n*25. The following is examples of calculation of *n*0 and *n*1. On *n*0, the initial values for both prey-predator are *Tn* = 200 and *Bn* = 3.

To simplify understanding and calculation, the formula (2.1) and (2.2) can be rewritten as follows:

$$\Delta T_n = T_{n+1} - T_n = aT_n - bT_nB_n \qquad (2.3)$$

$$\Delta B_n = B_{n+1} - B_n = cT_nB_n - dB_n \qquad (2.4)$$

If T_n and B_n are incorporated in the formulae (2.3) and (2.4),

$$T_{n+1} = T_n + aT_n - bT_nB_n$$

$$T_{n+1} = T_n(1+a) - bT_nB_n$$

$$B_{n+1} = B_n + cT_nB_n - dB_n$$

$$B_{n+1} = B_n - dB_n + cT_nB_n$$

$$B_{n+1} = B_n(1-d)B_n + cT_nB_n$$

$$T_{n+1} = T_n(1+a) - bT_nB_n = T_n(1+0.25) - 0.001T_nB_n = 1.25T_n - 0.001T_nB_n$$

$$B_{n+1} = B_n(1-d) + cT_nB_n = B_n(1-0.17) + 0.0001T_n B_n = 0.83B_n + 0.0001T_n B_n$$

on initial values T_0 = 200 and B_0 = 3 and at time n_0,

$$T_{0+1} = T_1 = 1.25T_0 - 0.001T_0 B_0 = 1.25(200) - 0.001(200)(3) = 249.4$$

$$B_{0+1} = B_1 = 0.83B_0 + 0.0001T_0 B_0 = 0.83(3) + 0.0001(200)(3) = 2.55$$

on T_1 = 249.4 and B_1 = 2.55 and at time n_1,

$$T_{1+1} = T_2 = 1.25T_1 - 0.001T_1 B_1 = 1.25(249.4) - 0.001(249.4)(2.55) = 311.11$$

$$B_{1+1} = B_2 = 0.83B_1 + 0.0001T_1 B_1 = 0.83(2.55) + 0.0001(249.4)(2.55) = 2.18$$

and subsequently calculated until n25. n25 refers to the economic period of palm-oil that is equivalent with 25 years. Table 1 and Fig. 1 are the outcomes of correlations between Tn and Bn based upon the calculations made.

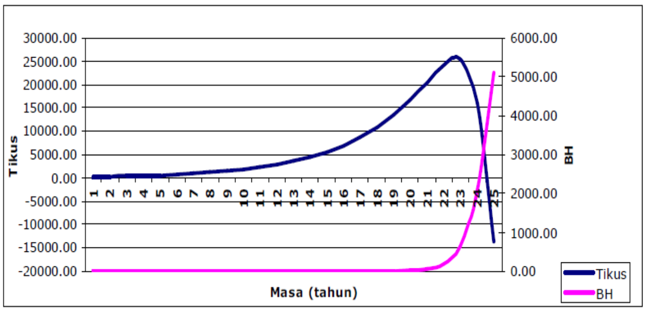

Fig. 1: Correlation graph of T_n and B_n populations on time *n*

Table 1. Correlation of T_n and B_n on time *n*

n	T_n	B_n
1	249.40	2.55
2	311.11	2.18
3	388.21	1.88
4	484.53	1.63
5	604.88	1.43
6	755.23	1.28
7	943.07	1.16
8	1177.75	1.07
9	1470.93	1.01
10	1837.17	0.99
11	2294.65	1.00
12	2866.01	1.06
13	3579.47	1.19
14	4470.09	1.41
15	5581.32	1.80
16	6966.61	2.50
17	8690.86	3.81
18	10830.45	6.48
19	13467.90	12.39
20	16667.98	26.98
21	20385.34	67.35
22	24108.66	193.20
23	25477.94	626.15
24	15894.46	2115.00
25	-13748.70	5117.13

As perceived in Table 1 and Fig. 1, the graph escalates from n = 0 to n = 10 on a circumstance when the rat population rises and owl population declines in exponential rate and distracts from the equilibrium level. On the other hand, this situation then changes from n = 11 to n = 25. As a whole, the correlation between rat and owl can be stated as unstable. To test the equilibrium on the correlation of rat and owl, the following formula is used,

$$B_e = \frac{a}{b} \text{ and } T_e = \frac{d}{c}$$

whereby Be and Te are deemed equilibrium if the calculation results of a / b and d / c are same as the initial values of B0 and T0.

Using values in correlation of rat and owl as a = 0.25, b = 0.001, c = 0.0001 and d = 0.17,

$$B_e = \frac{0.25}{0.001} = 250 \text{ and } T_e = \frac{0.17}{0.0001} = 1700$$

The calculation of equilibrium clarifies that if the study is willing to achieve equilibrium towards the model of prey-predator particularly rat-owl in this control biological technique, this study has to take the values of T0 = 1700 and B0 = 250 for the usage of constants of a = 0.25, b = 0.001, c = 0.0001 and d =

0.17. This also means that this empirical model is not able to describe entirely the actual situation of prey-predator correlation in biological control technique.

Through the literature review executed, the uncontrolled rat population can reach from 200 to 400 that is T0 = 200 per hectare [16]. For each and every 25 hectares of palm-oil farm, only one owl cage is placed to curb the rat population [13]. Every cage is assumed to contain 3 owls that is B0 = 3 consisting of 1 male owl, 1 female owl and 1 owlet.

III. Simulated Prey-Predator Model

This simulated model is developed using Stella 8 software. Stella 8 software is a graphical simulation program developed by Isee Systems Inc. in Windows environment. The model uses the same constant values as the empirical model to explain the birth rate.

Rat birth rate, $a = 0.25$

Owl birth rate, $d = 0.17$

The death rates of rat and owl whereas are explained further in sections 3.1 and 3.2.

A. Rat Sector

The starting value set is 200 rats. The area of palm-oil farm concerned in this study is 100 hectares. The overall total population of rat is:

Rat $= 200 \times 100$ ha $= 20{,}000$

The rat population size annually depends upon the total population of rat in the previous year and the rat birth and death rates. The change of rate population every year is calculated using the Runge-Kutta 4th Order algorithm. This algorithm is to determine the change towards time in Stella 8 simulation software. The correlation among these factors is clarified through the following formula:

Rat (t) = Rat$(t - dt)$ + (Rat birth − Rat death) $\times$ dt

Fig. 2 illustrates the rat sector in the simulation carried out. The constant values and variables concerned in this rat sector are postulated.

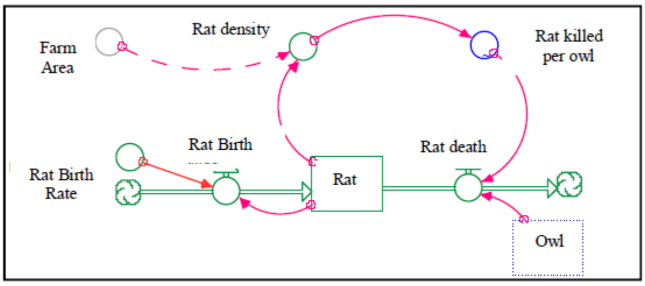

Fig. 2: Rat sector in simulated model

Rat birth rate = 3 times yearly = 3 / 12 = 0.25

Rat birth = Rat × Rat birth rate

Rat density = Rat / Farm area

Rat death = Owl (BH) × Rats killed per owl

This study presumes that the killing by owl is the only a reason that brings to the rat death. The rats killed per owl increases exponentially in tandem with the increased pattern of rat population also exponentially. The estimation of rat nutrition by a pair of owls and its owlet is 1,300 rats yearly [2]. Based upon this fact, researcher projects the rat nutrition rate of owl is 5 times greater than the rat population.

Rats killed per owl = GRAPH(Rat Density)

(0.00, 0.00), (50.0, 250), (100, 720), (150, 1080), (200, 1640), (250, 2160), (300, 2800), (350, 3700), (400, 4700), (450, 6080), (500, 8000)

B. Owl Sector

The starting value set is 1200 owls. The formula as follows demonstrates the owl early population size:

Owl = (100 ha / 25 ha) × 3 Owl = 12

The owl population size annually depends upon the total population of owl in the previous year and the owl birth and death rates. The correlation among these factors is clarified through the following formula:

Owl(t) = Owl(t − dt) + (Owl birth − Owl death) × dt

Fig. 3 illustrates the owl sector in the simulation carried out. The constant values and variables concerned in this owl sector are postulated.

Owl birth rate = 0.17

Owl birth = Owl × Owl birth rate

Owl death = Owl × Owl death rate

This study presumes that the owl death rate relies upon the rat density. This simulation describes that the owl death rate decreases exponentially towards to the rat density values.

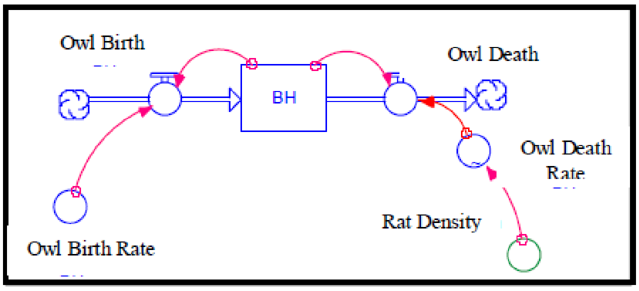

Fig. 3: Owl sector in simulated model

Owl death rate = GRAPH(Rat density)

(0.00, 50.0), (10.0, 49.0), (20.0, 47.0), (30.0, 44.0), (40.0, 40.0), (50.0, 35.0), (60.0, 29.0), (70.0, 22.0), (80.0, 14.0), (90.0, 3.00), (100, 0.00)

C. Equilibrium of Entities

The correlation between rat and owl attains equilibrium on the constant value and variable imparted in this simulation. Fig. 4 indicates a population graph for the both entities concerned.

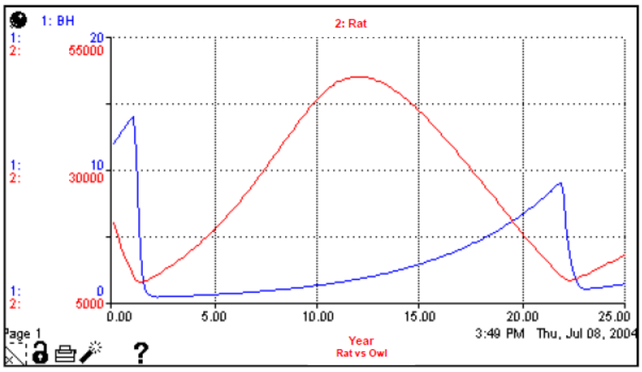

Fig. 4: Population graph for rat and owl

The positive correlation is produced between rat and owl. By observing the graph, the owl population declines when the rat population also declines due to the lack of food supply. In period 1.25 years, the rat population re-escalates due to the declination of owl. In period 1.3 years, the owl population re-escalates in accordance with the escalation of rat population. In 12th year, the rat population starts to drop on account of the raise of owl population. In period 21.75 years, the owl population is found to re-deteriorate because the rat population deteriorates either.

IV. Conclusion

Through these two types of model developed, the results obtained using Stella 8 software is more accurate to illustrate the correlation of prey-predator in biological control technique. The model constructed using Stella 8 is more dynamic and possesses additional constants as rat density and the rats killed per owl that are not incorporated in empirical model. The model from this Stella 8 software is also credible to indicate the equilibrium of correlation at extreme starting value (T0 = 200, B0 = 3). After proving the accuracy of the simulated model using Runge-Kutta 4th Order algorithm, we will further our simulation to perceive the long-term effects concerned rat and owl population with palm-oil crops for future work.

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