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Dynamic Simulation of the System of the Nymphalidae Larvae Based on STELLA

Sui Tao^{1,a}, Zeng Fanna², Zheng Ronghui² and Jiang Qiang¹

¹ School of Automobiles and Transportation Shenyang Ligong University, Shenyang, Liaoning, PR.China

² School of Information Science and Engineering Shenyang Ligong University, Shenyang, Liaoning, PR.China

^a Corresponding author: mutong1978@163.com

Abstract. In this paper, the colour, grayscale and edge of the Nymphalidae larvae are analyzed by using the image segmentation technology, the results are applied to the data of system simulation. Then the Nymphalidae larvae is proposed as the target system. It predicts the population of the larvae by simulating the larval system by using STELLA software. It is also mainly to understand the influence of the environmental fitness on the number of larvae at each stage.

1. Introduction

A creature can simulate another creature to deceive and escape the enemy ^[2]. This is a special survival strategy that was first described by British naturalist Henry W. Bates in 1862. He called this phenomenon mimicry ^[1]. Mimicry refers to the phenomenon that the appearance or colour formed by certain organisms during evolution is very similar to living or non-living. This is the most typical example of a biological adaptation environment. Biological mimicry includes protection colour, warning colour and narrow mimicry. For example, the larvae of the Nymphalidae have a survival advantage due to the similarity of the colour and shape of the leaves. System dynamics software is a branch of systems science. It is also a close combination of system science theory and computer simulation. It divides the research object into different subsystems, and establishes a causal network between systems. Then it expresses the relationship between the system and the environment and the subsystems within the system through differential equations and function relationships. This software enables quantitative simulation and prediction of trends.

2. Image analysis

Euthalia phemius, a species of the *Euthalia kardama* family of the Nymphalidae genera. Its host plants are usually mango trees and the leaves of other plants of the anacardiaceae. Environmental fitness is the degree of mimicry of the larvae and environment after the image is processed by image segmentation.



Figure 1. *Euthalia phemius*

2.1. Image analysis by the grayscale histogram

The grayscale histogram indicates that the image includes background, leaves, leaves containing worms, leaf stems, etc. They have corresponding gray peaks. If the number of peaks in the gray histogram is smaller, it means that the content in the picture is more single, that is, the mimetic effect of the insect is the best. Because the color itself is very susceptible to factors such as light, there are many variations in the color of similar objects. It is difficult to provide key information, which naturally uses grayscale images.

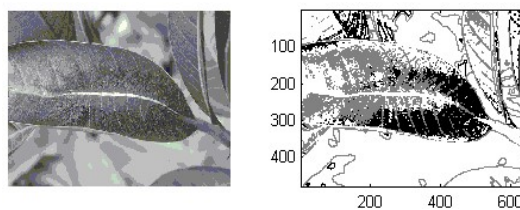


Figure 2. Grayscale image

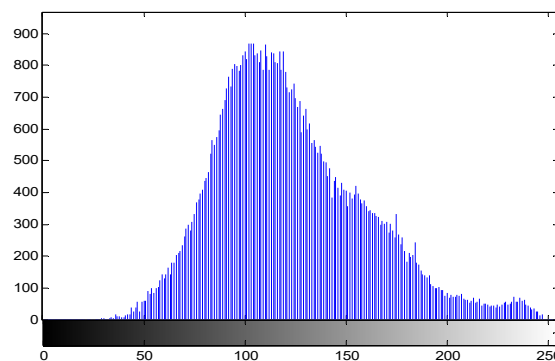


Figure 3. Density histogram

2.2. The HSV colour space

The HSV color space is an important color space model that is suitable for human eye resolution and visual consistency. It converts images from RGB color space to HSV color space, and some images are better. By analyzing the images of different parameters, the mimetic effect between the larva and the environment can be better described.



Figure 4. HSV space H component image

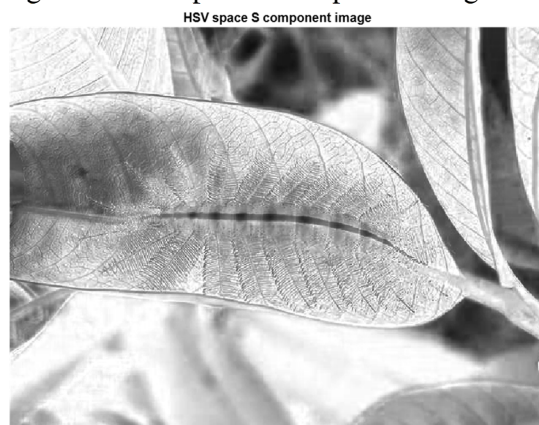


Figure 5. HSV space S component image

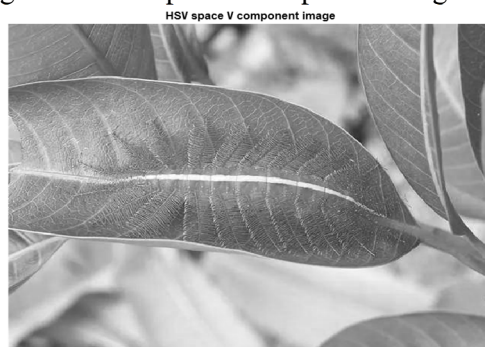


Figure 6. HSV space V component image

2.3. Sobel edge detection

Sobel operator is one of the most important operators in image edge detection, and plays an important role in the field of information technology such as machine learning, digital media and computer vision. Since the Sobel operator weights the gray value of the field of each pixel to reduce the degree of edge blur, the edge detection effect is better.



Figure 7. Sobolev edge detection

3. Dynamic simulation of the system by STELLA

During the development of the *Euthalia kardama*, different obvious morphological characteristics will have different effects on the population at the development stage. As a research stage, the larvae of the *Euthalia kardama* were studied to study the effects of biological and environmental fitness on the number of larvae. Based on this, the simulation process of the population life system was started.

According to the growth and development rules of the larvae, the model is divided into four stages: egg stage, larval stage, pupa stage and adult stage. The larval stage is divided into five age classes. In the model, the larvae of different stages are regarded as "stock". Eight stocks are used to indicate the number of different periods (egg for egg stage, larvae1~larvae5 for five ages, pupa for sputum, and adult for adult).

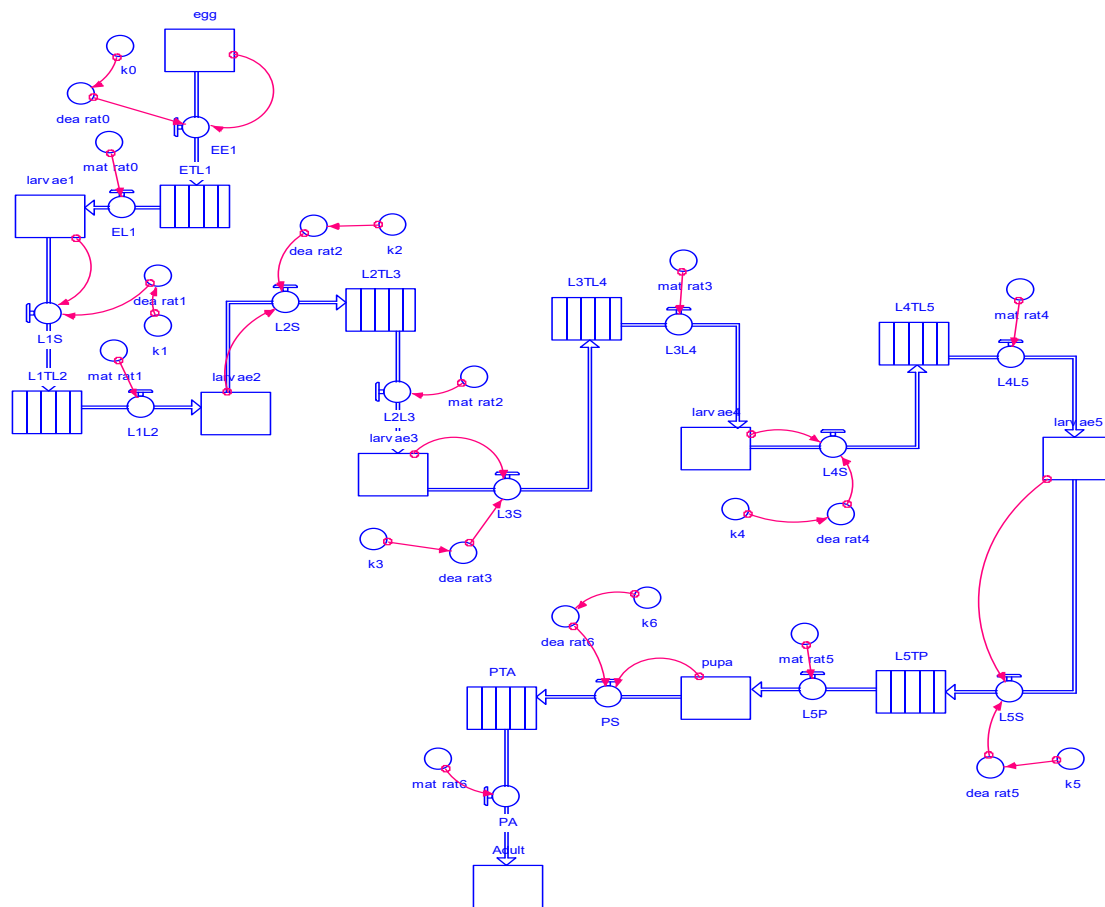


Figure 8. System dynamics model of growth and development

The number of conversions of the population from the previous one to the latter is considered a "flow". The parameter that affects the "stock" and "flow" state changes is "converter". The environmental fitness in the study was used as the main control variable to control the survival rate of larvae at different stages. According to the mutual constraint relationship and its dynamic characteristics between the larvae and the environmental fitness, the corresponding model is constructed by using STELLA software, and the corresponding flow graph is drawn.

Add data and function relationships to the already established system model as needed. The initial egg size of the larvae is 200, and the number of larvae of other ages is 0, which are used as initial values. Due to the different morphology of larvae at different ages, the image-segmentation techniques can be used to obtain the mimicry of different age-level larvae and the environment from high to low, which are larvae5, larvae4, larvae3, larvae2, larvae1, and pupa. Set to a different k value ($k_0 \sim k_6$). The model assumes that other conditions, such as temperature, are consistent and has no effect on the overall larval dynamics. Davidson of the University of Adelaide, Australia, proposed using a logistic model to describe the effect of temperature on insect growth rate ^[7] in 1994. The model is as follows:

$$R(T) = \frac{c}{1 + e^{(a+bT)}} \quad (1)$$

Where c is the maximum development rate and a and b are empirical constants. The developmental period of the population (mat rat) can be regarded as the reciprocal of the development rate of the same period (see Table 1). Due to the limited conditions, the calculation parameters of *Cnaphalocrocis medinalis* are used at the temperature of 25°C in the literature ^[3], and the development rate is calculated. These conditions were used to simulate changes in the number of larvae under different environmental fitness.

Table 1. Dynamically changing equations

Different insect states	Equation of state	Equation of process
Egg	$Egg(t) = egg(t - dt) + (-EE1) * dt$ INIT egg = 200	input: output: EE1 = egg*(1-dea_rat0)
larvae1	$larvae1(t) = larvae1(t - dt) + (EL1 - L1S) * dt$ INIT larvae1 = 0	input: TRANSIT TIME = mat_rat0 output: L1S = larvae1*(1-dea_rat1)
larvae2	$larvae2(t) = larvae2(t - dt) + (L1L2 - L2S) * dt$ INIT larvae2 = 0	input: TRANSIT TIME = mat_rat1 output: L2S = larvae2*(1-dea_rat2)
larvae3	$larvae3(t) = larvae3(t - dt) + (L2L3 - L3S) * dt$ INIT larvae3 = 0	input: TRANSIT TIME = mat_rat2 output: L3S = larvae3*(1-dea_rat3)
larvae4	$larvae4(t) = larvae4(t - dt) + (L3L4 - L4S) * dt$ INIT larvae4 = 0	input: TRANSIT TIME = mat_rat3 output: L4S = larvae4*(1-dea_rat4)
larvae5	$larvae5(t) = larvae5(t - dt) + (L4L5 - L5S) * dt$ INIT larvae5 = 0	input: TRANSIT TIME = mat_rat4 output: L5S = larvae5*(1-dea_rat5)
Pupa	$Pupa(t) = pupa(t - dt) + (L5P - PS) * dt$ INIT pupa = 0	input: TRANSIT TIME = mat_rat5 output: PS = pupa*(1-dea_rat6)
Adult	$Adult(t) = Adult(t - dt) + (PA) * dt$ INIT Adult = 0	input TRANSIT TIME = mat_rat6

4. Result analysis

As shown in figure 9, the dynamic curves of the number of larvae from larvae1 to larvae5 under different environmental fitness are shown. By observing the peak number of larvae, it shows that there are 150 first-instar larvae, 125 second-instar larvae, 111 third-instar larvae, 100 fourth-instar larvae, and 92 fifth-instar larvae. The number of larvae from the first to the second instar decreased by 25, 14 from the second to the third, and 11 from the third to the fourth, and 8 from the fourth to the fifth. According to the above, as the environmental fitness increases, the number of larvae decreases.

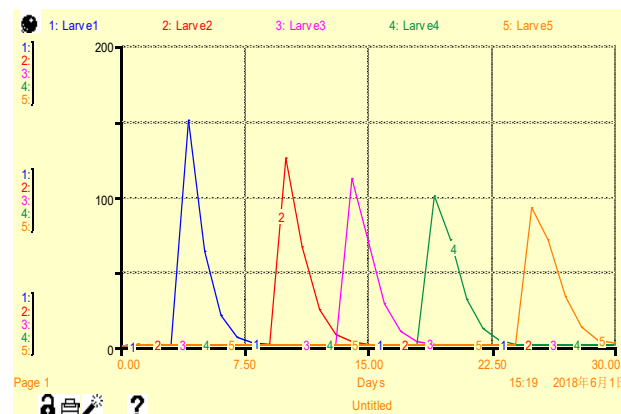


Figure 9. Dynamic changes in the number of different larval states

Table 2. Comparison of results

K value	Different insect states	Mortality rate	Quantity	
0.2	Egg	—	200	—
0.3	larvae1	0.25	150	50
0.45	larvae2	0.167	125	25
0.5	larvae3	0.112	111	14
0.65	larvae4	0.099	100	11
0.8	larvae5	0.08	92	8

5. Conclusion

According to the relevant results of image processing, the corresponding model is constructed with the related methods of system dynamics as the center. In the dynamic simulation of the number of different insect states, the parameters of the model operation are adjusted through the visual environment of the STELLA software. The number of larvae with different environmental fits is predicted with a certain initial egg population. The higher the fitness is, the less the larva reduces, which is understood to be the lower the mortality rate. This idea was verified by a dynamic quantity plot. Due to limited data, it is not possible to consider various factors for calculation and in-depth analysis. It is only based on other data for simple predictions and simulations. And this research will continue to be improved with relevant experiments in the future studies.

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