D.2 Cicada Population Dynamics

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Abstract

This study investigates the population dynamics of $Magicicadaseptendecim$ a species of cicada which have cyclical growth cycles. We model the growth cycle using a discrete growth model, the Hassell equation. We explore how fast the cicada can repopulate a new revitalized hardwood forest to its max capacity with various initial population and found that the most feasible yet fast way to repopulate the cicadas would be to repopulate in 102 years with a starting population of 500 thousand.

Introduction

$Magicicadaseptendecim$ is a species of periodic cicada with a 17-year life cycle. During its mating phase, an adult female will lay 200-400 egg. The eggs hatch and young cicadas live underground for 17 years going through 5 growth stages until it reaches adult hood and comes out to start the mating cycle again. With a clearly periodic growth cycle we will model the growth using a discrete time growth model, specifically the Hassell Equation:

$$N_{n+1} = \frac{R_0 N_n}{(1 + aN_n)^b}$$

Results and Discussion

Given that newly revitalized healthy hardwood forests can support up to about 250 million cicadas per square kilometer, the carrying capacity, K, of a hardwood forest with an area of 350 km^2 is:

$$K = 350\,\mathrm{km}^2 \times 2.5 \times 10^8\,\mathrm{cicadas/km}^2 = 8.75 \times 10^{10}\,\mathrm{cicadas}$$

If, in absence of competition, a cicada population is equally split between males and females, 80% of adults are able to reproduce, each female lays 300 eggs, and 20% of eggs survive to adulthood, the effective per capita growth rate, Ro, in terms of the total (male and female) population is:

$$R_0 = .5 \times .8 \times .2 \times 300 \text{ eggs} = 24 \text{ eggs}$$

We implement the Hassell equation in MATLAB as shown in Figure 1.

```
N0 = 100; % Starting population
R0 = 24; % Per capita growth rate
K = 8.75e10; % Carrying capacity
a = R0 / K; % Competitive rate
b = 1;
cycleLen = 17; % Cicada life cycle (in years)
years = 170; % Total years
numCycles = floor(years / cycleLen);

pop = zeros(1, numCycles + 1);
pop(1) = N0; % Init pop

for i = 2:numCycles + 1
    Ni = pop(i - 1);
    pop(i) = (R0 * Ni) / ((1 + a * Ni)^b);
end

plot(0:numCycles, pop, '-bo');
xlabel('Cycle Number');
ylabel('Population');
title('Cicada Population Growth Over Time');
legend('Hassel, N0=100, b=1, a=R0/k, k=8.75e10, R0=24','Location','northwest')
grid on;
```

Figure 1: Implementation of Hassell equation

In our implementation we assume that $b = 1$, $a = \frac{R_0}{K}$ and a starting population of 100. We run the simulation for 170 years(10 cycles) which gives us the graph in Figure 2.

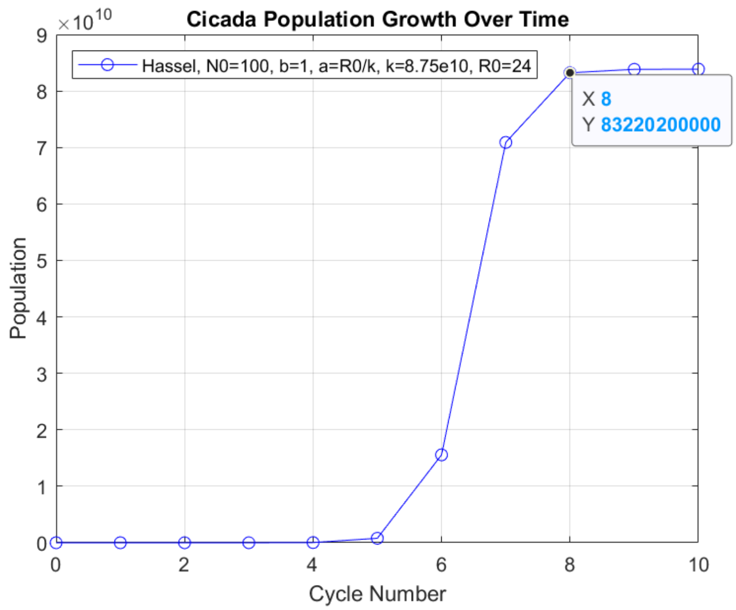

Figure 2: Hassell equation, $N_0 = 100$

As we can see the cicada population growth starts to plateau after 8 cycles(136 years) and reaches a population of 83.22 billion.

Additionally we can also plot the population as a graph of N_{n+1} vs N_n and add the line of y = x as shown in Figure 3. We are able to do this by adding the code we see in the Figure 4 to the code in Figure 1.

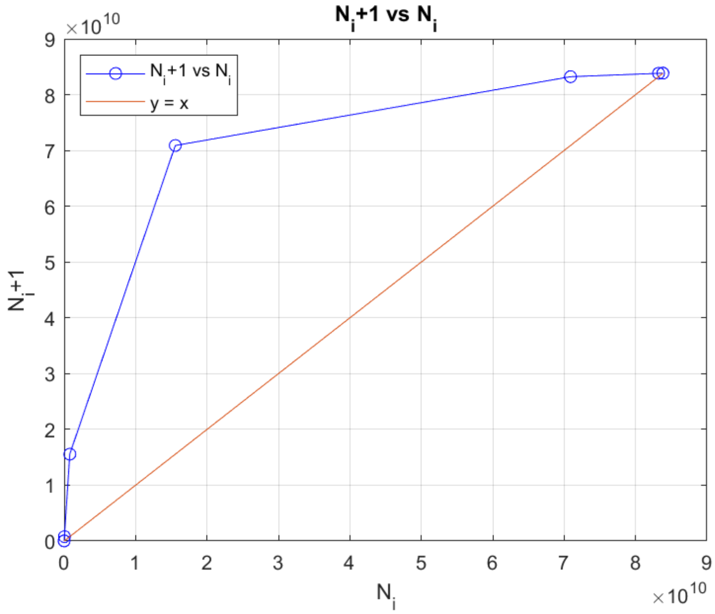

Figure 3: N_{i+1} vs N_n

```
Ni = pop(1:end-1);
Ni_plus_1 = pop(2:end);
plot(Ni, Ni plus 1, '-bo');
```

Figure 4: Enter Caption

We can repeat the growth over time simulation two more times to see what initial population we need to reach the max capacity in 102 years(6 cycles) and 51 years(3 cycles). Figure 5 and Figure 6 show results respectively. We can change the N_0 variable in our code to easily test various initial populations while keeping the rest of the code the same.

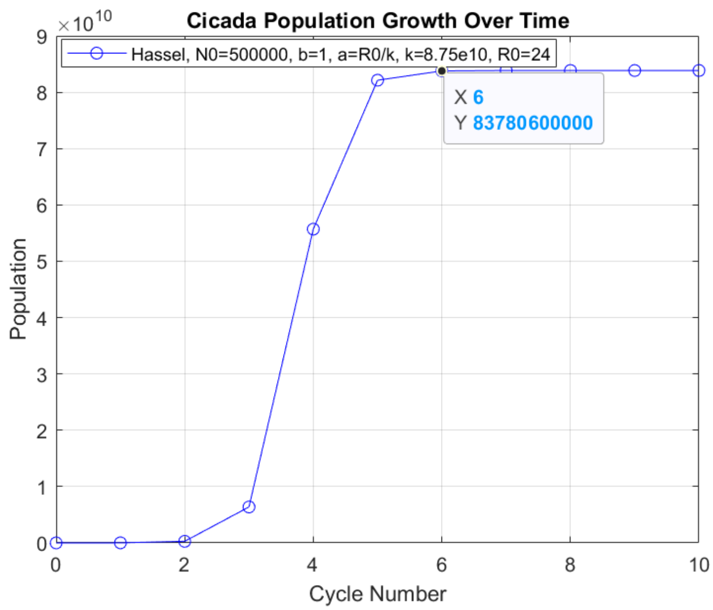

Figure 5: Hassell equation, $N_0 = 500000$

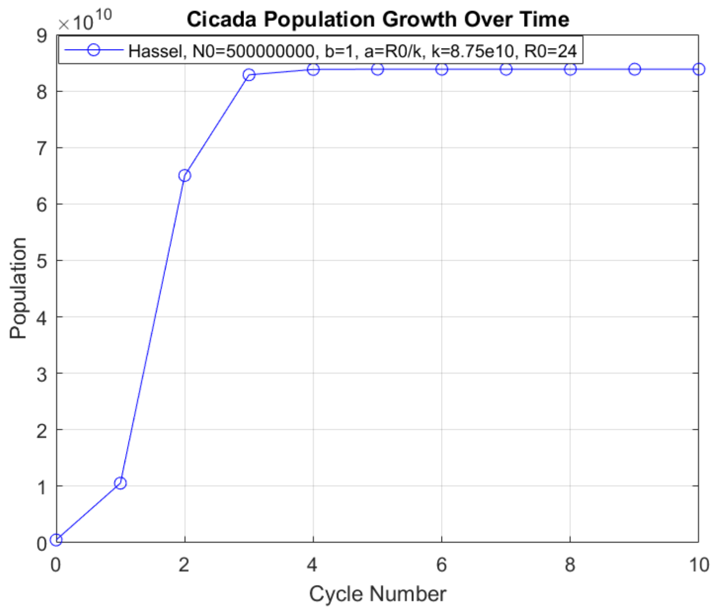

Figure 6: Hassell equation, $N_0 = 500000000$

In Figure 5 we see that with an initial population of 500 thousand, we are close to max capacity in 102 years(6 cycles) before growth starts to plateau. In Figure 6 we see that with an initial population of 500mil we reach close to the max capacity in 51 years(3 cycles) before growth starts to plateau as well.

It can be difficult to visualize the size of large numbers of cicadas. Given that an adult cicada weighs approximately 2 grams, we can convert the populations found above into kilograms and then into the equivalent number of people (assuming an average mass of 70 kg per person). We also perform the same calculation for the carrying capacity of the forest.

First, we calculate the total mass of the cicada population found earlier:

$$2\,\mathrm{g/cicada} \times 83,220,200,000\,\mathrm{cicadas} \Rightarrow \frac{166,440,400,000\,\mathrm{g}}{1000\,\mathrm{g/kg}} = 166,440,400\,\mathrm{kg}$$

Next, we convert this to the equivalent number of people:

$$\frac{166,440,400\,\mathrm{kg}}{70\,\mathrm{kg/person}} = 2,377,720\,\mathrm{people}$$

Now, for the carrying capacity of the forest (found to be 8.75×10^{10} cicadas):

$$8.75 \times 10^{10}\,\text{cicadas} \times 2\,\text{g/cicada} = 175,000,000,000\,\text{g}$$

Converting this to kilograms:

$$\frac{175,000,000,000\,\text{g}}{1000\,\text{g/kg}} = 175,000,000\,\text{kg}$$

And finally, converting this mass to the equivalent number of people:

$$\frac{175,000,000\,\text{kg}}{70\,\text{kg/person}} = 2,500,000\,\text{people}$$

Thus, the equivalent mass of the cicada population is approximately 2,395,834 people, and the carrying capacity of the forest is equivalent to the mass of 2,500,000 people.

Given the data we have found we can make an estimate of weather it is feasible to repopulate a newly revitalized hardwood forest of $350km^2$. If we want to see if it is feasible to repopulate the forest to its max capacity in 51 years then we can first estimate the weight of the initial population of cicadas to know whether we can transport such large amount of cicadas. The total weight of the initial population required to repopulate in 51 years is:

$$2\,\text{g/cicada} \times 500,000,000\,\text{cicadas} \Rightarrow \frac{1,000,000,000\,\text{g}}{1000\,\text{g/kg}} = 1,000,000\,\text{kg}$$

We can further analyze by the fact 1 ton is equivalent to about 1000kg which means 500mil cicadas wight about 1000 tons. In the US, an 18 wheel truck can carry at maximum 40 tons of cargo. Logistically speaking transporting and keeping alive this many cicadas is practically impossible with the amount of transportation vehicles it will require. On the other hand it may be feasible to repopulate the forest to its capacity in 102 years.

$$2\,\text{g/cicada} \times 500,000\,\text{cicadas} \Rightarrow \frac{1,000,000\,\text{g}}{1000\,\text{g/kg}} = 1000\,\text{kg}$$

1000kg is about 1 ton which is much more feasible to transport.

Conclusion

The Hassell growth model used in this study provides a reasonable simulation for cicada population growth. After solving the carrying capacity for a $350km^2$ to be about 8.75×10^{10} cicadas we used the Hassell model to find that with a 51 year plan to repopulate the forest, it requires an initial population of 500 million cicadas which we concluded to to be logistically impossible to transport due to the sheer weight of the total population of a total of 1000 tons. However it is much easier to repopulate the $350km^2$ forest in 102 years since we only need an initial cicada population of 500 thousand which weighs around 1 ton, easily transportable by multiple trucks. While the Hassel equation doesnt reach our found carrying capcity it comes close to it at 8.322×10^{10} cicadas.