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An Insight: Spruce budworm outbreak model

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Announcement

The spruce budworm (Choristoneura fumiferana) is one of the most harmful invasive insects in the Eastern United States and Canada's spruce and fir forests. The majority of the time, the number of budworms remains minimal. However, every forty years or so, the population of budworms grows to large proportions, wreaking havoc on the forest and killing many trees before returning to pre-explosion stages. These outbreaks seem to have occurred on a daily basis for hundreds, if not thousands, of years, according to evidence.

The wood products industry would like to understand the cycles of spruce budworm species as a first step toward improving successful control of the issue, as these outbreaks have resulted in the loss of millions of cords of spruce and fir. We look at a model developed by University of British Columbia scientists D. Ludwig, D. D. Jones, and C.S. Holling that describes some of the characteristics of the budworm cycle.

The continuous logistic equation is modified for the budworm population size model. Let $\mathbf{tt}$ denote time on any arbitrary scale, and $w(t)w(t)$ represent the size of the budworm population at time $\mathbf{tt}$. We use an autonomous differential equation of the form to model the evolution of $w(t)w(t)$.

$\mathbf{dwdt = rw(1-wa)-h(w), dwdt = rw(1-wa)-h(w)}$,with $\mathbf{aa}$ carrying power and a medium density growth rate $\mathbf{rr}$ The last word, $\mathbf{h(w)h(w)}$,simulates budworm mortality due to predatory birds. This concept is analogous to harvesting, which we used in the discrete logistic model.

In a unique manner, the rate of predation $\mathbf{h(w)h(w)}$ is influenced by the budworm population. Second, if the spruce budworm population is low, the predation rate is low, almost zero, so the birds will search out other prey. When the number of budworms increases, so will the rate of predation. However, the second significant aspect is that the predation rate cannot reach a certain level. Instead, if the budworm population is high enough, the rate of predation approaches a limit.

The outbreak

If the condition was shaky when $\mathbf{a = 20 a = 20}$, it becomes downright ugly when the forest expands and the carrying capacity increases. If the carrying potential exceeds $\mathbf{a = 27 a = 27}$, something happens to the equilibrium. When the carrying capacity is about $\mathbf{a = 30 a = 30}$, explain the condition. What is the number of equilibria in the equation? What are their priorities? Are they steady or unsteady? Determine the initial conditions under which the solution will converge to the equilibrium with each stable equilibrium.

Don't put your confidence in the graph's Forward Euler approximation (blue curve). Use the Forward Euler approximation as a reference, but also use a graphical method based on the graph of $\mathbf{f(w)f}$ to approximate a solution $\mathbf{(w)}$.

If the blue curve tends to pause where it shouldn't (for example, away from an equilibrium), try increasing the simulation's total time $\mathbf{tftf}$ to see if you can get the blue curve to behave as you want it to (based on the graph of $\mathbf{f(w)f(w)}$). You should have found that when the forest is large enough for the carrying potential to be about $\mathbf{a = 30 a = 30}$ (and the growth rate is set at $\mathbf{r = 0.52 r - 0.52}$), the spruce budworm population explosion is unavoidable. The population almost doubles to $w = 30w = 30$. Budworms are entering the forest, chewing the leaves off the trees and decimating the forest. Is the situation under control thanks to the birds? For the epidemic equilibrium, what is $\mathbf{h(w)h(w)}$? Is it any bigger than it was when the budworm population was a quarter of what it is now? The birds are having a good time, but they are just making a small dent in the budworm population.

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