Individual-based simulations

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Learning objectives

1. Understand what individual-based models are
2. Try implementing individual-based models in R

Today’s outline

1. Basic population models
2. Introduction to individual-based models
3. Introduction to Programming Project 3,

Opening discussion

Many mathematical models in biology consider the dynamics of a system, that is how the system changes in space or time, without explicitly modeling individual organisms (or cells, etc.). Can you think of any examples of models that fit this description? Discuss in your groups.

Example 1: Exponential population growth

Simple mathematical model for change in population size, *N*, over time:

$$\frac{dN}{dt} = (b - d)N = rN$$

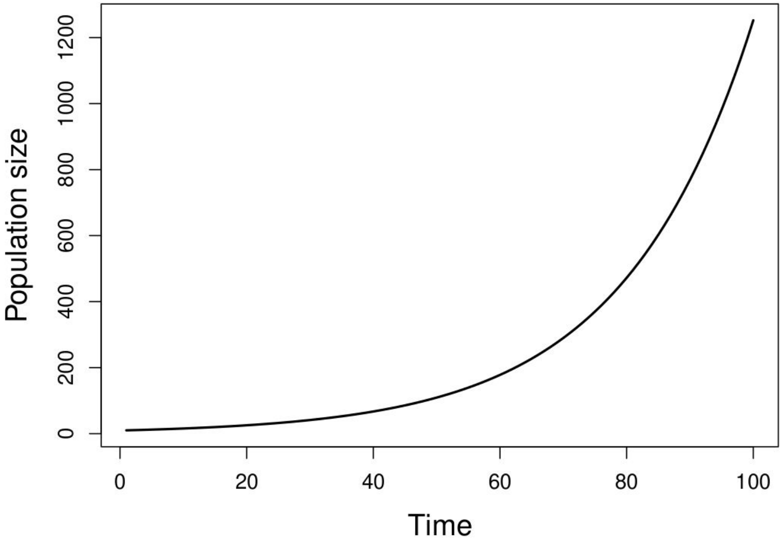
b and *d* denote birth/death rates, which can be combined to give *r*, the intrinsic growth rate. Growth is positive when $r > 0$, and decline occurs when $r < 0$.

Example 1: Exponential population growth

Simple mathematical model for change in population size, *N*, over time:

```
expGrowth<-function(N0,time=100,b=1,d=.95){
   N<-rep(N0,time)
   for(i in 2:time){
      N[i]<-N[i-1] + (b-d) * N[i-1]
   }
   return(N)
}
```

Example 1: Exponential population growth



$r = 0.05, N_0 = 10$

Example 2: Logistic population growth

In reality, most populations cannot grow indefinitely but are instead limited by some resource. This leads to logistic growth:

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$

r is again the intrinsic growth rate (b - d), and K is the carrying capacity

Example 2: Logistic population growth

Using the exponential growth function for inspiration, take five minutes to implement this model in R among your groups

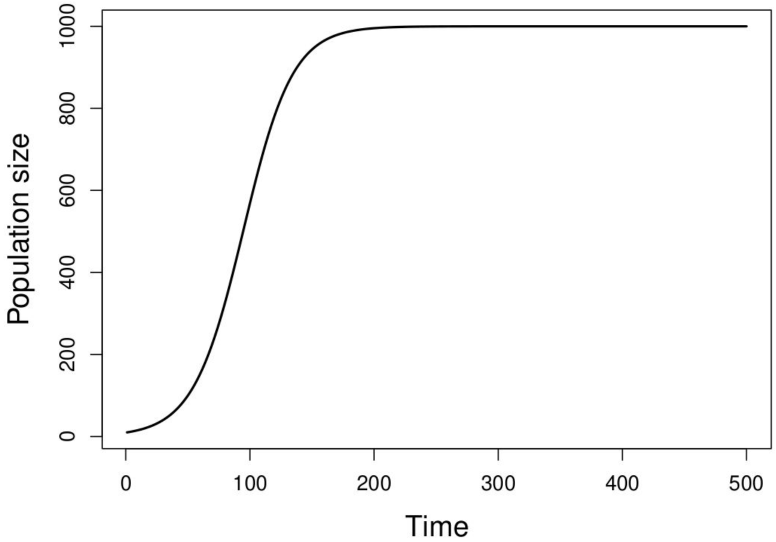
$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$

Example 2: Logistic population growth

My function for logistic growth:

```
logGrowth<-function(N0,time=100,r=0.05,K=1000){
    N<-rep(N0,time)
    for(i in 2:time){
        N[i]<-N[i-1] + r * N[i-1] * (1 - N[i-1]/K)
    }
    return(N)
}
```

Example 2: Logistic population growth



$r = 0.05, N_0 = 10, K = 1000$

Example 3: Growth with competition

We can also model population dynamics in the presence of competition between two species with population sizes N_1 and N_2:

$$\frac{dN_1}{dt} = r_1 N_1 \left(\frac{K_1 - N_1 - \alpha N_2}{K_1} \right)$$

$$\frac{dN_2}{dt} = r_2 N_2 \left(\frac{K_2 - N_2 - \beta N_1}{K_2} \right)$$

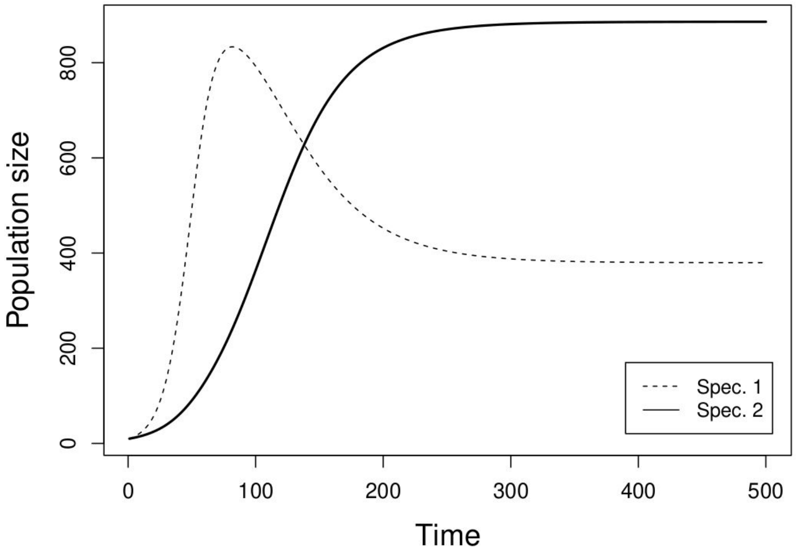
α measures the effect of species 2 on species 1; β measures the effect of species 1 on species 2

Example 3: Growth with competition

My function for logistic growth:

```
competition<-function(N0_1,N0_2,r_1,r_2,K_1,K_2,
                        alpha,beta,time){
   N<-matrix(0,nrow=2,ncol=time)
   N[1,1]<-N0_1;N[2,1]<-N0_2
   for(i in 2:time){
      N[1,i]<-N[1,i-1] + r_1 * N[1,i-1] *
          ((K_1 - N[1,i-1] - alpha * N[2,i-1])/K_1)
      N[2,i]<-N[2,i-1] + r_2 * N[2,i-1] *
          ((K_2 - N[2,i-1] - beta * N[1,i-1])/K_2)
   }
   return(N)
}
```

Example 3: Growth with competition



$$r_1 = 0.1,\ r_2 = 0.05,\ K_1 = K_2 = 1000,\ \alpha = 0.7,\ \beta = 0.3$$

Useful models, but not without limitations

- ➢ Deterministic, though random noise can be added
- ➢ Not spatially explicit
- ➢ All individuals are the same, with some exceptions

This is where individual-based models come in. These models add considerable flexibility and allow for the emergence of complex dynamics.

Brief introduction to individual-based models

Individual-based models are computational models for simulating the actions and interactions of individuals or groups, in order to understand the behavior of a system and what governs its outcomes.

Example: Conway's game of life

While different in some ways than the models we'll be building, this is a nice example of how rules affecting birth/death in a spatially explicit model can lead to complex emergent dynamics

Rules:

1. A dead cell with three live neighbors becomes alive in the next generation
2. A live cell with one or fewer live neighbors dies in the next generation
3. A live cell with four or more live neighbors dies in the next generation
4. A live cell with two or three live neighbors survives to the next generation

Brief introduction to individual-based models

Individual-based models are computational models for simulating the actions and interactions of individuals or groups, in order to understand the behavior of a system and what governs its outcomes.

- ➢ Stochasticity, individual differences, interactions, and spatial context easily included
- ➢ Many applications in biology: spread of epidemics, species interactions, eco-evolutionary dynamics, etc.

Let’s build one together: Seed dispersal

Open R, let’s code this one together

Programming project 3, an eco-evolutionary individual-based model

See project 3 handout