

Predator / Prey

In this lab, you will become a population of ravenous predators in search of your favorite prey—juicy little plastic beads that live deep in the steaming jungle of grass blades in the lawn (outdoor version)—or juicy dots of colored paper that live on a habitat background of patterned fabric (indoor version). Reproduction in both predator and prey must, perforce, be imaginary, but we will compute the expected number of offspring of each, and adjust the "populations" accordingly as the imaginary years go by.

There are three related exercises to be done. In the first, we will use beads (or dots) of different colors (different "species") to study the role of coloration in susceptibility to predation—beads/dots of some colors are harder to find in the grass or on the cloth. In the second exercise, once we know which colors are better suited for "escape" from capture, we will explore the effect of prey reproductive rate as a compensating factor for predation. In the third exercise, with only one color prey, we will attempt to simulate cyclic fluctuations of predator and prey populations.

General Procedure

All three exercises share some procedures, which will be described here. The class will divide into teams of 3-5 people. Team members take turns being predator, computing population changes, timing the predator, counting beads/dots, and taking records. For lab sections doing the outdoor version, the "habitat" for each exercise will be a square plot of lawn, 1-meter square. Mark your plot perimeter with rope that has been marked in half-meter increments. Plastic beads of different colors serve as the prey. For the indoor version, the "habitat" for each exercise will be a 1-meter square plot of patterned cloth. Colored paper dots serve as the prey.

The number of individuals in the prey populations is simply the number of beads/dots in the plot. At each episode of prey "reproduction," more beads/dots may be added to the plot. Prey beads/dots are counted out according to the instructions for each exercise, and then scattered haphazardly within the plot by someone on your team who is not currently acting as predator, while the predator turns his or her back on the plot.

An increase or decrease in predator population size is represented not by more or fewer people scrambling around in the plot (not practical), but rather by adjusting the length of time allowed for a single predatory person to find and capture beads/dots. You should find ways to make it difficult for the predators to capture the beads/dots. For example, you can make the predator spin around, stand on one leg, use a fork or chop sticks, etc. When the timer says "Go!," the predator begins gathering as many beads/dots as possible before the timer stops him or her when the allotted time has elapsed. Captured beads/dots are put in a container to be counted after the predation episode. In the calculations of this lab exercise, round off the values to the nearest whole number.

Glossary of Symbols

*(NOTE: Keywords in **bold** letters are intended to help recall the meaning of the variables. Variables shown here with the subscript "j" appear later in some equations without a subscript, when there is only one prey species in an exercise).*

t = number of "generations" (**time** units) since beginning the experiment (t=0, 1, 2, . . .)

$N_j(t)$ = population size (**number**) of prey species j at the start of generation t

r_j = rate of prey **reproduction** for prey species j

Y_j = number of individuals of prey species j captured by predators during a particular generation (the **yield** to predators)

L_j = number of individuals of prey species j **left** in the plot immediately after predation, before prey reproduce

M_j = number of prey of each species there would be in the next generation if there were no equilibrium density

A_j = number of prey (plastic beads or paper dots) that you must **add** to the plot to simulate reproduction in prey species j in a particular generation

K_j = equilibrium density of the plot for prey species j

P(t) = **predator** population size at the beginning of generation t

b = predator **birth** constant: number of captured prey required to produce each new predator of the next generation

Exercise 1:

Natural selection for camouflage

In this exercise there are three species of prey, each a different color of bead or dot. The three colors start off at the same density, and they have the same reproductive rate, but not all the colors are equally easy to see on the cloth. Population growth is exponential, but there is a single constant equilibrium density for the three species combined. In this exercise, the predator population does not reproduce or starve; a constant predation time is used throughout. As predation and reproduction of the prey proceed, you should be able to document "natural selection" for camouflage.

Assumptions

Prey populations:

(a) Three prey species (colors).

(b) Discrete generations: in each generation, the prey reproduce, and then the "parents" all die—there is no overlap between generations.

(c) Each of the three prey populations grow according to the discrete generation form of the exponential growth equations, with predation:

$$\mathbf{N_j(t+1) = r[N_j(t) - Y_j] = rL_j,}$$

where the subscript j = 1, 2, or 3, depending on prey species.

(d) Prey reproductive rate r is the same for all 3 species.

(e) There is a "ceiling" (equilibrium density K) on the combined population size of all three prey.

Predator population:

(a) No population dynamics: a constant "number" of predators (P) capture as many prey as possible after each generation of prey reproduction.

Conditions

(a) Set starting numbers of prey:

$$\mathbf{N_1(0) = N_2(0) = N_3(0) = 15 \text{ beads/dots of each color.}}$$

(b) Set prey reproductive rate r = 1.2.

(c) Set prey equilibrium density K = 60.

(d) Set number of predators P = 20 (constant), at one second per predator (i.e., each episode of predation lasts 20 seconds).

Procedure

Scatter the initial prey populations on the plot of grass or cloth. A predator then captures as many prey as possible in 20 seconds. Reproduction by the prey that remain uncaptured in the plot is then computed, and the number of beads/dots in the plot is adjusted accordingly. The predator strikes again for 20 seconds, and the cycle repeats until the proportions of the prey species cease to change much between generations.

Prey reproduction can be easily computed as follows: count the captured beads/dots of each color (j = 1, 2, or 3) and subtract the number captured from the number that were in the plot before the last episode of predation to get the number of each species left in the plot:

$$\mathbf{L_j = N_j(t) - Y_j}$$

Next, compute the number of prey of each species there would be in the next generation if there were no equilibrium density; we will call this number M_j :

$$\mathbf{M_j = rL_j}$$

Now compute the total number of prey of all species combined that would be in the plot in the next generation if there were no equilibrium density; we will call this total T:

$$\mathbf{T = M_1 + M_2 + M_3}$$

This number would soon be so large that Biology 1 would go bankrupt buying beads if there were no equilibrium density. Therefore, we will keep the proportions of species the same as they would be with no equilibrium density, but adjust the total number in the plot to K = 60 whenever T exceeds 60:

$$\mathbf{N_j(t+1) = (K\,M_j)/T,\ \text{if T greater than K;}}$$

$$\mathbf{Nj(t+1) = M_j,\ \text{if T less than or equal to K.}}$$

Finally, because some beads/dots remain in the plot, only enough new beads/dots to equal Nj(t+1) need to be added before the next predation episode. The number of each color to add is just:

$$\mathbf{Aj = N_j(t+1) - L_j}$$

► To simplify computations and record-keeping, use Table 1 to record your data (rows = generation, columns = other variables). **Complete Worksheet 1** using the data you collected and recorded in Table 1.

Exercise 2:

A tradeoff between vulnerability to predation and reproductive rate, with density-dependent population growth

In this exercise, we add two kinds of realism to the model for prey population growth. First, all prey populations will no longer be assumed to have identical reproductive rates. In particular, using two prey species (two bead/dot colors), we will give a reproductive advantage to the species shown in Exercise 1 to be the more vulnerable of the two to predation. The second realistic addition will be to compute prey population growth with an assumption of density-dependence.

Assumptions

Prey populations:

(a) Two prey species: the "winner" (best camouflaged) and a more conspicuous species from Exercise 1.

(b) Each of the two prey species grows according to the special version of the logistic equation, with predation (see procedure below).

(c) Reproductive rate of the more conspicuous prey species exceeds that of the less conspicuous prey species.

(d) Each prey species has its own equilibrium density, K_j, although they are the same (i.e. $K_1 = K_2$).

(e) Overlapping generations: after each episode of predation, the size of each prey population is separately adjusted for its net increase (if the number of prey left, after predation, is less than the equilibrium density, K_j) or net decrease (if the number of prey left exceeds K_j).

Predator population:

(a) No dynamics; same assumptions as in Exercise 1.

Conditions

(a) Set starting numbers of prey: $N_1(0) = N_2(0) = 15$.

(b) Set prey reproductive rates: Less conspicuous (better camouflaged) prey species $r_1 = 0.8$. More conspicuous prey species $r_2 = 0.8$ (control), 0.9, 1.1, or 1.5 (do not exceed 2.0). Different groups should try different values of r_2.

(c) Set prey equilibrium densities $K_1 = K_2 = 30$.

(d) Set number of predators $P = 20$ (constant), at one second per predator, as in Exercise 1.

Procedure

The procedure is the same as in Exercise 1, except for the computation of prey reproduction. After each episode of predation, count the captured dots of the two prey species to get Y_1 and Y_2. Then compute the number of beads/dots of each color left in the plot as before:

$$\mathbf{L_j = N_j(t) - Y_j}$$

Next, compute the number of prey of each species in the next generation, according to the following special version of the logistic equation:

$$\mathbf{N_j(t+1) = L_j + r_j L_j \left(\frac{K_j - L_j}{K_j} \right)}$$

Finally, compute the number of dots of each color to be added to the plot:

$$\mathbf{A_j = N_j(t+1) - L_j.}$$

► Use Table 2 to record your data for this exercise. **Complete Worksheet 2** using your data from Table 2.

Exercise 3:

Predator – prey cycles

In this exercise, we will try to capture the dynamics of predator-prey interactions. For a wide variety of models and parameter values, cyclicity or stable coexistence is predicted by theory. The Lotka-Volterra equations are the simplest of these models. Here we will use a discrete-generation model. The equation we will use for predator population growth is essentially the same as that of the Lotka-Volterra model, with predator births dependent only on the number of prey captured, and predator deaths independent of both prey and predator density (since all predators of each generation die after producing offspring). The single prey species in this exercise differs from the Lotka-Volterra model in being subject to an equilibrium density, even in the absence of predation.

Assumptions

Prey population:

(a) One prey species: A prey color of moderate conspicuousness is a good choice. (Different groups may need to use different colors so there will be enough beads/dots.)

(b) The prey species grows according to the same special version of the logistic equation, with predation, as in Exercise 2.

Predator population:

(a) Discrete generations: after capturing as many prey as possible during an episode of predation, the predators produce young and then die.

(b) The number of young produced is simply the number of prey captured, divided by the number of captured prey required to produce each new predator of the next generation (a variable we will call b, the "predator birth constant").

Conditions

(a) Set starting numbers of prey: N(0) = 30.

(b) Set prey reproductive rate: try r = 0.75 and adjust up or down if time permits, or different groups may try different values of r (values above 2 are likely to give chaotic results).

(c) Set prey equilibrium density K = 50.

(d) Set starting number of predators P = 20, at one second per predator.

(e) Set predator birth constant b, the number of prey required per predator offspring. Try b = 0.8 and adjust if time permits, or different groups may try different values of b.

Procedure

The procedure is the same as in Exercise 2, except for the computation of predator reproduction. After each episode of predation, count the captured dots to get Y. Then compute:

$$\mathbf{L = N(t) - Y}$$

Next, compute the number of prey in the next generation:

$$\mathbf{N(t+1) = L + rL\,\frac{K - L}{K}}$$

Compute the number of beads/dots to be added to the plot:

$$\mathbf{A = N(t+1) - L}$$

Finally, compute the number of predators (= seconds of predation) in the next generation (next episode of predation):

$$P(t+1) = Y/b$$

► Use Table 3 to record your data from this exercise. *Be sure to record the values you used for r and b*. **Complete Worksheet 3**, making two graphs as follows:

1) plot N(t) vs. t and P(t) vs. t on the same graph [with N(t) and P(t) on the y-axis and t on the x-axis].

2) plot N(t) on the x-axis vs. P(t) on the y-axis. This is called the "predator-prey" phase plane. Connect the points in order from t=0 to t=10. Run this exercise for 10 generations. If your population goes extinct in 2 or 3 generations, start again to see if you can get a cycle.

Table 1

Natural selection for camouflage

	Color 1: ________					Color 2: ________					Color 3: ________					
Generation t	Pop. Size N_1	Captured Prey Y_1	# of Prey Left L_1 (N_1-Y_1)	# of Prey Next Gen. M_1 $(L_1 \times r)$	Added Prey A_1 (M_1-L_1)	Pop. Size N_2	Captured Prey Y_2	# of Prey Left L_2 (N_2-Y_2)	# of Prey Next Gen. M_2 $(L_2 \times r)$	Added Prey A_2 (M_2-L_2)	Pop. Size N_3	Captured Prey Y_3	# of Prey Left L_3 (N_3-Y_3)	# of Prey Next Gen. M_3 $(L_3 \times r)$	Added Prey A_3 (M_3-L_3)	Total Prey Next Gen. T (ΣM)
0	15					15					15					
1																
2																
3																
4																
5																

Table 2

Vulnerability to predation vs. reproductivce rate with density-dependent growth

Reproductive Rates (r_i):

r_1 = ___________ r_2 = ___________

	Color 1: ________________					Color 2: ________________				
Gener-ation **t**	Pop. Size N_1	Captured Prey Y_1	# of Prey Left L_1 (N_1-Y_1)	Addit. Prey Next Gen. A_1 See formula *	Density K = 30 (L + A ≤ 30)	Pop. Size N_2	Captured Prey Y_2	# of Prey Left L_2 (N_2-Y_2)	Addit. Prey Next Gen. A_2 See formula *	Density K = 30 (L + A ≤ 30)
0	**15**					**15**				
1										
2										
3										
4										
5										

* **Formula for Additional Prey in the next generation:** $A_j = r_j L_j \bullet \frac{(k_j - L_j)}{k_j}$

Table 3

Predator - prey cycles

Moderately conspicuous color: ________________						
Gener-ation **t**	Pop. Size $\mathbf{N_t}$	Predators (seconds) $\mathbf{P_{t+1}}$ **(Y/b)**	Captured Prey $\mathbf{Y_t}$	# of Prey Left $\mathbf{L_t}$ $\mathbf{(N_t\text{-}Y_t)}$	Addit. Prey Next Gen. $\mathbf{A_t}$ See formula *	# Prey Next Gen. $\mathbf{N_{t+1}}$ $\mathbf{(L_t+A_t)}$
0	**30**	**20** (P_t)				
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

*** Formula for additional prey in the next generation**
(add this number of beads or paper dots to population):

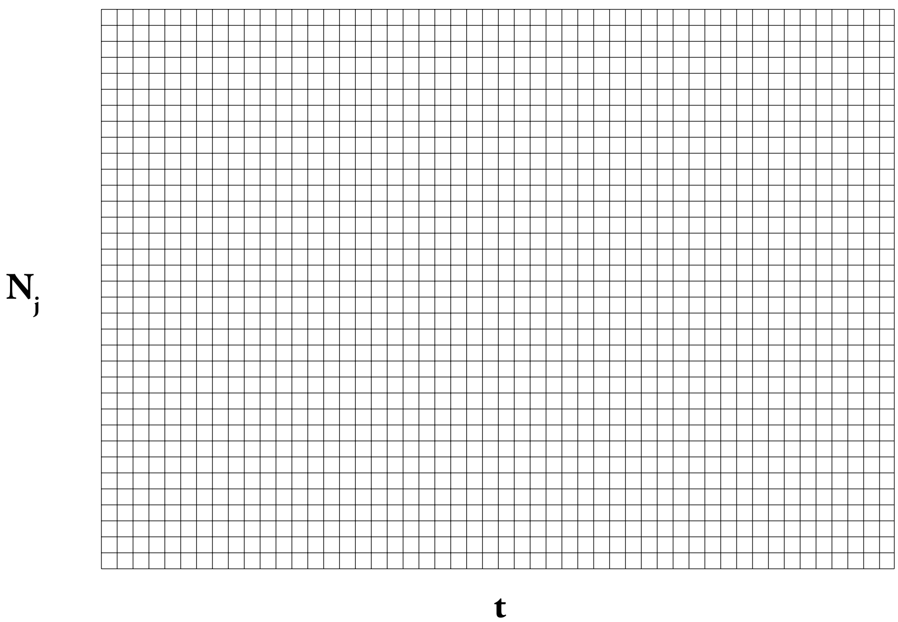
$$A = rL \bullet \frac{(k-L)}{k}$$

Name ________________________________ **Section** ___________

Predator/Prey Worksheet

1. a) Graph your results from exercise 1: Nj(t) vs. t. Plot the population sizes of all 3 prey species on one graph. Be sure to label both axes and provide a legend indicating which line is which prey.

Prey colors: $N_1(t)$ = ____________ $N_2(t)$ ____________ $N_3(t)$ = ____________



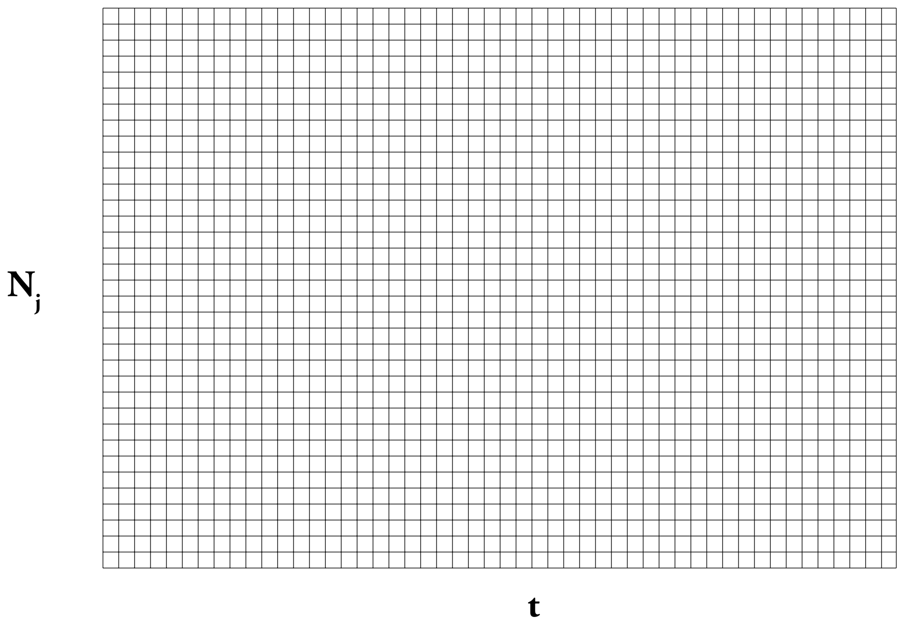
b) Which color was most cryptic? Which was least cryptic? How did the color of each prey species affect its population size over time?

c) Identify two things that are unrealistic and two things that are realistic about this model/exercise?

2. a) Graph your results from exercise 2: Nj vs. t.

Prey colors: $N_1(t)$ = ____________ $N_2(t)$ ____________

r_1 = ____________ r_2 = ____________



b) How did an increased reproductive rate compensate for a high vulnerability to predation?

c) How else could an organism compensate for high vulnerability to **visual** predators? What environmental factors might affect the vulnerability of prey to the predator?

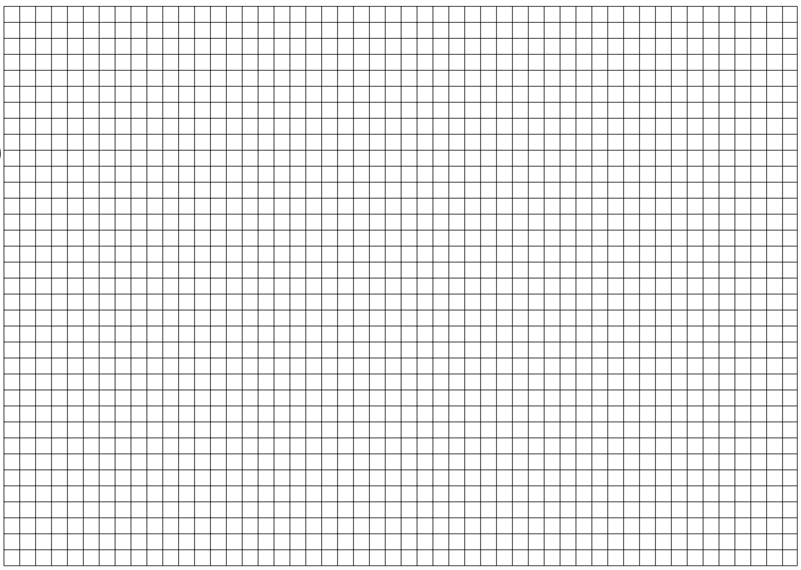
3. a) Graph your results from exercise 3:

r_1 = ______________ b = ______________

N(t) and P(t) vs. t

N(t)

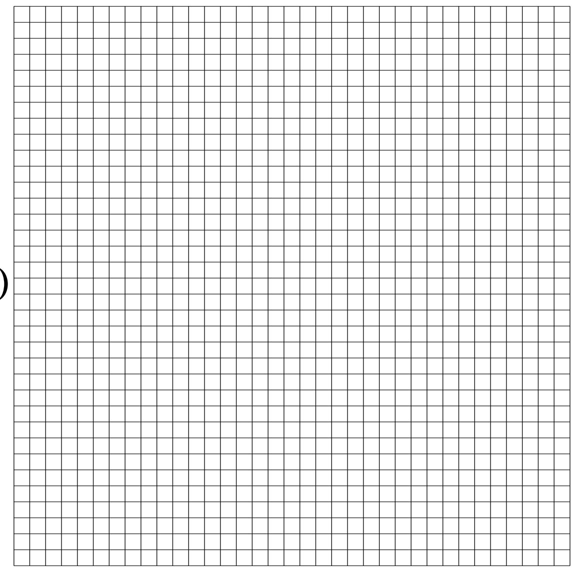
P(t)



t

P(t) vs. N(t)
connect the point in order
t=0, t=2, t=3, etc.
(This may be circular)

P(t)



N(t)

b) Compare the changes in numbers of prey over time with the changes in numbers of predators over time (e.g. were the temporal fluctuations synchronous; was there a lag in the response of one or the other; was there a cycle; did there appear to be no relationship?).

c) Evaluate the statement: Predators control the sizes of the populations of their prey.