# Modeling Predation

**SC Academic Standards**: 5.L.4A, 4B; 7.EC.5A, 5B; H.B.6A-6C.

**NGSS DCI:** 5-LS2.A; 5-LS2.B; MS-LS2.A-C; HS-LS2.A-C.

**Science and Engineering Practices:** S.1A.1; S.1A.2; S.1A.4; S.1A.5; S.1A.7

**Crosscutting Concepts:** Patterns; Cause and Effect: Mechanism and Explanation; Systems and Systems Models; Energy and Matter: Flows, Cycles, and Conservation; and Stability and Change.

**Focus Question(s): How are predator and prey population sizes related? How do predators function to keep prey populations low and stable? How do prey population sizes limit predator populations?**

**Conceptual Understanding:** Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. Limiting factors include the availability of biotic and abiotic resources and challenges such as predation, competition, and disease.

A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively stable over long periods of time. Fluctuations in conditions can challenge the functioning of ecosystems in terms of resource and habitat availability

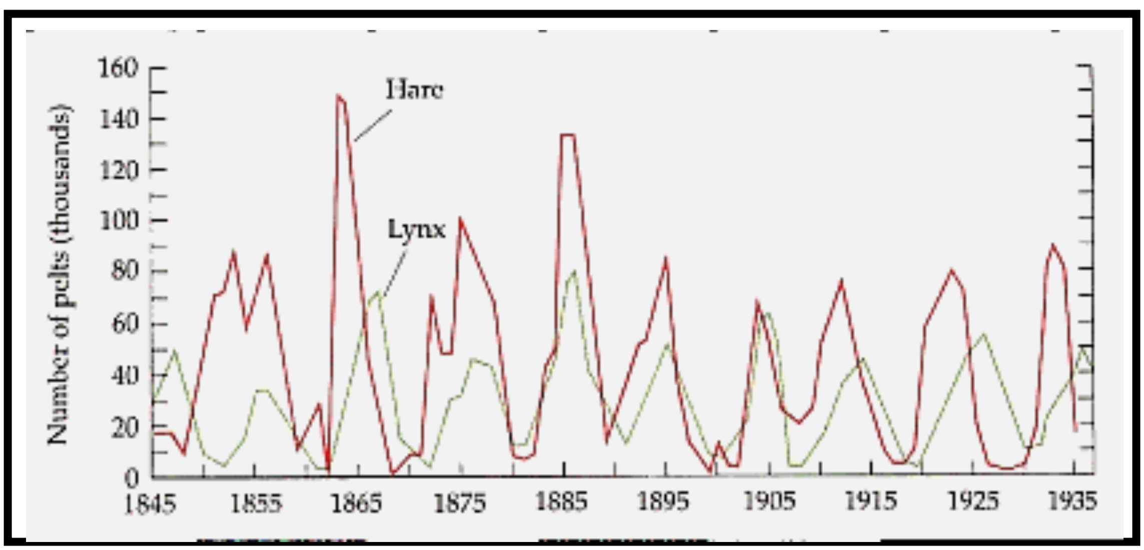
In all ecosystems, organisms and populations of organisms depend on their environmental interactions with other living things (biotic factors) and with physical (abiotic) factors (such as light, temperature, water, or soil quality). Disruptions to any component of an ecosystem can lead to shifts in its diversity and abundance of populations.

**Background**: Interactions between species within a habitat or ecosystem are normal and often predictable. For example, in a predator / prey interaction, predator (consumer) population density oscillates with a time lag behind prey population density **oscillations.** Both predator and prey populations follow the same cycles indefinitely until external factors cause a shift in the population density of one population, then a new cycle begins. However, environmental conditions do change and this could cause erratic patterns of population density change over time. Also, when prey populations begin to decline, the predator may “switch” prey – or find something else to eat which means that the predator population may not show the oscillation cycle. Thus, the overall pattern may appear to be neither stable nor cyclical.

A famous example of a predator / prey oscillation curve is the lynx and snowshoe hare (Figure 1). Between 1845 and 1935, the Hudson Bay Company of Canada kept records of the number of lynx (a cat) and snowshoe hare (a rabbit) pelts which were brought in by trappers. The Hudson Bay Company would buy the pelts and resell them to furriers. Of course, the lynx is a predator on the hare and so we expect to find cyclic changes in the populations. The Hudson Bay Company records do show a remarkable, long-lived cyclic behavior. But, in the period between 1875 and 1905, the cyclic change goes in the wrong direction. This indicates that the hare is the predator of the lynx, a very unlikely possibility! Many people have thought about this anomaly - one possible explanation is that the trappers are also a predator. Or, the cycles in lynx and snowshoe hare populations may result from cycles in the food supply of the hare, or alternate prey items for the lynx. Lynx population densities may simply be tracking the temporal variation in hare densities. Oscillation does not characterize every predator-prey system, and oscillation may not be due to the predator-prey interaction alone.

The sum total of all the producer – consumer interactions in a community is called the **food web**. Another way of looking at a food web is through a **trophic pyramid**, which tracks energy flow through a community or ecosystem. In a trophic pyramid, the producer level is at the base, and has the most energy, and, usually, the greatest number of species and greatest amount of biomass. As you move up through the levels (**producer** to primary consumer (the **herbivore**) to secondary **consumer** (the primary **carnivore**) to tertiary consumer (the secondary carnivore) and so on), you see that it isn't just nutrients that get transferred – energy is transferred too.

**Figure 1: The Predator (Lynx) and Prey (Snowshoe Hare) Oscillation Curve**




Plants capture energy from the sun, but most of this energy is used or lost and so not available to the next level. When an herbivore eats a plant, the herbivore uses much of the plants energy, some energy is lost (through excretion, respiration, inefficient digestion, or because the energy is put into an inedible part, like the husk of a nut), and only 10% of the energy is available to be eaten by the next organism in the food chain. In sum, only about 10% of the energy from one level is available to the next level up; this is known as the 10% rule. For this reason, food chains and trophic pyramids are not very long – there just isn't enough energy to sustain more links!

**Energy travels through the community in a one-way flow, but nutrients get recycled.** In general, predation is an interaction that takes place between trophic levels (feeding levels), where one organism directly benefits by obtaining nutrients and energy by feeding on part or all of another organism (which is thus harmed).

Predation is important because animals must feed on other organisms to obtain energy. **Predation helps to transfer energy** from one trophic level to another. It is also important because it helps to maintain a "**check**" on prey populations – so that they do not rise above the **carrying capacity** of the environment. When any population goes above carrying capacity, there are not enough resources, or space, or there are too many waste products, and some members die. If there are no other factors influencing population size (for example, hunting), some populations, over time, tends to stabilize at carrying capacity. The environment has a different carrying capacity number for every population, and the number may change (as it did for humans, with the agricultural revolution). Other populations show, instead of a nice S-shaped curve with a carrying capacity, the oscillation curves of the lynx / hare example. Here, the predators keep the prey from going above carrying capacity, but as predator numbers increase, and they eat more, they drive prey numbers down. Then, as the predators start going hungry, their populations drop. As the predation pressure is relieved, the prey populations start to recover and increase, starting the cycle again.

**Food webs** are essential features of every ecosystem and consumer-prey interactions are fundamental linkages between species. Ecologists divide predator-prey relationships into bottom-up and top-down processes. A **bottom-up system** looks at how resources (such as space, or nutrients) influence higher trophic levels (for example, when soil nutrients are low, plant growth is limited. Fewer plants means fewer herbivores, which, in turn, means fewer carnivores). A **top-down system** focuses on interactions between top-level predators and their lower trophic level prey (for example, an abundance of sea otters (the predator) lowers the population size of urchins (their prey). When the otters were removed (by overhunting), the urchin population grew). A top-down trophic model predicts changes in density at one trophic level caused by opposite changes in the next higher trophic level, and such inverse correlations cascade down the food chain – resulting in a graphical representation of prey and predator numbers that looks like an **oscillation curve.**

**In this lab we will investigate** the effect of predation on predator and prey population densities. Our hypothetical predator – prey populations consist of *Pikus* *carnivora* (the predator) and *Beadus rougii* (the prey). *Beadus rougii* forages inside of meadows (11 plastic cups, numbered 2-12). Follow the rules for this exercise, and record your data and plot your predator / prey oscillation curve on the graph paper provided.

**Materials**: for each group: about 150 blue beads (=prey) and about 75 yellow beads (=predator), 11 small 'dixie' paper cups, a marker, and 2 dice.

**Previous Knowledge: (ecology):** All of the populations of **species** that live together in a given area make up a **community**. Species within a community may interact with each other in a variety of ways including **predation**, **competition** and / or **symbiosis.** For example, in a typical mixed hardwood forest in the southeast United States, you may find deer and squirrels both competing interspecifically for acorns as a food resource (and squirrels competing with other squirrels as well – this is intraspecific competition). Food webs are essential features of every ecosystem and consumer-prey interactions are fundamental linkages between species; thus you may also find wolves preying upon the deer, and deer preying upon the plant materials that they eat. Some of these plant materials may have lichens growing upon them, and lichens are a good example of a symbiotic relationship between cyanobacteria and fungi. Some of these interactions are beneficial to both species involved, some are beneficial to only one (or none) of the species (Table 1).

| Interaction | Direct effect on species 1 | Direct effect on species 2 | Example |
|---|---|---|---|
| **Predation** | - (prey) | + (predator) | Hare / Lynx |
| **Parasitism** | - (host) | + (parasite) | Oak / Mistletoe |
| **Competition** | - (competitor) | - (competitor) | Cardinals / Blackbirds |
| **Mutualism** | + (mutualist) | + (mutualist) | Rhino / Oxpecker |
| **Commensalism** | 0 (host) | + (commensalist) | Oak / Spanish Moss |

**Table 1: Types of Interactions between Species in a Community**

The abundances of organisms at lower trophic levels can be strongly affected by their own predation, that is, by **top-down control**. Ecosystems often have been assumed to be controlled from the **bottom-up**, wherein nutrients and light stimulate primary production by plants, and the greater primary production in turn supports more animal production at higher trophic levels. With top-down control, because the predator eats prey, the prey population is reduced, so when predators are removed, the prey species can become more abundant. Evidence of such top-down control of prey populations was seen when large predators like wolves were extirpated from much of the US and deer became very abundant, indeed a pest, in many areas. In Yosemite National Park, reduced numbers of bobcats, cougars and coyotes led to increased numbers of mule deer, which then led to declines in evening primrose and young black oaks, which are grazed by deer. Top-down control of lower trophic levels as a result of direct consumption and reduction of prey population size is referred to as "density-mediated" control, because predators reduce density of prey. However, predators can affect populations of their prey without actually eating them but in a more indirect ways, for example by influencing their behavior, physiology, or morphology. For example, water-borne chemicals ("risk cues") released by predators can cause changes in prey behavior such as feeding rates, thereby altering the impact of the prey species on their own resources. When prey species detect the presence of predators they often alter their behavior by spending more time hiding and generally being inconspicuous, thus reducing the amount of time they spend feeding. The reduced food intake by these prey animals can result in slower growth and reproduction, and ultimately result in population reductions. The reduced feeding rates by the prey then cascade down to release the prey's own food (e.g., plants) from top-down control, causing a trophic cascade based not on changes in prey abundance but by changes in prey behavior. This more subtle mechanism is called "trait-mediated" control. Trait-mediated interactions represent the nonlethal effects of predators, and contrast with the more traditional emphasis on lethal effects. An example of this from the intertidal zones is the effect of risk cues from green crabs that reduce feeding by snails and consequently allow increases in the snails' food, barnacles and algae. Carnivorous snails exposed to cues from green crabs consumed fewer barnacles, and herbivorous snails exposed to risk cues from crabs consumed far less algae. Both species of snails spent more time in refuges and grew less, while populations of the barnacles and algae increased as a result of reduced top-down control.

**<u>Previous Knowledge:</u> (foraging behavior / co-evolution):** Optimal foraging theory states that organisms forage in such a way as to maximize their net energy intake per unit time. In other words, they behave in such a way as to find, capture and consume food, containing the most calories, in the least amount of time. Foraging is critical to the survival of every animal. More successful foragers are assumed to increase their reproductive fitness, passing their genes (including genes for foraging strategy) on into the next generation.

Evolution has led to the survival of predators that select the "right" food items – and the co-evolution of prey that can avoid the predators. Some predators employ a **generalist** strategy, and tend to have broad diets; they chase and eat many of the prey/food items with which they come into contact. There are also those with a more **specialist** strategy, having a narrow diet and ignoring many of the prey items they come across, instead searching preferentially for a few specific types of food. Usually, animals exhibit strategies ranging across a continuum between these two extremes.

Predation involves four steps: **search**, **recognition**, **capture**, and **handling**. The possibility of co-evolution of predator and prey operates at each of these steps. Predators search the environment for acceptable prey. Predator adaptations to improve foraging success include better visual acuity, development of a search image, and limiting searches to prey-rich habitats. Predators quickly learn prey types and adapt to recognize prey and to avoid inedible species. Predators must be able to capture prey. Adaptations to improve capture efficiency include improved motor skills and appendage modification. Finally, predators must handle prey by efficiently subduing them and detoxifying any defensive compounds. Adaptations promoting handling efficiency include improved foraging appendages to reduce the probability of injury and physiological specialization on otherwise poisonous prey. Predators also improve foraging efficiency by **learned avoidance**, a behavior in which predators quickly learn to recognize poisonous or distasteful species by remembering adverse reactions from attempted predation events.

Because life depends on taking life, almost all organisms on earth are potential **prey** for at least one other species. To escape this predation pressure, natural selection has favored individuals that are more difficult to find, capture, subdue, and consume. Adaptations that have **co-evolved** along with the predator's adaptations to increase foraging success, are adaptations that will decrease predation, including both warning (bright) coloration and cryptic coloration (camouflage), behavioral defenses (like the roly poly bug curling up into a ball), morphology (spines, armour), and physiology (bombardier beetle, skunk).

**Procedure:** Each group of four students should have 11 cups numbered 2-12, a cup of 150 blue beads, a cup of 75 yellow beads, and 2 dice. Also each group should record its data in the table provided in the lab manual.

Follow the **predator rules** to determine who "lives" and who "dies".

**Predator Rules:**

a) When a predator lands in a cup, it kills **all** of the prey in the cup (remove the blue beads).

b) Each predator must capture a least 3 prey in order to survive to the next time period, if it lands in a cup with fewer than 3 prey then the predator as well as the prey dies (prey die from predation, predators die from starvation).

c) For every 3 additional prey in the cup greater than 3, the predator produces 1 offspring. If the predator lands in a cup with 10 prey, then it will survive and produce 2 offspring.

d) If more than one predator lands in a cup, they must **split the prey evenly** amongst themselves. For example if there are 4 prey in the cup and 2 predators then each predator gets 2 prey and everyone (prey and predators) die (the prey are eaten, but the predators are still hungry and starve to death). If there are 10 prey, then each predator gets 5 – so each predator lives, but make no babies. If there are 12 prey, each predator lives and makes one baby so you now have 4 predators total.

**The Game:**

1. To begin, put one prey (blue) bead in each of your 11 cups ("meadows"). Each of these prey reproduce to make one offspring each, so put another blue bead in each cup (now you should have two blue beads in each cup). In subsequent generations, the number of blue beads in each cup will double at each time step (each prey bead produces one offspring).

    - If at any time a cup becomes empty, put one blue bead in that cup to start the population in that cup over. You can have a max number of 10 beads in each cup.

    - The maximum population size of the prey in the entire population is therefore 110 (which is K, or **carrying capacity**, for the prey).

2. Take one predator (yellow) bead and roll the 2 dice to determine which cup it will go into. For example, if you roll a 3 and a 5, you add the digits together and the predator will go into cup #8. Do this for each predator that you have.

3. All prey in the same meadow (cup) as the predators die – remove them from the cups. Follow the **predator rules** to determine which predators have eaten enough to survive and / or reproduce. Put all living predators (and their babies) in a pile to the side (take out of cup).

4. At the end of each generation the prey reproduce. First, for every empty cup, add one prey (immigration). Then, for each prey in a meadow, add one more (up to ten total). Over ten prey in a cup leads to overuse of the available resources and any prey over the first ten die of starvation.

5. At the end of each generation, you also bring in one new additional predator – add this to your predator pile.

6. RECORD the number of prey and number of predators in your populations. You are now starting the next generation.

7. The predators are considered mobile and can move from meadow to meadow (cup to cup). The predators who remained alive after the previous generation (plus your one new predator) are randomly placed

back into their meadows. Redistribute the predators like this: Roll 2 dice for each predator. The total of the 2 dice is the cup # the predator goes into (you don't change their numbers, just redistribute them). After all predators are in cups, go to step 8.

8. Follow the predator Rules: (back to step # 3).

9. Repeat these steps for 20 generations.

Once you have gone through the steps once, it may be easier to follow these abbreviated instructions: (I print these and place on each desk. After going through 2 generations as a class, I will let the groups work at their own pace using the abbreviated instructions as I walk around monitoring).

1. Reproduce your Prey (any empty cups get one bead – then another as they reproduce)
2. Add your new predator
3. Record your number of Prey and number of Predators on Table 1
4. Roll the 2 dice once for <u>each</u> predator – place predators in corresponding cups
5. With all predators in cups, figure out which ones die (starve), live, live and reproduce (predator rules). Put living predators (and babies) aside.
6. Go back to step 1.

**<u>Data Analysis:</u>**

First, ask your students first to **graph** the # predators in each generation and the # of prey in each generation on one graph. The # of predators and prey should be on the Y axis, and generation on the X axis. What do they notice? (because there are always much fewer predators you will get an oscillating line down low, and an oscillating line much higher up (for the more numerous prey) – with no overlap).

Then, have them re-graph the information but this time use 2 "Y" axes – one on the left (# prey) and one on the right (# predators) – and so the scale can be different. Have the students adjust the scale so that the two oscillation curves overlap.

Third, have the students **describe** the graphs they have drawn, and

Last, have your students try to **explain** the pattern they see (why does the number of predators decrease slightly after (lag time) the # of prey starts to decrease? (Because the predators aren't getting enough food, its harder to find prey, they are hungry and thus not reproducing as well). Why do the numbers of prey increase after the number of predators decreases? (Because without predation, hare (prey) reproduction is more successful, and so the population swells).

**Table 1: Predation and its effect on Prey Populations**

| Generation | Prey numbers (blue) | Predator numbers (yellow) |
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| 1 | | |
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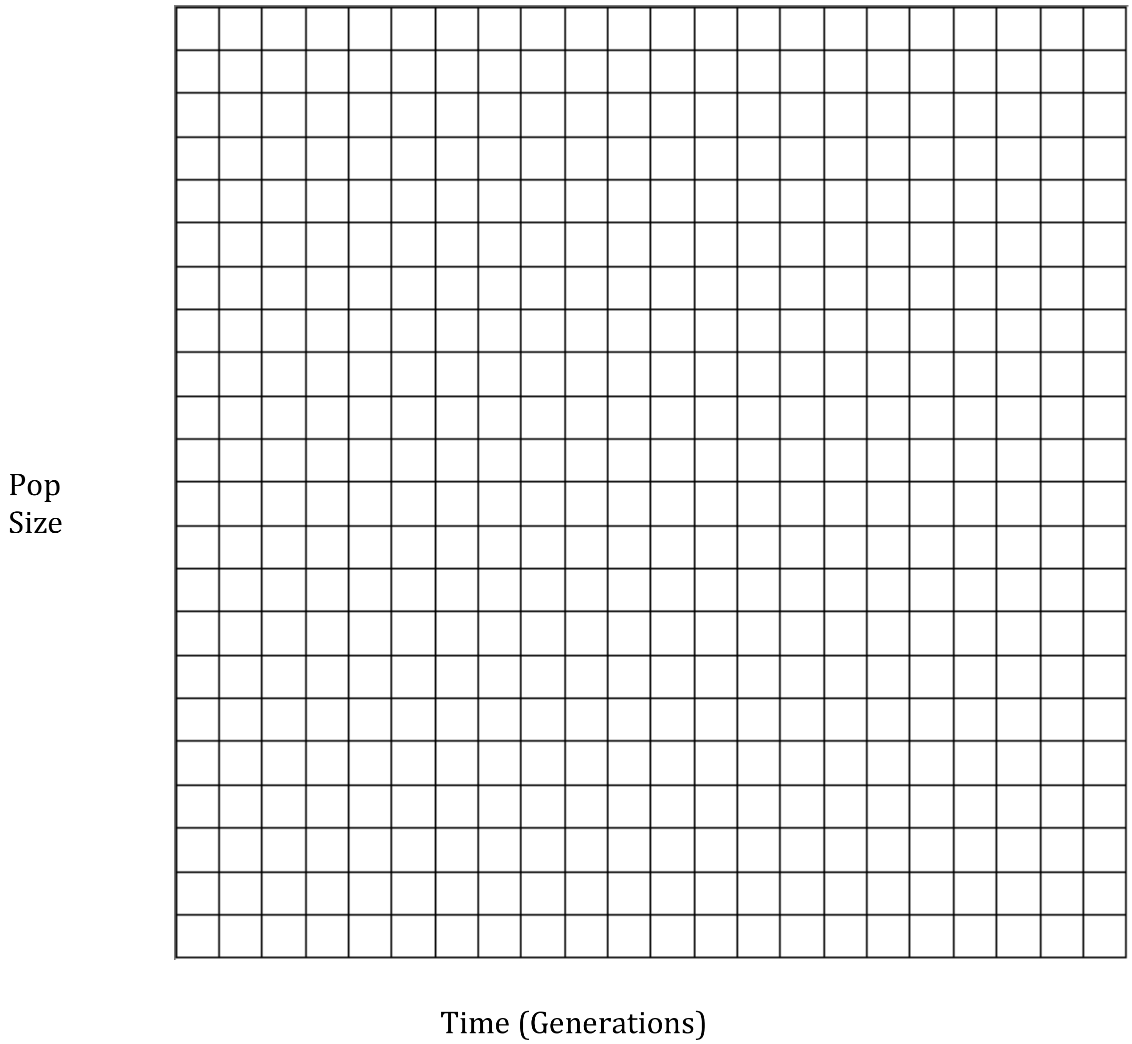


**Figure 1: A Predator / Prey Oscillation Curve**

**Extensions**: Explore insect foraging behavior with a lab from http://www.esa.org/tiee/vol/v4/experiments/insect_predation/description.html It uses different "appendages" (forks, knives, etc) to capture prey (m&m's, candy corn, skittles), including scenarios where one prey is toxic.

You can also do the Project Learning Tree "Birds and Worms" exercise, which shows how camouflage has been naturally selected for to help prey avoid predation, or, for older students, a natural selection lab using different colored macaroni (FAR guide to teach simulations: an example of natural selection by A. Sickel and P. Friedrichsen, The American Biology Teacher Vol. 74.

**Reflection Questions:**

- **Describe the graph that you have produced: what happens to the predator population as the prey population is reduced? What happens to the prey population when the predators start to die of starvation?** (The oscillation (up-down-up-down) is due to top-down control; because the predator eats prey, the prey population is reduced, so when predators are removed, the prey species can become more abundant. Evidence of such top-down control of prey populations was seen when large predators like wolves were extirpated from much of the US and deer became very abundant, indeed a pest, in many areas. In Yosemite National Park, reduced numbers of bobcats, cougars and coyotes led to increased numbers of mule deer, which then led to declines in evening primrose and young black oaks, which are grazed by deer. Top-down control of lower trophic levels as a result of direct consumption and reduction of prey population size is referred to as "density-mediated" control, because predators reduce density of prey. There will be a slight lag time between lowing of prey population size and lowering of predator populations, and increasing of prey population and increase of predators – due to faster reproduction among the smaller prey, fat reserves in predators that may allow them to survive for a while without food, etc).

- **In your first graph, why don't the prey and predator lines overlap?** (Remember the 10% rule – only about 10% of the energy one level takes in is available to the next level up - most of the energy a herbivore eats gets used (respiration, cell division, protein synthesis, etc) or lost (excretion, respiration), or put into inedible parts (hoofs, hair, teeth) and so isn't available to the predator. With the 10% rule, there are generally 1/10 the number of individuals at the next highest level. So, if you had 1000 plants, you could support 100 herbivores, 10 primary carnivores, and 1 secondary carnivore. You won't see a tertiary carnivore because there isn't enough energy to sustain that population. So, if prey are numbering in the hundreds, predators will number in the tens).

- **In your second graph, describe the difference between the scales on the left and right Y axis. Why is there this difference? (**With the 10% rule, there are generally 1/10 the number of individuals at the next highest level. So, if you had 1000 plants, you could support 100 herbivores, 10 primary carnivores, and 1 secondary carnivore. You won't see a tertiary carnivore because there isn't enough energy to sustain that population. So, if prey are numbering in the hundreds, predators will number in the tens – and so the scale on the predator side of graph will show lower numbers, 1-15 usually, where the prey will number closer to 100).

- **What might explain a graph where the prey population oscillates but the predator population does not?** (optimal foraging theory usually incudes things like alternate prey. If the prey (hares) decrease, then the predator (the lynx) needs to find alternate prey or its population will also be reduced. So, perhaps without the one prey, the predator is eating something else and thus able to maintain its population size. This alternate prey may be harder to find or catch, or worth fewer calories, so when the hare population rebounds the predator will switch back).

**Models and Explanations:** In this lab we explored a top-down control pattern between predator and prey population sizes. **A student who demonstrates understanding** of these concepts can **explain** how and why an oscillation curve is produced when graphing the numbers of prey and predators over generations of time, specifically referencing how the 'top' (the predator) influences the population size of the 'bottom' (the prey) through predation. This student can also reference the 10% rule when explaining why there are always so many more prey than predators.

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## Student Worksheet:

The sum total of all the producer – consumer interactions in a community is called the **food web**. Another way of looking at a food web is through a **trophic pyramid**, which tracks energy flow through a community or ecosystem. In a trophic pyramid, the producer level is at the base, and is has the most energy, and, usually, the greatest number of species and amount of biomass. As you move up through the levels you see that it isn't just nutrients that get transferred – energy is transferred too. Food webs are essential features of every ecosystem and consumer-prey interactions are fundamental linkages between species. Ecologists divide predator-prey relationships into bottom-up and top-down processes. A **bottom-up system** looks at how resources (such as space, or nutrients) influence higher trophic levels (for example, when soil nutrients are low, plant growth is limited. Fewer plants means fewer herbivores, which, in turn, means fewer carnivores). A **top-down system** focuses on interactions between top-level predators and their lower trophic level prey (for example, an abundance of sea otters (the predator) lowers the population size of urchins (their prey). When the otters were removed (by overhunting), the urchin population grew). A top-down trophic model predicts changes in density at one trophic level caused by opposite changes in the next higher trophic level, and such inverse correlations cascade down the food chain – resulting in a graphical representation of prey and predator numbers that looks like an oscillation curve.

**In this lab we will investigate** the effect of predation on predator and prey population densities. Our hypothetical predator – prey populations consist of *Pikus carnivora* (the predator) and *Beadus rougii* (the prey). *Beadus rougii* forages inside of meadows (paper cups), each of which has a carrying capacity of 10 prey.

Follow the rules, record your data, and plot your predator / prey oscillation curve on the graph paper provided. Make 2 graphs: one, with both predator and prey population sizes on the left Y axis, and one with the # prey on the left Y axis and # predators on the right Y axis. Draw a dotted line for prey carrying capacity.

### Reflection:

- Describe the graph that you have produced: what happens to the predator population as the prey population is reduced? What happens to the prey population when the predators start to die of starvation?

- In your first graph, why don't the prey and predator lines overlap?

- In your second graph, describe the difference between the scales on the left and right Y axis. Why is there this difference?

- What might explain a graph where the prey population oscillates but the predator population does not?

**Table 1: Predation and its effect on Prey Populations**

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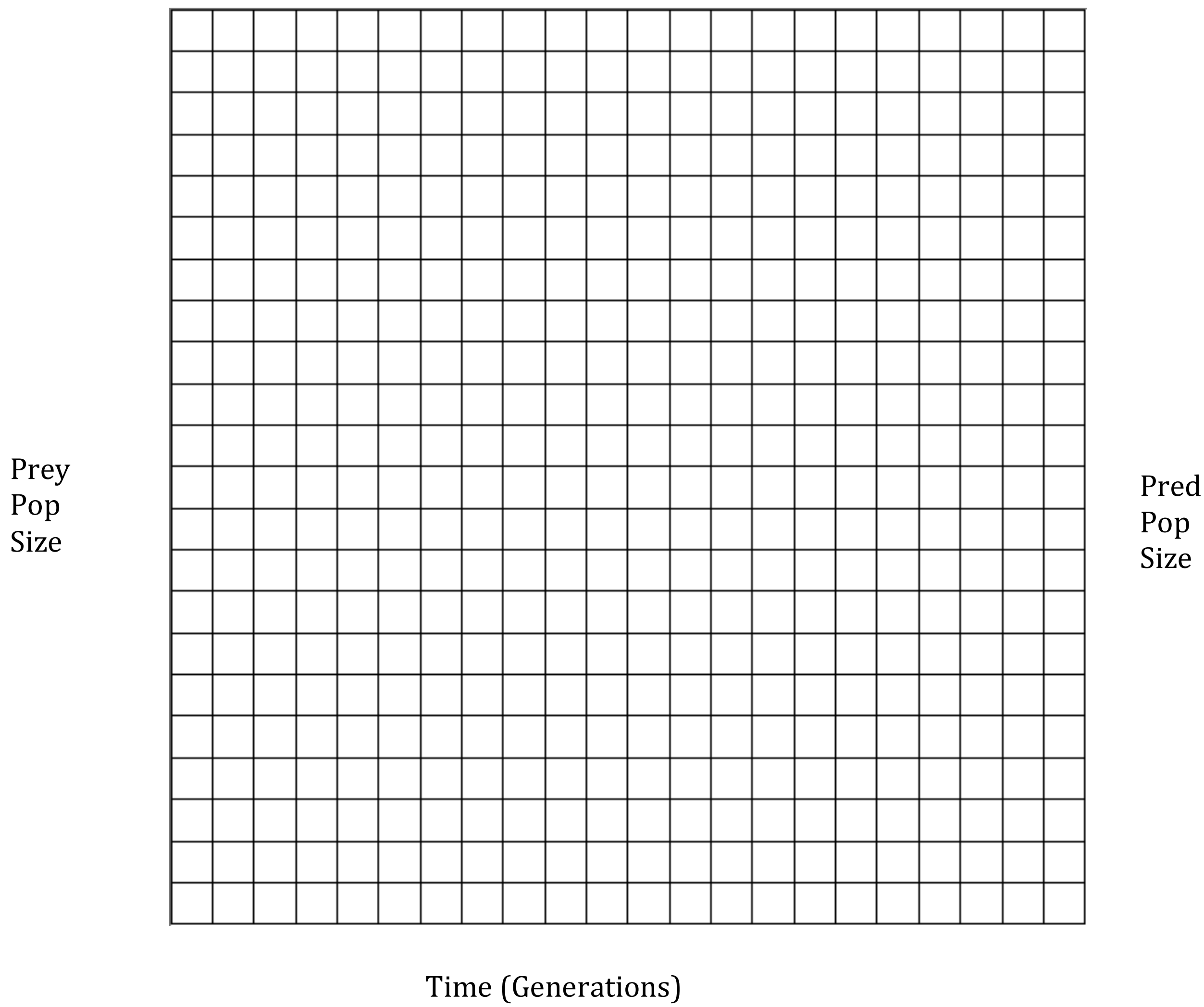
**Figure 1: A Predator / Prey Oscillation Curve**



**<u>PROCEDURE</u>**: Each group of four should have 11 cups numbered 2-12, a cup of 150 blue beads, a cup of 75 yellow beads, and 2 dice. Each group should also record its data in the table provided in the lab manual. Follow the **predator rules** to determine who "lives" and who "dies".

**Predator Rules:**

a) When a predator lands in a cup, it kills **<u>all</u>** of the prey in the cup (remove the blue beads).

b) Each predator must capture a least 3 prey in order to survive to the next time period, if it lands in a cup with fewer than 3 prey then the predator as well as the prey dies (prey die from predation, predators die from starvation).

c) For every 3 additional prey in the cup greater than 3, the predator produces 1 offspring. If the predator lands in a cup with 10 prey, then it will survive and produce 2 offspring.

d) If more than one predator lands in a cup, they must **<u>split the prey evenly</u>** amongst themselves. For example if there are 4 prey in the cup and 2 predators then each predator gets 2 prey and everyone (prey and predators) die (the prey are eaten, but the predators are still hungry and starve to death). If there are 10 prey, then each predator gets 5 – so each predator lives, but make no babies. If there are 12 prey, each predator lives and makes one baby so you now have 4 predators total.

**The Game:**

1. To begin, put one prey (blue) bead in each of your 11 cups ("meadows"). Each of these prey reproduce to make one offspring each, so put another blue bead in each cup (now you should have two blue beads in each cup). In subsequent generations, the number of blue beads in each cup will double at each time step (each prey bead produces one offspring).

    - If at any time a cup becomes empty, put one blue bead in that cup to start the population in that cup over. You can have a <u>max number</u> of 10 beads in each cup.

    - The maximum population size of the prey in the entire population is therefore 110 (which is K, or **carrying capacity**, for the prey).

2. Take one predator (yellow) bead and roll the 2 dice to determine which cup it will go into. For example, if you roll a 3 and a 5, you add the digits together and the predator will go into cup #8. Do this for each predator that you have.

3. All prey in the same meadow (cup) as the predators die – remove them from the cups. Follow the **predator rules** to determine which predators have eaten enough to survive and / or reproduce. Put all living predators (and their babies) in a pile to the side (take out of cup).

4. At the end of each generation the prey reproduce. First, for every empty cup, add one prey (immigration). Then, for each prey in a meadow, add one more (up to ten total). Over ten prey in a cup leads to overuse of the available resources and any prey over the first ten die of starvation.

5. At the end of each generation, you also bring in one new additional predator – add this to your predator pile.

6. RECORD the number of prey and number of predators in your populations. You are now starting the next generation.

7. The predators are considered mobile and can move from meadow to meadow (cup to cup). The predators who remained alive after the previous generation (plus your one new predator) are randomly placed back into their meadows. Redistribute the predators like this: Roll 2 dice for each predator. The total of the 2 dice is the cup # the predator goes into (you don't change their numbers, just redistribute them). After all predators are in cups, go to step 8.

8. Follow the predator Rules: (back to step # 3).

9. Repeat these steps for 20 generations.

Once you have gone through the steps once, it may be easier to follow these abbreviated instructions:

1. Reproduce your Prey (any empty cups get one bead – then another as they reproduce)
2. Add your new predator
3. Record your number of Prey and number of Predators on Table 1
4. Roll the 2 dice once for each predator – place predators in corresponding cups
5. With all predators in cups, figure out which ones die (starve), live, live and reproduce (predator rules). Put living predators (and babies) aside.
6. Go back to step 1.