

# Population Ecology

by C. Kohn, Waterford, WI

Adrian Treves is a scientist at UW-Madison. Treves's clients are unusual in the respect that they can't talk. They also tend to eat dead carcasses and the occasional calf. These clients are none other than the gray wolves of Wisconsin. As co-investigator with the group Living With Wolves, Treves researches these animals and tries to figure out when, where, and why these animals kill calves and hunting dogs. Furthermore, he studies people's attitudes toward wolves in an attempt to determine why they would risk being charged with a felony for shooting one.

However, the risk of a felony charge may soon become a thing of the past. The wolf was removed from the federal endangered species list in March of 2007. Discussions have been rampant about whether there should be a wolf hunt or even if there should be wolves in the state at all. This raises a slew of questions including whether or not the wolf could withstand the pressures of a hunt, if a hunt would help or hurt the wolf, and how this would affect the surrounding ecology of Wisconsin's woods and forests.

While this is certainly a more publicized case, decisions must be made every year, every month, and every week about the health of Wisconsin's wildlife and plant species populations. How does someone decide that one animal can be hunted while another can't? Why is it that some species, like the whitetail deer, are so prevalent while others like the Whooping crane, are endangered or even near extinction? And how do we even know how many deer or cranes there are?

## Populations



A **population** is the number of individuals for a species in one area. Populations can change depending on the context. For example, the 2004 population of deer statewide was 1.64 million. However, we could also look at the population of the 262 area code, the population of all southeastern counties, or the population of deer just in Racine County. Each would provide us with different numbers from which to make decisions.

However we define it, populations of individuals of a species are all influenced by the same environmental factors and have a high likelihood of breeding and interacting with each other. The distinctiveness of a population is determined by the interactions between individuals, their environment, and the resources of that environment. Natural selection, disease, and the availability of food and shelter can shape a population, changing not just the numbers of individuals but also their physical characteristics.

For example, a lake full of bluegills can see the average size of those individual fish change as population changes, with smaller fish resulting from higher concentrations of species within the same area. We call the concentration of species within a given area the **density** of the species, or the number of individuals per area or volume. All told, populations are shifting, dynamic relationships between individuals of a species and the living and nonliving resources around them.

When a natural resources official must make a determination about whether or not to allow a hunt of a species, or whether to increase the number of hunts for that species, he or she must take into consideration not just the population of the animal but also the density and **dispersion**. Dispersion of a species is the pattern of spacing of an

Population: the number of individuals of a species in one area

Density: the concentration of the individuals of a species

Dispersion: the pattern of spacing of a population's individuals

individual. For example, are individual turkeys found evenly spaced throughout Racine County, or are they grouped in specific sections in high densities?

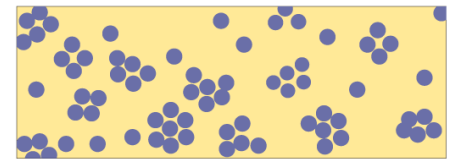
## Patterns of Dispersion

Because not all areas provide suitable habitat equally for a species, dispersion of individuals tends to be **clumped**. Mushrooms tend to locate in high numbers on rotting logs. Deer may move in herds. Trees of similar type or variety tend to occur in patches. Wolves run in packs.

Some species may have a **uniform** dispersal. For example, territorial animals such as black bears will intentionally avoid each other most of the time in order to maximize their food availability. Animals at the top of the food chain often require the most space and resources and tend to be evenly dispersed as individuals or as groups because of this.

Rarely a species will show **random** dispersion, or dispersion that is completely unrelated to any other individual. This is least likely to occur as most species show an inclination towards a clumping dispersion. This is largely due to the range of availability of resources in a given area, with some areas having more abundant resources than others. For example, mushrooms will find their needs are best met by decaying material, which is usually concentrated around the remains of formerly living organism.

Solomon: Biology, 5/e  
Figure 51.1



(a)



(b)



(c)

## Measuring Population, Density, and Dispersion

Only rarely is it possible to determine a population by counting every individual of a species within a given area. Even our own censuses of Americans fail to do this accurately. It is even more unlikely that animals will voluntarily report to a game warden for counting.

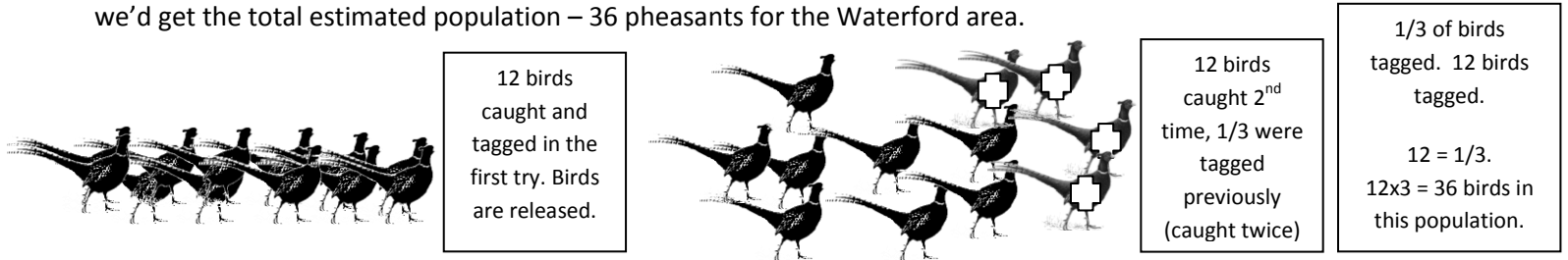
In some cases, aerial flyovers can give us a picture of the population level of a species. For example, in large open areas like the prairies, a DNR plane could estimate the numbers of pronghorn antelope with relative accuracy for an area. However, in thick wooded areas this is not as feasible, especially for plants and animals that are not visible from the air.

Instead, ecologists use a wide variety of sampling techniques to predict a species' population density. Usually, an ecologist must break the area into plots, or evenly spaced sections, and randomly select plots in which to count the number of individuals present. This approach is more accurate when there are many sample plots and when the habitat is homogenous, or evenly distributed.

Fish and wildlife populations are most commonly estimated using **mark-recapture methods**. Traps are placed within a boundary and captured animals are marked with tags, collars, bands, or spots of dye and then released. When enough time has been allowed for animals to disperse and mix randomly, the traps are set again. The proportion of marked (recaptured) animals is equivalent to the proportion of marked animals in the total population.

**Mark – Recapture:** a method of determining the size of a population in which individuals are trapped and marked. Traps are set at a later date, and the proportion of individuals recaptured is used to determine the size of the population.

For example, let's imagine we are counting pheasant populations in the Waterford area. We set traps and catch 12 birds, which we then tag. These birds are released, and several weeks later we re-set the same traps. Of the 12 birds we catch, 4 have been previously tagged. This means that for this area, 4 out of 12, or 1/3 are tagged. If 1/3 are tagged, and we tagged 12, that would mean that 12 is 1/3 of the total population for this area. If we multiply 12 times 3, we'd get the total estimated population – 36 pheasants for the Waterford area.



The mark recapture method is valuable because it only requires an ecologist to catch *some* individuals. By repeating the same experiment, we can use a simple formula to estimate the population level. If  $N$  is the population of a species:

$$N = \frac{[\text{number marked in first catch}] \times [\text{total number in second catch}]}{[\text{number re-captured in second catch}]}$$



For example, imagine we catch 50 grouse in traps and give them a metal band on their foot. Two weeks later, we catch 100 grouse, of which 10 have metal foot bands. According to our formula,  $N = [50] \times [100] / [10] = 500$  grouse.

This approach is not perfect, however. For one, it assumes that each marked individual has the same probability of being caught as an unmarked individual. This is not always true – an animal that has been caught once may be more likely to avoid an area simply because it was caught and handled previously. It also does not account for losses of species – for example, marking an individual may make it more likely to be targeted by a predator.

Besides counting, population ecologists can rely on other methods. Size and density can be estimated from signs of an organisms' presence, such as scat, nests, burrows, tracks, and other indirect pieces of evidence.

## Demography

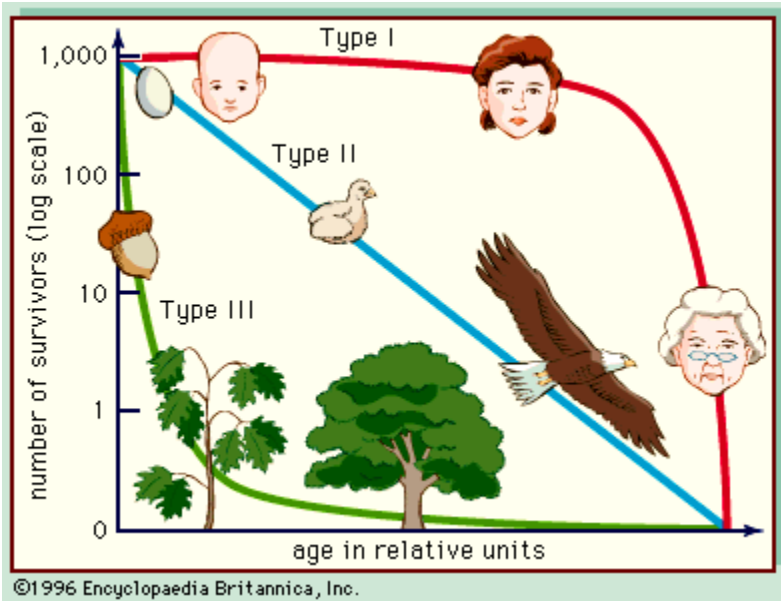
**Demography** is the study of the factors that affect population size. In other words, it is the analysis primarily of birth and death rates, and the factors that affect them. When ecologists study demographics, they create **cohorts**, or groups of individuals who are all within the same age range. By analyzing the number alive at the start of the year vs. the number alive at the end of a year, we can determine detailed information about the survivorship trends of a species.

This information can then be graphed to create a **survivorship curve**. A survivorship curve represents the numbers in a species cohort that are alive at each stage of life. A survivorship can fall into one of three categories. **Type I** on the survivorship curve starts off relatively flat and then drops off steeply at an older age. In this case, death rates are relatively low until later in life when old age claims most individuals. The death rate for Type I species is highest at old age. These species tend to produce few young, as they are less likely to die due to good care. **Type II** is the intermediate category, with a steady even death rate over the

Demography: the study of factors that affect a population's size.

Survivorship Curve: a graph demonstrating when most deaths for a species occur; Type I species die mostly at an old age while Type III die shortly after birth in most cases.

course of a species expected lifespan. **Type III** curves drop off steeply immediately, representing high infant mortality, but then levels off for adults. This type of curve is affiliated with species that produce large numbers of young with the expectation that few of them will make it to maturity. Fish and frogs, for example, lay large numbers of eggs with only a small percentage making it to adulthood.



Most species do not follow these three curves exactly, but often show a combination of two or three. For example, many birds have high infant mortality which levels off during adulthood, representing a start with Type III and then a shift to Type II. Some species may even shift during adulthood; for example, when a crab sheds its exoskeleton, it briefly becomes highly vulnerable (Type III) followed by near-insusceptibility (Type I) when the exoskeleton hardens again.

## Population Growth and Decline

Knowing these trends in births and deaths, we can then ask what controls and stabilizes biological

populations. After all, our main goal is to predict population growth and change. Population ecologists attempt to understand how ecological communities and ecosystems function by building upon an understanding of individual populations.

Population growth is determined by **reproduction, mortality (deaths), immigration, and emigration.**

Reproduction can be broken into two categories:

1. **Fecundity** is the number of individuals that reproduce under ideal circumstances. This limit is determined by organism's genes. For example, deer typically only have one or two young per birthing, while fish may lay considerably more eggs.
2. **Fertility** is the number of young borne under actual environmental conditions. The fertility rate is always less than the fecundity rate, as the fecundity rate is the maximum fertility rate under ideal circumstances.

For example, a herd of whitetail deer have 20 does. Those does could have 40 young as a result of their genetic makeup. However, not all the does are fertilized and some may have poor nutrition. As a result, while the *fecundity* rate is 40, the *fertility* rate in this case might only be 20 fawns.

Usually fecundity and fertility are not expressed as whole numbers, but rather as offspring per individual. In the former example, it would be more correct to say the *fecundity* rate was 2 fawns per doe and the *fertility* rate was 1 fawn per doe.

Besides births and reproduction, the **mortality** rate also plays an equally large part. Mortality is expressed as a rate. That is, the

Fecundity: the maximum number of offspring a species can have.

Fertility: the actual number of offspring a species has

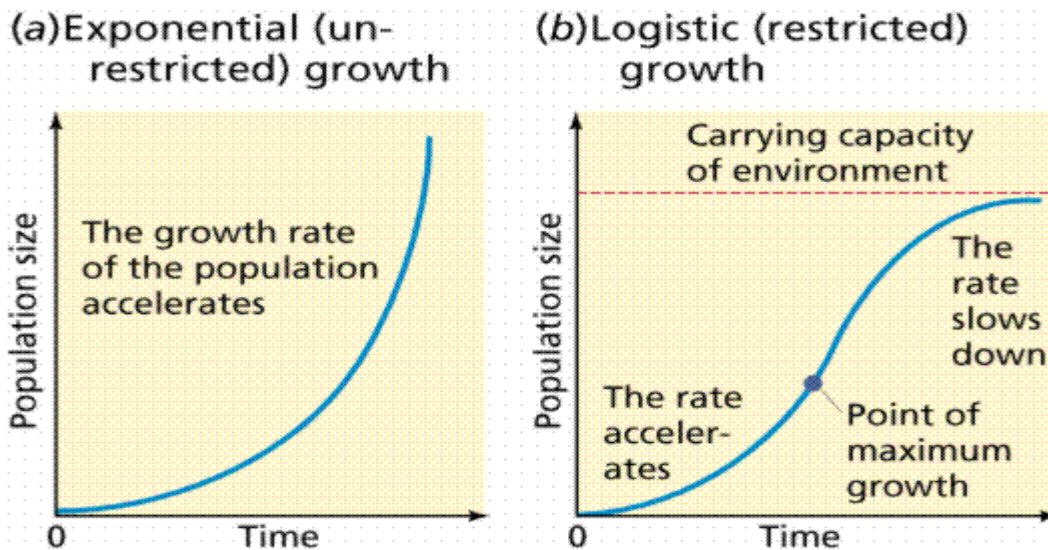
Mortality: the death rate.

Immigration: the number of individuals that join a population

Emigration: the number of individuals that leave a population

average (mean) number of deaths per thousand or per individual, per unit time, per area. For example, imagine there was a population of 1.0 million deer in a given year. 500,000 deer were harvested by hunters in Wisconsin that year. This would give us a mortality rate of 500 per 1000 per year for Wisconsin.

Finally, **immigration** and **emigration** play a large role in shaping the population of a species. *Immigration* is the number of individuals who join a population each year from another location, while *emigration* is the number of individuals who leave for another area. Often these figures are nearly impossible to determine in biological populations are often ignored. After all, we can't tell if a deer was born in Minnesota or Michigan, nor does this largely affect our population measurement.



Often we plot the changes in the population of a species to determine any trends or to make predictions. Populations can change rapidly if the balance between births and deaths is upset. For example, if a population experienced more births than deaths on a regular basis, the graph for that population would look like that on the left.

As you can see on the graph (a) the curve becomes steeper and steeper with time, representing an addition of individuals at an increasing rate. This makes sense – if the max number of individuals are being born and the minimum number are dying, that means more individuals are able to reproduce each year, adding more individuals each time.

However, no species can grow exponentially forever. Exponential growth most often occurs in a species' population after a dramatic event that wiped out large numbers of species. For example, whooping cranes are now experiencing exponential growth in Wisconsin. Their population was nearly decimated by habitat loss. With concerted efforts, their numbers are now rebounding, but they can't increase at this rate forever. At some point, their numbers will level off as they reach the **carrying capacity** of their habitat, as shown in Figure (b). The carrying capacity is maximum number of individuals an environment can sustain at a particular time with no resulting degradation of that habitat.

Carrying Capacity (K): the maximum number of individuals a habitat can support at a given time. This value changes continuously.

Carrying capacity is often symbolized by the letter **K**. **K** is not a fixed value, but will fluctuate with different areas and time. For example, the carrying capacity for whooping cranes is higher in Wisconsin, with more suitable habitat, than it

is in the deserts of Arizona. The **K-value** of Wisconsin is also higher now, with extensive wetland restoration efforts, than it was 50 years ago when wetlands were routinely drained for development.

Energy availability, shelter, refuge from predators, soil nutrients, water availability, and nesting/roosting sites all affect how large the K-value is for an area. As whooping cranes increase in numbers, proportionally smaller amounts of nutrition and habitat will be available to each bird. As such, they will have to work harder to perform the same physiological functions, decreasing their reproductive rates. Their population will level off at a specific number range, reflecting the carrying capacity of that habitat. If their habitat would be changed so that they could not find resources to function and reproduce, their K value would be lowered, increasing deaths and decreasing births.

r-value: the difference between births and deaths;  $r = b - d$

N: total population

$[K-N]/K$  = the fraction of the habitat that remains for population growth

Often ecologists must use complicated formulas to determine the direction a population is going. For example, you now know that K represents the carrying capacity of a habitat. Ecologists are also concerned about the **r-value**, or the difference between births and deaths (i.e.  $r = b - d$ ). In the case above, if a habitat were changed so that it had fewer available resources, this would create a smaller r-value. A smaller r-value would create a smaller total population for a species in the long run. In ecology, we represent the **total population** of a species with the letter **N**.

When a population's size (N) is well below the carrying capacity (K), growth is rapid and exponential. As the value of N gets closer and closer to K, growth slows, reflecting the limited availability of biotic and abiotic (non-living) resources.

Mathematically, we'd use the following equation to represent these phenomena:

$$[K-N] / K$$

$K-N / K$  tells us what fraction of the habitat remains for new individuals. For example, if the population (N) of deer in the environmental center was 10 and the current carrying capacity (K) was 40, half of the available habitat for whitetail deer would be still available and  $[K-N]/K = 0.5$ , or 50%.

A species' genetics will change throughout the entire species over time. The same species will have different traits depending on the conditions where it is found. For example, quail in a region with many quail will be more energy efficient and have fewer young than quail in a region where quail as a whole are rare.

Generally we divide changes within a species based on their environment and population into two categories – K-selection and r-selection. **K-selection** occurs when a species has a lot of competition. If the population is dense, an individual will benefit if it can use its resources efficiently and compete well with other individuals in the same species. Again, K represents the maximum carrying capacity, and so a K-selected species is one which performs best when the population of that species is the highest.

On the other hand, **r-selection** is when species are selected for traits that enable them to succeed when their populations are low. Again, r refers to the growth of a population. High r values occur with low death rates and high birth rates. Experiments have shown that species can show varying levels of r-selected and K-selected traits. For example, fruit flies grown in crowded conditions will show more of the K-selected trait of efficient metabolisms while showing fewer r-selected traits such as high reproductive rates.

# Population Dynamics

Populations rarely level off at a specific number. Carrying capacity (K) values can fluctuate among different parts of a habitat as well as with time. Most populations exhibit change over time due to these changing K values. For example, the moose populations on the Isle Royale off the coast of Michigan's Upper Peninsula have plummeted twice in the past 40 years. One was because of wolf predation, the second because a food shortage caused by a severe winter. The deepening snow not only limited the food that was available but required more energy to get it, causing a lowered K-value for moose on Isle Royale.

Some populations even have routine boom and busts. For example, snowshoe hare populations fluctuate in 10 year cycles. Lynx populations do so as well, but in a delayed fashion (i.e. the bust occurs after the hare bust). It appears that the hare is preyed to the point of exhaustion by the lynx, which then has its own populations plummet due to a lack of prey. This enables the hare to increase in numbers again, as does the lynx shortly thereon. Once again, the lynx population gets too high and the hare population reaches the K-value, causing it to plummet as lynx populations once again max out. This cycle occurs continuously roughly every decade.

The key to understanding these trends is long-term data. Ecologists must establish decades of data before they can determine the health of a species population in an area. For example, Pintail ducks have had fluctuating levels depending on the productivity of each year. However, population studies over the course of a half-century have shown their numbers have dropped precipitously over time due to loss of their wetland habitat to development and agriculture. Only by looking at long term data can we determine if a population boom is really a boom or just a temporary relative increase compared to long term trends.

## Conclusion

While it is impossible to determine the number of species in a population by counting every one of them, we can get a rough estimate of the size of a population through indirect methods. Some are subjective and only indicate a general presence; for example, spotting the tracks, scat, or nests of an animal indicates their presence. Other methods are more quantitative. For example, the mark-recapture method offers a solid number when estimating a population's size; however, this number can be thrown off by a number of factors. Population is affected by the density (how concentrated a species is) and dispersion (their pattern of arrangement in an area).

The size of a population is not our only concern. The range of ages of a population is also a key concern, particularly in regards to whether an animal has the highest mortality early or late in life. The study of these factors is known as demographics. Type I animals tend to have the highest mortality at the end of life, while Type III have mostly infant mortality with few young surviving into adulthood. Reproduction is quite necessary for their population; in this regard we must consider both fecundity (the maximum reproductive rate) and fertility (the actual reproductive rate). If fertility is equal to fecundity, and deaths are minimal, a species will exhibit exponential growth up to the point of the carrying capacity (K) of that population. As populations change, so does the genetic makeup of a species.

K-selection: when a species exhibits traits for competitiveness in dense populations, such as efficient use of resources and low reproductive rates



r-selection: when a species exhibits traits for building the size of a population when it becomes low, such as high reproductive rates and inefficient use of resources.



## Terms

Population: the number of individuals of a species in one area

Density: the concentration of the individuals of a species

Dispersion: the pattern of spacing of a population's individuals

Mark – Recapture: a method of determining the size of a population in which individuals are trapped and marked. Traps are set at a later date, and the proportion of individuals re-captured is used to determine the size of the population.

$$N = \frac{[\text{number marked in first catch}] \times [\text{total number in second catch}]}{[\text{number re-captured in second catch}]}$$

Demography: the study of factors that affect a population's size.

Survivorship Curve: a graph demonstrating when most deaths for a species occur; Type I species die mostly at an old age while Type III die shortly after birth in most cases.

Fecundity: the maximum number of offspring a species can have.

Fertility: the actual number of offspring a species has

Mortality: the death rate.

Immigration: the number of individuals that join a population

Emigration: the number of individuals that leave a population

Carrying Capacity (K): the maximum number of individuals a habitat can support at a given time. This value changes continuously.

r-value: the difference between births and deaths;  $r = b - d$

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$[K-N]/K$  = the fraction of the habitat that remains for population growth

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# Questions to Test Your Understanding – Population Ecology – 25 pts

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Name: \_\_\_\_\_ Hour \_\_\_\_\_ Date: \_\_\_\_\_

Date Assignment is due: \_\_\_\_\_ Why late? \_\_\_\_\_  
Day of Week                      Date    If your project was late, describe why

1. What is a population? Provide an accurate definition in your own words.
  
2. What factors can change a population's individuals and physical characteristics?
  
3. (2 pts) What is species density? What is species dispersion? Provide accurate definitions for both in your own words.
  
4. How does the mark-recapture method work?
  
5. (2 pts) If 1000 bluegills are caught and have their fins notched, and on a second catch 50 of the 1000 caught have notched fins, what is the population of bluegill fish in that lake? Show your work.
  
6. (3 pts) List and fully explain the three kinds of species dispersion.
  - a.
  
  - b.
  
  - c.
  
7. (3 pts) List and explain the three types of survivorship curves. Give an example of a species that would fit each curve (do not repeat examples from the reading)
  - a.
  
  - b.
  
  - c.

8. (2 pts) - Part 1: Define both fecundity *and* fertility. Part 2: Then explain how they are different.
9. According to the Wisc. DNR: *“There are approximately 85 whooping cranes in our Eastern Migratory Population with plans for roughly 30 birds to be added to the population each year until it becomes self-sustaining, perhaps by 2020.”*  
<http://dnr.wi.gov/org/land/er/birds/wcrane/index.htm>
- (1 pt): What is N currently?
  - (1 pt): If K is 500, what fraction of the available habitat is STILL available? Show your work.
  - (1 pt): If K is 500, are these birds more likely to show r-selected or K-selected traits? Why?
  - (1 pt): If growth is consistent at 30 birds per year and K is unchanged, when will Whooping Cranes exceed their carrying capacity? Show your work.
  - (1 pt): In 2020, are these birds more likely to show r-selected or K-selected traits? Why?
  - (1 pt): Based on your answer above, and based on what you know about both K- and r-selection, would an increase of 30 per year make sense? Should this number be higher or lower? Explain. (Hint: focus on 30 as a percentage of N as it increases each year)
10. Coyote populations are closely linked to pheasant populations. Pheasants Forever, a state and national hunting group, has contacted you to address their concerns regarding the Racine Co. Pheasant population. Show your work if there is math.
- (1 pt): UW Biologists have estimated that Racine County could handle up to 1000 pheasants before harming the area’s ecosystems. If the current Racine population of pheasants is 250, what fraction of their habitat remains?
  - (1 pt): Would transplanting pheasants from heavily populated areas be more, less, or equally as effective as moving pheasants from areas with fewer birds? Explain using the terms r-selected and K-selected
  - (1 pt): If coyote populations are high, would we expect a single coyote to consume fewer or greater numbers of pheasants compared to areas with much lower concentrations of coyotes? Explain.
  - (1 pt): Would pheasants become smaller or larger as the population becomes more numerous?