Topics 3.4 and 3.5

Carrying Capacity and Population Growth and Resource Availability

Enduring Understanding: Populations change over time in reaction to a variety of factors.

Learning Objectives: Describe carrying Capacity and its effect on ecosystems. Explain how resource availability affects population growth.

Related Readings: Pg. 61 -69, “Environment; The Science Behind The Stories” 5th Edition, Withgott, Jay and Laposata, Matthew.

Unregulated populations increase by exponential growth

- If a population is small, resources abundant, and abiotic conditions are optimized to the species range of tolerance, then the population will exhibit ***exponential growth***.
  - Exponential growth is unconstrained growth.
  - Such conditions rarely exist in the natural world and are usually short lived when they do.
  - Introduced species may experience such conditions when first introduced to a new area.
- Populations growing exponentially will increase by a percentage of its current population size, rather than a fixed amount (linear increase).
  - The larger the population is, the more individuals it will add per unit of time.
  - Exponential growth is an example of positive feedback.
- Exponential growth is described by the following equation:
  - *dN/dt* = rN, which, when integrated results in the equation:

$$N_t = N_0e^{rt}$$

  - Graphing results in a **J-shaped exponential growth curve**

Exponential Population Growth (r = 0.10)		
Time	N	# ADDED
1	100	-
2	110	11
3	121	12
4	133	13
5	146	15
6	161	16
7	177	18
8	195	20
9	215	22

$$N_t = N_0e^{rt}$$

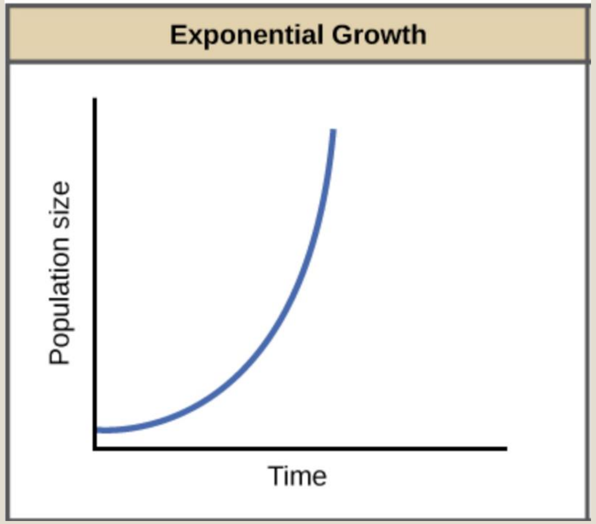
N_0 = Initial population size

r = rate of growth

e = a constant (2.7)

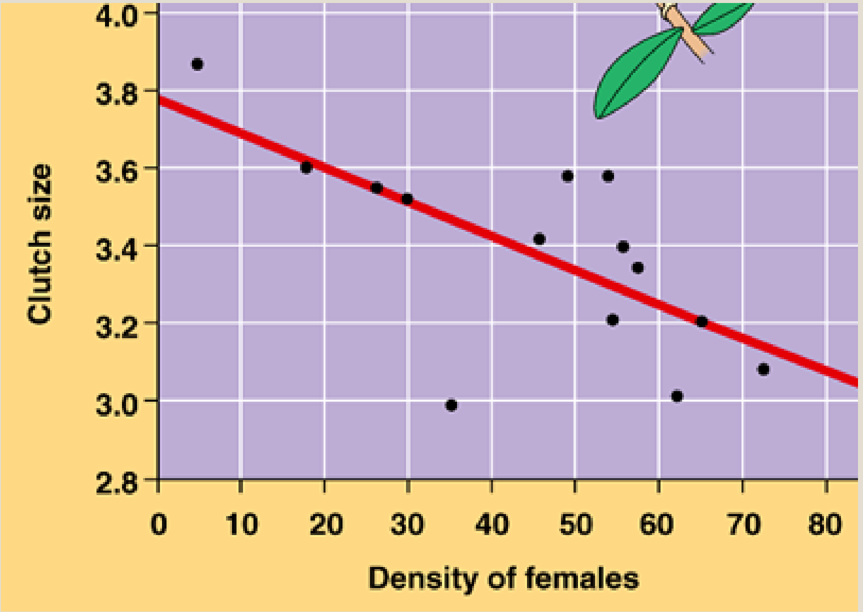
t = amount of time

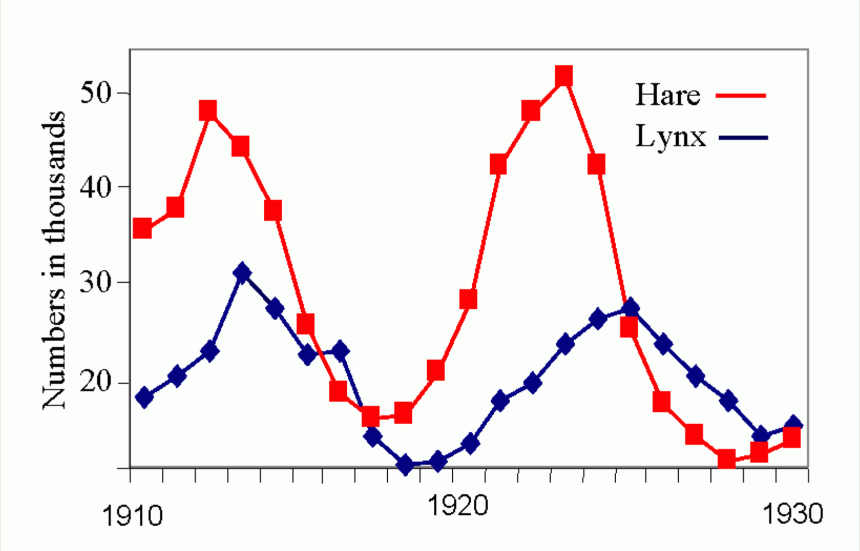
N_t = Final population size



Long Term Exponential Growth is Unsustainable

- The continuously accelerating growth of exponentially increasing populations can not go on indefinitely.
  - Individuals in a population depend on finite resources from their environment in order to survive, grow and reproduce.
  - As population density increases, shortages of one or more resources will begin to limit further population growth.
  - Space, food, water, mates, shelter are examples of density-dependent limiting factors.
- The affect of ***Density-dependent limiting factors*** increases as populations density increases.
  - As populations get larger and/or more concentrated, the population experiences stronger effects of density-dependent limiting factors
  - In addition to specific resources that are in short supply, disease and predation are examples of density-dependent limiting factors.
  - Density-dependent limiting factors slow the exponential growth of populations and eventually limit the population to its maximum sustainable population size in that environment, the ***carrying capacity (K).***



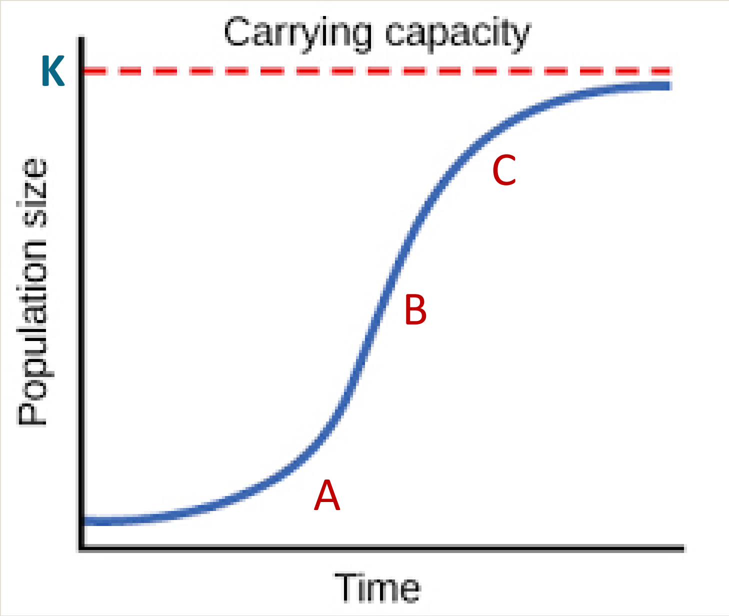


Logistic Population Growth Model

- The logistic model of population growth accounts for the slowing growth of populations affected by density-dependent limiting factors.
- ***Logistic Growth Model***
  - The equation describing logistic growth is:

    $$dN/dt = rN\,[(K-N) / K)]$$

  - Results in an S-shaped ***logistic growth curve***
  - When populations are small, and resources are abundant, competition is low, and populations grow exponentially (A).
  - At the inflection point of the curve, the population achieves its ***biotic potential*** (maximum population growth rate, r_{max}) (B)
  - Beyond this population size, density-dependent limiting factors slow further growth of the population, but population size continues to increase, at a decreasing rate of growth. (C)
  - Eventually the population growth rate (r), reaches zero, and population size stabilizes at ***carrying capacity (K).***
  - Growth rate of the population decreases due to increased death rates and/or decreased birth rate.
    - dN/dt = 0 when (birth rate = death rate)



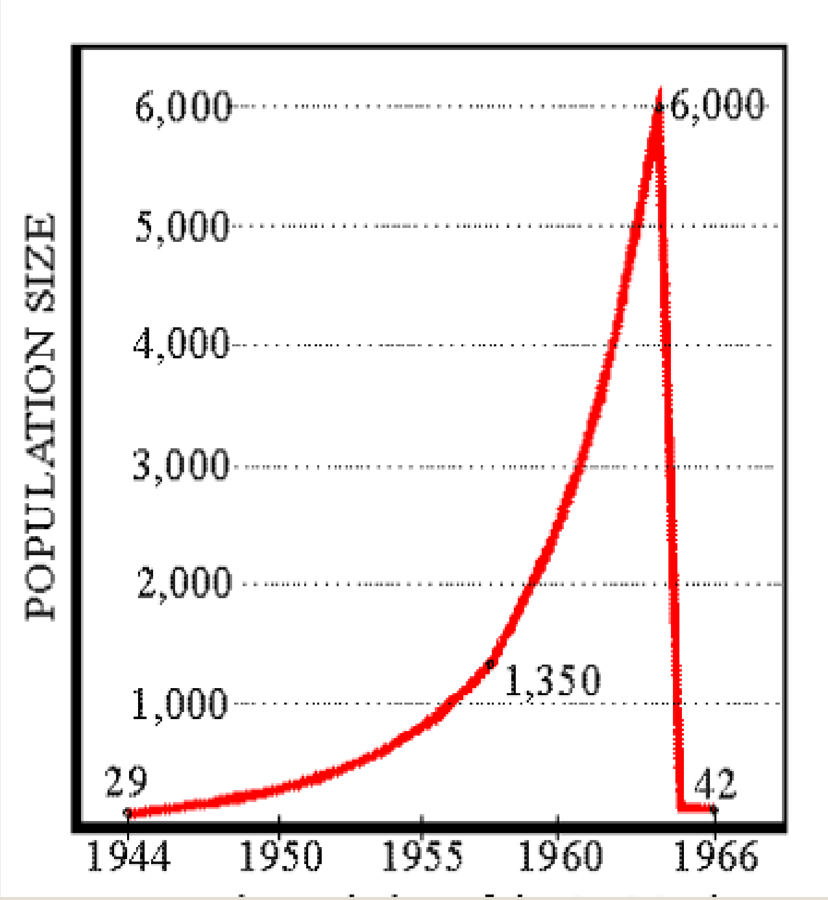
$$\frac{dN}{dt} = rN\left(\frac{K-N}{K}\right)$$

r = growth rate
N = population size
K = carrying capacity

The Logistic Model Oversimplifies Actual Population Growth

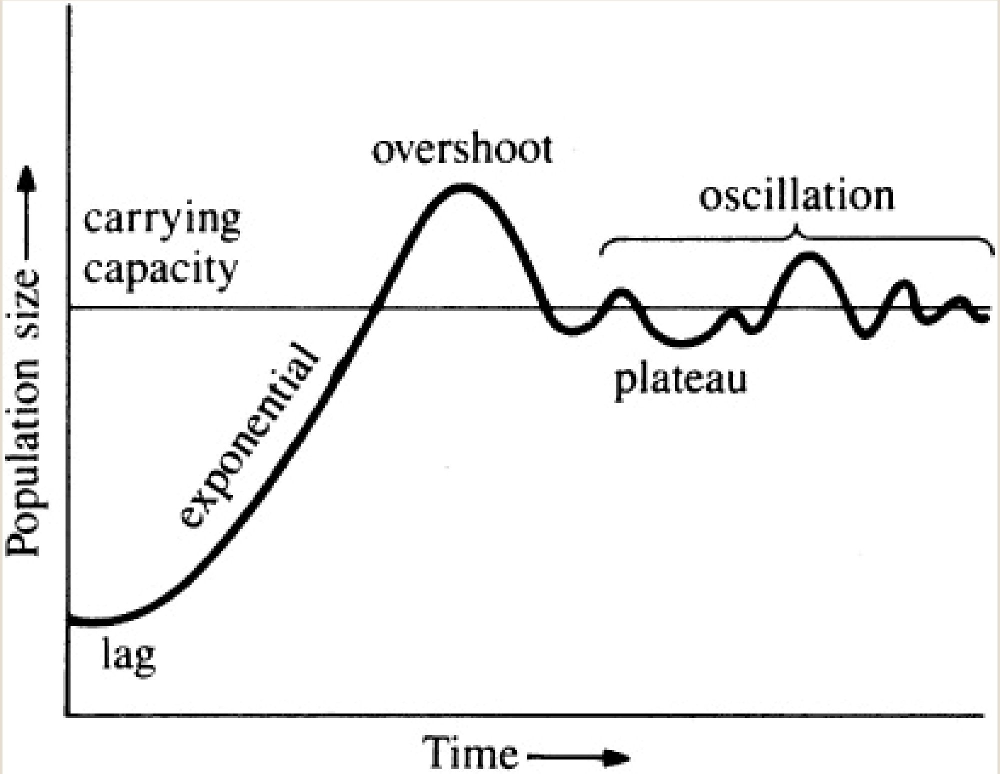
- Population of 29 reindeer introduced in 1944 to St. Matthews Island as an emergency food source for the U.S. Coast Guard, who abandoned the island two years later.
- The reindeer had no predators on the island and the island, 120 mi^2 in area, was covered in their favorite food source, lichen.
- Weather throughout the mid to late 1950's and early 60's was unusually mild.
- The winter of 1963-64 was harsh, but no worse than the winter of 1950-51.
- Visitors to the island in the summer of 1964 found many dead reindeer on the island including many females who appeared to have been pregnant. There were only 42 reindeer at this time. By 1965 there were no reindeer remaining on the island. What do you think happened to the reindeer herd of St Matthews Island?

Reindeer Population of St. Matthews Island



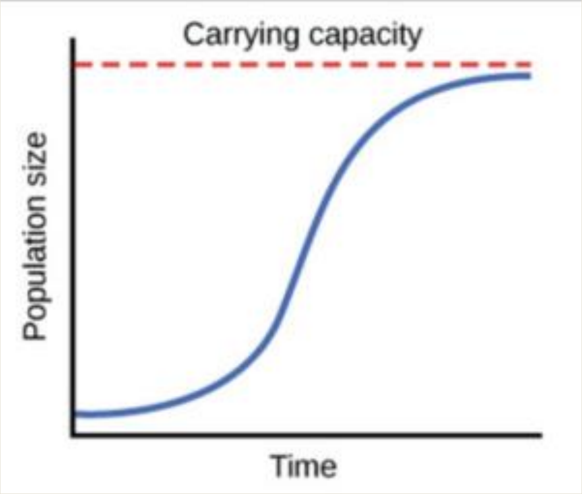
Many Populations Overshoot the Carrying Capacity of Their Environment

- Many populations exceed, or ***overshoot***, the carrying capacity of their environment, when their population grows too rapidly.
- This damages resources the population depends on, causing significant increases in the death rate and/or decreases in the birth rate and causing the overall population to shrink (negative growth rate).
- Most populations do not overshoot their carrying capacity as severely as the reindeer.
  - As they die off, the resource recovers some, allowing for some population recovery, which then leads to a second, smaller overshoot. This cycle continues to repeat leading to ***oscillation around the carrying capacity.***
  - r-selected species often show greater amplitude in their oscillations than K-selected species. Why?

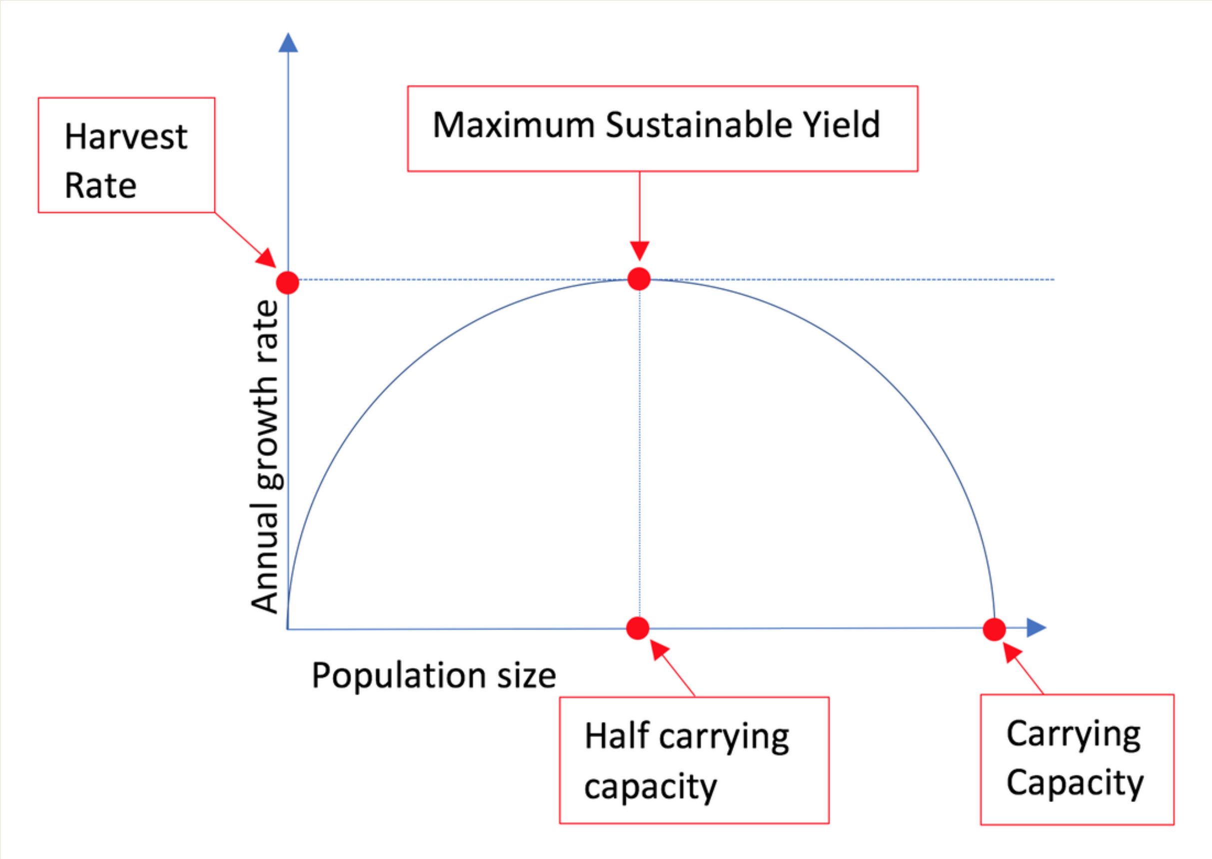


- The ideal conditions on St. Matthews Island caused the newly introduced herd to grow exponentially at an exceptionally high rate, likely adding close to 1000 individuals to their population during a single year early in the 1960’s.
- Such rapid growth decimated the lichen population, their food source. Due to its reduced population size, the lichen experienced slow growth in the following seasons, reducing the food available to the reindeer and weakening them.
- The harsh winter of 1963-64 likely killed off many reindeer who were already slowly dying of starvation.

Maximum Sustainable Yield (MSY)

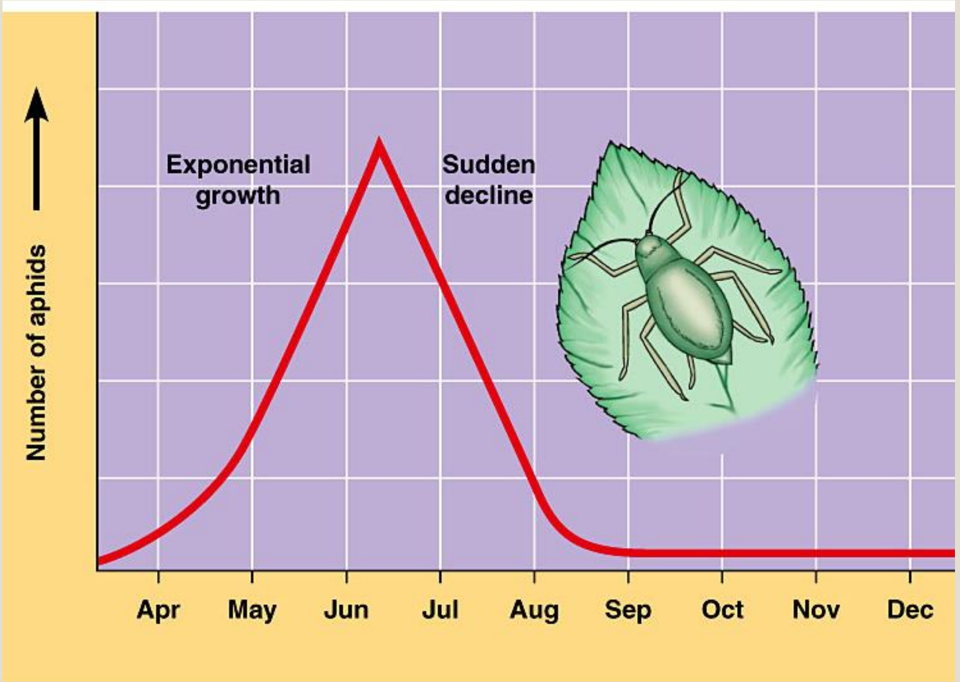


- Logistic Growth Models Can be Used to Determine the **Maximum Sustainable Yield (MSY)**
  - Maximizes harvest while maintaining populations of game species for the future.
  - Managers may limit the harvest or restrict gear used
- Despite management, stocks have plummeted
  - MSY requires accurate measurement of initial population size or precise estimates of carrying capacity of the environment for the population
  - Overestimates and a lack of ongoing monitoring often result in overharvesting



Density-Independent Factors Limit Some Populations

- ***Density-independent limiting factors*** are those whose influence does not change in response to changes in population density.
    - Events such as floods, fires, seasonal changes, extreme weather events and landslides will occur and reduce the population size, regardless of population density, thus changing the population growth rate independent of population density
- Although the populations of many K-selected species are regulated by density-dependent limiting factors, density-independent limiting factors are often more important in regulating r-selected populations.
    - r-selected species are opportunists who thrive in disturbed environments with low levels of competition.
    - As, r-selected species exploit these disturbed environments, their populations grow rapidly.
    - Given their small size, short life spans, and lower resource needs, their populations can continue to grow for longer periods without reaching carrying capacity.
    - Fluctuations in the abiotic factors of the diverse environments these generalists attempt to colonize may exceed the species range of tolerance and reduce their population size before they reach carrying capacity.



Determining Population Size

- Most populations are too large, and too dispersed over difficult to access locations, to easily count all individuals in the population.
  - Ecologists estimate population sizes through the use of sampling techniques.
- Non-motile species are randomly sampled using ***transects*** and ***quadrats***.
  - Transects are lines of fixed length, with marks at regular intervals to mark locations where samples will be collected.
  - Quadrats are frames with a constant area inside the frame.
  - At each sampling location along a transect, researchers count all individuals inside the quadrat.
  - Then they divide the number of individuals in the quadrat by the area of the quadrat to determine the ***population density*** (# of individuals/area) inside the quadrat.
  - If quadrat area = 2m^2 and there are 10 barnacles/quadrat then population density = (10 barnacles) / (2 m^2) = 5 barnacles/m^2
  - The average population density can now be multiplied by the total study area to find the population size (N)
  - Therefore in a study area of 100m^2, N = (5 Barnacles/m^2) x (100m^2) or 500 barnacles

Transects (white lines) laid out at regular intervals in the intertidal zone. A quadrat (white frame in front of researcher) is used to randomly sample areas at predetermined distances along each transect.

Population density =
\# of individuals in quadrat / quadrat area

Population Size (N) Estimate =
Average population density x Total area

Estimating Population Size

- For motile species that will not stand still so that researchers can count them, ***mark and recapture methods*** are used to estimate population size.
- There are many subtle variations to mark and recapture techniques, but the general principal is the same.
    - Researches capture as many live individuals of a target species in a single effort as they can. These individuals are marked and returned to the habitat.
    - After allowing time for marked individuals to disperse into the environment (time varies by species) a second trapping effort of equal intensity is made.
    - In the second effort, the number of previously caught individuals (with markings), and the total number of individuals caught in this second effort (with **and** without any markings) are both recorded.
    - A simple proportion is then set up and solved for N, the population size to estimate the overall population size in the habitat.

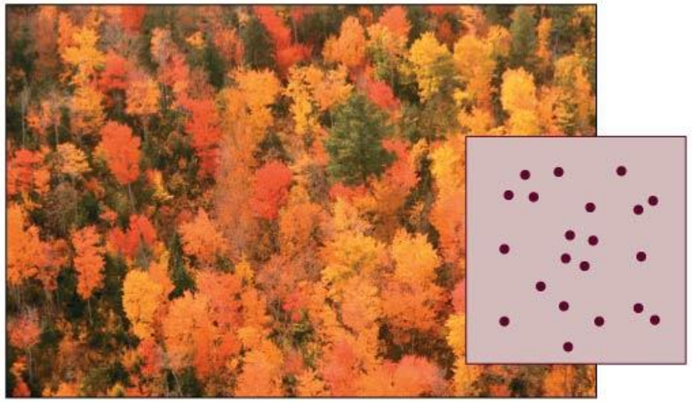
Mark and Recapture Population Estimate (Lincoln-Petersen Index)

$$\frac{M}{N} = \frac{R}{S} \quad \text{or} \quad N = \frac{M \times S}{R}$$

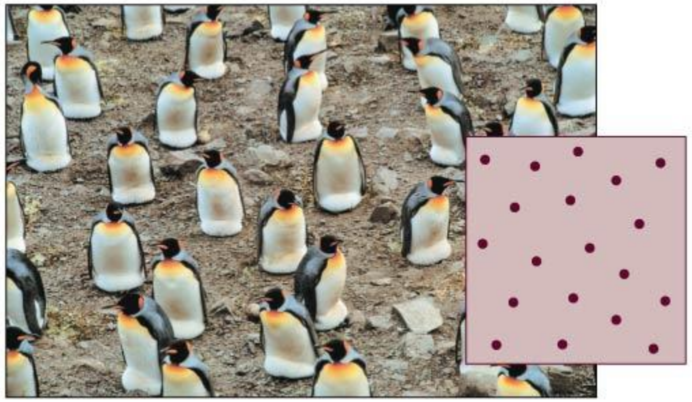
N = Population Size
M = Total # of marked individuals
S = Total size of sample
R = # of marked animals that are recaptured

Population Distribution

- **Population distribution (dispersion pattern)** is the spatial arrangement of organisms in a habitat or ecosystem.
  - *Random*
    - haphazardly located individuals, with no pattern
  - *Uniform*
    - individuals are evenly spaced
    - Territoriality, competition
  - *Clumped*
    - organisms found close to other members of population
    - Most common in nature
    - Clustering around resources
    - Mutual defense



(a) Random: Distribution of organisms displays no pattern.



(b) Uniform: Individuals are spaced evenly.

(c) Clumped: Individuals concentrate in certain areas.