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Topic: Prey-Predator Dynamics

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PREY- PREDATOR DYNAMICS

- Predation is commonly associated with the strong attacking the weak, the lion pouncing on the deer, the hawk upon the sparrow.
- Predation also includes parasitoidism, a case of the weak attacking the strong.
- In this situation, one organism, the parasitoid, attacks the host by laying its egg in or on the body of the host. After the eggs hatch, the larvae feeds on the tissues of the host until it dies. The effect is the same as that of predation.
- Another form of predation is cannibalism, in which the predators and prey are the same species.
- Predation also include herbivory, in which grazing animals of all types feed on plants. Hervibores kill their prey when consuming seeds or the whole plant, or they functions as parasites when they consume only part of the plant but do not destroy it.
- Thus predation in its broadest sense can be defined as one organism feeding on other living organism, or biophagy.

- Ecologically. Predation is more than just a transfer of energy and nutrients.
- It represents a direct and often complex interaction of two or more species, of the eaters and the eaten.
- The numbers of some predators may depend upon the abundance of prey and predation may be involved in the regulation of prey population.

Models of Predation

In 1925 A.J.Lotka, proposed the first model of predator-prey interaction.

In 1926 A Volterra independently came up with a similar model. Neither of the two extended the logistic equation to the two-species system.

- Lotka adapted the chemical principle of mass action.
- Mass action assumes that individual predators and individual prey encounter each other randomly in the same way that molecules interact in a chemical solution.
- The responses of predator and prey populations are assumed to be proportional to the product of their population densities.
- Law of mass action, law stating that the rate of any chemical reaction is proportional to the product of the masses of the reacting substances.
- considering the following general reaction
- $A + B = C + D$

Law of mass action is represented by the following expression:

$$K = [C][D] / [A][B]$$

where K is the equilibrium constant

This mathematical expression holds that for a reversible reaction at equilibrium and at constant temperature, a certain ratio of reactant and product concentration has a constant value, K (equilibrium constant).

- Based on a number of following assumptions:

1. In the absence of predation, the prey experiences exponential growth.
2. The predator population declines exponentially in the absence of prey.
3. Predators move at random among randomly distributed prey.
4. The proportion of encounters that result in the capture and consumption of prey are constant at all predator and prey densities.
5. The number of prey taken increases in direct proportion to the number of predators, a linear response.
6. All response are instantaneous with no time lag for handling and ingesting prey.
7. Energy inputs to predators is immediately converted to the birth of predators.

The model makes no allowance for age structure, for interaction of prey with their own food supply, or for density-dependent mortality of the predator.

- The Lotka-Volterra model involves paired equations, one for the prey population and one for the predator population.
- The prey growth equation has two components, the maximum rate of increase per individual and the predatory removal of prey from the population:
- $$\frac{dN_{prey}}{dt} = rN_{prey} - cN_{prey}N_{pred}$$

- For the predatory population:

$$\frac{dN_{pred}}{dt} = b(cN_{prey}N_{pred}) - dN_{pred}$$

- Where N prey and N predator are the densities of the prey and the predator respectively, r and d are per capita rates of changes in absence of each other and c and b are the rates of change for prey and predator resulting from the interaction of the two population.

The Lotka-Volterra equations for predator and prey population growth therefore explicitly link the two populations, each functioning as a density-dependent regulator on the other.

Predators regulate the growth of the prey population by functioning as a density-dependent regulator on the other.

The prey population functioning as a source of density-dependent regulation on the birthrate of the predator population.

With the help of graph, we can see how these two populations interact with each other.

In the absence of predators (or very low predator density), the prey population will grow exponentially.As the predator population increases prey mortality will increase until eventually the rate of mortality due to predation is equal to the inherent growth rate of the prey population, and the net population growth for the prey species wll be zero.

$$\frac{dN_{prey}}{dt} = rN_{prey} - cN_{prey}N_{pred}$$

Rate of change in the prey population

The growth rate of the prey Population is zero when the number of predators is equal to the per capita growth rate of the prey population divided by the efficiency of predation

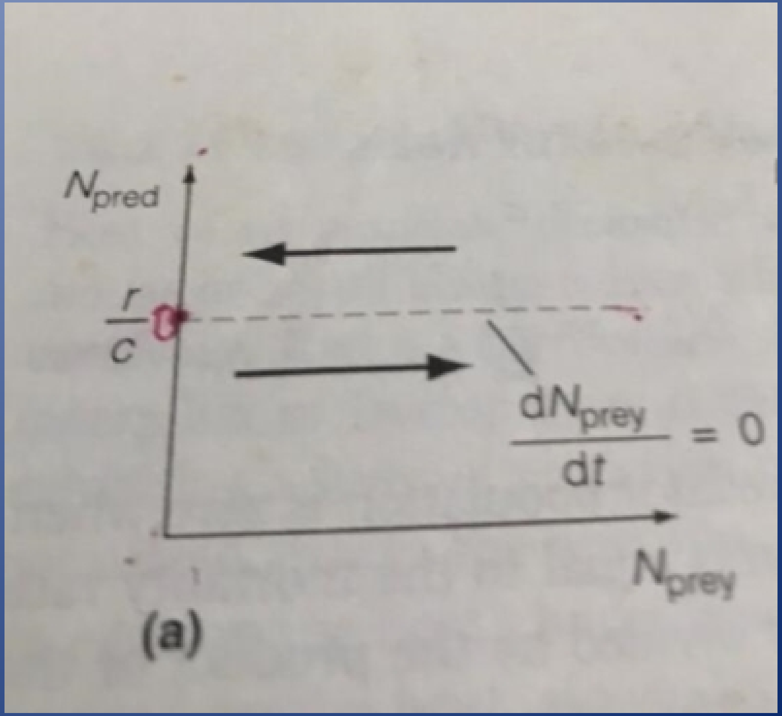
$$cN_{prey}N_{pred} = rN_{prey}$$

$$cN_{pred} = r$$

$$N_{pred} = \frac{r}{c}$$

We can examine these results graphically (Figure A) using two axes that represent the population sizes of the prey (x-axis) and predator (y-axis). First defined the size of the prey population at which the growth of the predator population is equal to zero and the number of predators at which growth rate of prey population is zero (N_{pred}=r/c, We can draw the zero isocline.

If values of the predator population are above the prey isocline, the prey growth rate is negative. For values of predator population below the prey isocline, the prey growth rate is positive. Zero isocline for the prey population is defined by fixed number of predators.



The growth rate of the predator population will be zero when the rate of predator increase (resulting from the consumption of prey) is equal to the rate of mortality.

$$\frac{dN_{pred}}{dt} = b(cN_{prey}N_{pred}) - dN_{pred}$$

Rate of change in the predator population

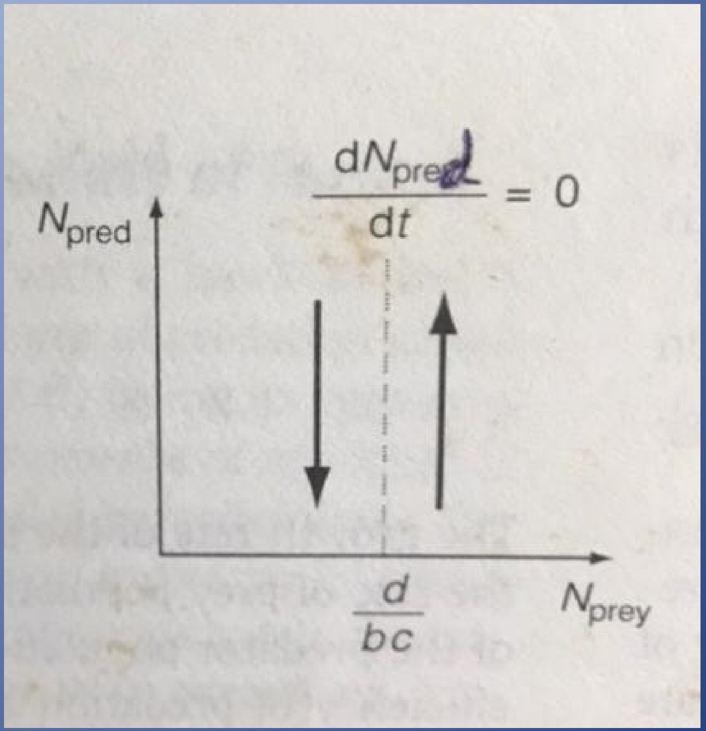
$$b(cN_{prey}N_{pred}) = dN_{pred}$$

$$bcN_{pred} = d$$

$$N_{prey} = \frac{d}{bc}$$

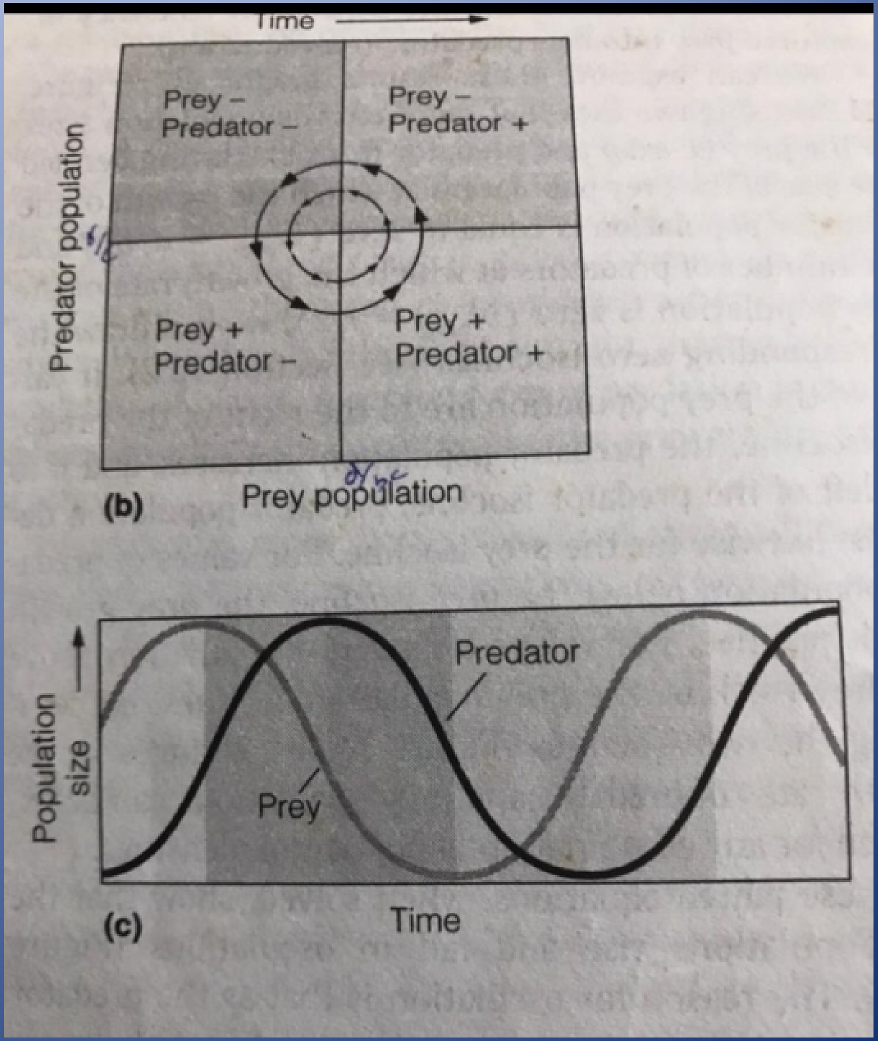
The growth rate of the predator population is zero when the size of prey population is equal to the mortality rate of the predator population divided by the product of the efficiency of predation and the conversion efficiency of captured prey into new predators (reproduction).

If values of the prey population are
to the right of the predator isocline
the predator population increases
and if to the left of the predator isocline
Predator population declines.
Zero isocline for the predator population
is defined by a fixed number of prey.



The combined zero isoclines provides a means of examining the combined Population trajectories of the predator and prey populations.

By combining the two isoclines, changes in the growth rates of predator and prey populations can be examined for any combination of population densities.



These paired equations, when solved, show that the two populations rise and fall in oscillations.

- The reason for oscillation is that as the predator population increases, it consumes a progressively larger number of prey, until
- The prey population begins to decline. The decliing prey population no longer support the large predator population. The predator
- Now face a food shortage and many of them fail to reproduce. The predator population declines sharply to a point where reproduction of prey
- More than balances its losses through predation.The prey increase, eventually followed by an increase in the population of predators . The cycle may continue indifinitely.

MODEL SUGGESTS MUTUAL POPULATION REGULATION

- Lotka- Volterra model of predator-prey interactions assumes a utual regulation of predator and prey populations.
- The growth of predator and prey populations are linked by the single term relating to the consumption of prey: $cN_{prey}N_{pred}$
- For the prey population, this term serves to regulate population growth through mortality.
- In the predator population, it serves to regulate population growth through reproduction.

- **FUCTIONAL AND NUMERICAL RESPONSE**
- The regulation of the predator population growth is a direct result of two distinct responses of the predator to changes in prey population.
- First, the growth of the predator population is dependent on the rate at which prey are captured ($cN_{prey}N_{pred}$).
- The equation implies that the greater the number of prey, the more the predator eats.
- The relationship between the per capita rate of consumption and the number of prey is referred to as the predator's functional response.
- Increased consumption of prey results in an increase in predator reproduction[$b(cN_{prey}N_{pred}$)], referred to as the predator's numerical response

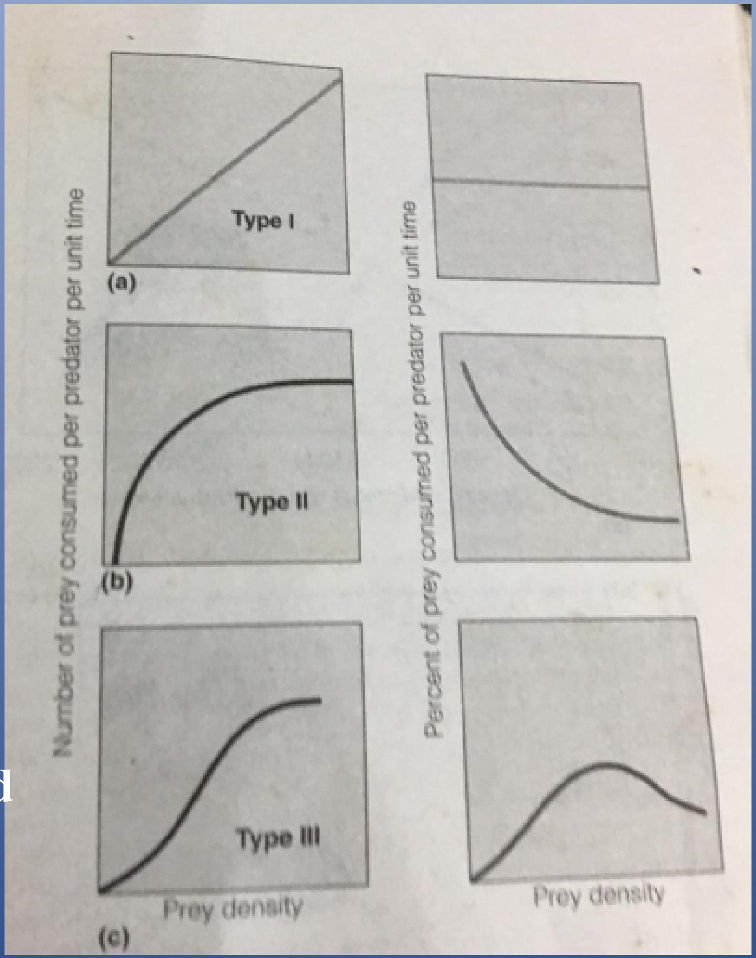
- **FUNCTIONAL RESPONSES RELATE PREY CONSUMED TO PREY DENSITY:**
- M.E. Solomon introduced the idea of functional response in 1949
- C.S. Holling developed a simple classification based on three general types of functional response.
- Functional response is the relationship between the per capita rate of predation (number of prey consumed per unit time) and the density of prey.
- Per capita rate of predation=$cN_{prey,}$ where c is the “efficiency of predation and N_{prey} is the number of prey.
- If we define the rate of predation as the number of prey eaten by a single predator during a period of search time (T_s), as N_e,
- Per capita rate of predation as :
- $N_e = (cN_{prey})\, T_s$
- N_e =per capita rate of predation : the number of prey eaten during a given period of search time as T_s
- T_s = period of search time,c is the “efficiency of predation and N_{prey} is the number of prey.

THREE TYPES OF FUNCTIONAL RESPONSE CURVE, WHICH RELATE THE PER CAPITA RATE OF PREDATION TO PREY DENSITY

Type I. The no. of prey taken per predator increases linearly as prey density increase

Type II. The predation rate rises at a decreasing rate to a maximum level

Type III. The rate of predation is low at first then increases in a sigmoid fashion, approaching Asymptote.



Expressed as proportion of the prey density, the rate of predation is constant i.e. independent of prey density

Expressed as proportion of prey density, the rate of predation declines as the prey population grows

Expressed as proportion of prey density, the rate of predation is low at low prey density, rising to a maximum before declining the rate of predation reaches its maximum.

$$T = T_s + (N_e T_h)$$

rearranging the above equation, we can now define search time as:

$$T_s = T - N_e T_h$$

$$N_e = c(T - N_e T_h) N_{prey}$$

Note that N_e, the number of prey consumed during the time period T, appears on both sides of the equation, so to solve for N_e, we need to rearrange the equation.

$$N_e = c(N_{prey} T - N_{prey} N_e T_h)$$

Move c inside the brackets, giving:

$$N_e = cN_{prey} T - N_e c N_{prey} T_h$$

Add $N_e c N_{\text{prey}} T_h$ to both sides of the equation, giving:

$$N_e + N_e c N_{\text{prey}} T_h = c N_{\text{prey}} T$$

Rearrange the left-hand side of the equation, giving:

$$N_e(1 + c N_{\text{prey}} T_h) = c N_{\text{prey}} T$$

Divide both sides of the equation by $(1 + c N_{\text{prey}} T_h)$, giving:

$$N_e = \frac{c N_{\text{prey}} T}{(1 + c N_{\text{prey}} T_h)}$$