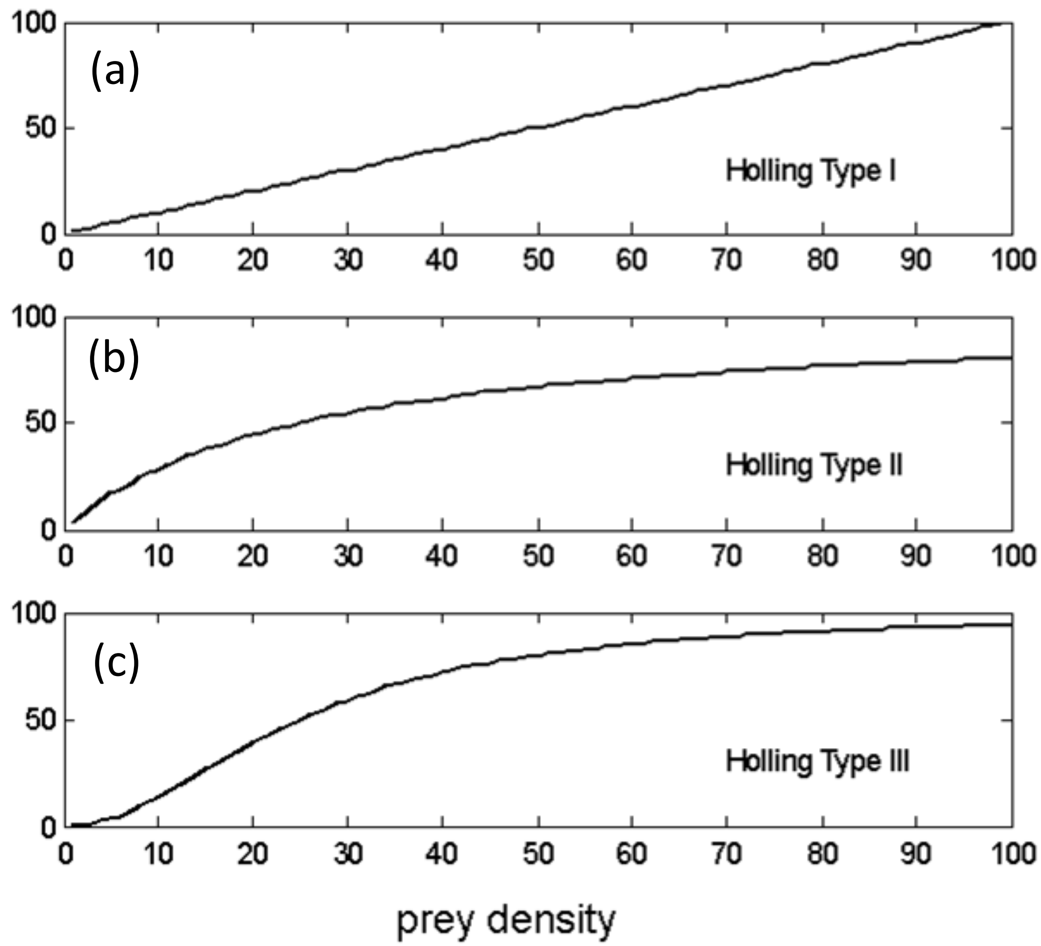
Quiz



Which *functional response* is a result of search and handling of prey by predators?
(a), (b), or (c)

Frequency of Cyclical Dynamics

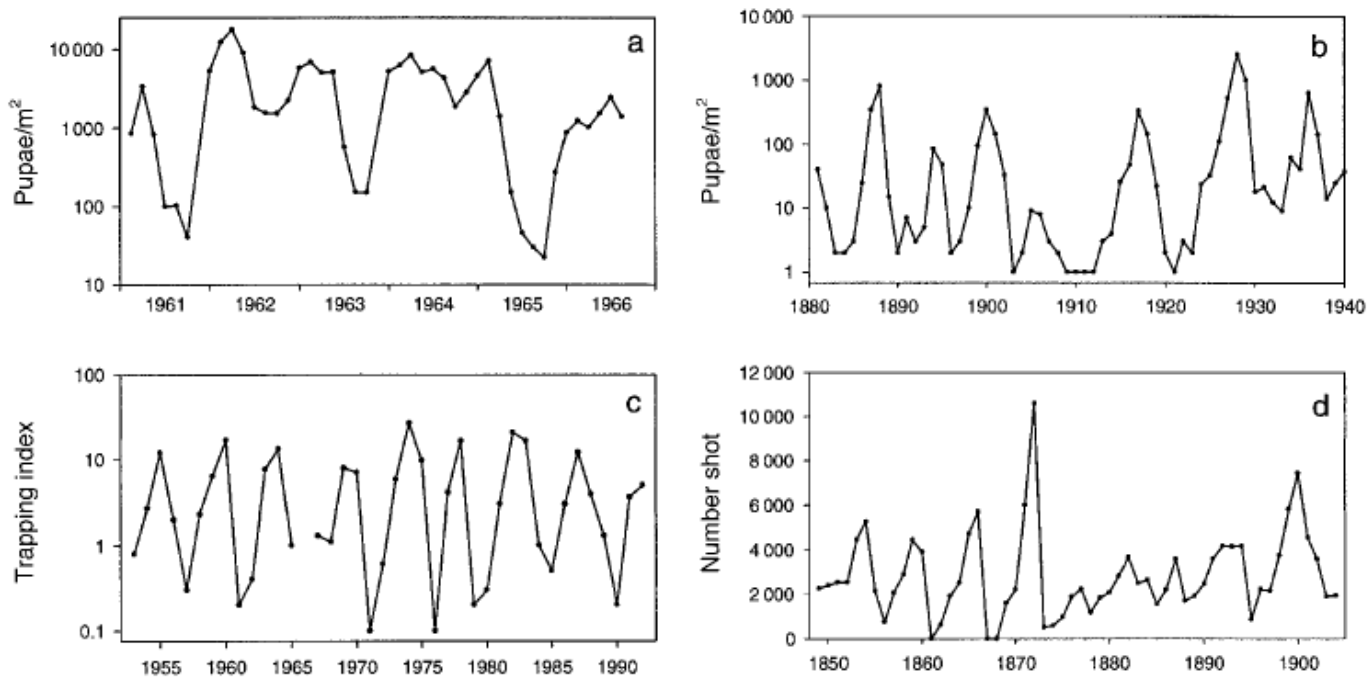
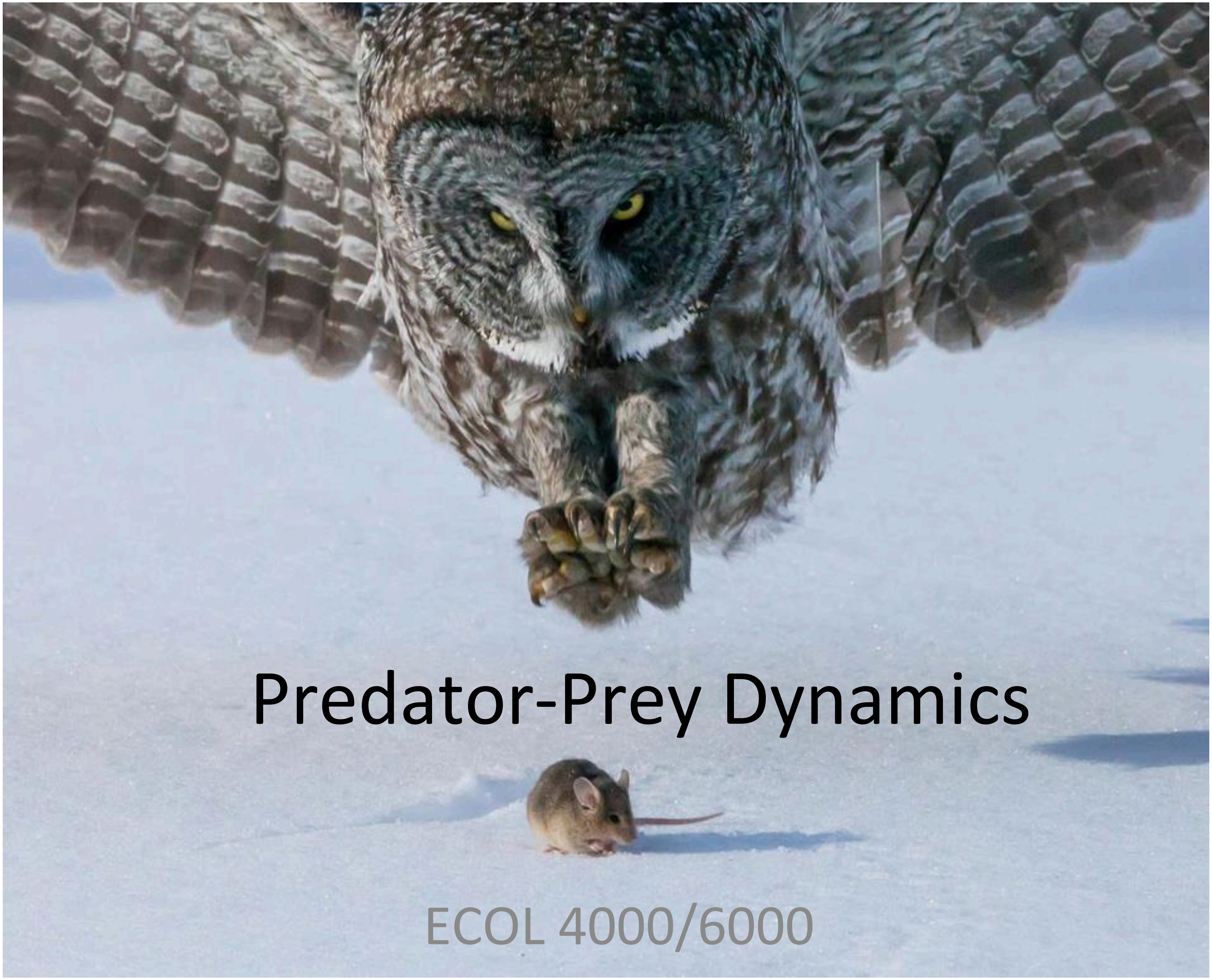


FIG. 1. Examples of cyclic population dynamics. (a) Coffee leaf-miners (*Leucoptera* spp.) at Lyamungu, Tanzania (Bigger 1973). (b) Pine looper (*Bupalus piniarius*) in Germany (Schwerdtfeger 1941). (c) Voles (*Microtus* and *Clethrionomys*) at Kilpisjärvi, northern Finland (Laine and Henttonen 1983, Hanski et al. 1993). (d) Red Grouse (*Lagopus lagopus scotius*) in Scotland (Middleton 1934).

From Kendall et al. (1999) Ecology 80: 1789-1805.

30% of long term time series exhibit periodic oscillations



Predator-Prey Dynamics

ECOL 4000/6000

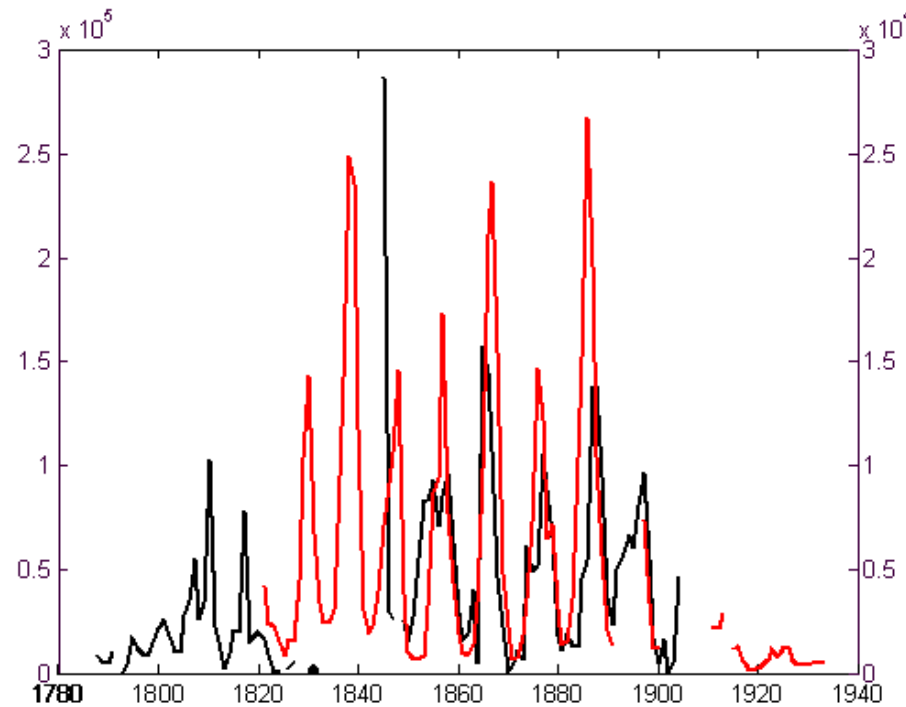
Key points

- Recall two sources of predator-prey dynamics
- Identify basic components of predator-prey models (births, deaths, predation, other terms)
- Understand, write down, sketch functional responses 1,2,3 (recall sources for each of 2 and 3)
- Understand/identify key stabilizing and destabilizing mechanisms
- Translate predator-prey dynamics to phase plane (and vice-versa)
- Calculate straightforward coexistence equilibria
- Sketch null clines (ZNGIs) for key models
- Populate Jacobian matrix for certain predator-prey models (as in lecture/reading)
- Understand the principle of linearization and the meaning of the zones in a trace-determinant map
- Articulate the principle of the ‘paradox of enrichment)

Predator-Prey Dynamics

- A ubiquitous inter-specific interaction in nature
- A building block for understanding food webs
- An explanation for cyclical population dynamics

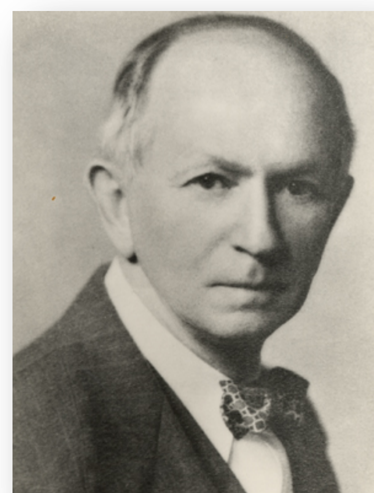
Hare-Lynx pelts from the Hudson's Bay Co.



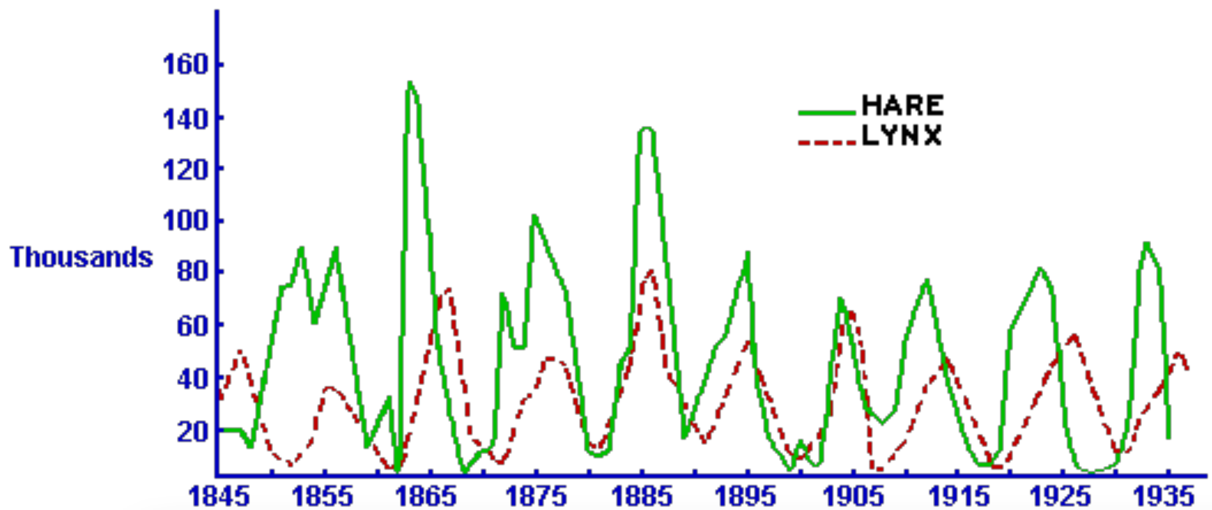
Lotka-Volterra Model

(Predator-Prey)

- Vito Volterra (1860-1940)
  - Italian Mathematician
  - Studied these equations in 1926
- Alfred J. Lotka (1880-1949)
  - Statistician and actuarial demographer
  - Studied these equations in 1925



Hare-Lynx Dynamics in Canada



Lotka-Volterra Model

(Predator-Prey)

Population growth through reproduction and non-predator mortality

$$\frac{dN}{dt} = rN - cNP$$

Rate of change of the prey population

Mortality due to predation is the product of:

1. per capita predation rate (c)
2. number of predator (P)
3. number of prey (N)

Lotka-Volterra Model

(Predator-Prey)

Population growth through "conversion" of prey

$$\frac{dP}{dt} = bNP - mP$$

Mortality

Rate of change of the predator population

Lotka-Volterra Model

(Predator-Prey)

$$\frac{dN}{dt} = rN - cNP$$

$$\frac{dP}{dt} = bNP - mP$$

Solution of a simple ODE

Diff'l eqn

$$\frac{dN}{dt} = rN$$

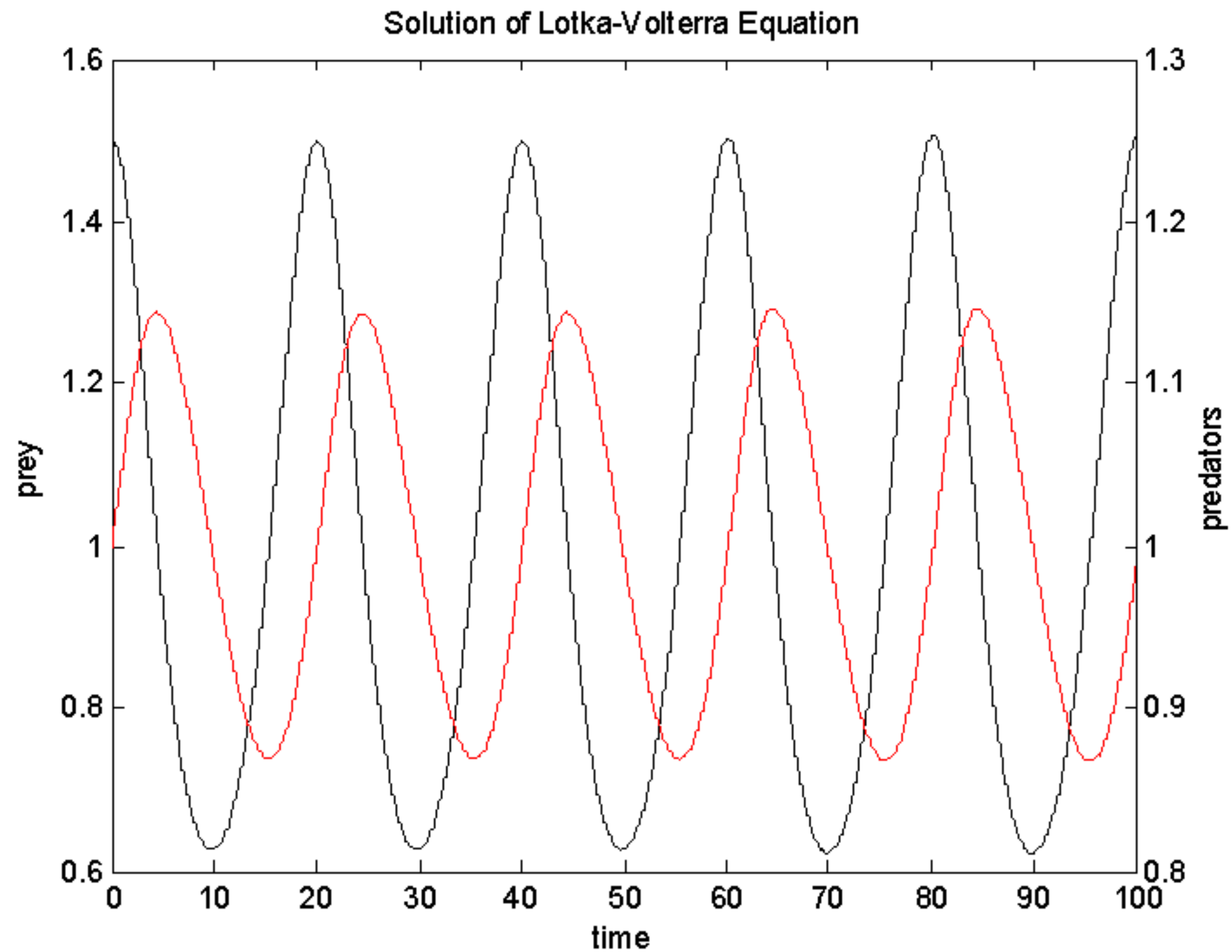
$$N_t = N_0 e^{rt}$$

Solution

No simple solution: Alternative strategies needed to study this model

- Graphical Analysis
- Local stability analysis

Graphical Analysis



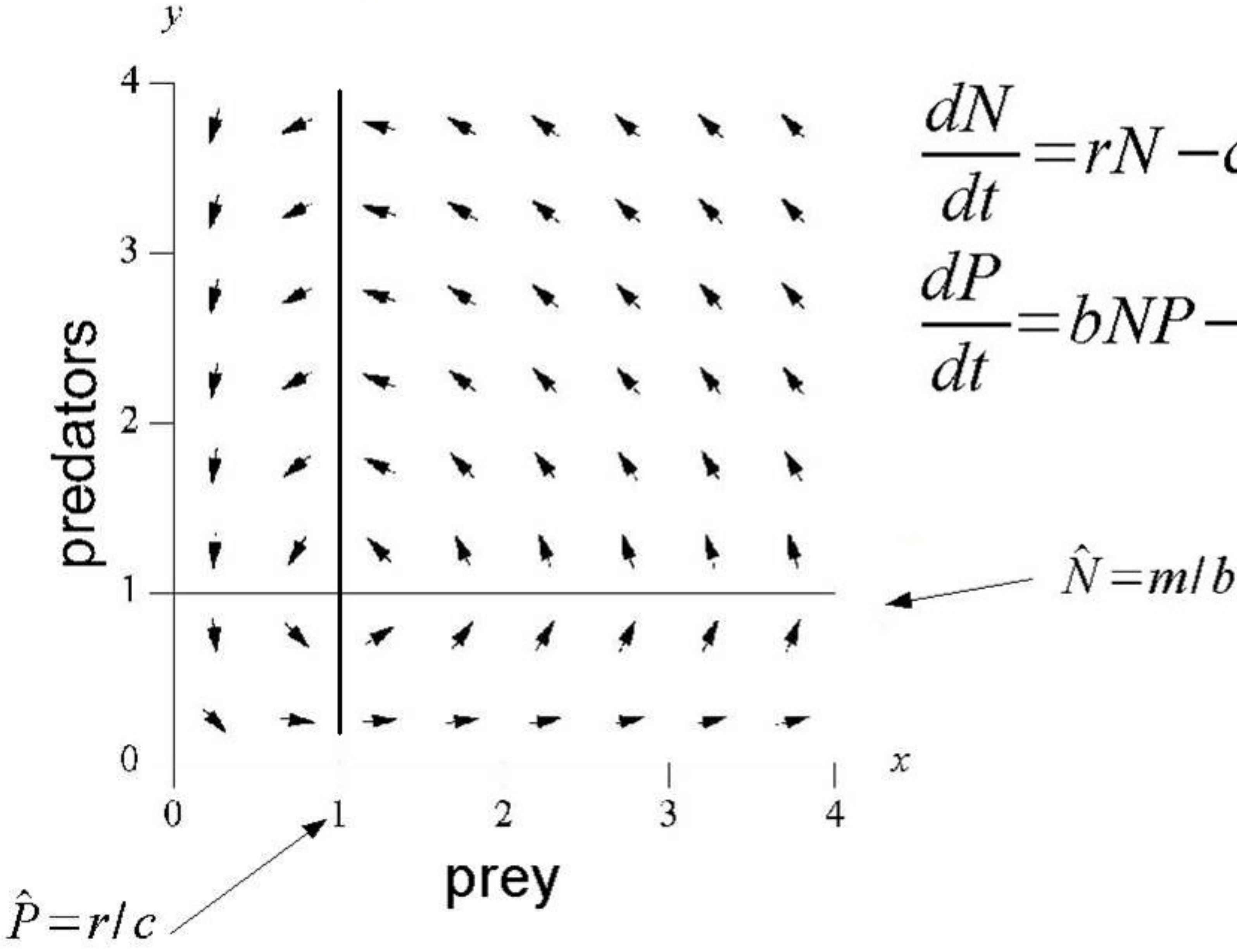
Step 1: Find equilibria

$$\frac{dN}{dt} = rN - cNP \qquad \longrightarrow \qquad \frac{dN}{dt} = N(r - cP)$$

$$\frac{dP}{dt} = bNP - mP \qquad \qquad \frac{dP}{dt} = P(bN - m)$$

$$(N^*, P^*) = (0,0), \left(\frac{m}{b}, \frac{r}{c}\right)$$

Step 2: Sketch Null Clines

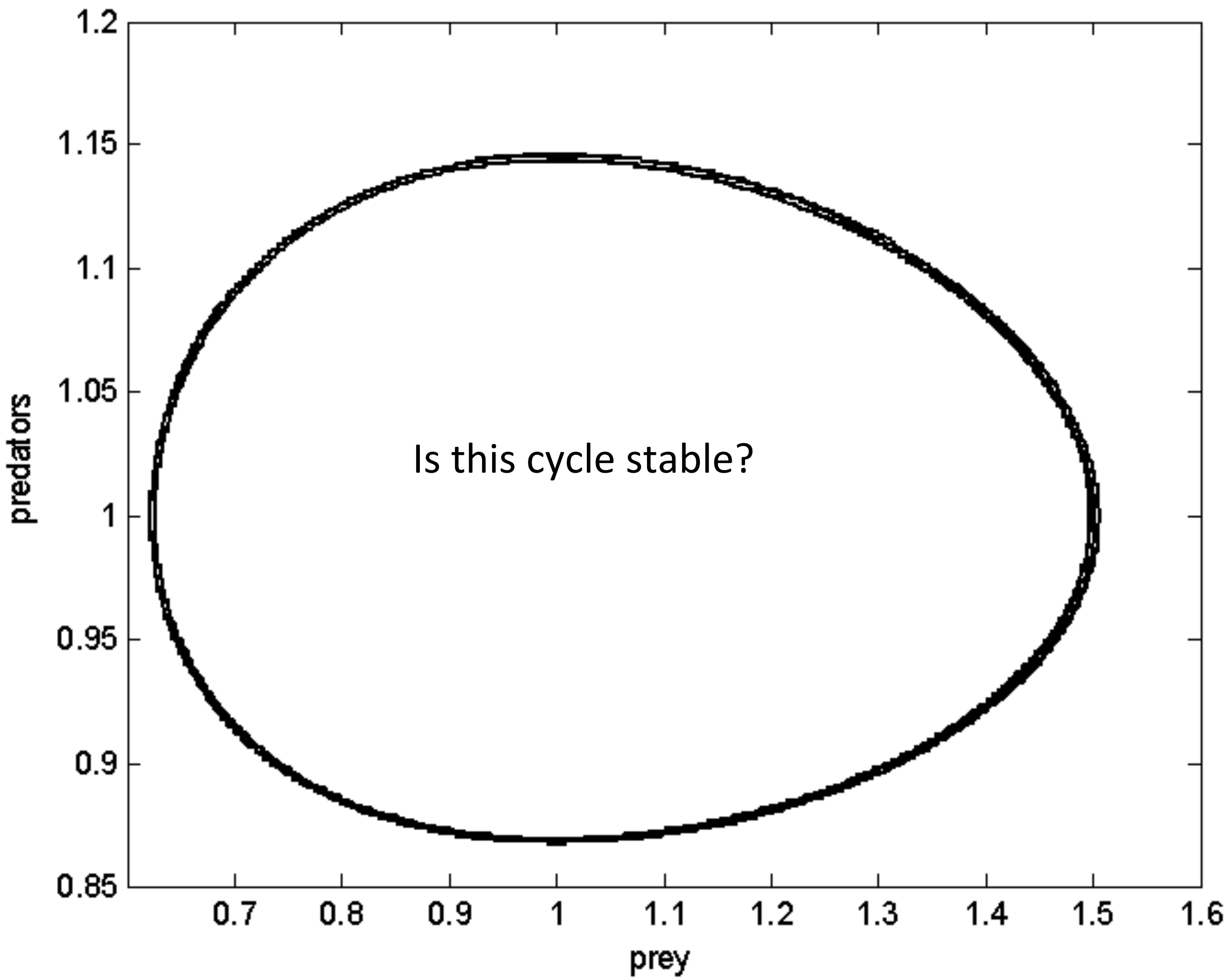


$$\frac{dN}{dt} = rN - cNP$$

$$\frac{dP}{dt} = bNP - mP$$

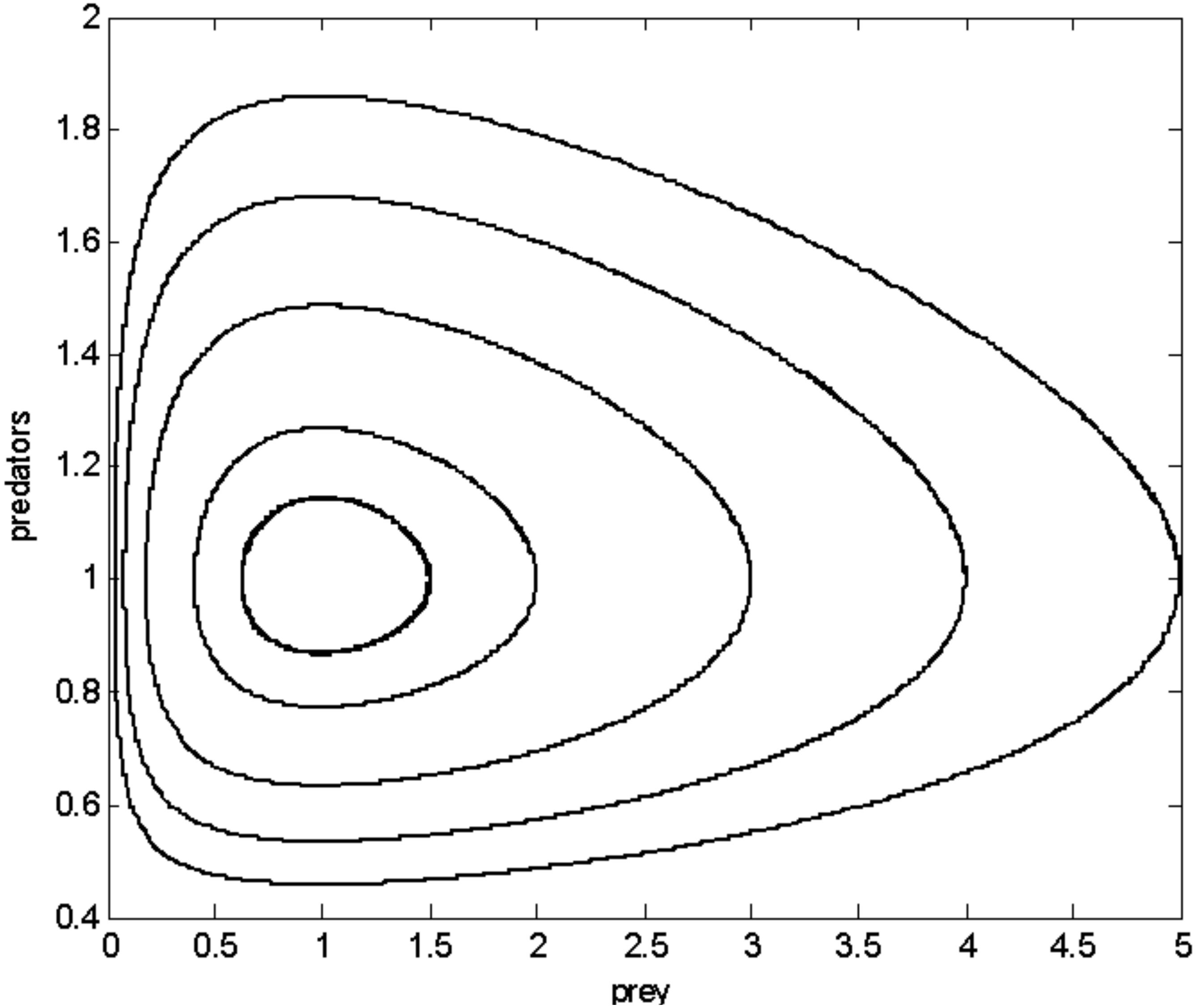
Phase Portrait

initial condition: prey=1.5 predators=1



The L-V model is neutrally stable

initial condition: prey=[1.5, 2,3,4,5], predators=1



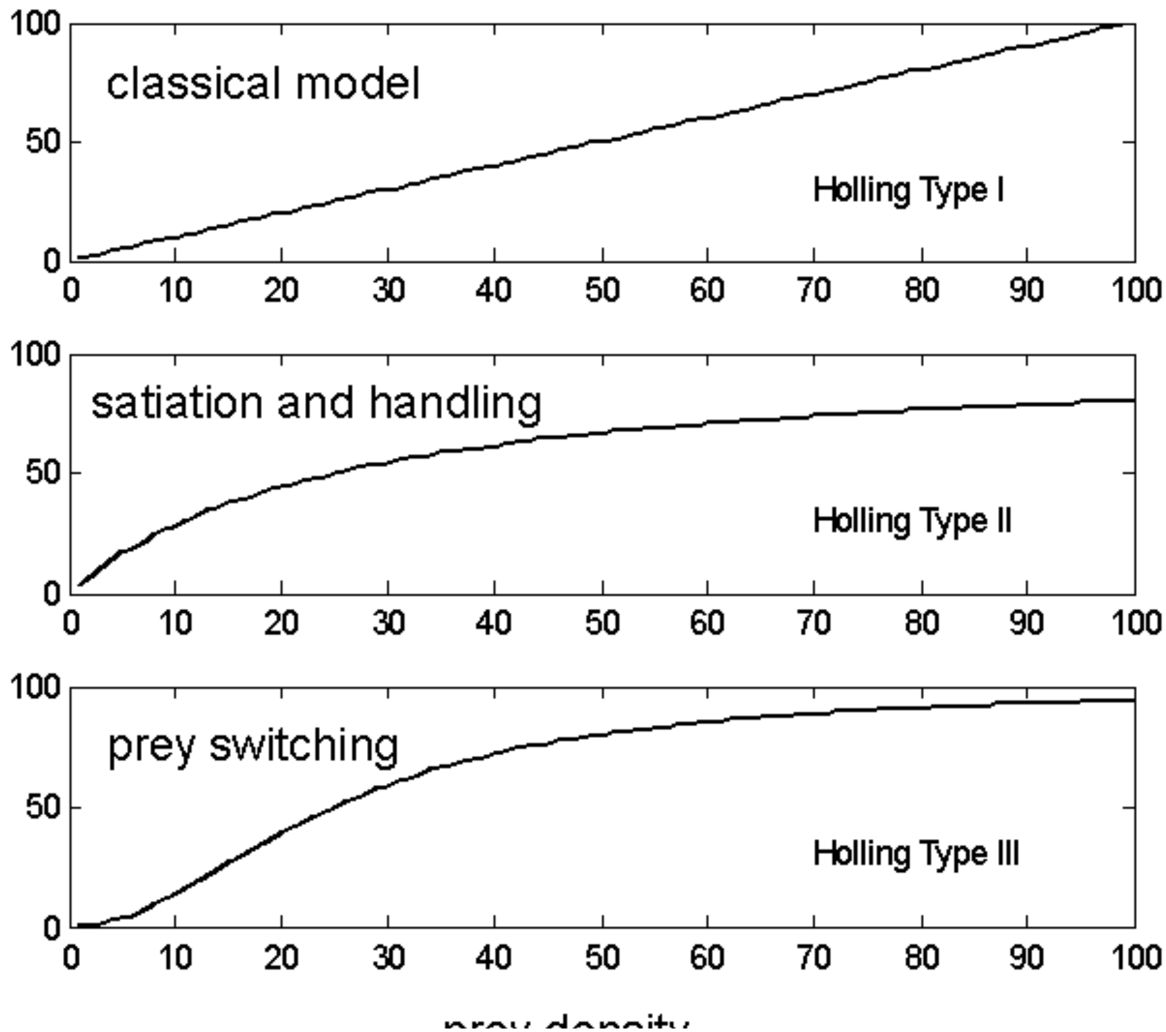
Stabilizing Mechanisms

$$\frac{dN}{dt} = f(N) - g(N)P$$

$$\frac{dP}{dt} = h(g(N))P - m(P)$$

f(x) – prey regulation
g(x) – “functional response”
h(x) – “numerical response”
m(x) – predator mortality

Functional response

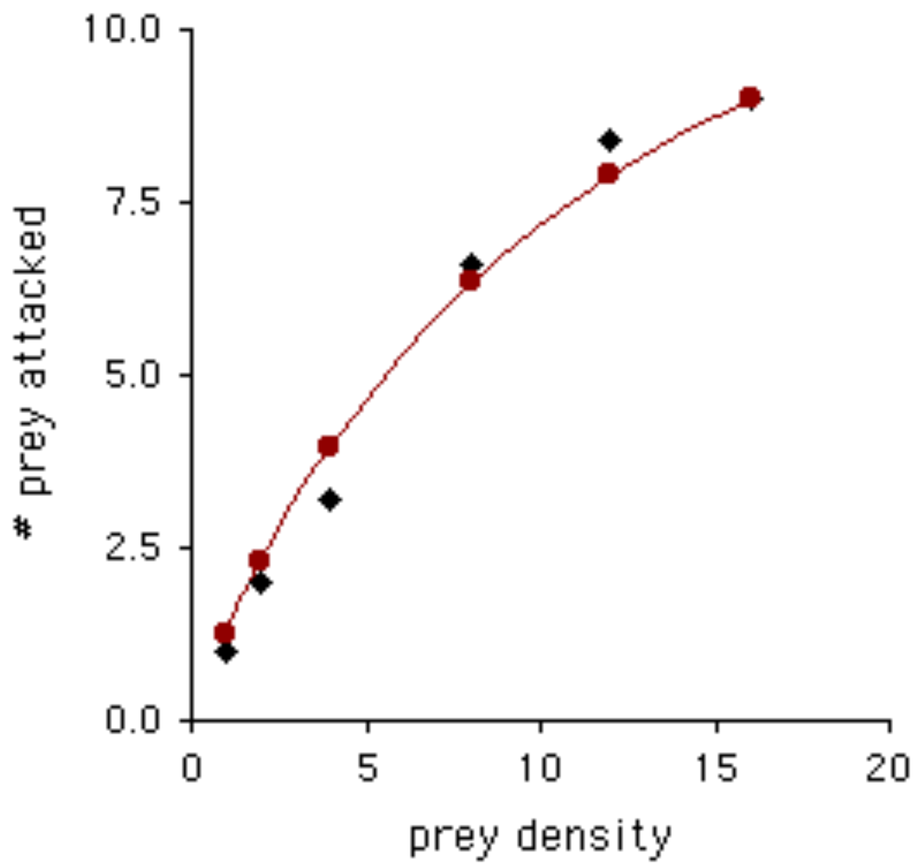


$$g(N) = cN$$

$$g(N) = \frac{\alpha N}{D + N}$$

$$g(N) = \frac{\alpha N^2}{D^2 + N^2}$$

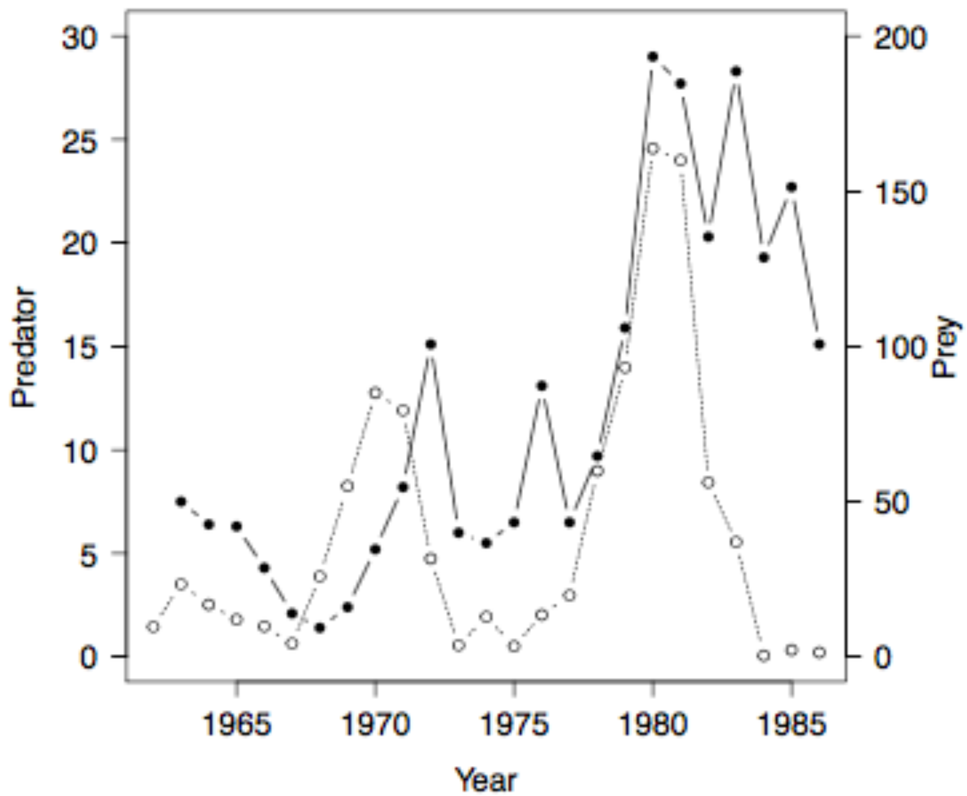
Type II Functional Response



Predator: Stinkbug
(*Podisus maculiventris*)

Prey: Mexican Bean Beetle
(*Epilachna varivestis*)

Type II Functional Response



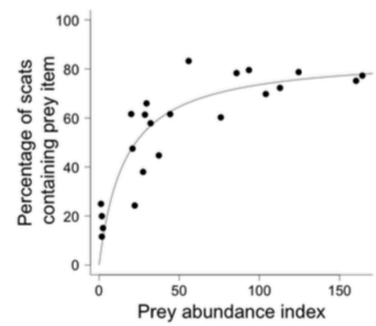
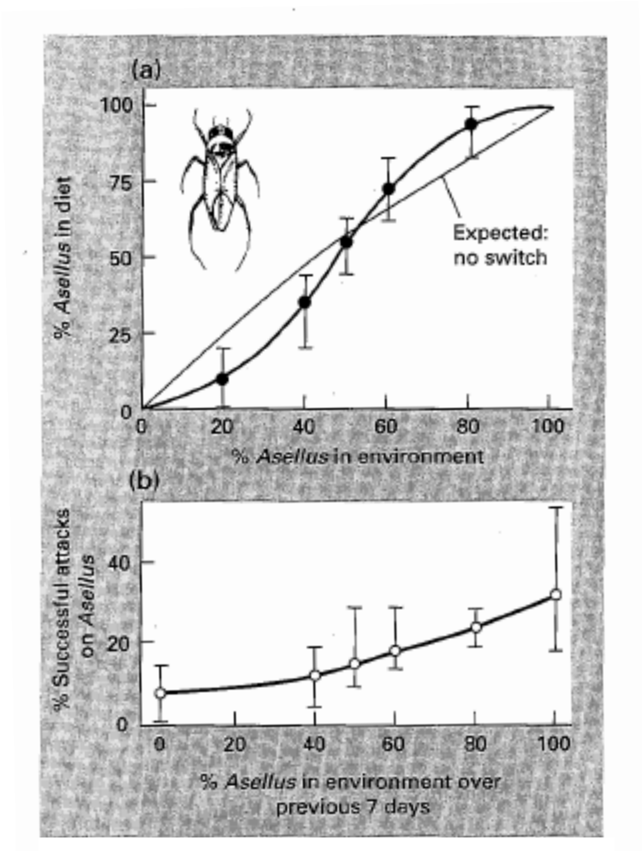
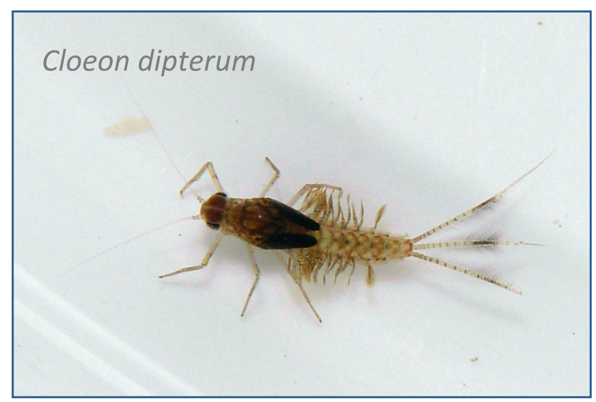


Figure 7: *C. latrans* functional feeding response to *L. californicus* abundance in Curlew Valley, Utah, 1977-1993. (Adapted from Bartel and Knowlton, 2005, *Canadian Journal of Zoology*)

Figure 1: Coyote (*Canis latrans*).

Type III Functional Response





$$g(N) = \frac{\alpha N^2}{D^2 + N^2}$$

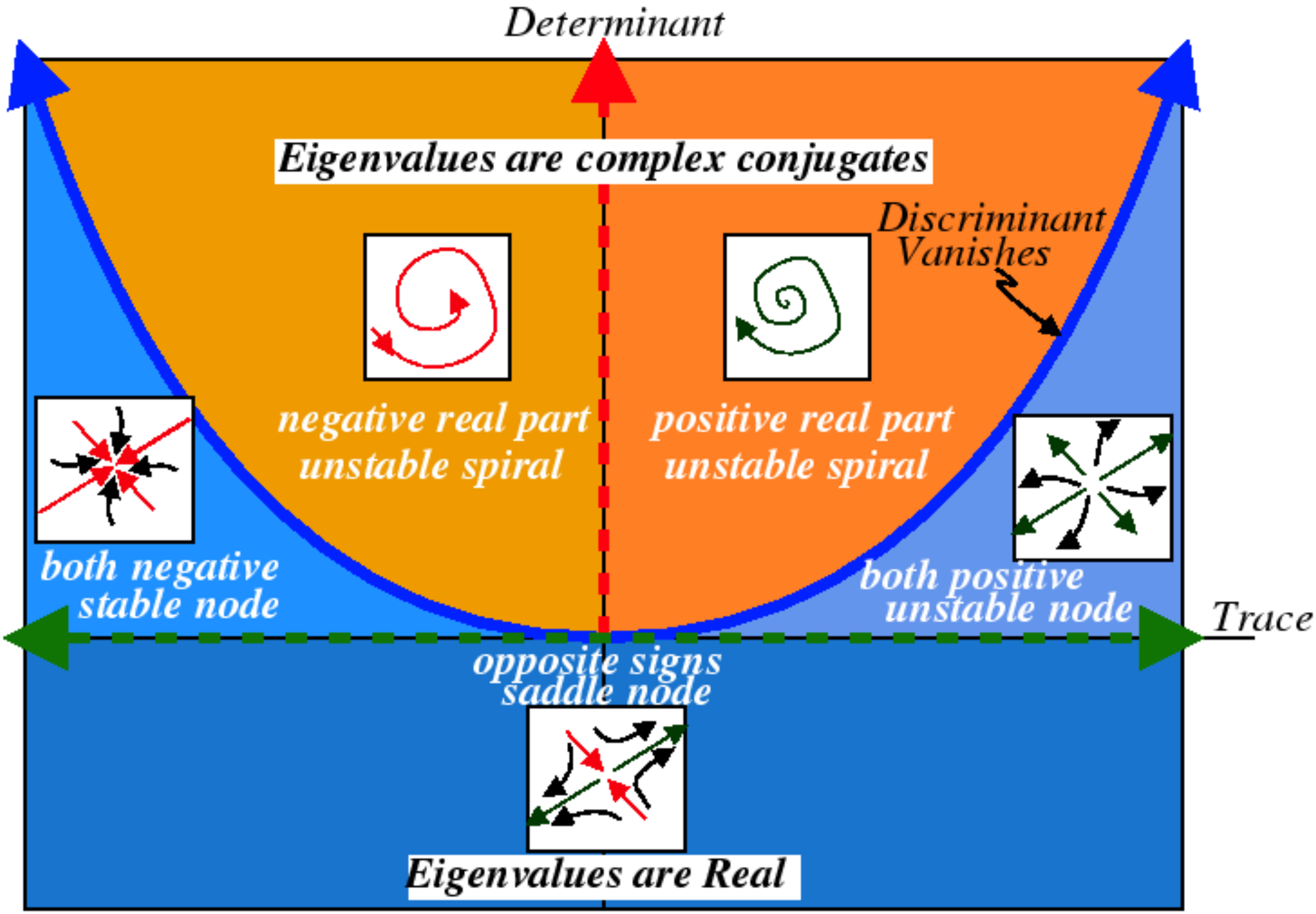
Prey Equation

(Type II functional response)

$$\frac{dN}{dt} = rN - \frac{\alpha N P}{D + N}$$

$$N_{eq} = 0, \frac{\alpha P - rD}{r}$$

Effect of Type II functional response is *destabilizing*


Determinant
Eigenvalues are complex conjugates
Discriminant Vanishes
negative real part
unstable spiral
positive real part
unstable spiral
both negative
stable node
both positive
unstable node
Trace
opposite signs
saddle node
Eigenvalues are Real

Stabilizing Mechanisms

- Basic L-V model is neutrally stable
- Type II (predator satiation) is destabilizing

Stabilizing Mechanisms

- Basic L-V model is neutrally stable
- Type II (predator satiation) is destabilizing
- Prey regulation (logistic) is stabilizing
- Type III is parameter dependent and initial condition dependent
- Predator regulation (logistic) is stabilizing
- Prey refuge is stabilizing
- Predator immigration is stabilizing

Explaining Persistent Cycles

- We started with a biological observation – evidently persistent cycles in hare and lynx
- We developed a model (L-V) to explain these cycles, but it was neutrally stable and therefore biologically unrealistic
- We enriched the theory with the concept of "stabilizing mechanisms"
- But, have we explained persistent cycles?

Explaining Persistent Cycles

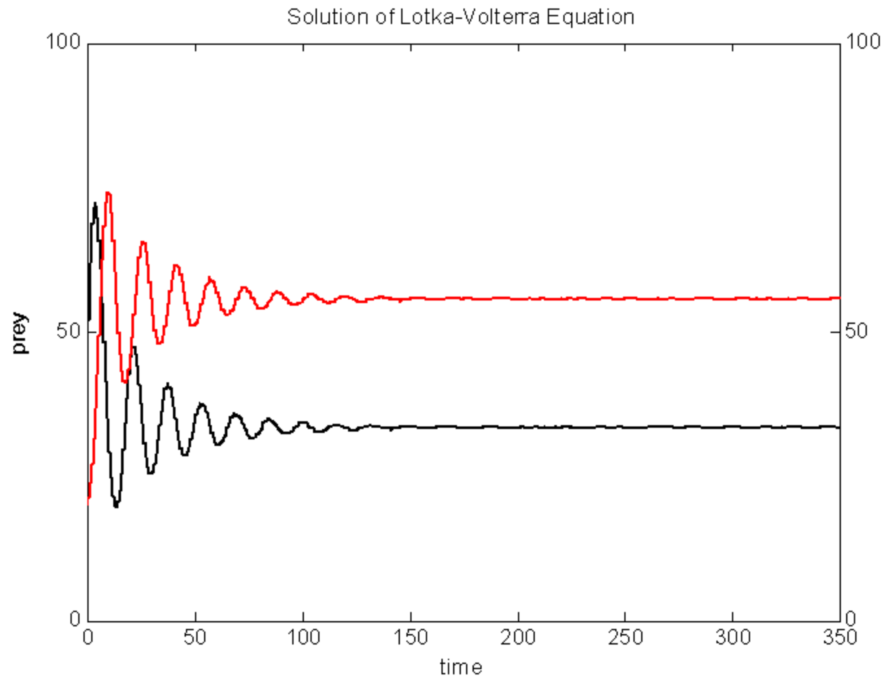
Combining stabilizing and destabilizing processes

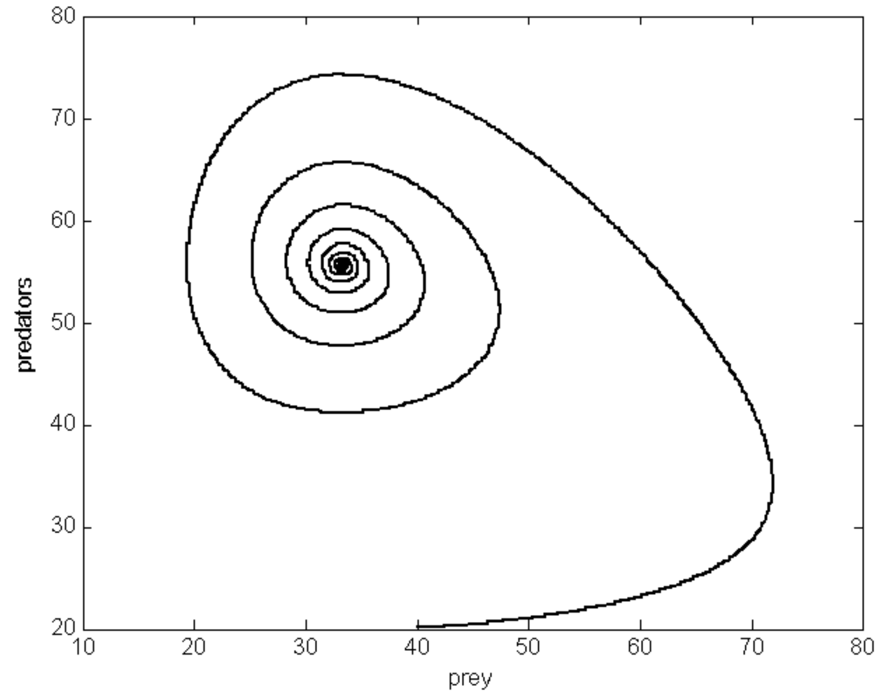
The Rosenzweig-MacArthur Model

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right) - \frac{\alpha N P}{1 + \alpha T_h N}$$

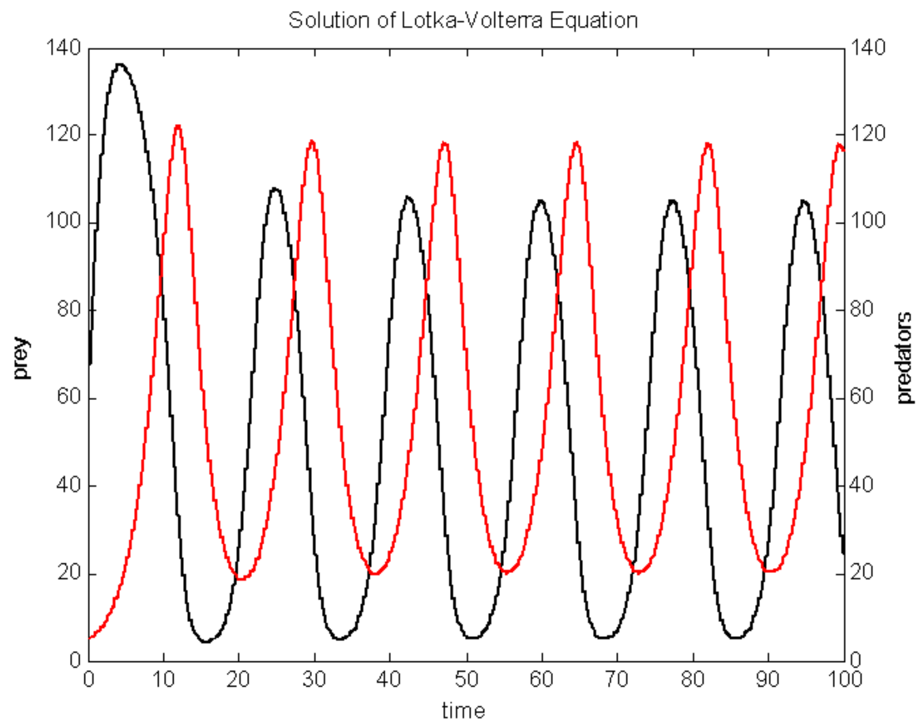
$$\frac{dP}{dt} = b\frac{\alpha N P}{1 + \alpha T_h N} - mP$$

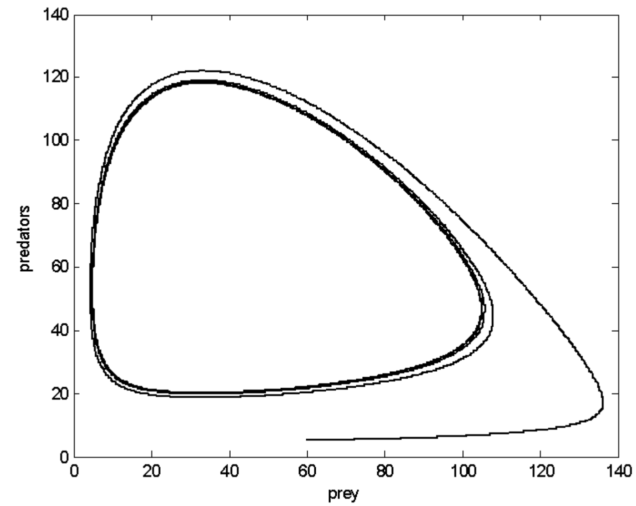
Exhibits Damped Oscillations

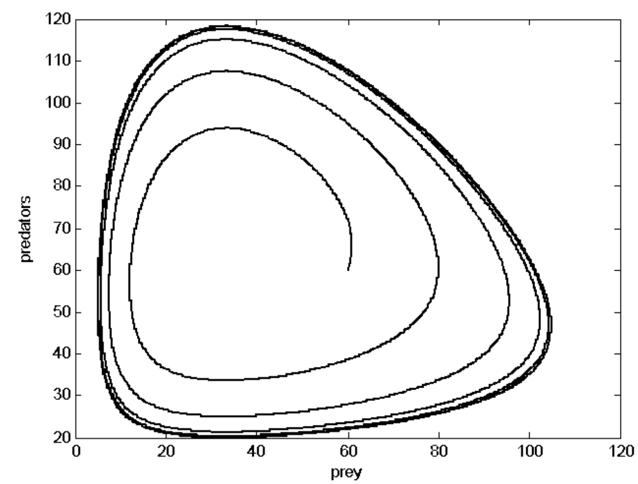




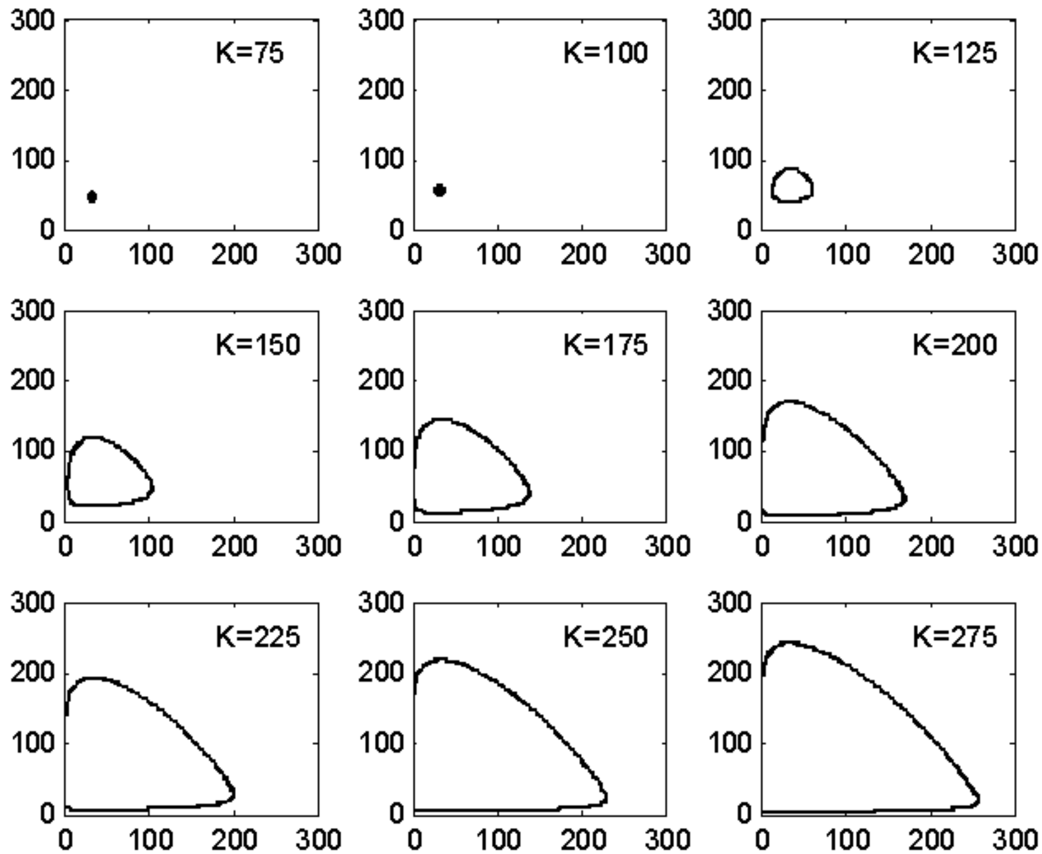
Or, Persistent Cycles

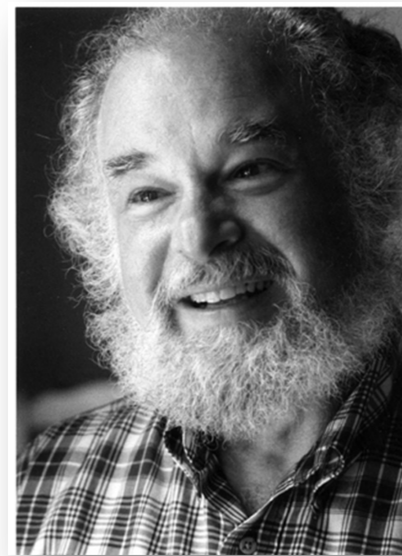






The Paradox of Enrichment





Conclusions

- Periodic population dynamics are common
- Periodicity appears most frequently among pairs of antagonistically interacting species
- Antagonistic interactions (i.e., predator-prey) are not sufficient to explain persistence, however, as revealed by the neutral stability of the Lotka-Volterra model
- Persistent periodic dynamics appear to result from the addition of both stabilizing and destabilizing mechanisms