COMPLEX DYNAMIC PHENOMENA IN ENVIRONMENTAL PLANNING AND MANAGEMENT

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1. ENVIROMENTAL MANAGEMENT AND NONLINEAR DYNAMICS
   An overwiew of the most typical problems one encounters in enviromental planning and management. Emphasis on relationships with nonlinear dynamics.Further reading: *Journal of Enviromental Management* (1996), 48, 357-373.

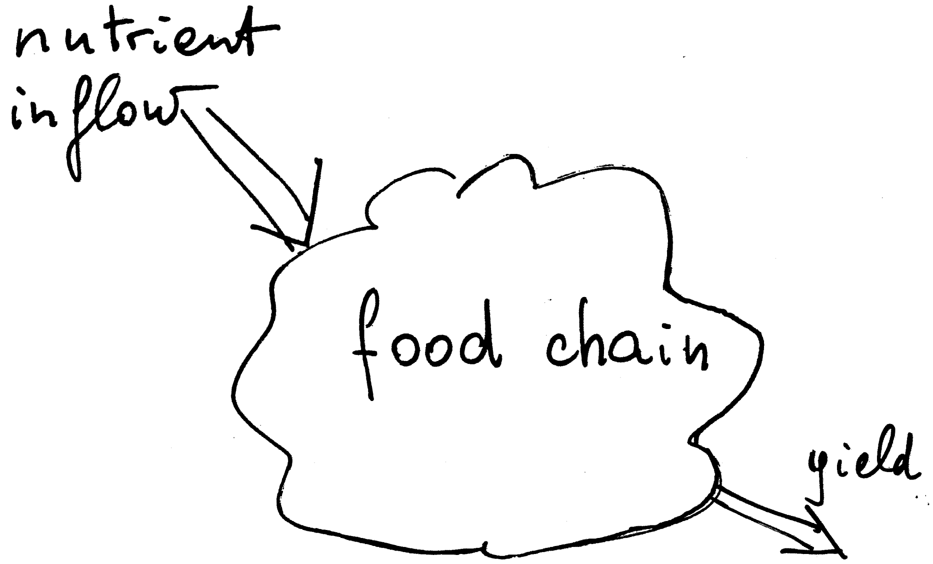
2. THE PROBLEM OF FLOATING PLANTS IN RESERVOIRS
   Description of the problem through a model of competition between floating and submerged plants. Analysis of the model: alternative stable states. Bifurcation analysis and derivation of possible control actions. Analysys of the history of Lake Kariba on the Zambesi river.
   Further raeading: *PNAS* (2003), 100, 4040-4045.

3. FOREST EXPLOITATION AND ACID RAIN: A DANGEROUS MIX
   Description of the problem through a series of minimal models. Existence of catastrophic bifurcations (forest collapse). Cusp bifurcation: negative synergistic effect of acid rain and exploitation.
   Further reading: *Vegetatio* (1987), 69, 213-222
   Appl. Math. Modelling (1989), 13, 674-681
   Theor. Pop. Biol. (1998), 54, 257-269.

4. THE RECLAMATION OF EUTROPHIC WATER BODIES
   Description of the problem in terms of minimal models involving algae, zooplankton and planktivorous fish. Analysis of the bifurcations of the model: the appearance and disappearance of clear-water regimes. Biological control.
   Further reading: *OIKOS* (1997), 80, 519-532.

5. TOURISM SUSTAINABILITY: AN OVERVIEW
   The three components of the problem: tourists, environment and facilities. Detection of possible scenarios. Profitable, compatible and sustainable policies. Adaptivity. The case of alternative classes of tourists and of diversified investments.
   Further reading: *Conservation Ecology* (2002), 6(1): 13 [online].
   Chaos and Complexity Letters (2004) first issue (in the press).

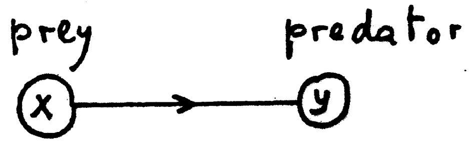
6. ENRICHMENT AND YIELD MAXIMIZATION
   Exploitation of renewable resources. Enrichment and mean yield maximization. Analysis of the case of tritrophic food chains. Optimality at the edge of chaos. Derivation of management rules.
   Further reading: *Am. Nat.* (1997) 150, 328-345
   Bull. Math. Biol. (1998) 60, 703-719
   Ecol. Lett. (1999) 2, 6-10
   J. Math. Biol. (2002) 45, 396-418.



dynamic complexity

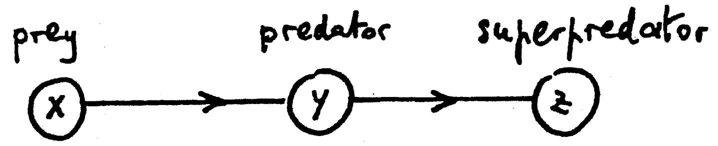
top-predator abundance

THE MODELS



$$\dot{x} = r x \left(1 - \frac{x}{K}\right) - \frac{a x}{b + x} y$$

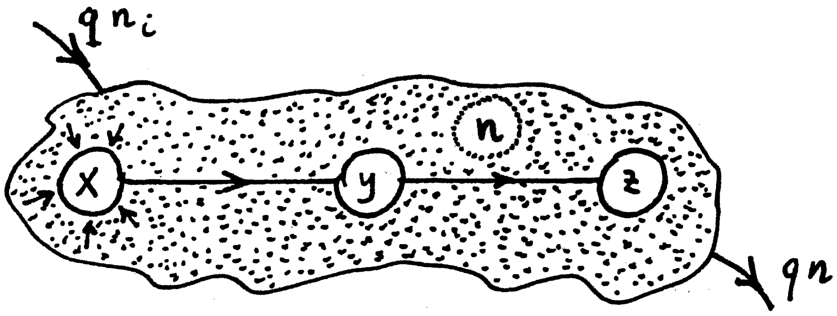
$$\dot{y} = e \frac{a x}{b + x} y - m y$$



$$\dot{x} = r x \left(1 - \frac{x}{K}\right) - \cdots$$

$$\dot{y} = \cdots$$

$$\dot{z} = \cdots$$

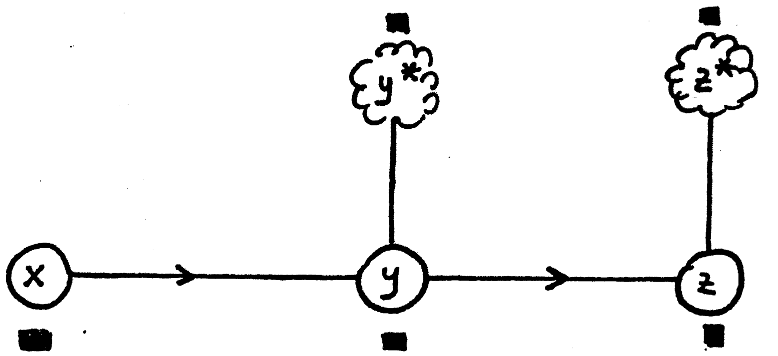


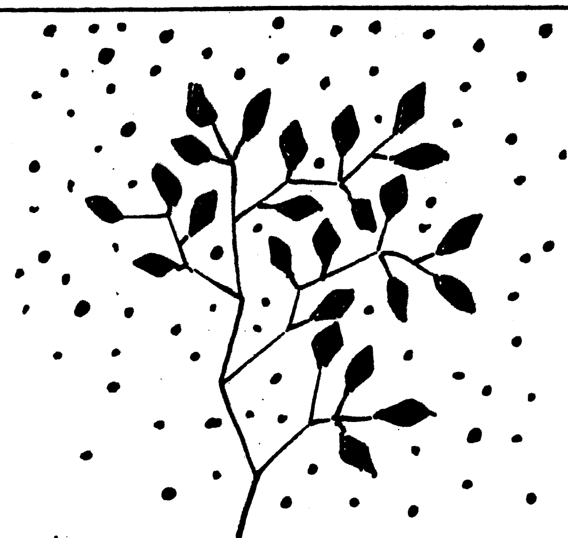
$$\dot{n} = q n_i - q n - \frac{a n}{b + n} x$$

$$\dot{x} = e \frac{a n}{b + n} x \cdots\cdots\cdots - q x$$

$$\dot{y} = \cdots\cdots\cdots - q y$$

$$\dot{z} = \cdots\cdots\cdots - \varepsilon q z$$

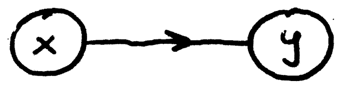




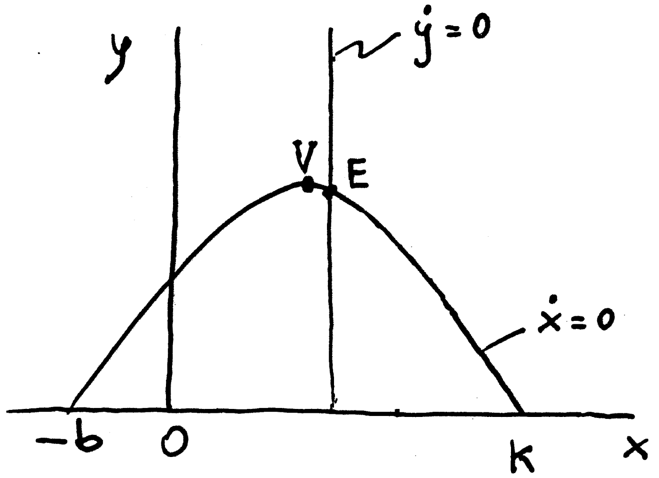
$$\dot{x} = r x \left(1 - \frac{x}{K}\right) \cdots\cdots$$

$$\dot{y} = \cdots$$

$$\vdots$$

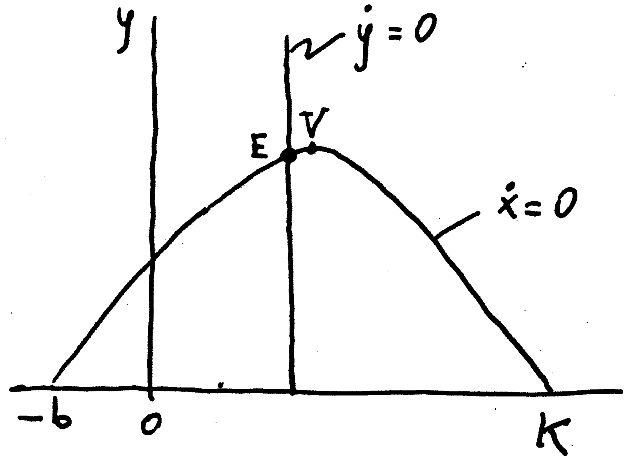


$$\begin{cases} \dot{x} = r x \left(1 - \frac{x}{K}\right) - \frac{a x}{b + x} y \\ \dot{y} = e \frac{a x}{b + x} y - m y \end{cases}$$



E is stable

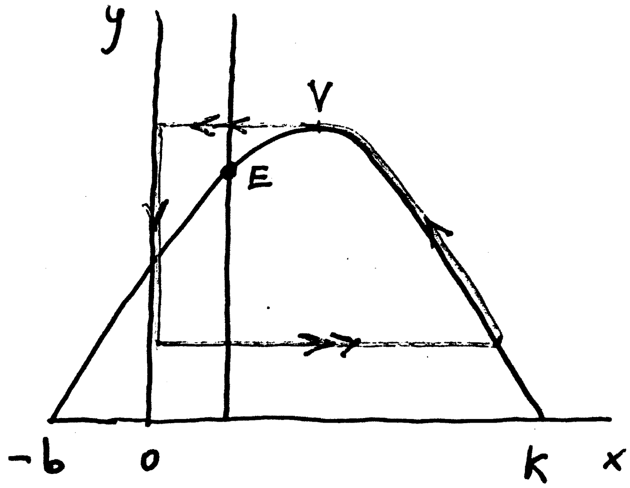
$$K < \frac{ea + m}{ea - m} b$$



E is unstable

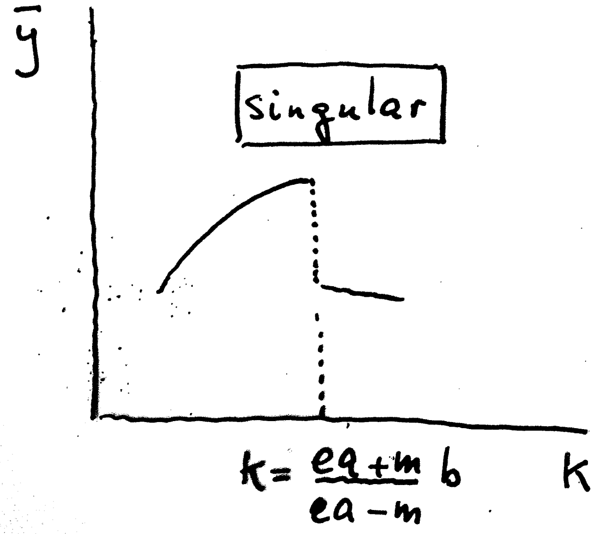
∃ stable limit cycle

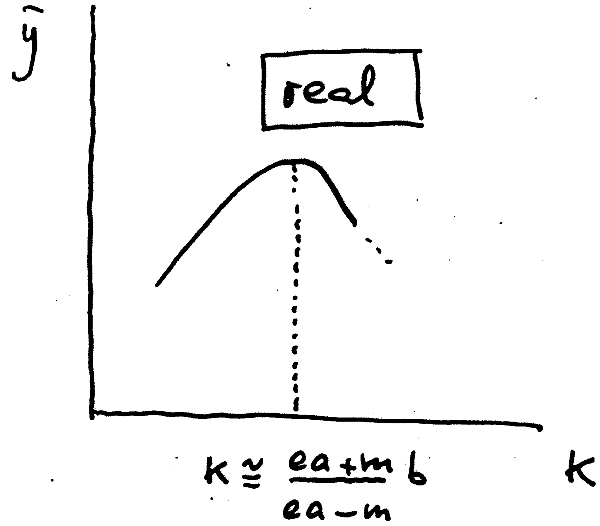
$$K > \frac{ea + m}{ea - m} b$$

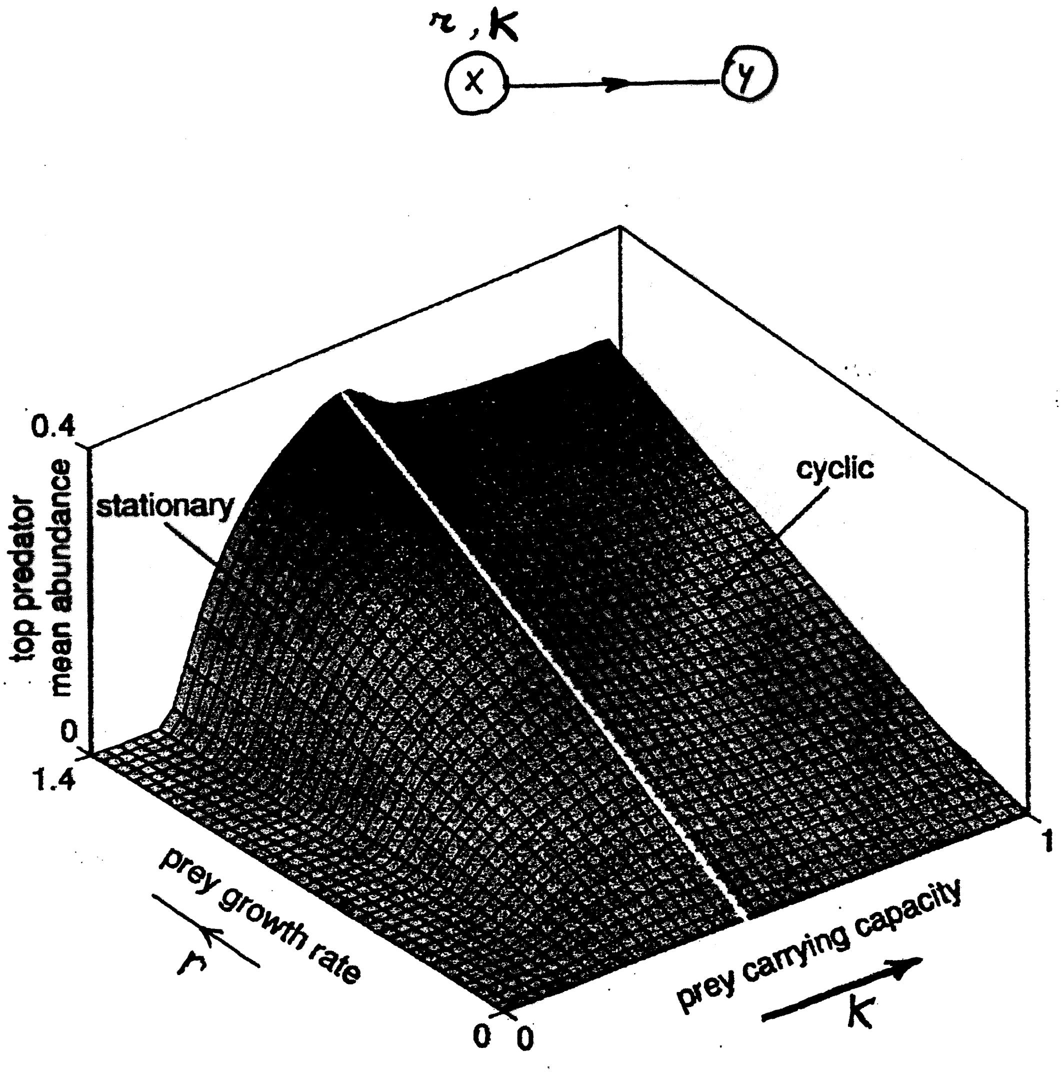


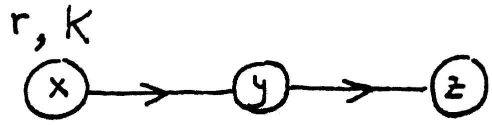
slow - fast dynamics

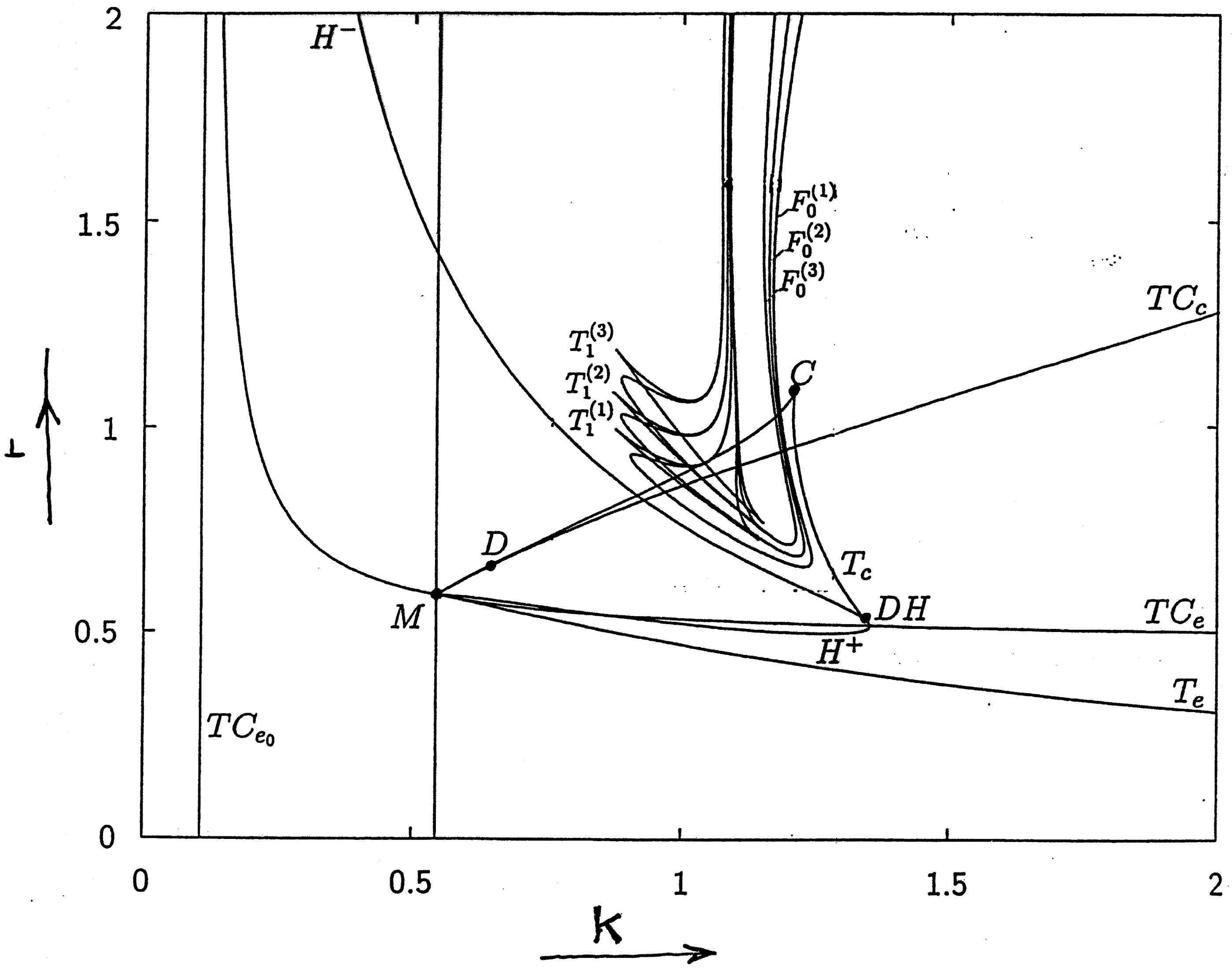
(slow ← predator, fast ← prey)

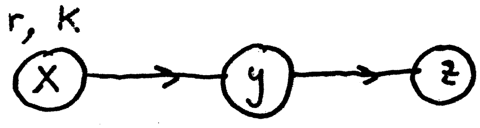


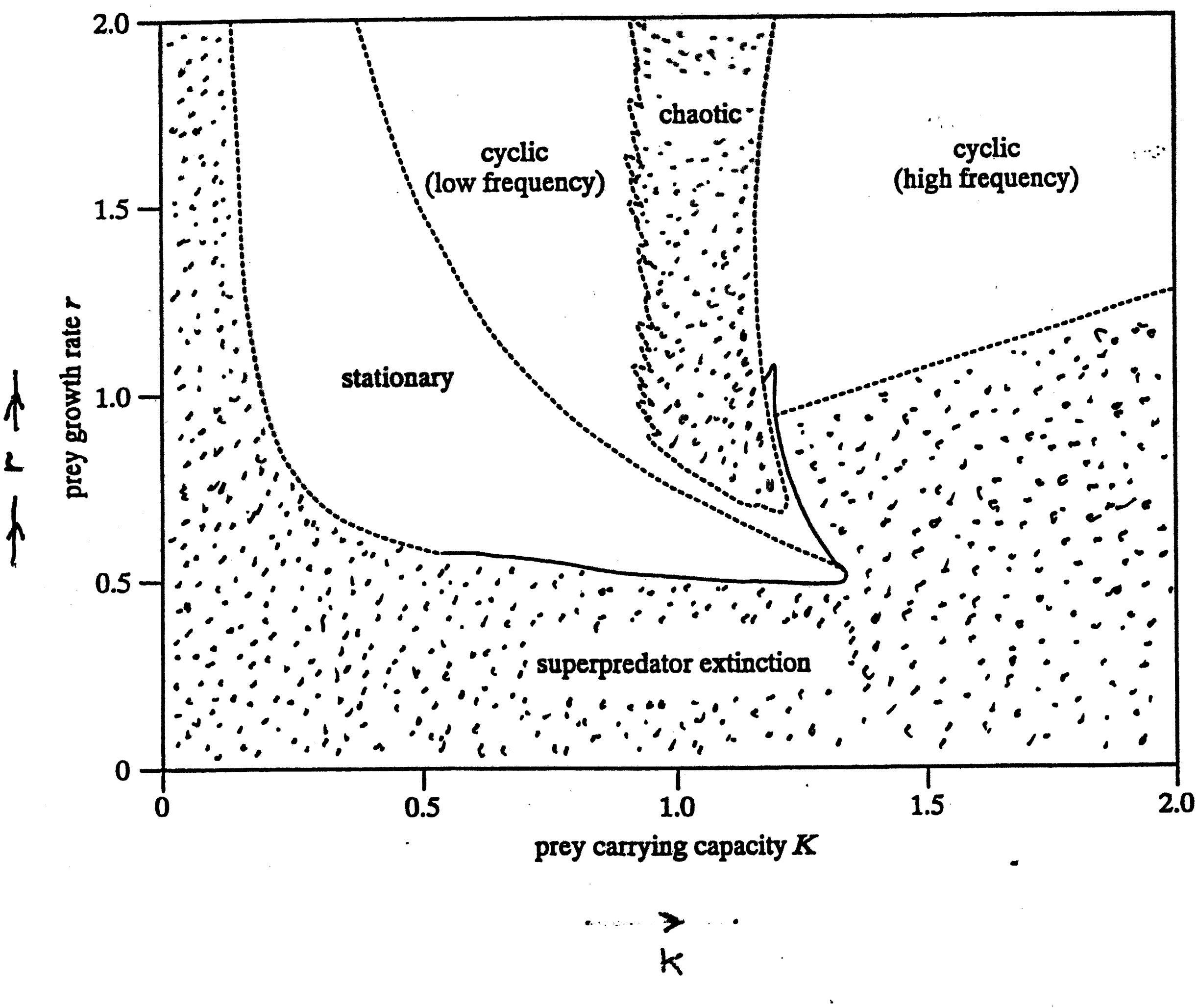



r, K
x
y
0.4
0
top predator mean abundance
stationary
cyclic
1.4
prey growth rate
r
0 0
prey carrying capacity
K
1

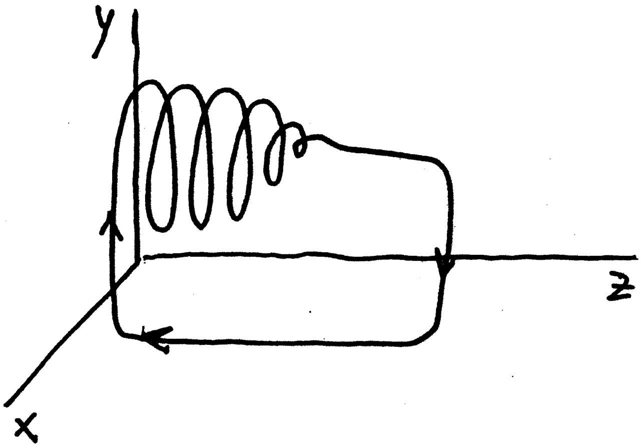

r, K
x
y
z

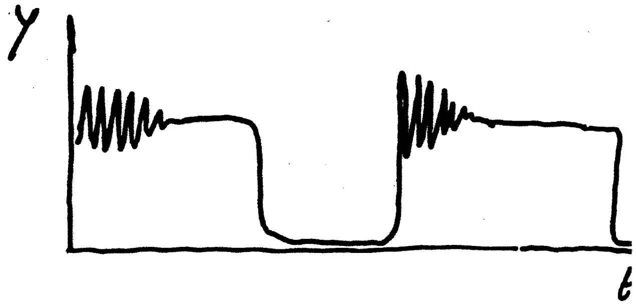

2
1.5
1
0.5
0
0
0.5
1
1.5
2
r
K
H⁻
H⁺
M
D
C
DH
TCc
TCe
TCe0
Tc
Te
F0(1)
F0(2)
F0(3)
T1(1)
T1(2)
T1(3)


r, K
X
y
z

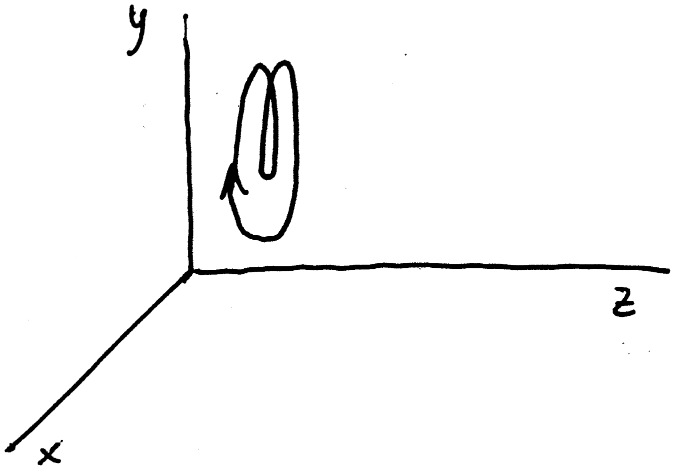

chaotic
cyclic
(low frequency)
cyclic
(high frequency)
stationary
superpredator extinction
prey growth rate r
prey carrying capacity K
2.0
1.5
1.0
0.5
0
0
0.5
1.0
1.5
2.0
r
K

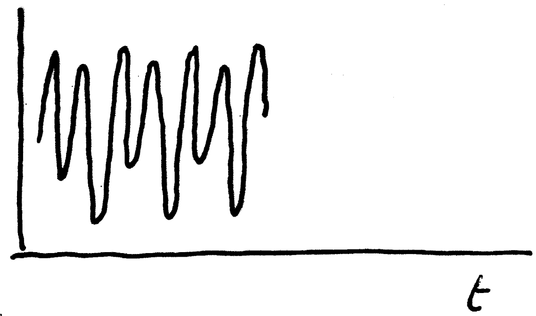
LOW FREQUENCY

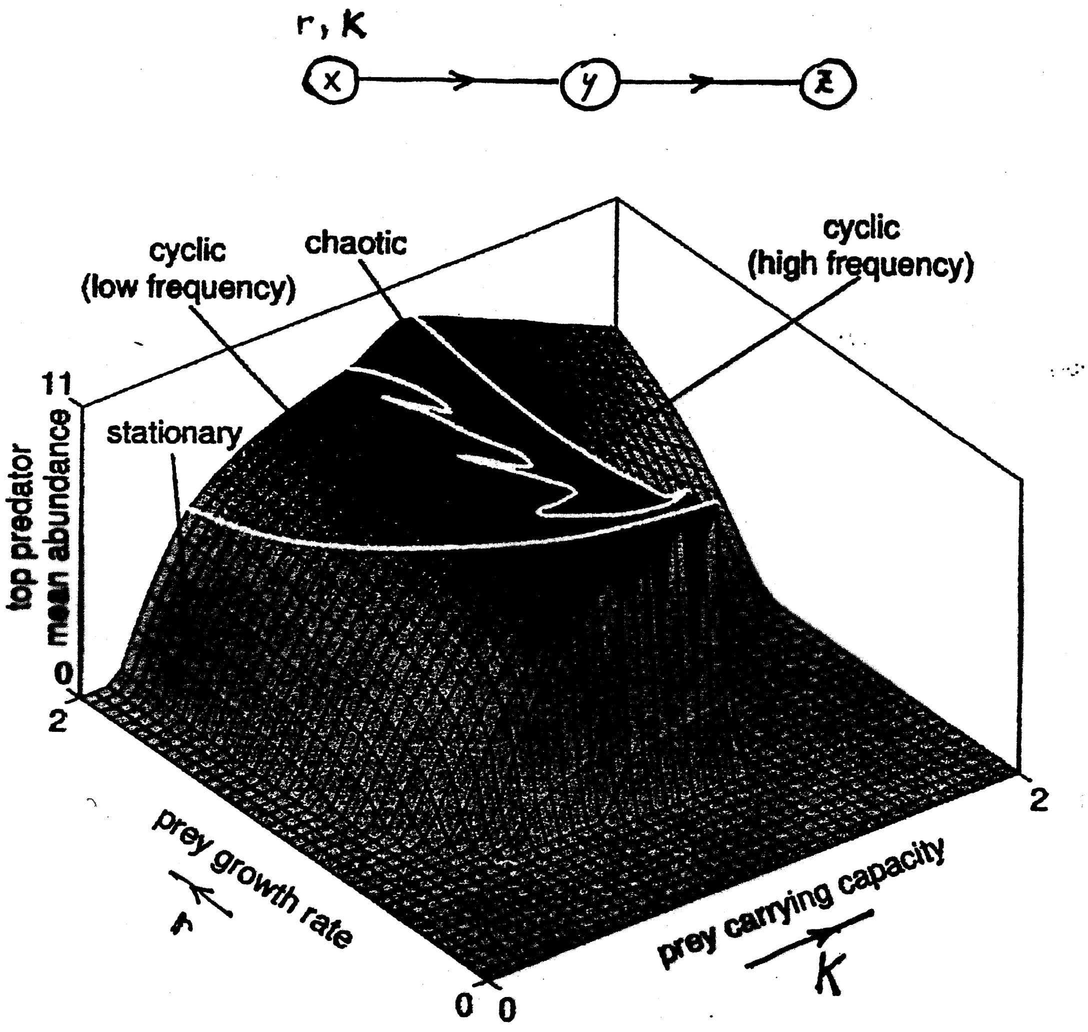




HIGH FREQUENCY



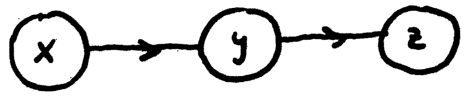



r, K
x
y
z
cyclic
(low frequency)
chaotic
cyclic
(high frequency)
stationary
top predator
mean abundance
11
0
2
0
0
2
prey growth rate
r
prey carrying capacity
K

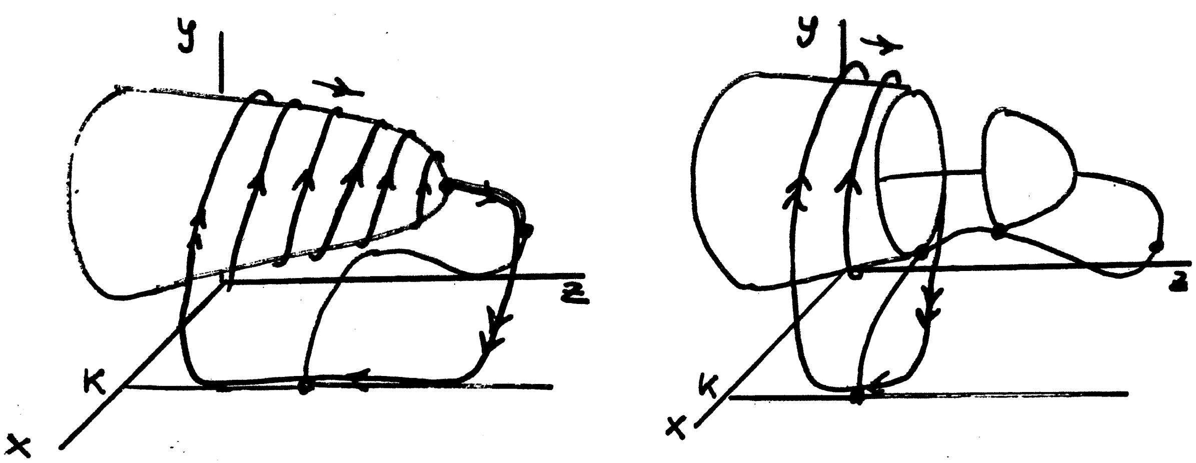
$$\dot{x} = \cdots$$

$$\dot{y} = \cdots$$

$$\dot{z} = z\left[e_2 \frac{a_2 y}{b_2 + y} - m_2\right]$$



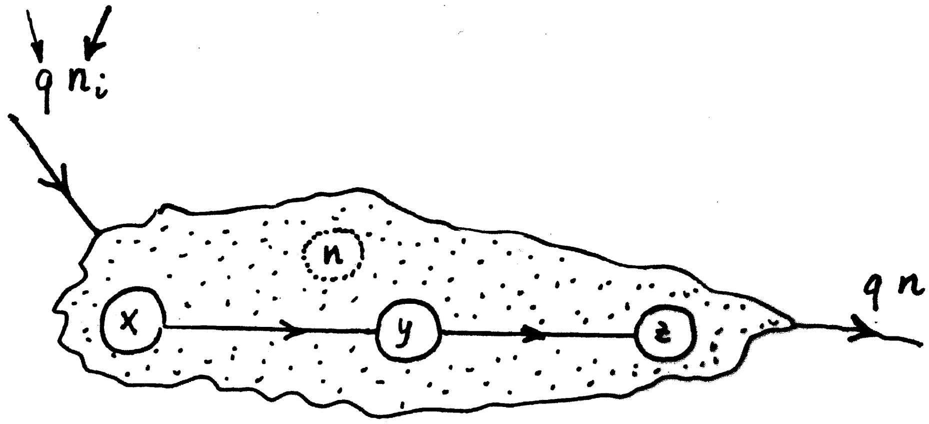
$K^* - \varepsilon$ $\qquad$ $K^* + \varepsilon$

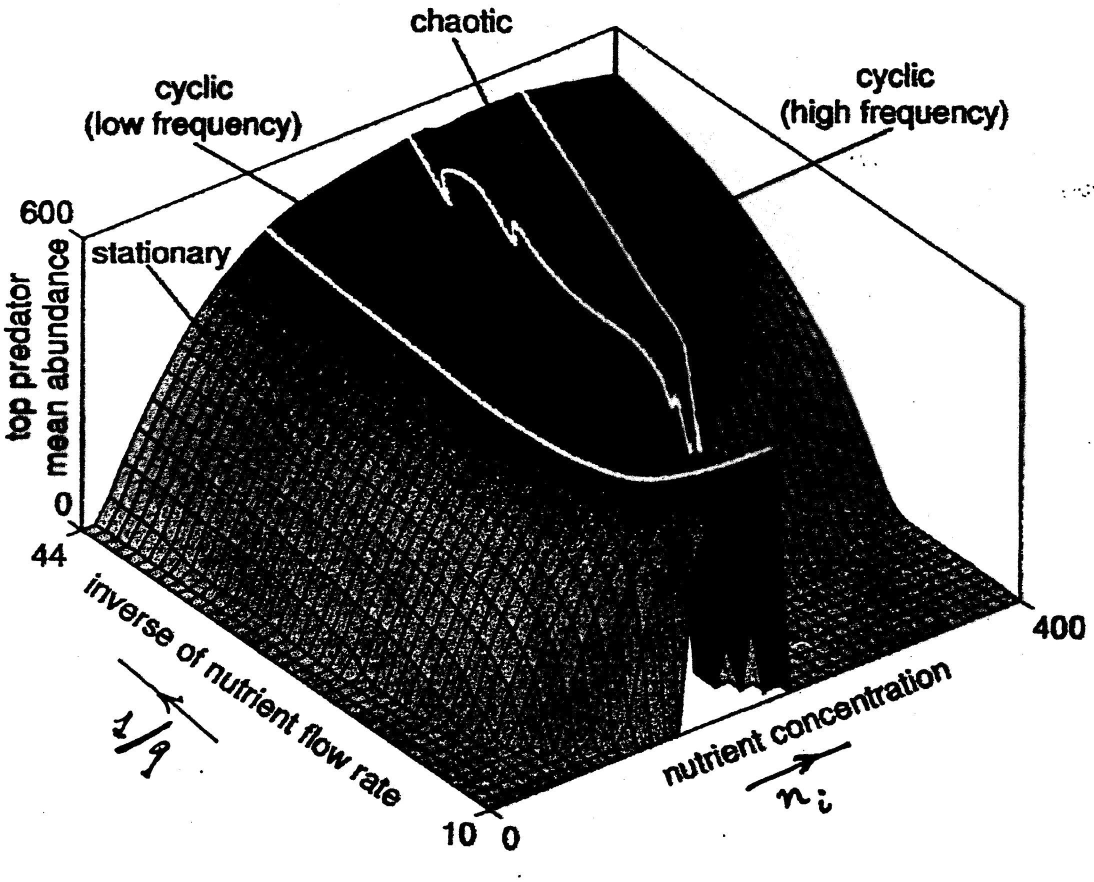


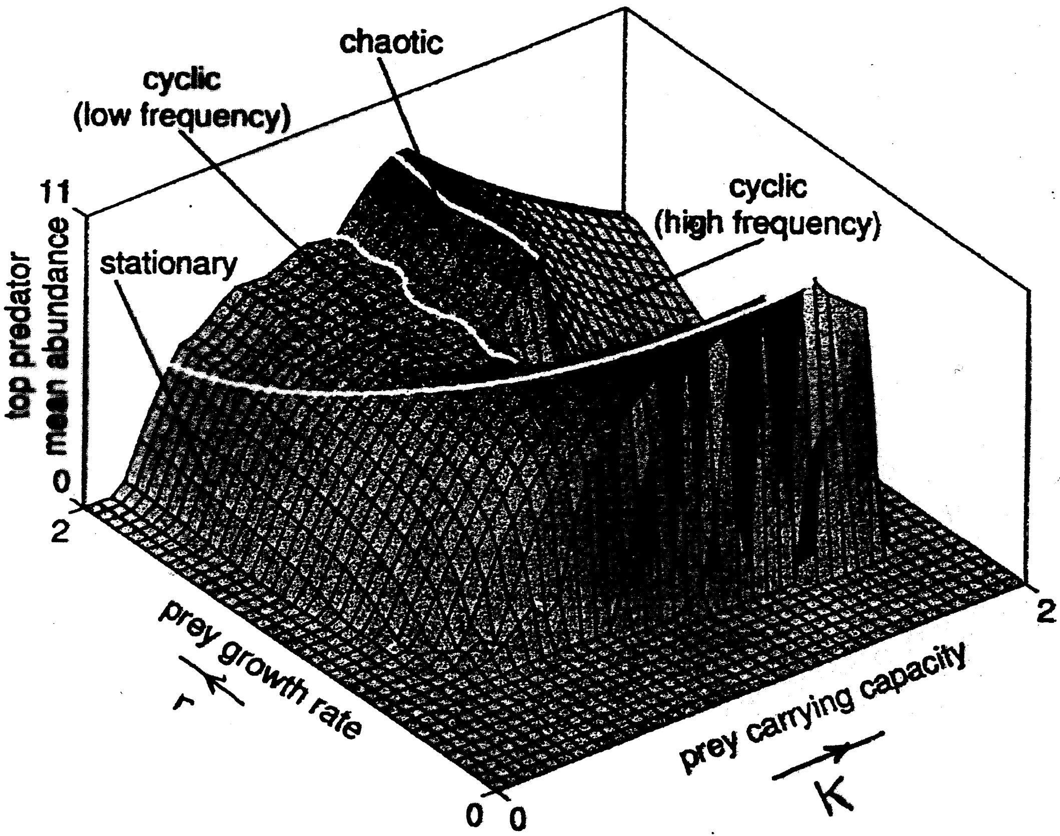
$$\dot{z} = 0 \Rightarrow z = 0 \quad , \quad y^* = \frac{m_2 b_2}{e_2 a_2 - m_2}$$

$y > y^* \Rightarrow \dot{z} > 0$ $\rightarrow$

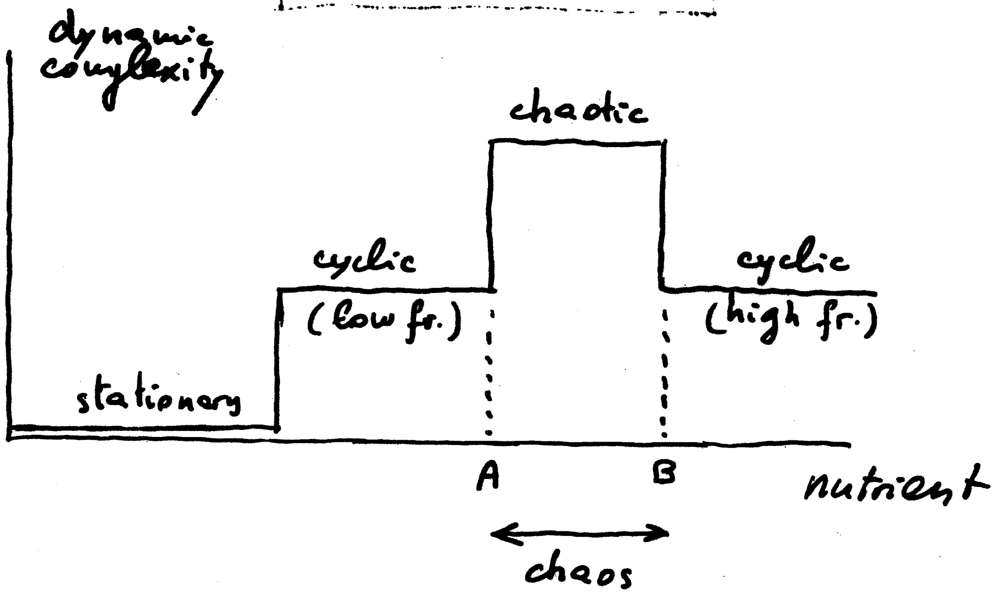
$y < y^* \Rightarrow \dot{z} < 0$ $\leftarrow$

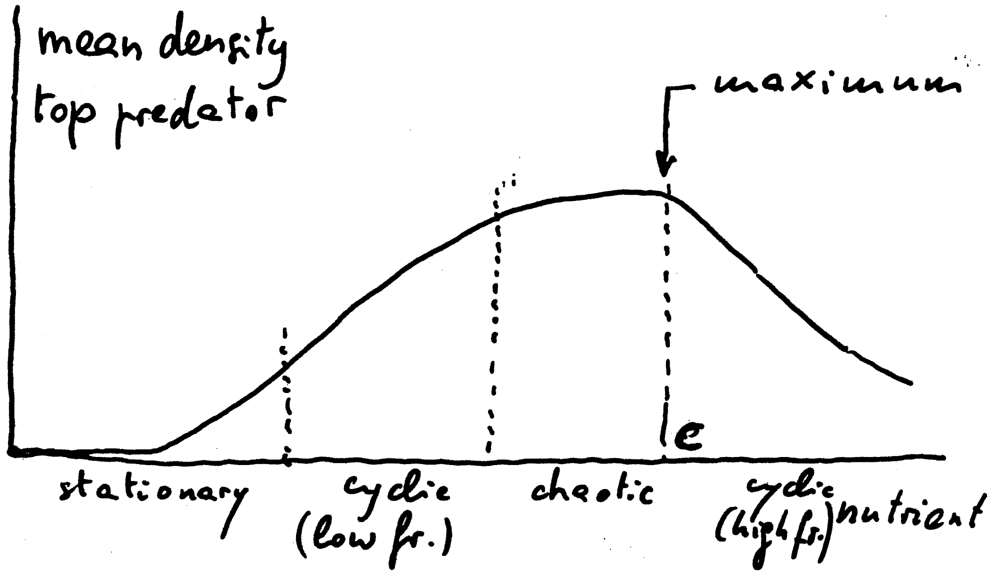

q
n_i
n
x
y
z
q n


chaotic
cyclic
(low frequency)
cyclic
(high frequency)
stationary
600
0
top predator
mean abundance
44
inverse of nutrient flow rate
1/q
10
0
400
nutrient concentration
n_i


chaotic
cyclic
(low frequency)
cyclic
(high frequency)
stationary
11
top predator
mean abundance
0
2
prey growth rate
r
0 0
prey carrying capacity
K
2

CONCLUSIONS

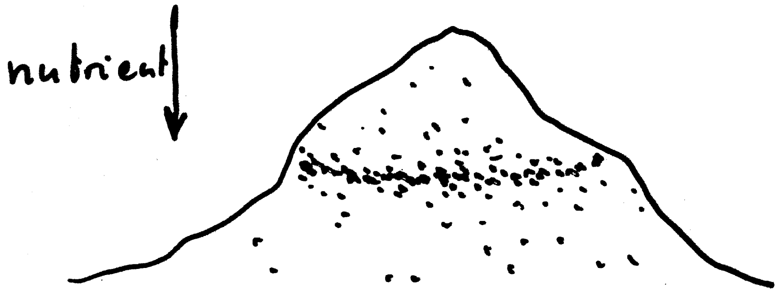


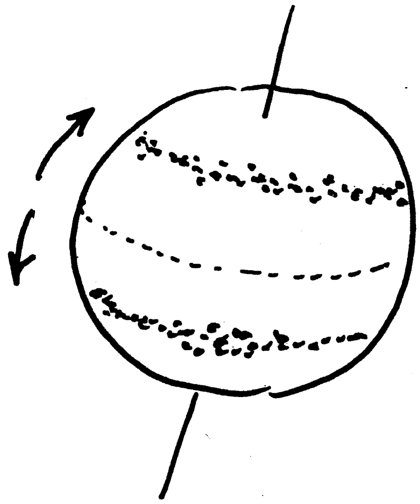


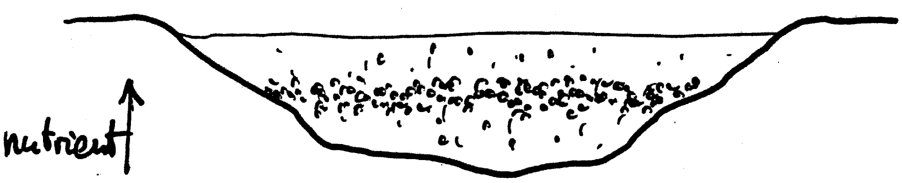
Surprising result $B \cong C$

CONSEQUENCE # 1

Species are more abundant at particular altitudes, latitudes and depths.







CONSEQUENCE # 2

Many data are needed to write a thesys

⇓

Data are collected where species are more abundant

⇓

Collected data reveal chaos or almost chaos

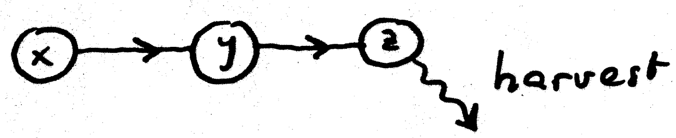
⇓ (as ascertained by Ellner and Turc

Ellner and Turchin findings have nothing to do with evolutionary principles of the kind

ECOSYSTEMS EVOLVE TOWARD THE EDGE OF CHAOS

CONSEQUENCE # 3

Assume top-predator is exploited at constant effort

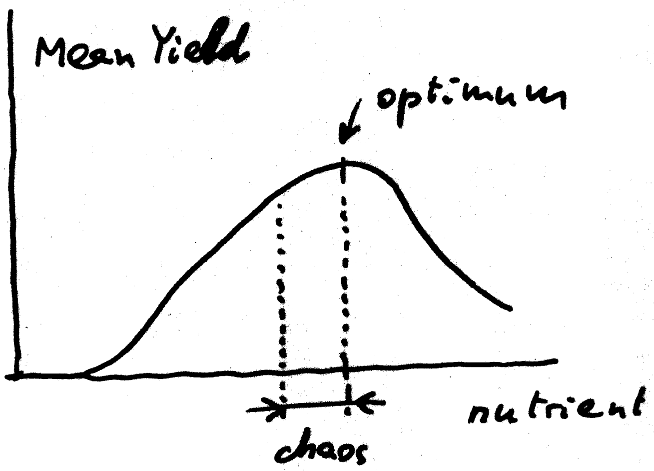


$\dot{x} = \ldots$

$\dot{y} = \ldots$

$\dot{z} = \ldots - m z$ $\qquad m = m_n + m_h$

Mean Yield $= m_h \cdot \bar{z}$



Maximum mean yield $\Rightarrow$ enrich (or impoverish) untill the ecosystem is at the edge of chaos

Biological machines are optimum at the edge of chaos
↓
for man