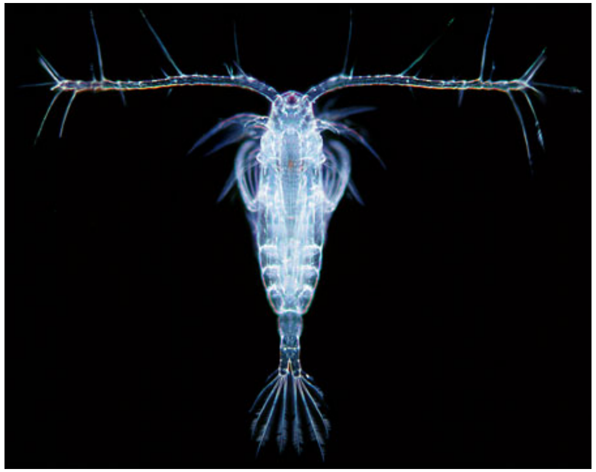
The Abdus Salam
International Centre for Theoretical Physics

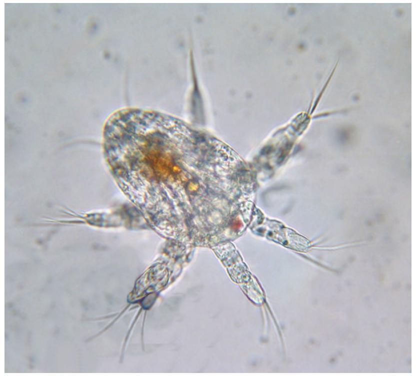
Advanced School on Complexity, Adaptation and Emergence in Marine Ecosystems

United Nations Educational, Scientific and Cultural Organization

IAEA
International Atomic Energy Agency

Mechanistic interactions in plankton, fitness and behaviour



André W. Visser

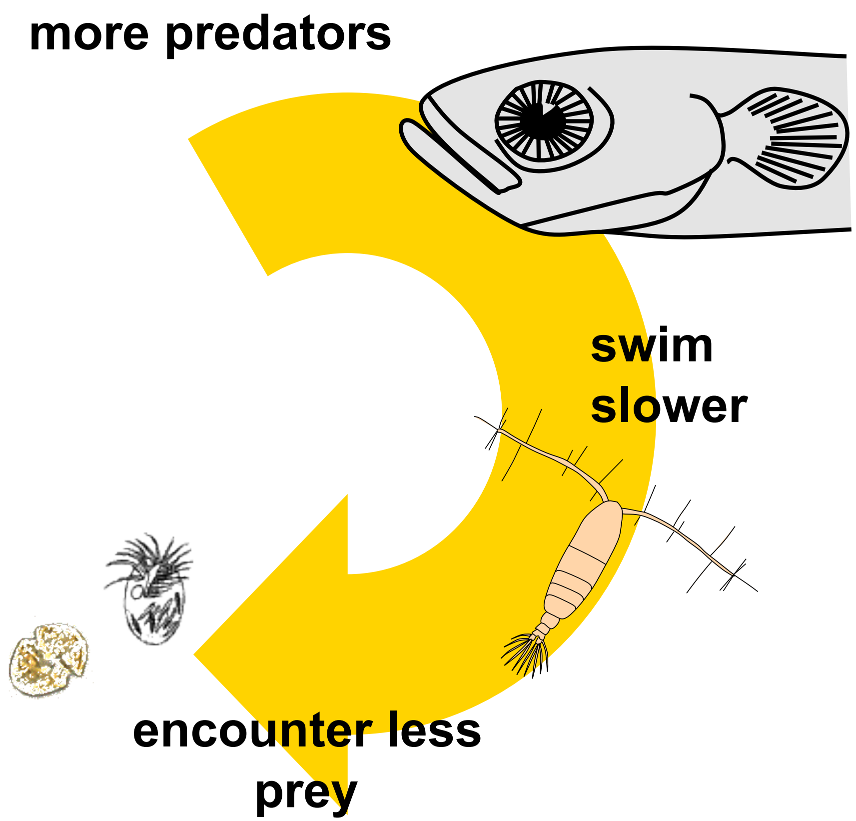
DTU Aqua
National Institute of Aquatic Resources

Behaviourally mediated trophic cascade

Mechanistic interactions in plankton, fitness and behaviour

Implications for population dynamics

Top predator abundance influences
grazing pressure on resource

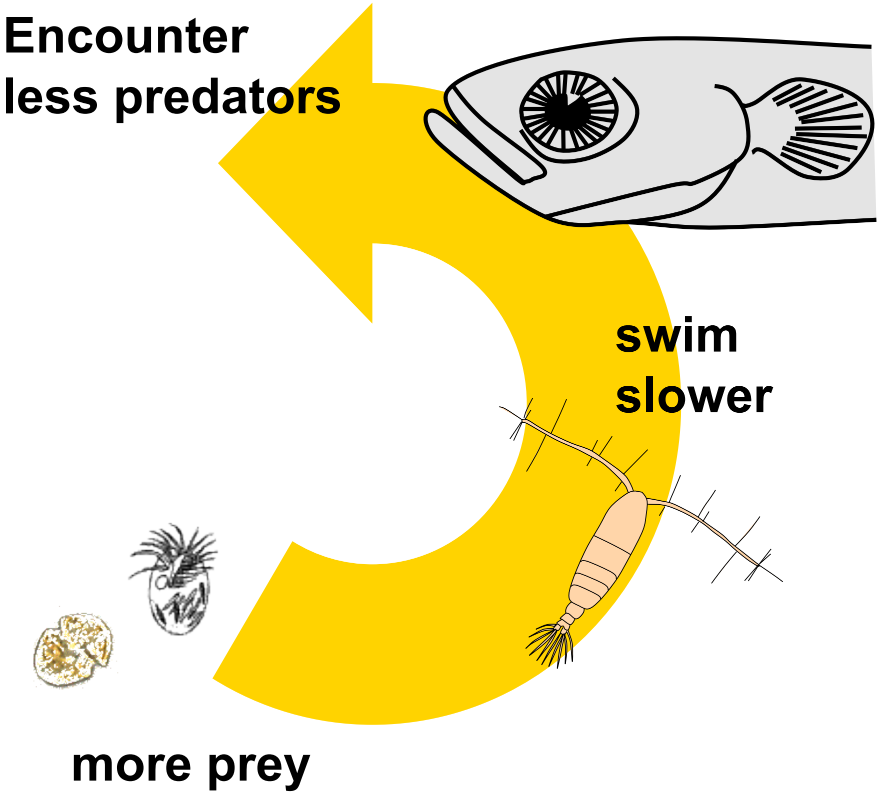


Behaviourally mediated trophic cascade

Mechanistic interactions in plankton, fitness and behaviour

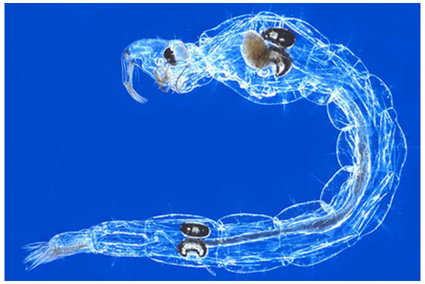
Implications for population dynamics

Resource abundance influences mortality rate of consumer and trophic transfer to top predator



Adaptive Behaviour

copepod



midge larvae

juvenile trout

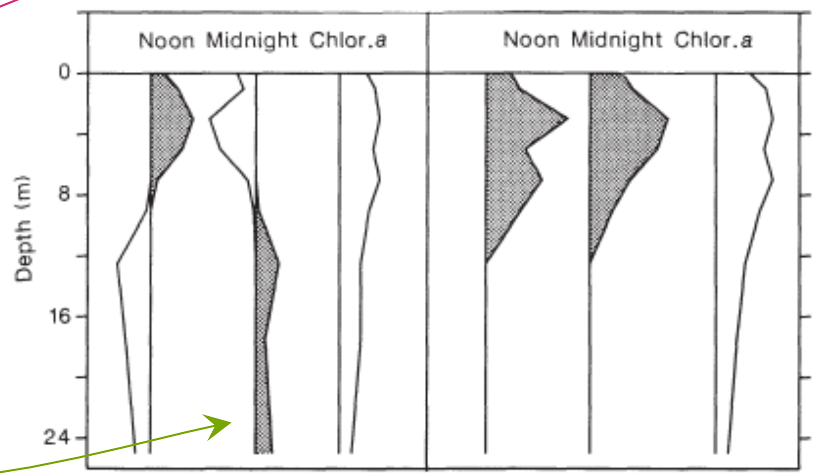
Induced vertical migration in copepods as a defence against invertebrate predation

William E. Neill

NATURE · VOL 345 · 7 JUNE 1990

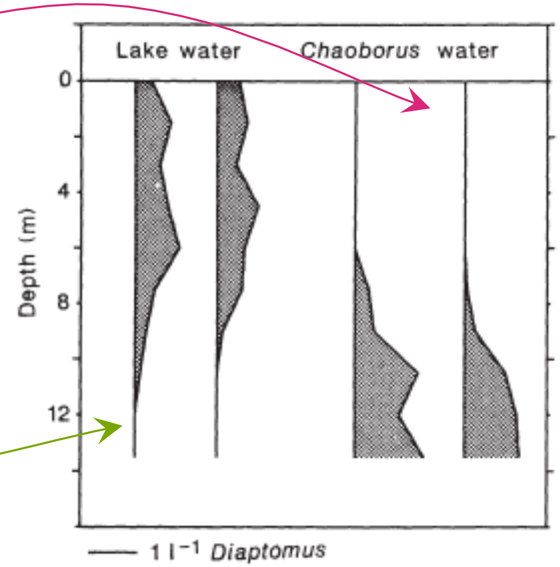
With trout

Without trout



With midge larvae "odour"

Without midge larvae "odour"



Dynamic systems

NATURE VOL. 238 AUGUST 18 1972

Will a Large Complex System be Stable?

ROBERT M. MAY*

Institute for Advanced Study, Princeton, New Jersey 08540

$$\frac{d\mathbf{x}}{dt} = M(\mathbf{x}, t)\mathbf{x}$$

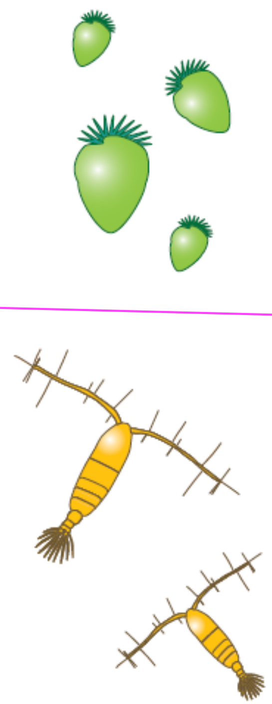
⇒ Theory: High Biodiversity is NOT conducive for Ecosystem Stability

Community matrix

Apparent paradox

Dynamic systems

Community matrix is
structured and dynamic



prey fitness

$$\frac{dP}{dt} = (\alpha - \beta Z)P$$

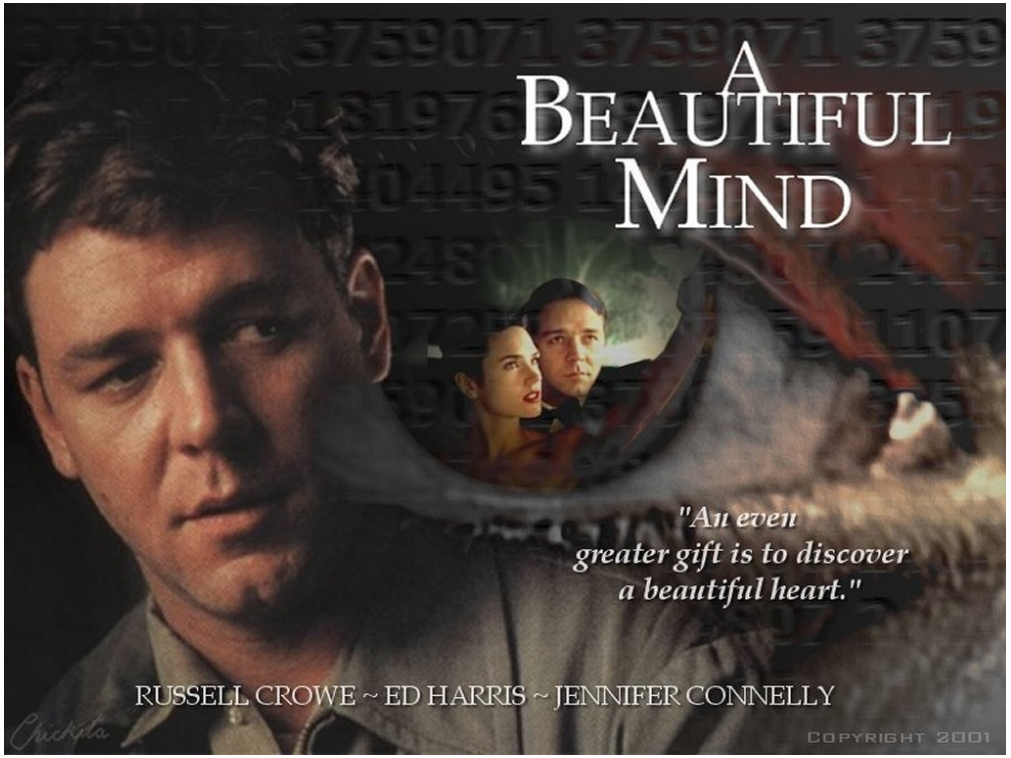
$$\frac{dZ}{dt} = (\varepsilon\beta P - \mu)Z$$

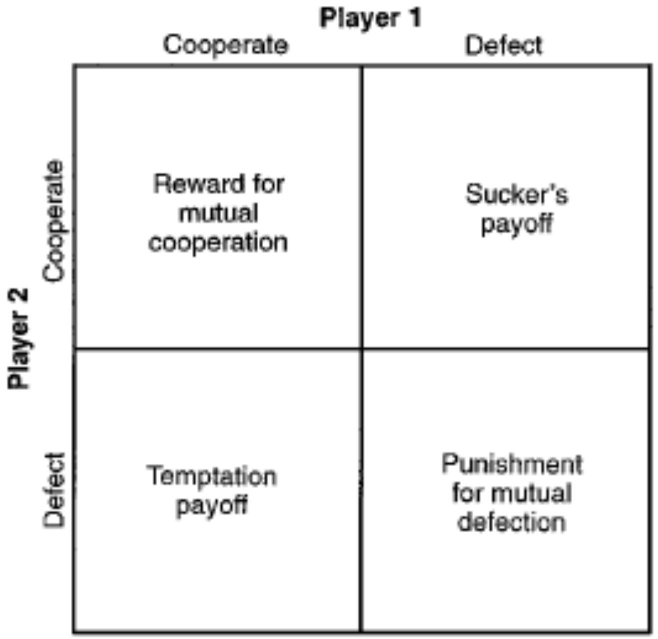
predator fitness

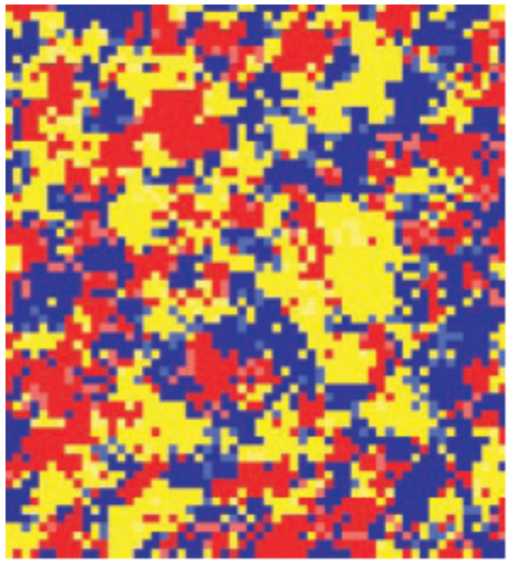
Interaction kernel depends on behaviour of both parties

Behaviour of each party adapts so as to optimize fitness

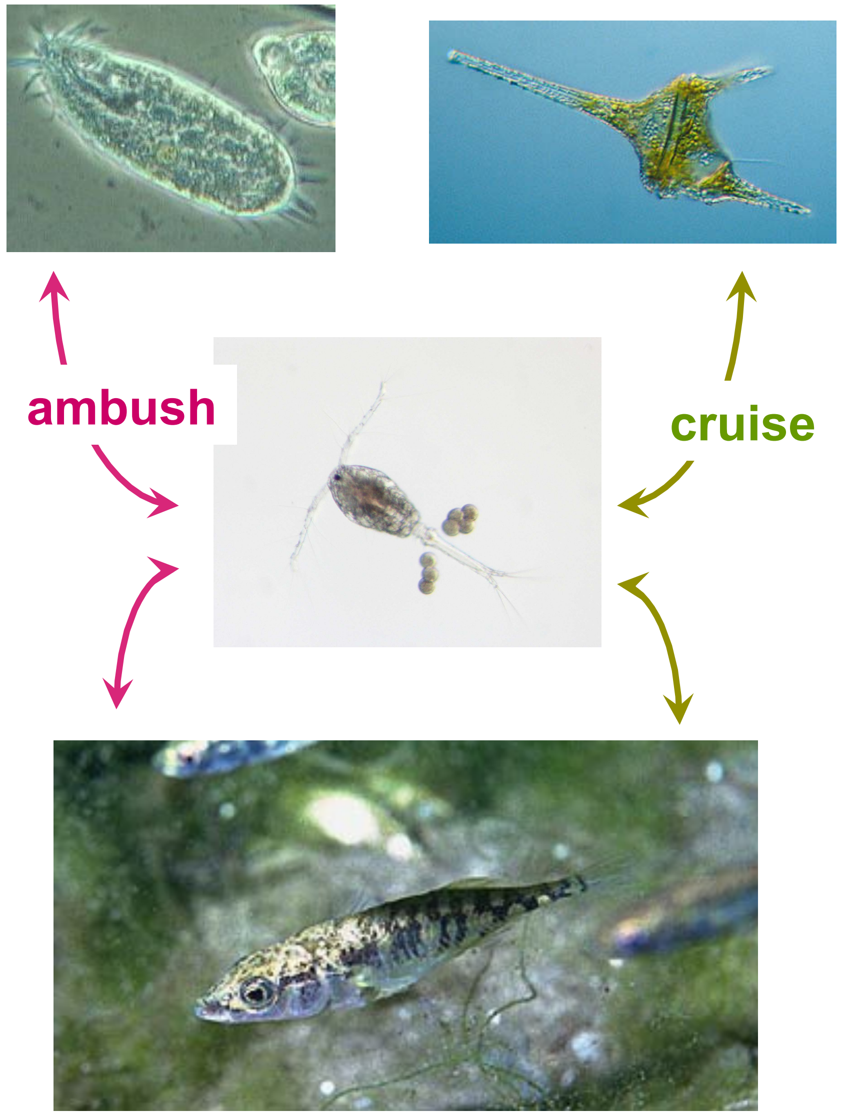
Game theory

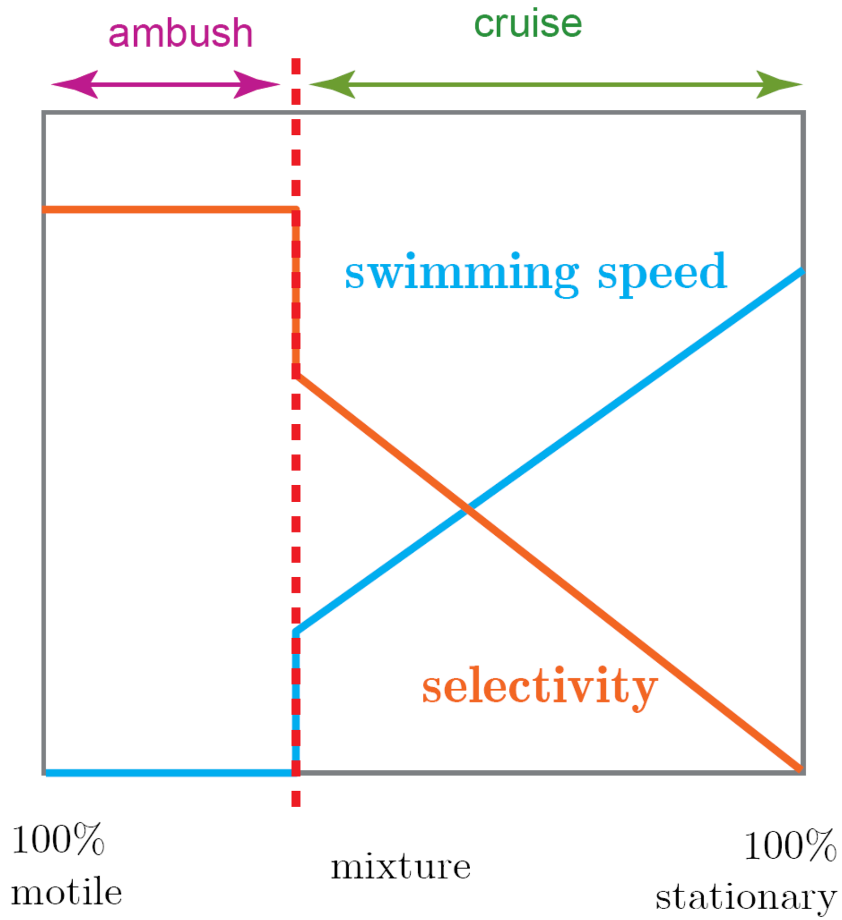

A BEAUTIFUL MIND
"An even greater gift is to discover a beautiful heart."
RUSSELL CROWE ~ ED HARRIS ~ JENNIFER CONNELLY
COPYRIGHT 2001


Player 1
Cooperate
Defect
Player 2
Cooperate
Defect
Reward for mutual cooperation
Sucker's payoff
Temptation payoff
Punishment for mutual defection



Prey switching



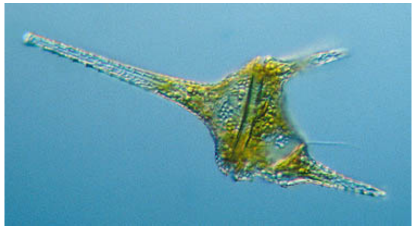


Prey switching

$C(1-r)$

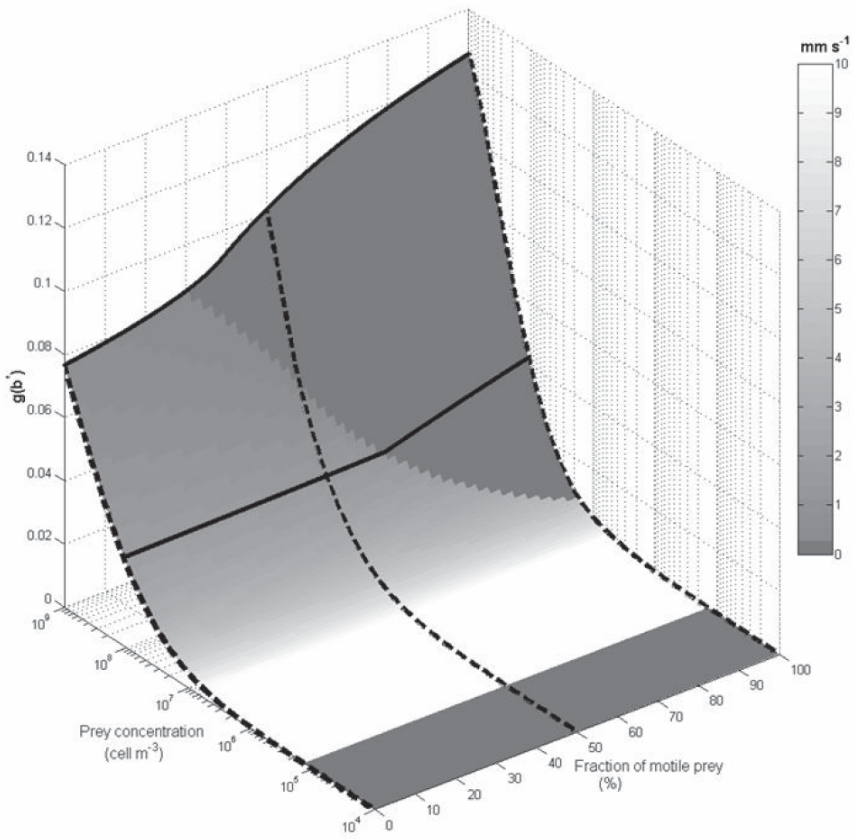
u

Cr



v

P



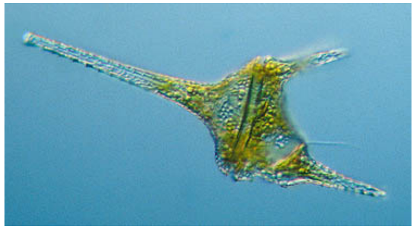
static	$Z_a = s_a C r v$	benefit
motile	$Z_b = s_b C(1-r)\sqrt{v^2 + u^2}$	
predator	$Z_p = s_p P(v + F)$	risk
	$m + qv^2$	cost

Prey switching

$C(1-r)$

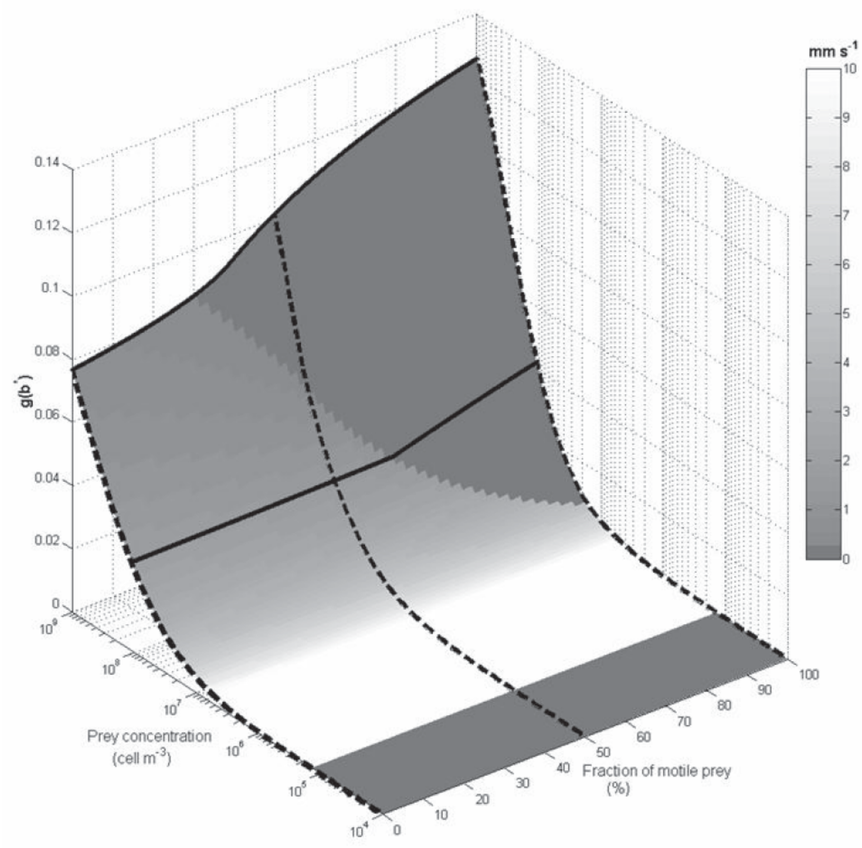
u

Cr



v

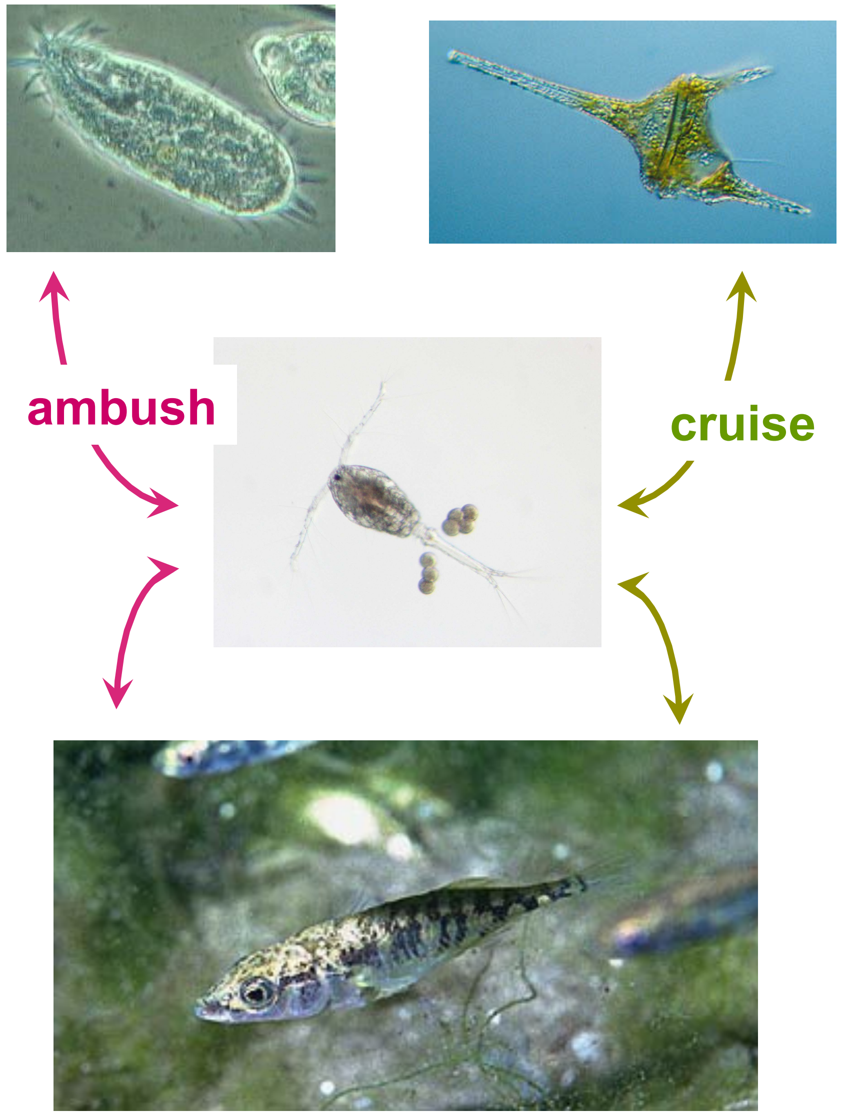
P

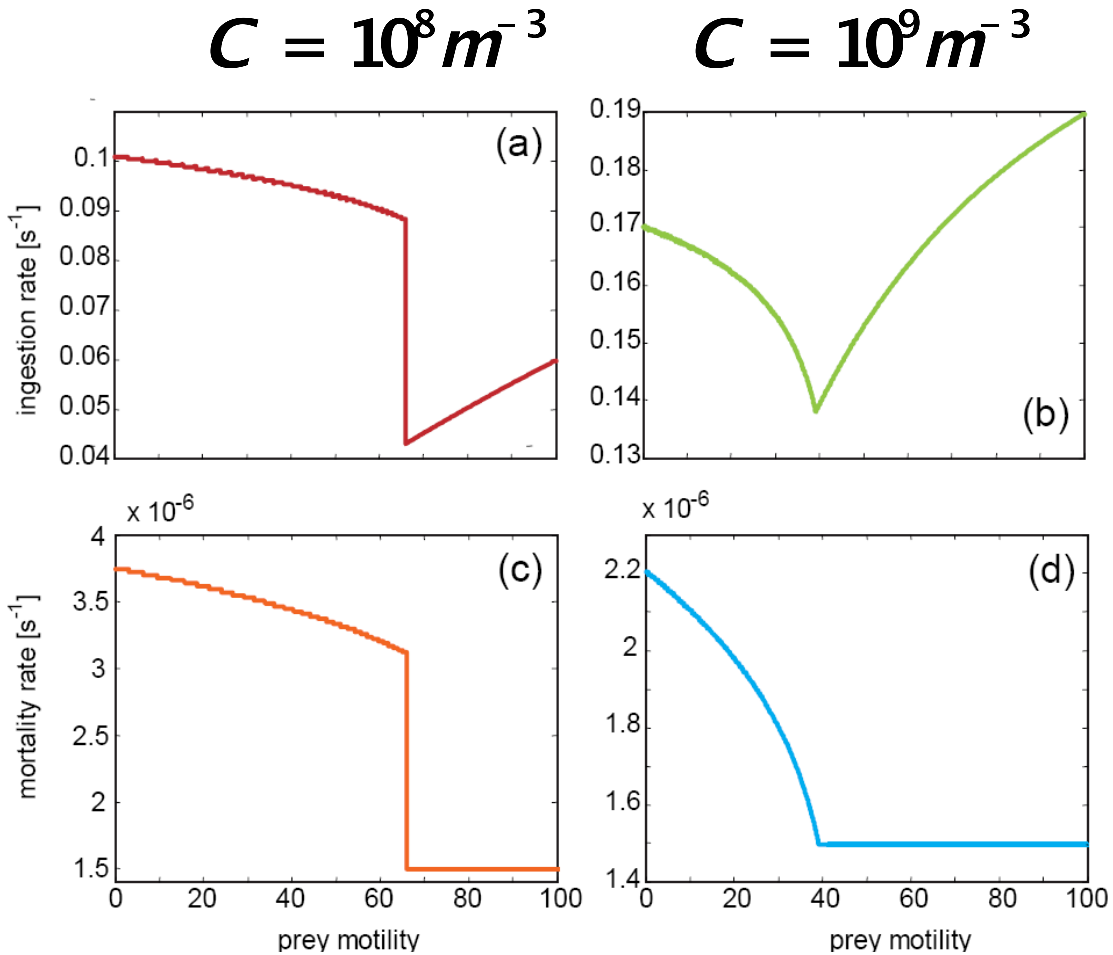


fitness

$$g = \frac{1}{Z_p}\left(\frac{e_a Z_a + e_b Z_b}{1 + h_a Z_a + h_b Z_b} - m - q v^2\right)$$

Prey switching





Abundance and type of resource influences the trophic transfer rates through out the food web

Dynamic systems

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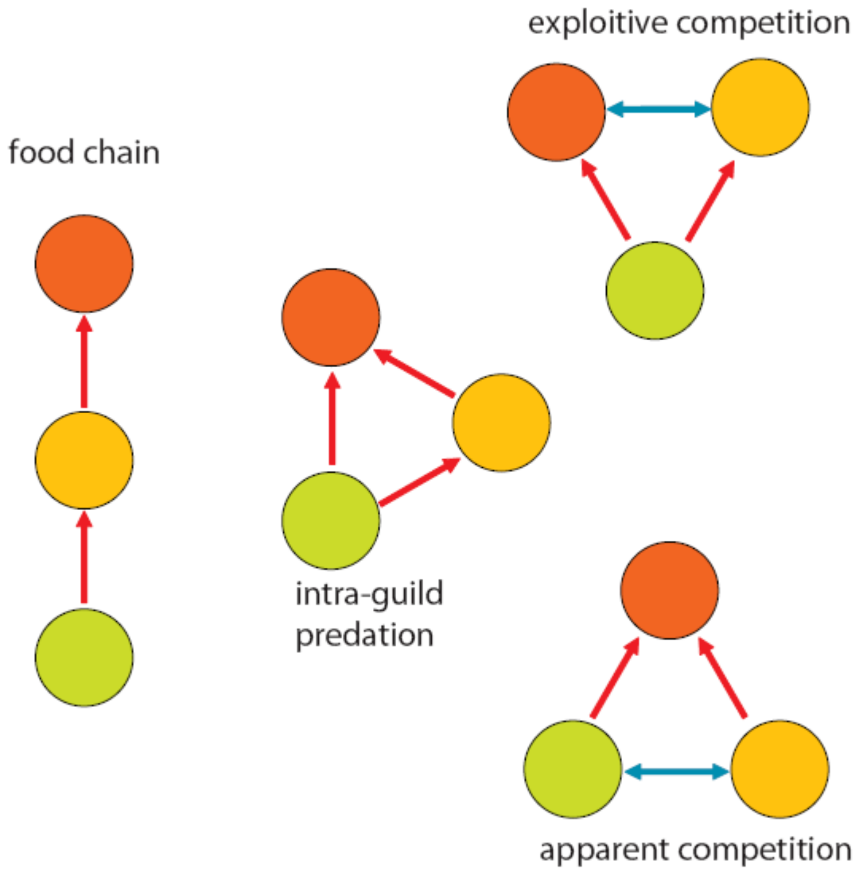
$$\frac{dx}{dt} = M(x, t)x$$

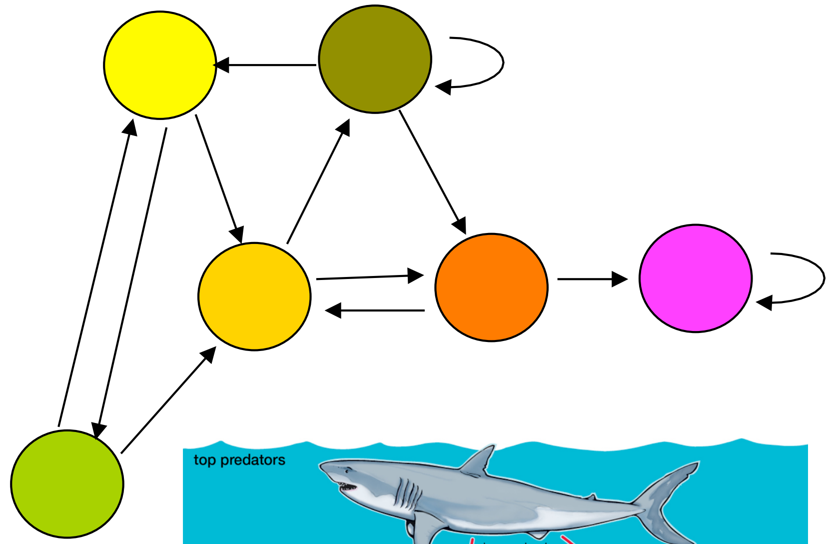
Community matrix

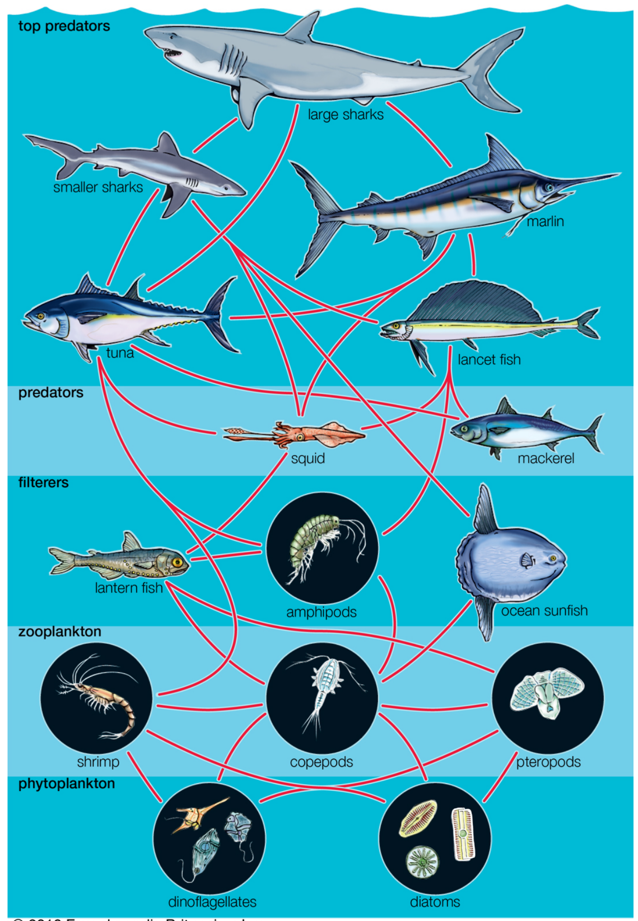
$\Rightarrow$ Theory: High Biodiversity is NOT conducive for Ecosystem Stability

Apparent paradox

Tri-trophic system

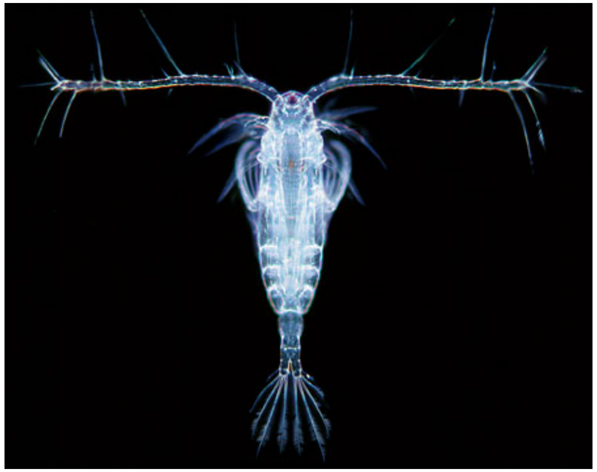


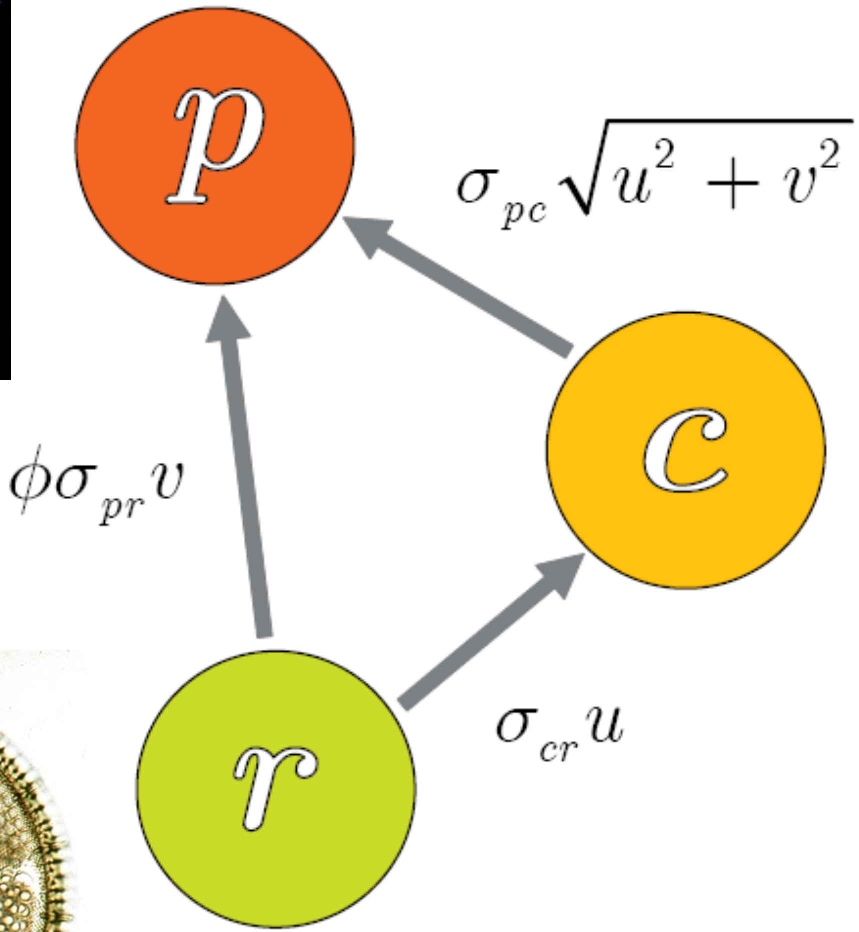


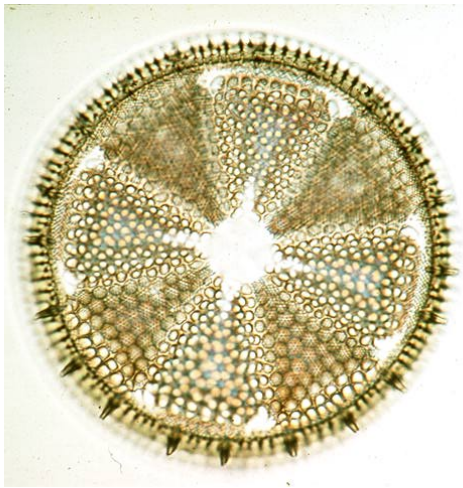


Tri-trophic system

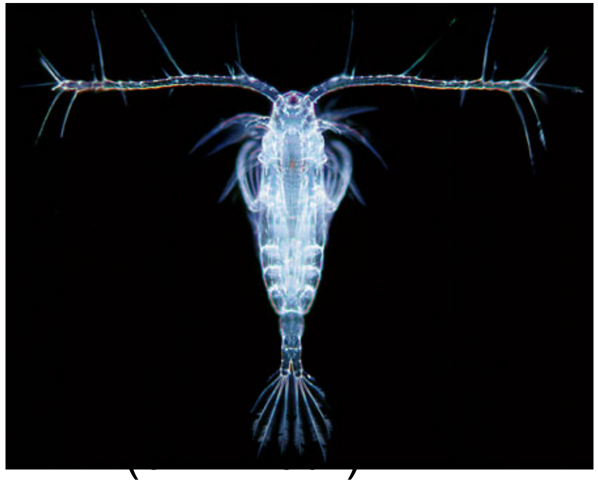
omnivory

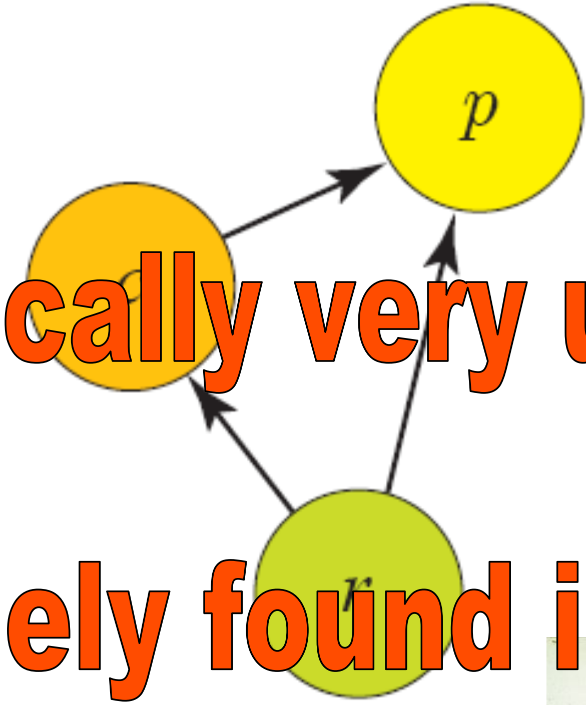






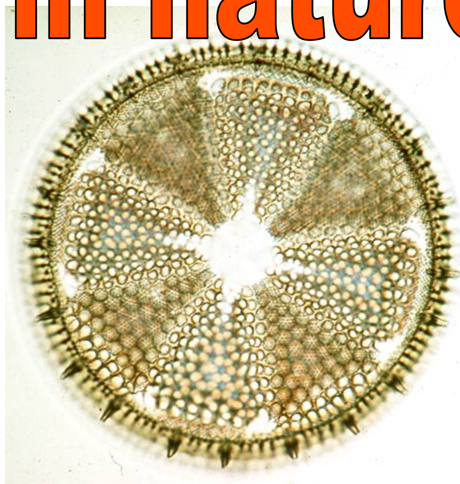
Tri-trophic system





theoretically very unstable

yet widely found in nature



Tri-trophic system: fixed

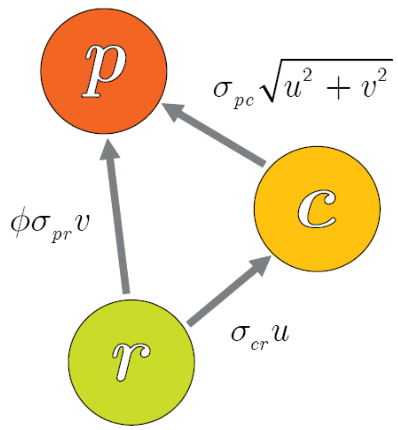
Omnivory parameter

resource
$$\frac{dr}{dt} = rf_r = r\left(\alpha\left(1-\frac{r}{k}\right)-\sigma_{cr}uc-\phi\sigma_{pr}vp\right)$$

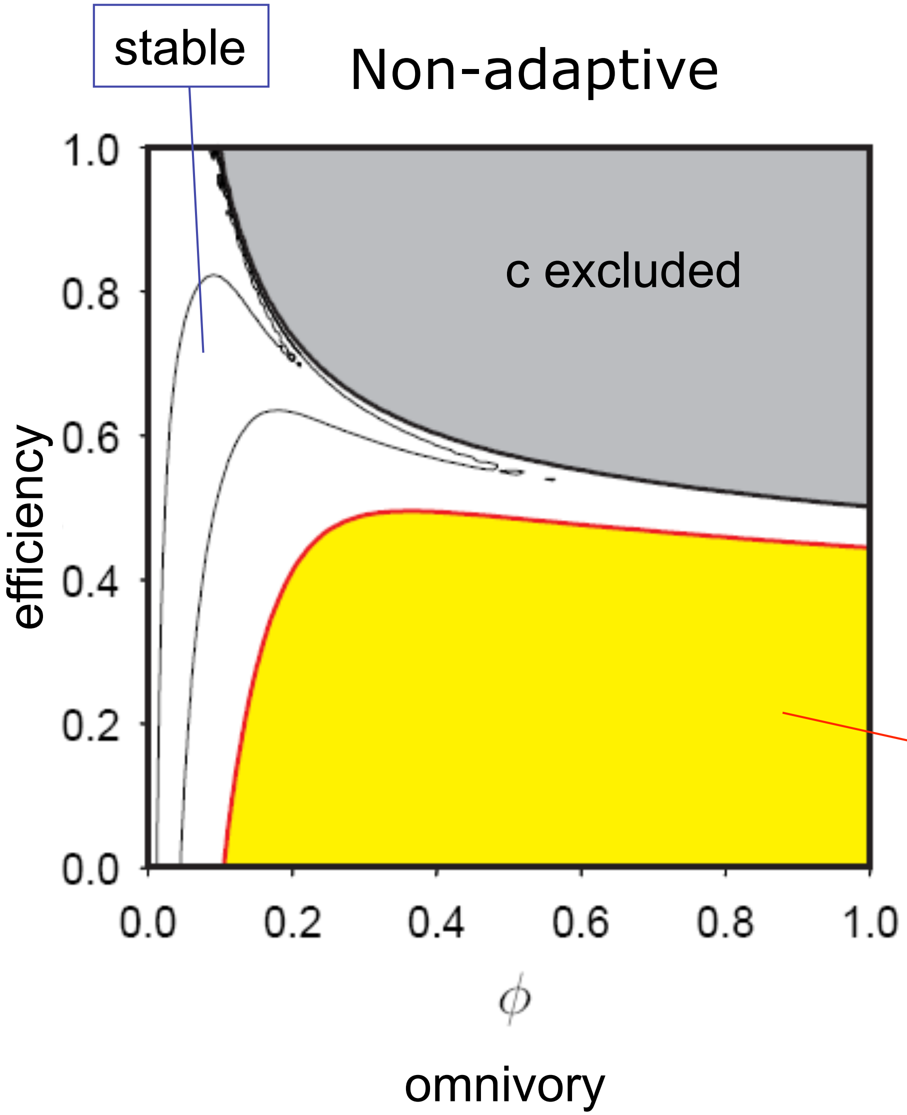
consumer
$$\frac{dc}{dt} = cf_c = c\left(\varepsilon_{cr}\sigma_{cr}ur-\sigma_{pc}(u^2+v^2)^{1/2}p-q_cu^2\right)$$

predator
$$\frac{dp}{dt} = pf_p = p\left(\varepsilon_{pr}\phi\sigma_{pr}vr+\varepsilon_{pc}\sigma_{pc}(u^2+v^2)^{1/2}c-\mu_p\right)$$

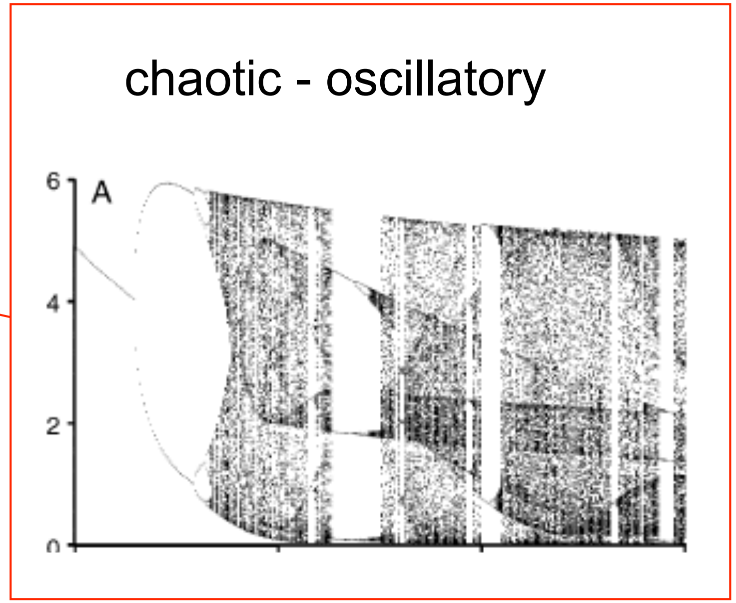
Conversion efficiency r to p



Tri-trophic system: fixed



subject to stochastic extinction



Omnivory system

benefit　　risk　　cost

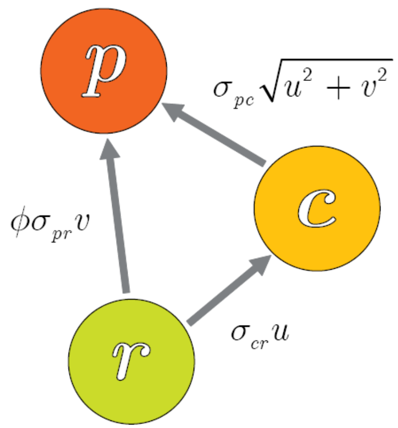
resource
$$\frac{dr}{dt} = rf_r = r\left(\alpha\left(1-\frac{r}{k}\right) - \sigma_{cr}uc - \phi\sigma_{pr}vp\right)$$

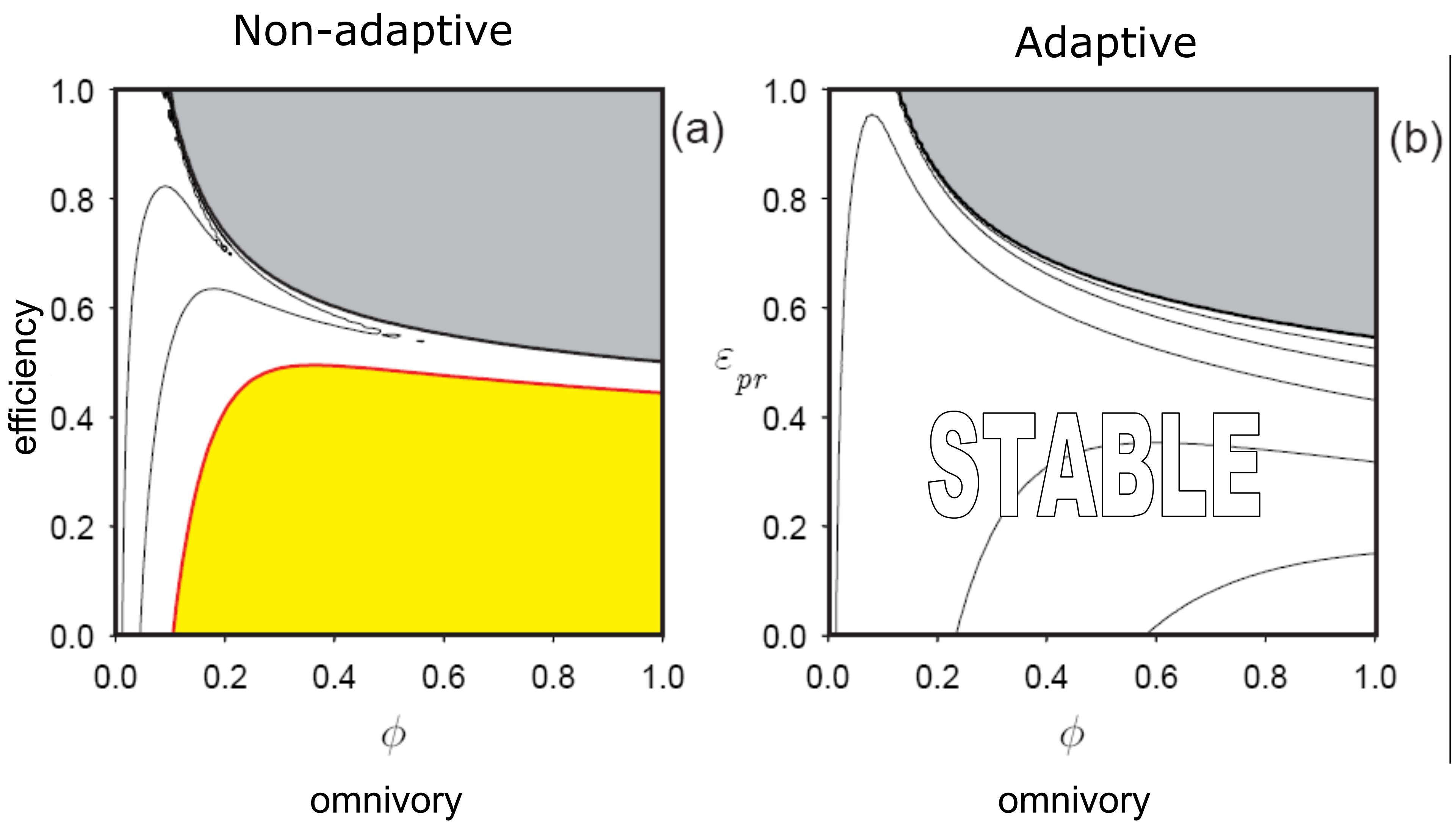
consumer
$$\frac{dc}{dt} = cf_c = c\left(\varepsilon_{cr}\sigma_{cr}ur - \sigma_{pc}(u^2+v^2)^{1/2}p - q_c u^2\right)$$

predator (omnivore)
$$\frac{dp}{dt} = pf_p = p\left(\varepsilon_{pr}\phi\sigma_{pr}vr + \varepsilon_{pc}\sigma_{pc}(u^2+v^2)^{1/2}c - \mu_p\right)$$

Consumer maximizes its fitness by adjusting its swimming speed

$$\frac{\text{benefit} - \text{cost}}{\text{risk}}$$




Non-adaptive
Adaptive
(a)
(b)
efficiency
ε_{pr}
STABLE
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
ϕ
omnivory
ϕ
omnivory

Analytic stability criterion

$$\lambda^3 + \alpha\lambda^2 + \beta\lambda + \gamma = 0$$ Characteristic equation of the Jacobian

Routh-Horowitz stability criterion $\alpha, \beta, \gamma > 0$ and $\alpha\beta > \gamma$

adaptive | non-adaptive

$$\alpha' > \alpha > 0$$

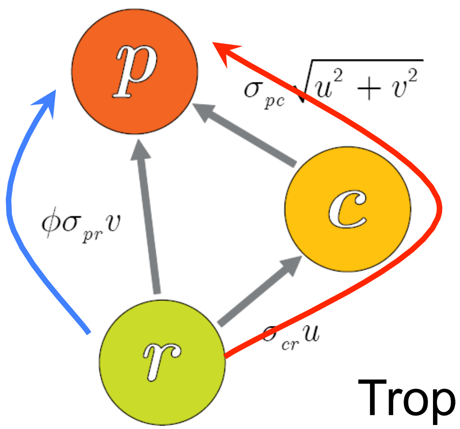
$$\beta' > \beta > 0$$

$$\gamma' > \gamma > 0$$

$$\alpha'\beta' - \gamma' > \alpha\beta - \gamma$$

Provided

$$\varepsilon_{cr}\varepsilon_{pc} > \varepsilon_{pr}$$

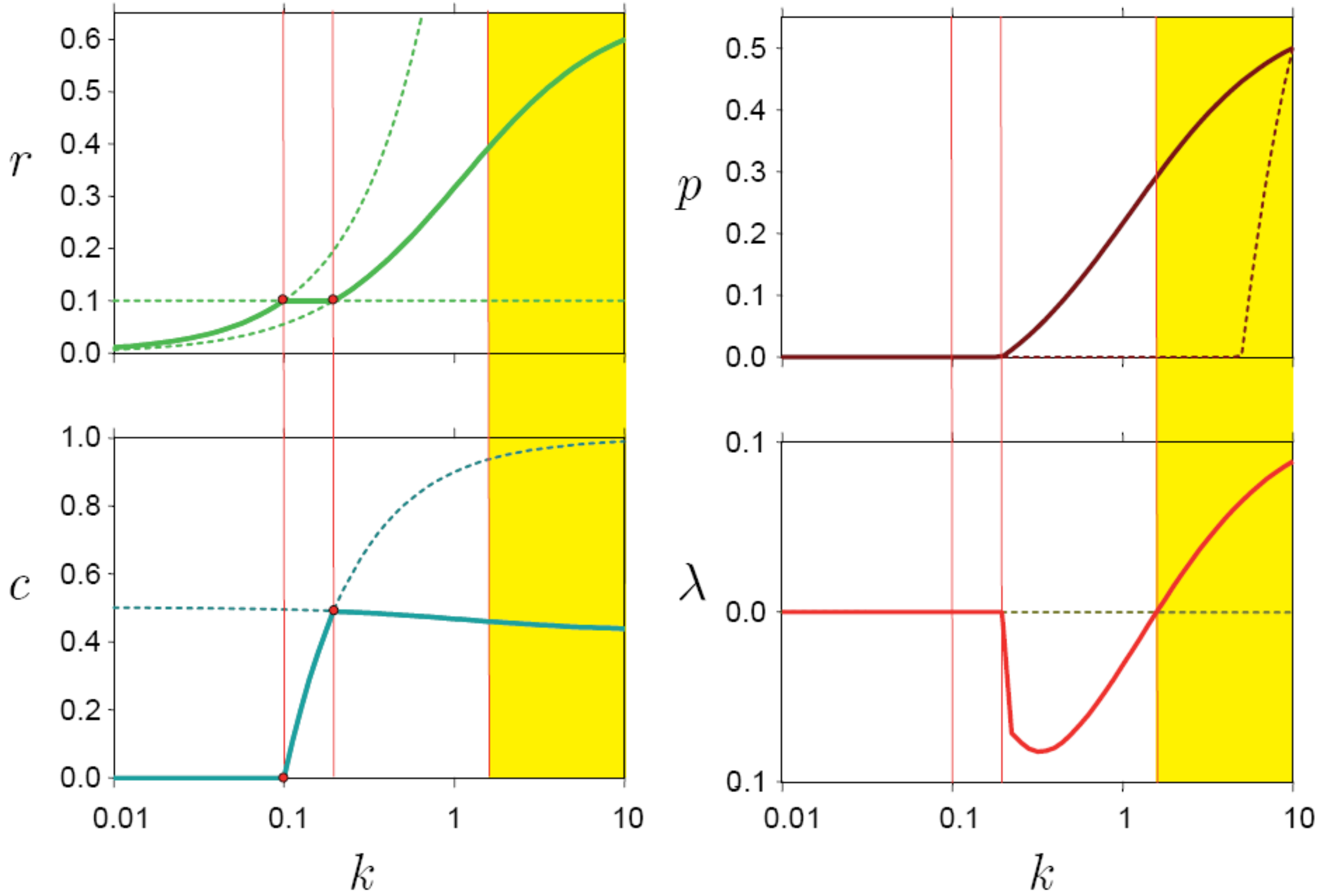


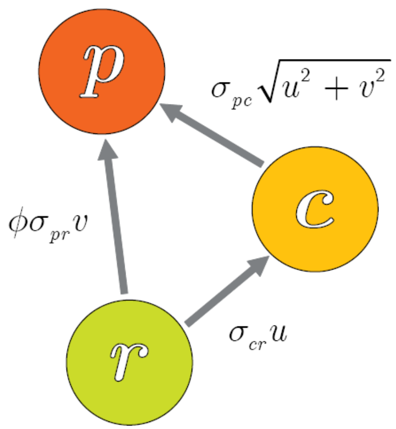
Trophic upgrading

Adaptive system is stable over a greater region of the parameter space than the non-adaptive system

Paradox of enrichment

Fixed behaviour

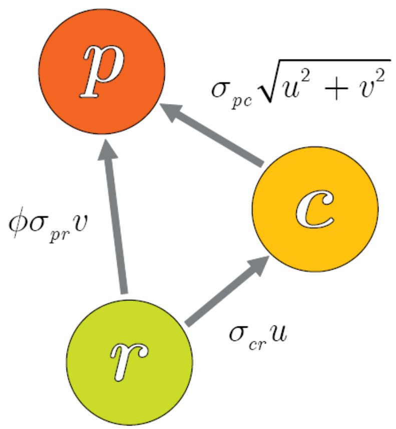


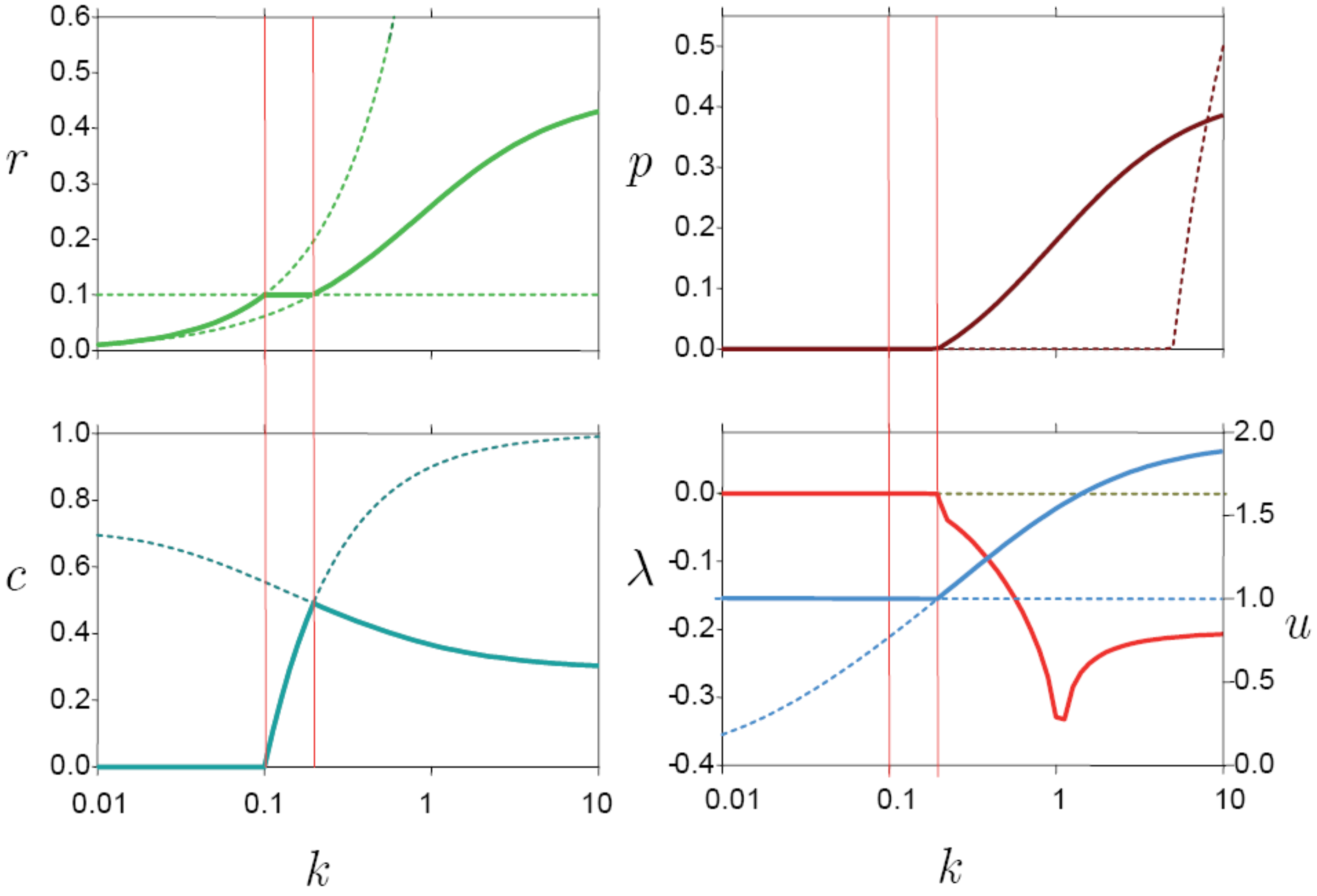


Increasing the carrying capacity of a system will decrease its stability

Paradox of enrichment

Adaptive (fitness seeking) behaviour





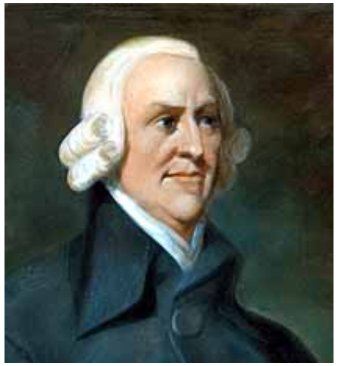
Increasing the carrying capacity of a system will decrease its stability

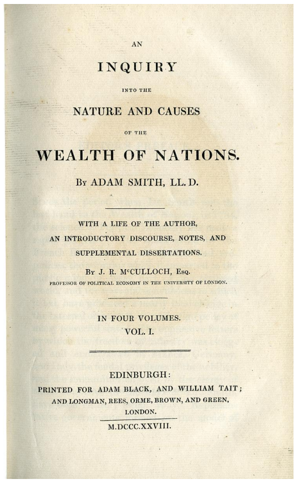
Adaptive behaviour promotes ecosystem stability by damping out oscillations

It is the evolutionary self interest of the “meat in the sandwich” that drives this

What is good for the individual is good for the system ?

Only sometimes





AN
INQUIRY
INTO THE
NATURE AND CAUSES
OF THE
WEALTH OF NATIONS.
By ADAM SMITH, LL.D.

WITH A LIFE OF THE AUTHOR,
AN INTRODUCTORY DISCOURSE, NOTES, AND
SUPPLEMENTAL DISSERTATIONS.
By J. R. M'CULLOCH, Esq.
PROFESSOR OF POLITICAL ECONOMY IN THE UNIVERSITY OF LONDON.

IN FOUR VOLUMES.
VOL. I.

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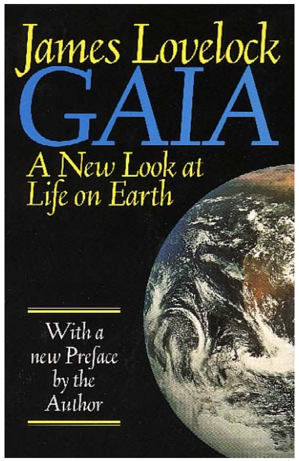

Towards integrated
behavioural, evolutionary and ecosystem ecology

Propositions

If we can devise mechanistic understanding of how specific behavioural options, tempered by environmental conditions, impact the fitness trade-offs faced by individual organisms, then we have a means of predicting rational behaviour.

Such behaviour not only has implications for the organism itself, but has cascading effects through populations, communities and ecosystems.

Emergent properties are manifest across scales from individuals to ecosystems.

⇒ Individual-based plankton ecology