living systems from the Earth to the Cell: principles, models, applications

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collective brainstorming

- what is a system / complex system ?
- what is a non-living / living system ?
- what is a biological / ecological system?
- are there common principles that govern these systems?
- which is the difference between theory, principles and models?

CONTRIBUTION TO THE ENERGETICS OF EVOLUTION*

BY ALFRED J. LOTKA

SCHOOL OF HYGIENE AND PUBLIC HEALTH, JOHNS HOPKINS UNIVERSITY

Communicated, May 6, 1922

It has been pointed out by Boltzmann[1] that the fundamental object of contention in the life-struggle, in the evolution of the organic world, is available energy.[2] In accord with this observation is the principle[3] that, in the struggle for existence, the advantage must go to those organisms whose energy-capturing devices are most efficient[4] in directing available energy into channels favorable to the preservation of the species.

The first effect of natural selection thus operating upon competing species will be to give relative preponderance (in number or mass) to those most efficient in guiding available energy in the manner indicated. Primarily the *path* of the energy flux through the system will be affected.

But the species possessing superior energy-capturing and directing devices may accomplish something more than merely to divert to its own advantage energy for which others are competing with it. If sources are presented, capable of supplying available energy in excess of that actually being tapped by the entire system of living organisms, then an opportunity is furnished for suitably constituted organisms to enlarge the total energy flux[5] through the system. Whenever such organisms arise, natural selection will operate to preserve and increase them. The result, in this case, is not a mere diversion of the energy flux through the system of organic nature along a new path, but an increase of the total flux through that system.

NATURAL SELECTION AS A PHYSICAL PRINCIPLE*

BY ALFRED J. LOTKA

SCHOOL OF HYGIENE AND PUBLIC HEALTH, JOHNS HOPKINS UNIVERSITY

Communicated May 6, 1922

The two fundamental laws of thermodynamics are, of course, insufficient to determine the course of events in a physical system. They tell us that certain things cannot happen, but they do not tell us what does happen.

system. Whether life is present or not, something more than the first and second laws of thermodynamics is required to predict the course of events. And, whether life is present or not, *something* definite *does happen*, the course of events is determinate, though not in terms of the first and second laws alone. The "freedom" of which living organisms avail themselves *under the laws of thermodynamics* is not a freedom in fact, but a spurious freedom[6] arising out of an incomplete statement of the physical laws applicable to the case. The strength of Carnot's principle is also its weakness: it holds true independently of the particular mechanism or configuration of the energy transformer (engine) to which it is applied; but, for that very reason it is also incompetent to yield essential information regarding the influence of mechanism upon the course of events. In the *ideal* case of a reversible heat engine the efficiency is independent of the mechanism. *Real* phenomena are irreversible; and, in particular, trigger action,[7] which plays so important a rôle in life processes, is a typically irreversible process, the release of available energy from a "false" equilibrium. Here mechanism is all-important. To deal with problems presented in these cases requires new methods,[8] requires the introduction, into the argument, of new principles. And a principle competent to extend our systematic knowledge in this field seems to be found in the principle of natural selection, the principle of the survival of the fittest, or, to speak in terms freed from biological implications, the principle of the persistence of stable forms.

For the battle array of organic evolution is presented to our view as an assembly of armies of energy transformers—accumulators (plants), and engines (animals); armies composed of multitudes of similar units, the individual organisms. The similarity of the units invites statistical treatment, the development of a statistical mechanics of which the units shall be, not simple *material particles* in ordinary reversible collision of the type familiar in the kinetic theory, collisions in which action and reaction were equal; the units in the new statistical mechanics will be *energy transformers* subject to irreversible collisions of peculiar type—collisions in which trigger action is a dominant feature:

When the beast of prey A sights its quarry B, the latter may be said to enter the field of influence of A, and, in that sense, to collide with A. The energy that enters the eye of A in these circumstances may be insignificant, but it is enough to work the relay, to release the energy for the fatal encounter. And because evolution works with armies built up of similar units, the seemingly erratic workings of the relay mechanism (in which action and reaction are not equal, and seem subject to no simple general law) are not, in effect, erratic, but range themselves according to law and order, for those species of units, those types of transformers, are picked out for survival, whose mechanism possesses certain definite properties. Thus the principle of natural selection makes its entry into dynamics.

FEBRUARY 15, 1931 PHYSICAL REVIEW VOLUME 37

RECIPROCAL RELATIONS IN IRREVERSIBLE PROCESSES. I.

BY LARS ONSAGER
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tromotive force, which we shall call X_1. In corresponding units the "force" which drives the flow of heat will be:

$$X_2 = -\frac{1}{T}\,\text{grad}\,T,$$

where T denotes the absolute temperature (Carnot). If the heat flow and the current were completely independent we should have relations of the type:

$$X_1 = R_1 J_1$$
$$X_2 = R_2 J_2$$

where R_1 is the electrical resistance and R_2 a "heat resistance." However, since the two processes interfere with each other we must use the more complicated phenomenological relations

$$\begin{aligned} X_1 &= R_{11}J_1 + R_{12}J_2 \\ X_2 &= R_{21}J_1 + R_{22}J_2. \end{aligned} \qquad (1.1)$$

$$\frac{dS}{dt} = \frac{1}{T}(X_1 J_1 + X_2 J_2)$$

TIME'S SPEED REGULATOR: THE OPTIMUM EFFICIENCY FOR MAXIMUM POWER OUTPUT IN PHYSICAL AND BIOLOGICAL SYSTEMS

By HOWARD T. ODUM[1] and RICHARD C. PINKERTON
University of Florida, Gainesville

AMONG THOSE who deal with the many separate sciences, and among those who seek universals common to the various sciences, there is a search to find out why the thousands of known processes are regulated, each one at a characteristic rate. A common denominator has been found in the concept of entropy which permits the comparative study of energy changes. For closed systems natural spontaneous processes are directed toward an entropy increase, so that entropy has been appropriately called "time's arrow."

What has been lacking, however, is a generalization applicable to open systems which would indicate the *rate* of entropy increase. The Second Law of Thermodynamics does not indicate the magnitudes of the rates or explain how open systems are adjusted. If it exists, we need to discover "time's speed regulator." Theories of rate processes are available for

$$P_2 = cf^2X_1^2R(1 - R)$$

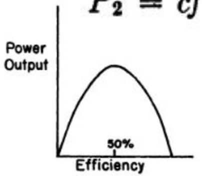


FIG. 2. Power output is given as a function of efficiency for systems where there is no leakage (l) and the efficiency (E) is thus equal to the force ratio (R).

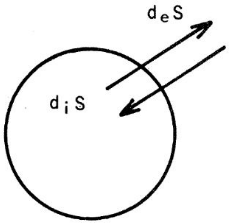
1 Sepember 1978, Volume 201, Number 4358 SCIENCE

Time, Structure, and Fluctuations

Ilya Prigogine

The problem of time (t) in physics and chemistry is closely related to the formulation of the second law of thermodynamics. Therefore, another possible title of this lecture could have been "The Macroscopic and Microscopic Aspects of the Second Law of Thermodynamics."

It is the main thesis of this lecture that we are only at the beginning of a new development of theoretical chemistry and physics in which thermodynamic concepts will play an even more basic role. Because of the complexity of the subject, I shall limit myself here mainly to conceptual problems. The conceptual

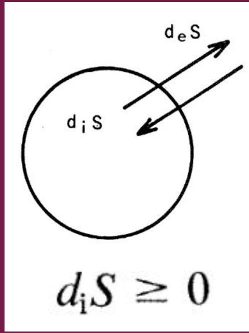


$$d_iS \geq 0$$

general thermodynamic theory

- thermodynamic forces and flows, entropy production
- free energy and complexity
- heat engines, Carnot and maximum power limits
- energy transformations and energy hierarchy

thermodynamic flows and forces, entropy production

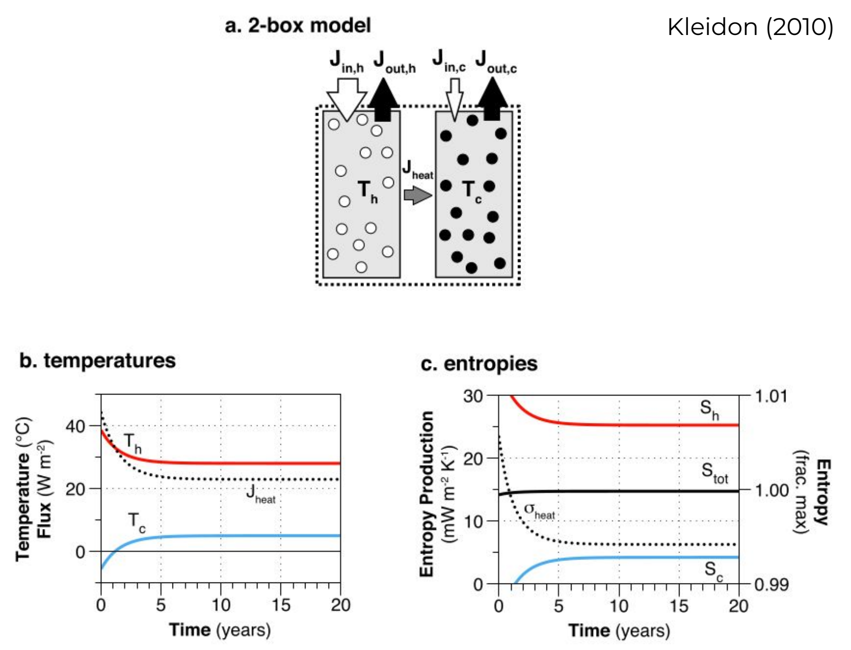


To extend thermodynamics to nonequilibrium processes, we need an explicit expression for the S production. Progress has been achieved along this line by supposing that even outside equilibrium S depends only on the same variables as at equilibrium. This is the assumption of "local" equilibrium (2). Once this assumption is accepted, we obtain for P, the entropy production per unit time,

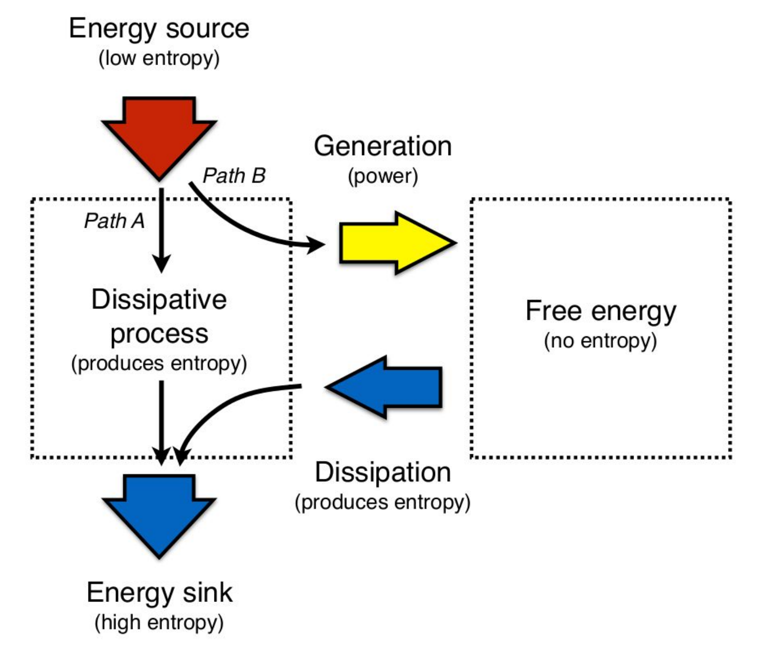
$$P = \frac{d_iS}{dt} = \sum_{\rho} J_\rho X_\rho \geqq 0 \qquad (4)$$

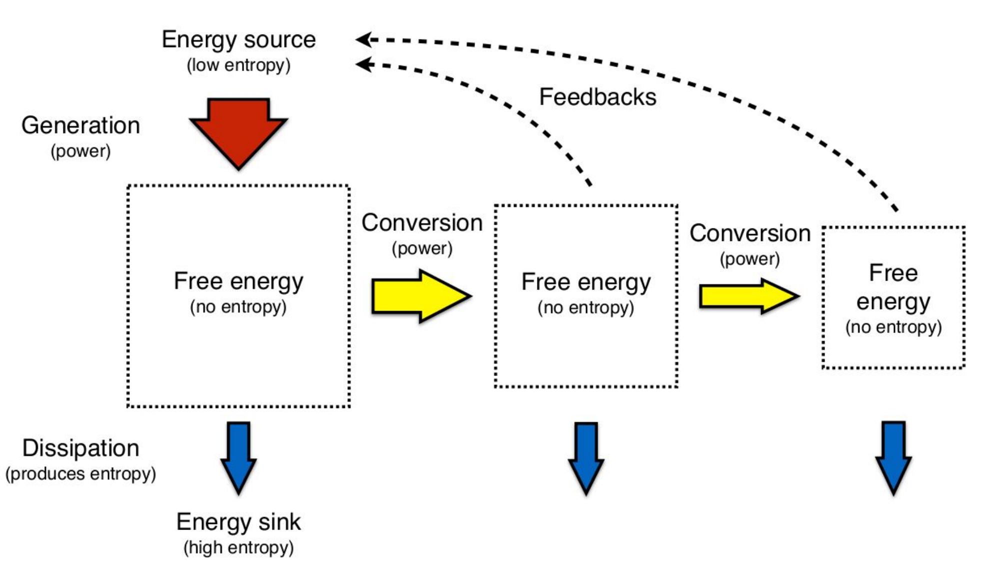
where the J_ρ are the rates of the various irreversible processes ρ involved (chemical reactions, heat flow, diffusion) and the X_ρ are the corresponding generalized forces (affinities, gradients of temperature, gradients of chemical potential). Equation 4 is the basic formula of macroscopic thermodynamics of irreversible processes.

Prigogine (1978)



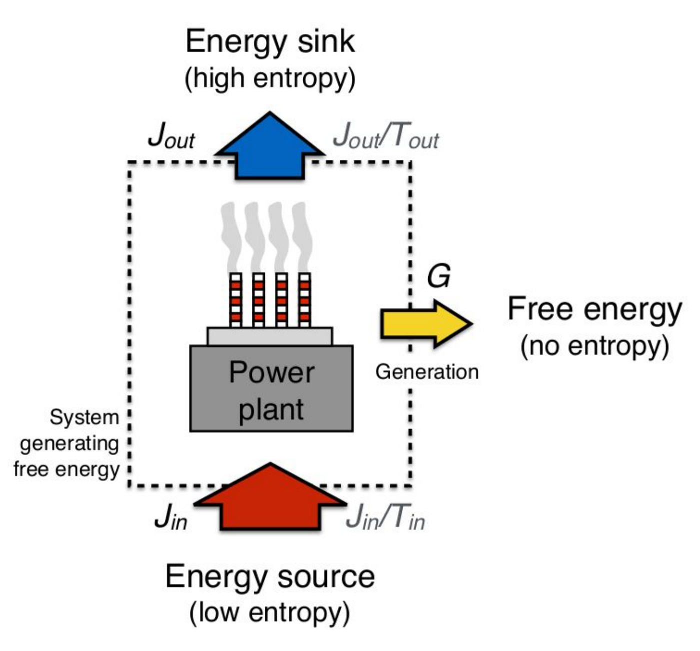
free energy and complexity

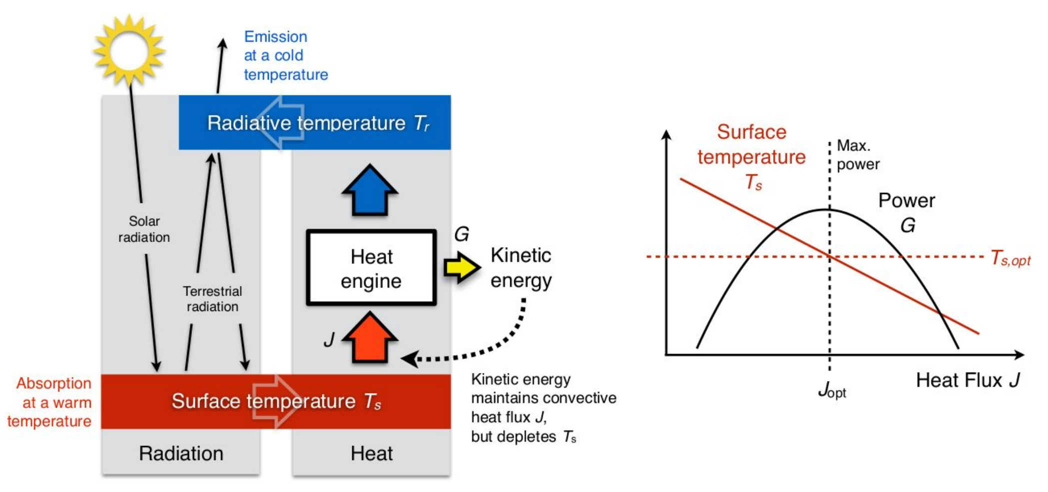




Kleidon (in press)

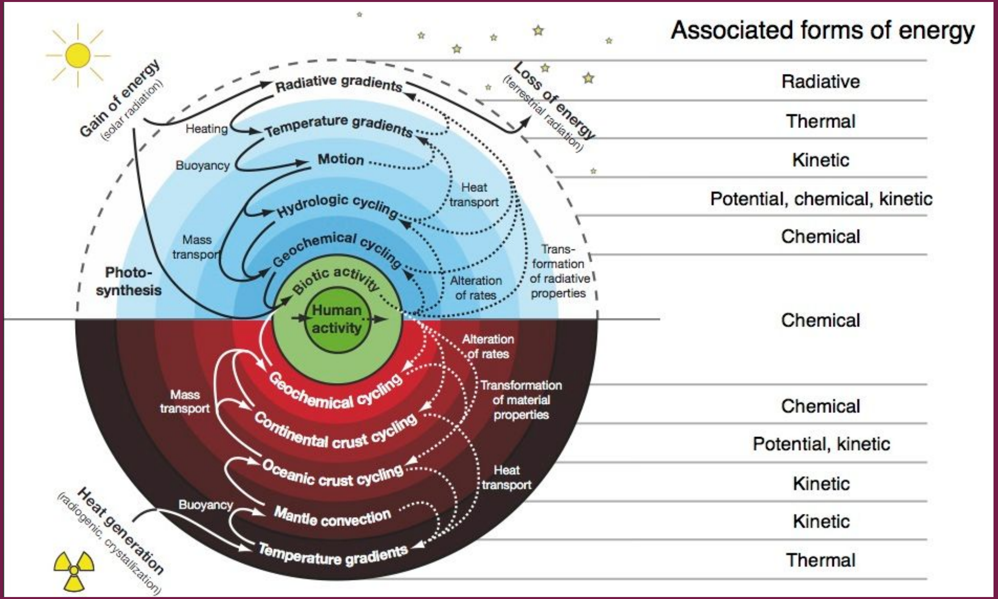
heat engines, Carnot and maximum power limits

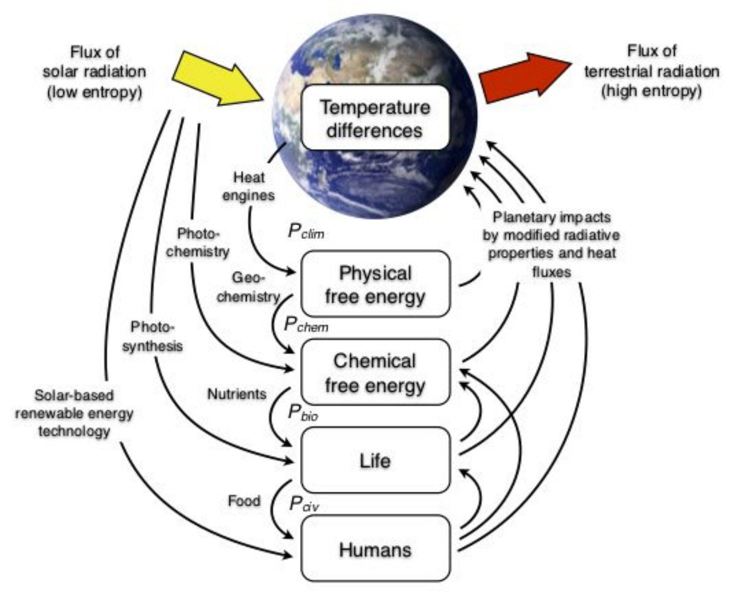




Kleidon (2016)

energy transformations and energy hierarchies



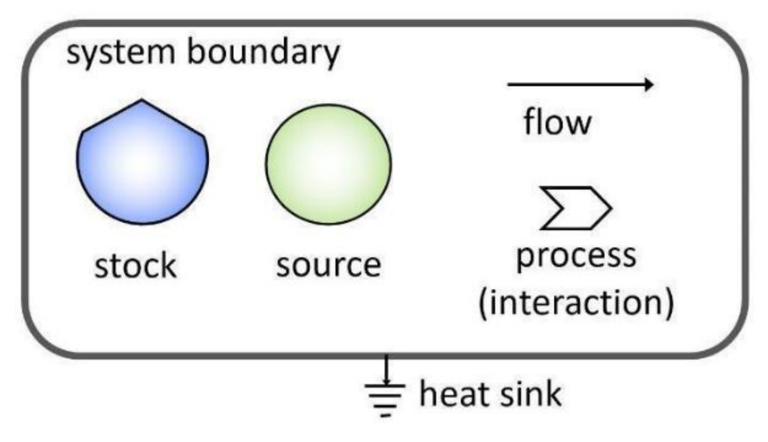


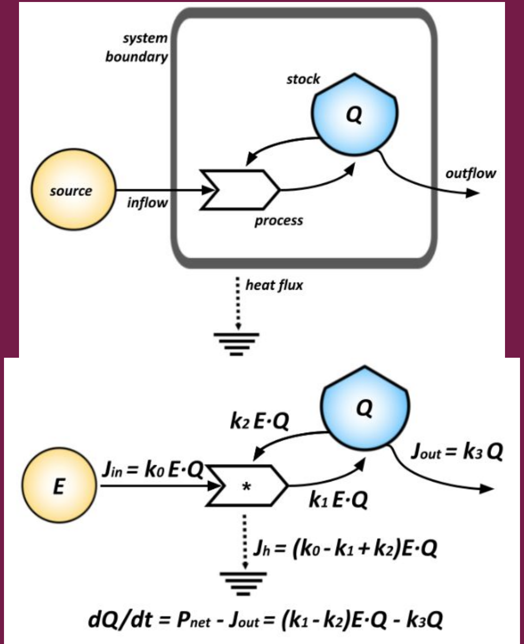
Kleidon (2016)

energy system language & models

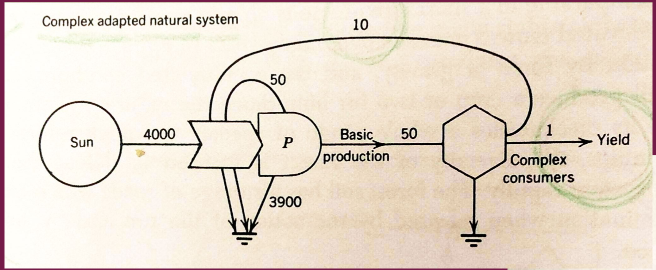
- stock-flow formalism
- growth, self-regulation and stability
- competition for maximum power and evolution
- ecosystems, complexity and energy hierarchies
- systems

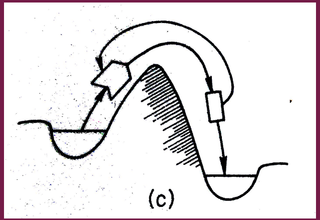
stock-flow formalism

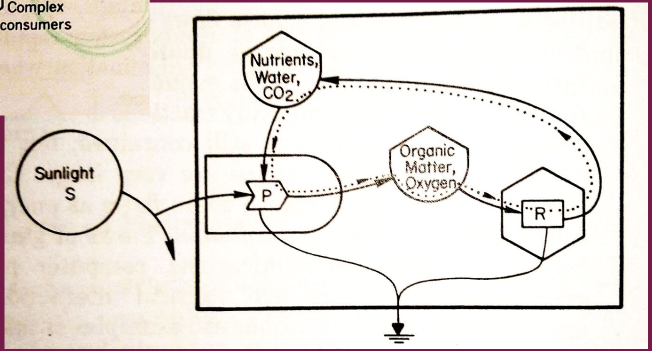


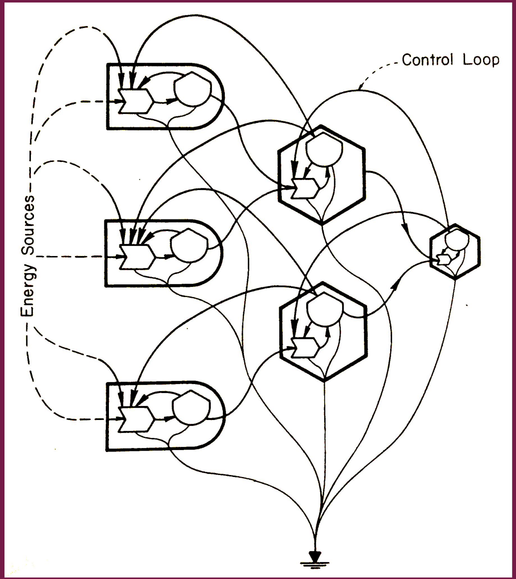


growth, self-regulation and stability



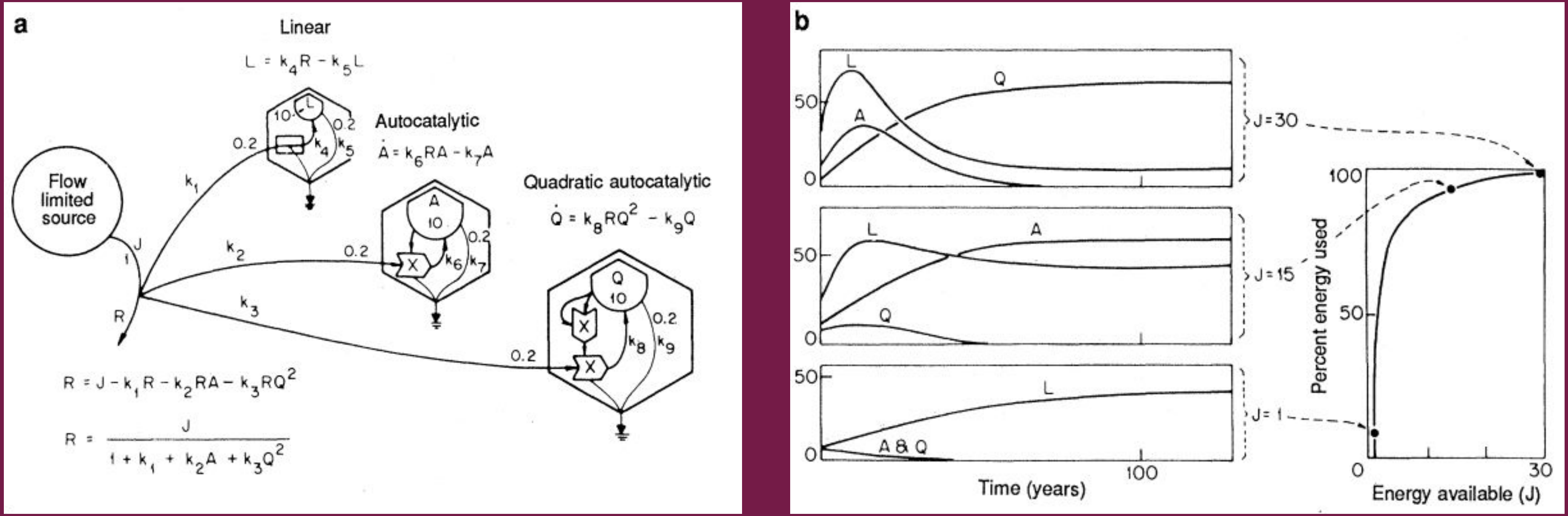






Odum (1970, 1983)

competition for maximum power



Odum (1983, 1988)

ecosystem, complexity, energy hierarchy, evolution

The Strategy of Ecosystem Development

An understanding of ecological succession provides a basis for resolving man's conflict with nature.

Eugene P. Odum

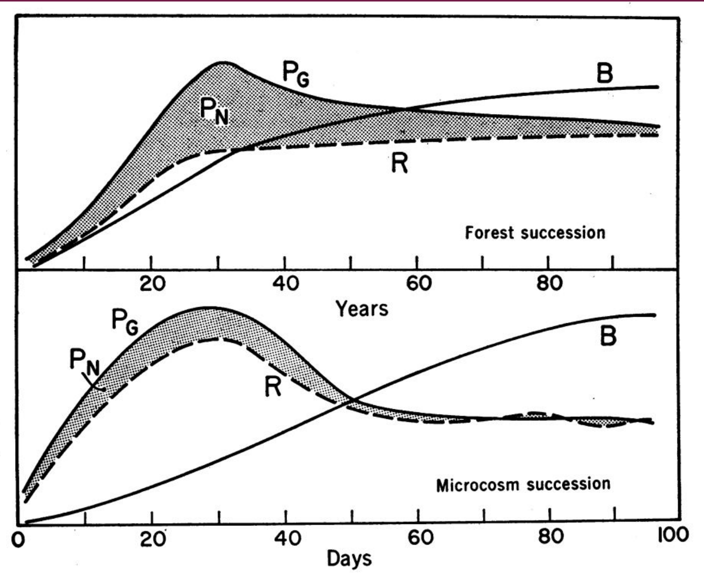
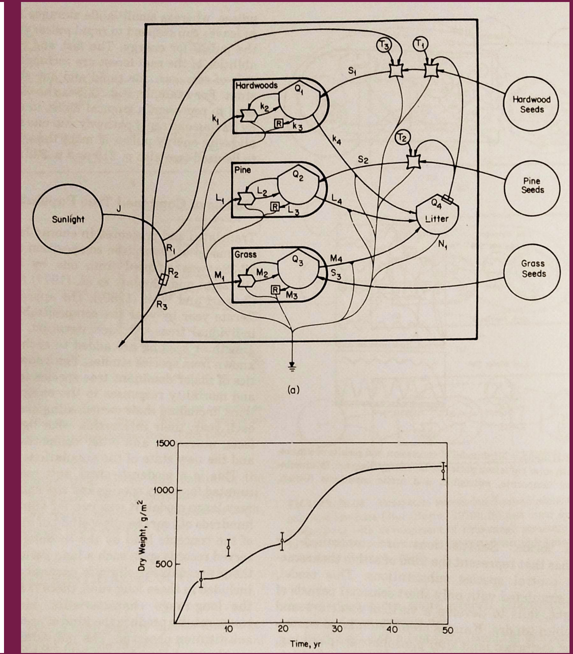


Fig. 1. Comparison of the energetics of succession in a forest and a laboratory microcosm. P_G, gross production; P_N, net production; R, total community respiration; B, total biomass.

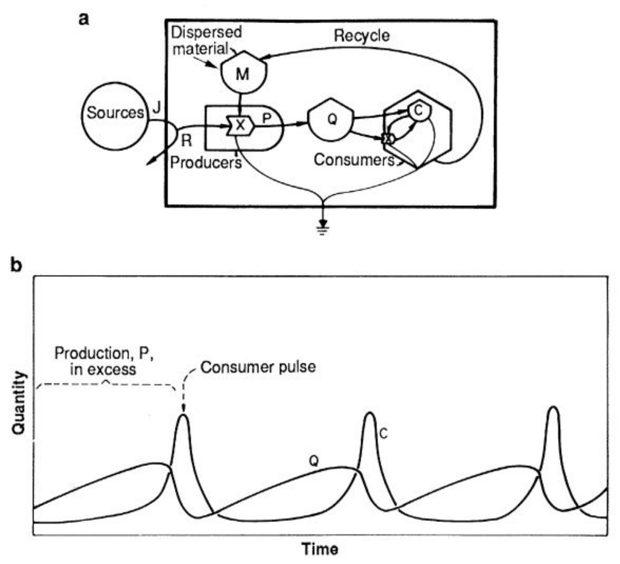


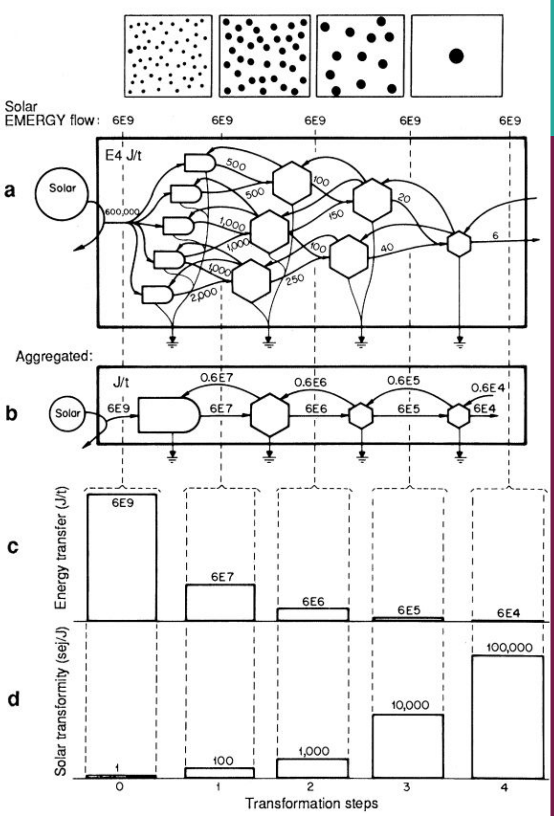
ecosystem, complexity, energy hierarchy, evolution


Articles

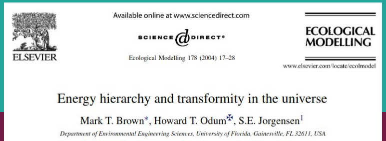
Self-Organization, Transformity, and Information

Howard T. Odum





ecosystem, complexity, energy hierarchy, evolution



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Energy hierarchy and transformity in the universe

Mark T. Brown*, Howard T. Odum, S.E. Jorgensen[1]
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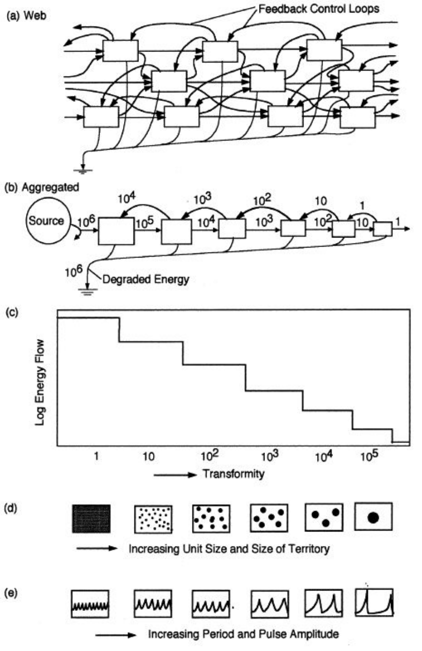
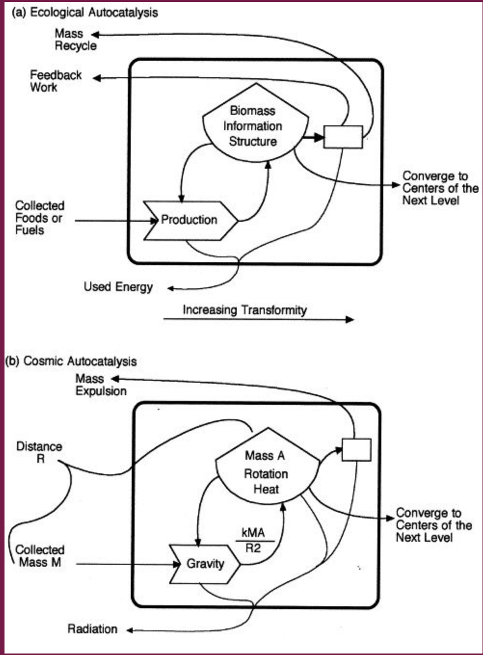
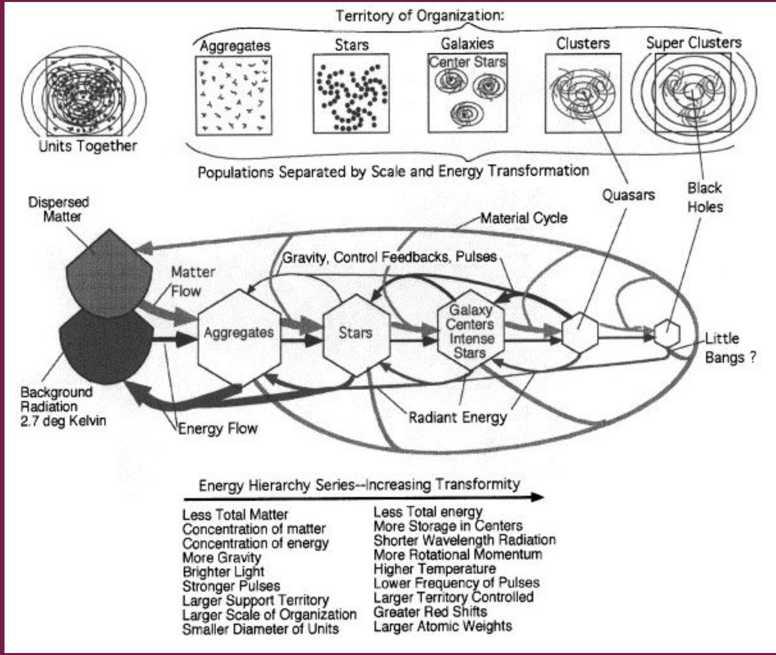
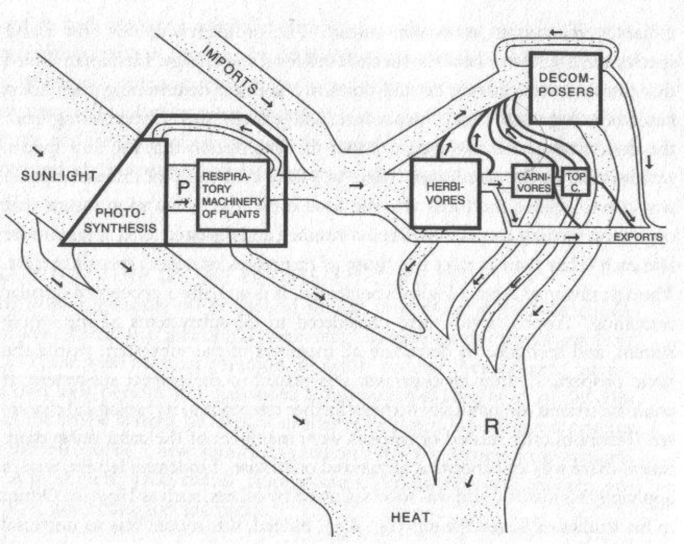


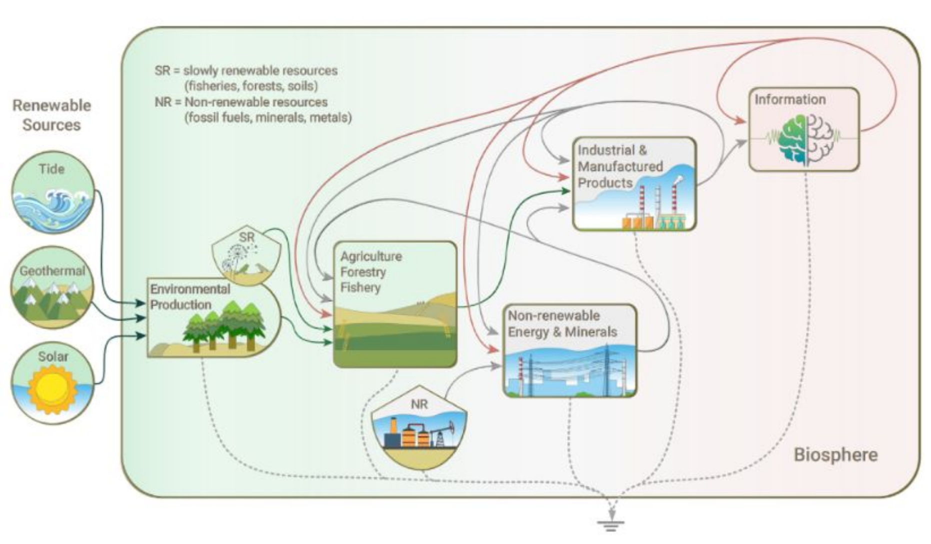




systems

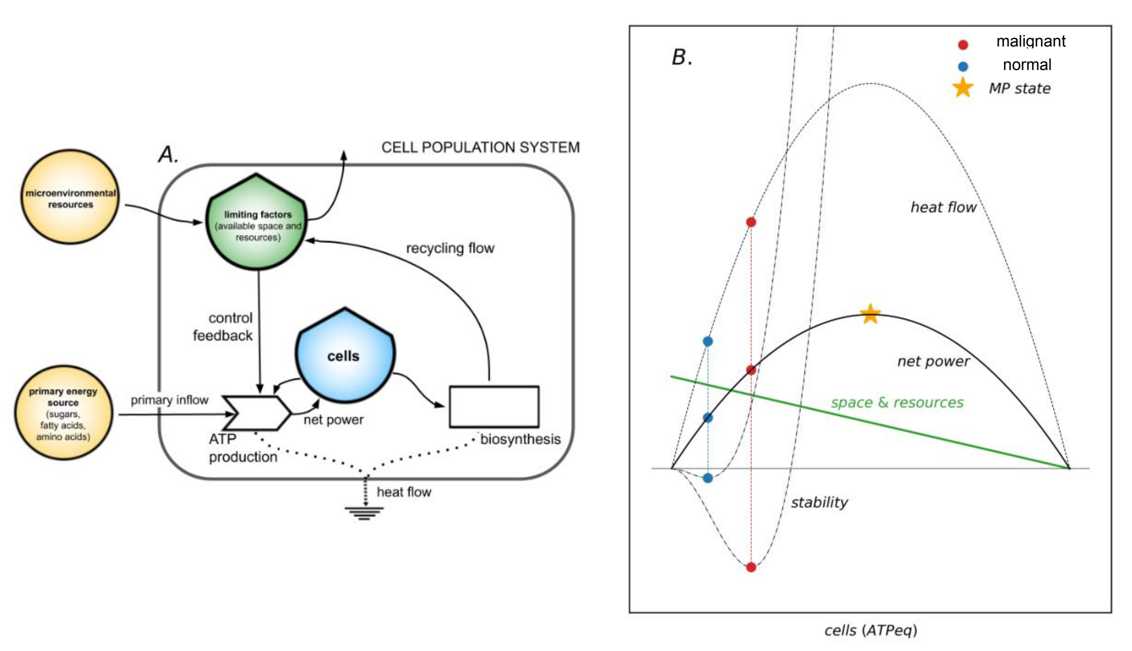


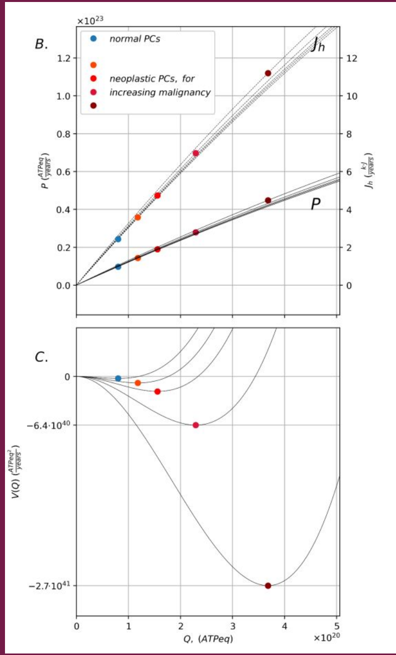
Odum (1970)



Liu+ (2021)

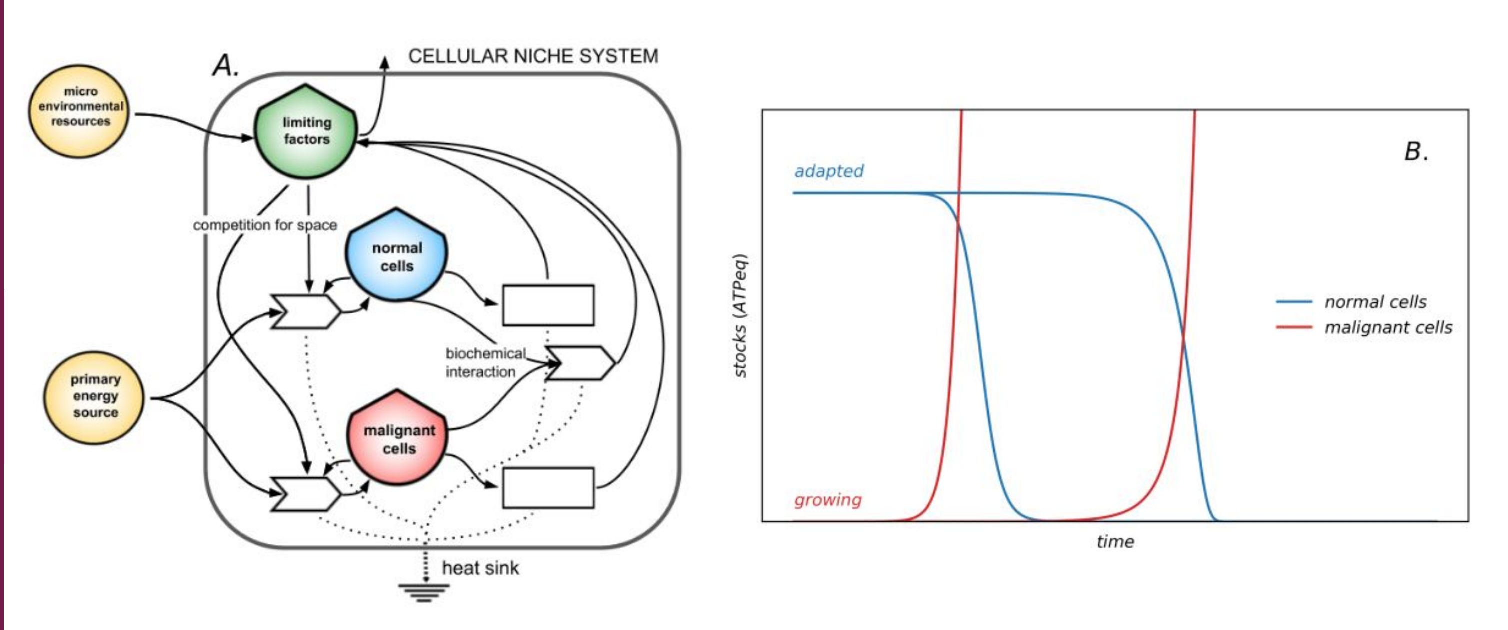
cancer ecology and evoution



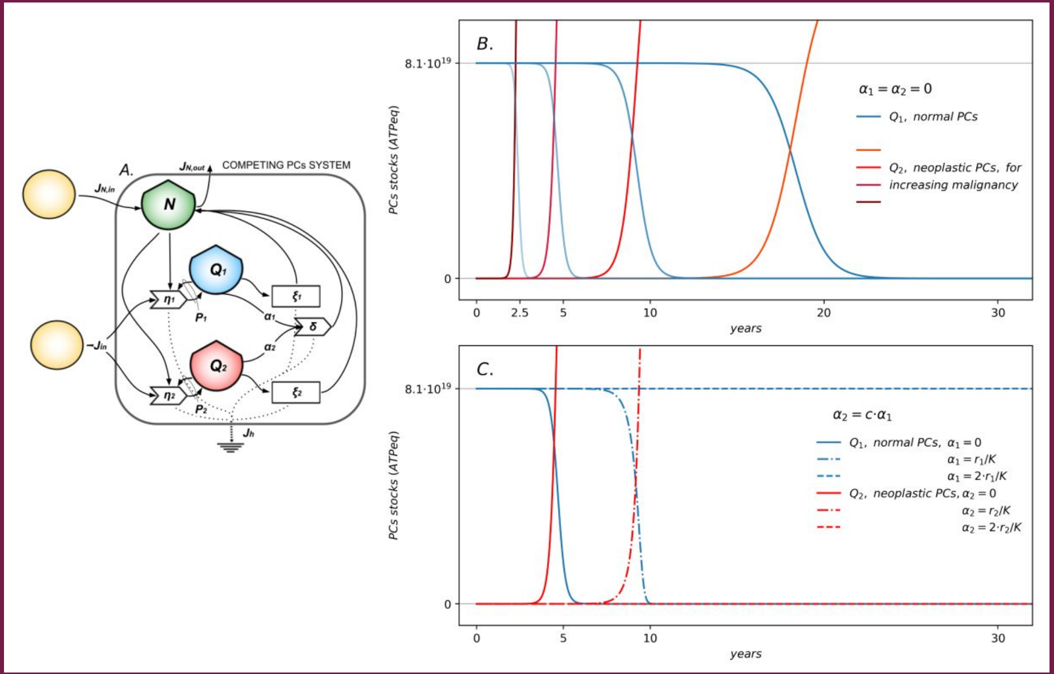


Conte+ (in review)

cancer ecology and evolution



cancer ecology and evolution



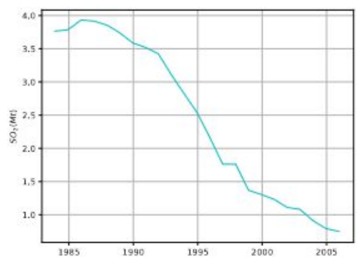
$$\frac{dQ_1}{dt} = P_1 - R_1 - I_1 = r_1 Q_1 \left(1 - \frac{Q_1}{K} - \frac{Q_2}{K}\right) - \frac{Q_1}{\tau_1} - \alpha_1 Q_1 \cdot Q_2$$

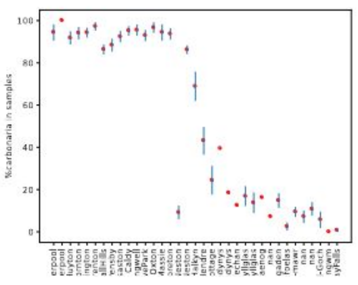
$$\frac{dQ_2}{dt} = P_2 - R_2 - I_2 = r_2 Q_2 \left(1 - \frac{Q_1}{K} - \frac{Q_2}{K}\right) - \frac{Q_2}{\tau_2} - \alpha_2 Q_1 \cdot Q_2$$

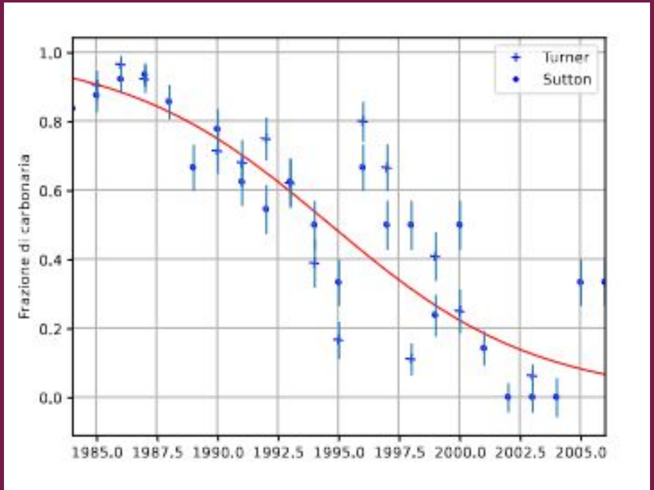
$$N = K - Q_1 - Q_2$$

population ecology and environmental change

$$\begin{cases} \dot{x}_1 = r_1 x_1 \left(1 - \frac{x_1}{k_1} - \frac{\alpha_{12}}{k_1} x_2\right) \\ \dot{x}_2 = r_2 x_2 \left(1 - \frac{x_2}{k_2} - \frac{\alpha_{21}}{k_2} x_1\right) \end{cases}$$







Leo, Modelli di evoluzione di Biston Betularia in risposta alle emissioni inquinanti nel Regno Unito