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# LIMITS OF INFORMATION AND BIODIVERSITY*

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## Introduction

In our times the information processing of human society seems to accelerate, but the genetic information content of the biosphere's biodiversity seems to be declining. Considering both kinds of information and their thermodynamics, are there limits to information? By considering fundamentals, both kinds of information can be placed on a common basis and related to the principles of economics. With these concepts we can try to anticipate what role information and biodiversity will play in fitting the human economy to the biosphere symbiotically, the immortal design that prevails by maximizing performance[1].

The mutual reinforcement of environment and economy supporting and using information is suggested with an energy systems diagram (Figure 1). It is called an energy systems diagram because all the energy inflows are accounted for in outflows or storages, showing the used energy (degraded and unable to do more work) exiting at the bottom of the diagram.

Figure 1a has energy transformations of the block on the left to support the block on the right that feeds back actions to the left that reinforces intake *and* efficiency. This is the essence of design required by the 4th energy law: self organization for maximum empower[1]. On the

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[1] Alfred Lotka in his National Academy of Science papers in 1922 suggested the maximum power principle as the 4th law of thermodynamics. However, "maximum power" might imply that lower parts of the energy chains prevail over higher levels, since there is more energy flow at lower levels. Recognizing that energies of different kind cannot be equated regarding their work, we have clarified the principle as the

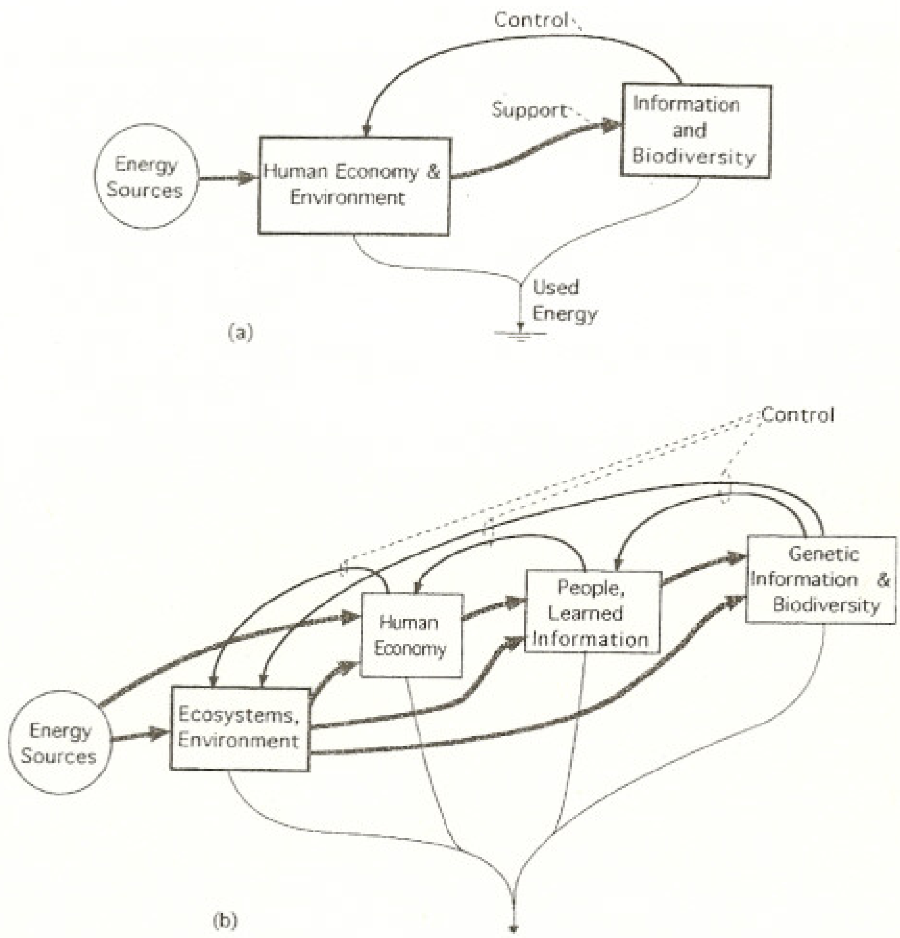


Fig. 1: Energy systems diagram of information of two kinds in reinforcing symbiosis of the global combination of economy and environment. (a) The basis for information and its role in reinforcing empower; (b) the reinforcing roles of learned and inherited information.

right genetic information and biodiversity are supported by and control the economy of humanity and nature.

Dissecting the system further, Figure 1b relates the economies of nature and humans to learned information and genetic information. Genetic information includes the biodiversity of nature and the genetic variety in humankind. As the diagram shows, all four boxes require

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maximum empower principle (Odum, 1996), which means that the principle applies equally to all levels in energy hierarchy.

each other. Pathways from left to right show the support of one box for another. The feedback pathways to the left show the reinforcement by information exerting control. The left-right position of items is in order of position in a universal energy hierarchy measured by transformity, explained next. The pathway from environment to humans acknowledges the "biophilia" hypothesis that humans need direct environmental influences.[2]

## Concepts and Measures

To understand information we need to use concepts of universal energy hierarchy, EMERGY (spelled with an "m"), transformity, empower, and emdollars. These were defined earlier, used in the literature, and recently summarized in the book: Environmental Accounting, EMERGY and Decision Making (Odum, 1996). Table 1 has definitions[3].

*Table 1: Summary of Definitions*

| | |
|---|---|
| Available Energy | Potential energy capable of doing work and being degraded in the process (units: kilocalories, joules, etc.) |
| Useful Energy | Available energy used to increase system production and efficiency |
| Power | Useful energy flow per unit time |
| EMERGY | Available energy of one kind previously required directly and indirectly to make a product or service (units: emjoules, emkilocalories, etc.) |
| Empower | EMERGY flow per unit time (units: emjoules per unit time) |
| Transformity | EMERGY per unit available energy (units: emjoule per joule) |
| Solar EMERGY | Solar energy required directly and indirectly to make a product or service (units: solar emjoules) |
| Solar Empower | Solar EMERGY flow per unit time (units: solar emjoules per unit time) |
| Solar Transformity | Solar EMERGY per unit available energy (units: solar emjoules per joule) |

[2] Humans genetically constituted to require direct ecosystem contact and support (E.O. Wilson). My own version was given earlier (Odum, 1962).

[3] Environmental Accounting, EMERGY and Decision Making (Odum, 1996).

*Energy Hierarchy*

We often use a food chain as an example to explain the steps of energy transformation from dilute, abundant energy of sunlight into lawn grass, and that into grazing sheep and that into human food, etc. For this paper, it is more appropriate to explain the concepts with an energy chain leading from environmental sources to information. The cartoon in Figure 2a shows the concept of energy hierarchy as a pyramid where a broad basis of low quality energy at the bottom is being transformed in successive stages to develop and sustain biodiversity and information at the top.

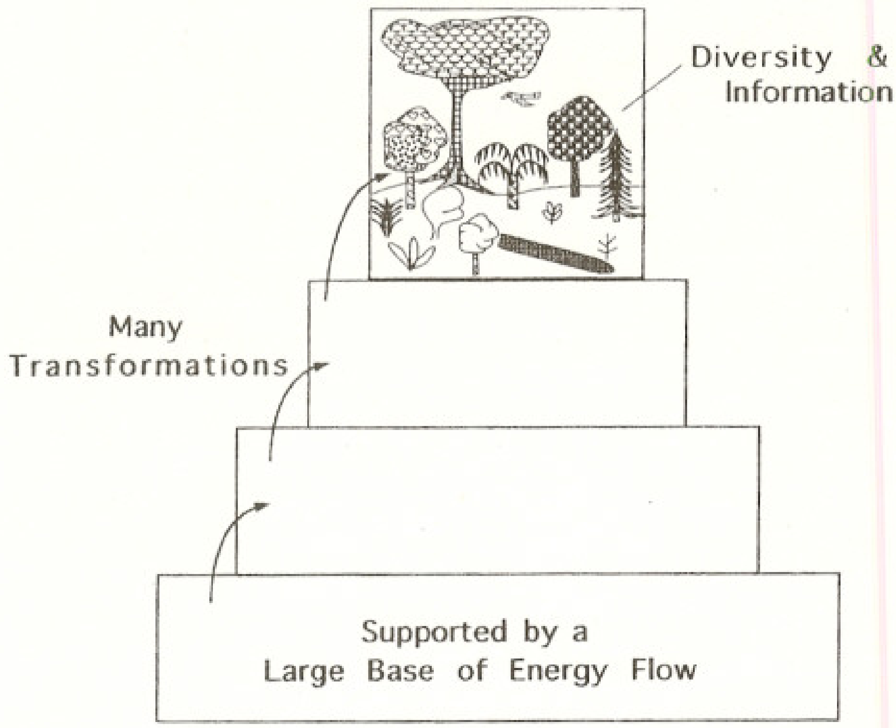


Fig. 2: Cartoon showing pyramid of energy transformations necessary to support information and biodiversity

In Figure 3, for purposes of relating information, economies, and environment we cluster the four stage chain from Figure 1b into a simple chain and add approximate estimates of the energy flows. Because the second energy law requires most of the available energy to be degraded in any transformation to make another kind of energy, the energy flow through each level drops rapidly (Figure 2b). The bar graph shows the way the transformed energy becomes less but more concentrated in a smaller area. On the far right humans and higher organisms are information centers that occupy a small area. However, the territory contributing to their support and the territory of their influence is the whole territory of the system.

In a military or industrial hierarchy many people at a lower level support and are controlled by a few people at the next higher level. Energy is like that. In the example in Figure 3, as everywhere else in the universe, many units of energy at one level are required in transformation to make one unit of available energy at the next level. The higher level uses the special properties of the transformed energy in feedback to reinforce the lower level processes with more energy (reinforcing pathways go from right to left in Figure 1 and Figure 3).

### *EMERGY and Empower*

Energies of different kinds should not be added to measure useful work. It is incorrect to add a joule of sunlight, a joule of electricity and a joule of human thinking as if they were equivalent. To put energy flows on a common basis, all are expressed in units of one kind of available energy previously used up to make them and given the name EMERGY, spelled with an "m". EMERGY is a common measure of previous work in generating real wealth. Its unit is the emjoule (Table 1). In this paper we use *solar* EMERGY as the common measure of useful work and real wealth.

The global solar EMERGY flow supporting the energy chain to information in Figure 2b is 9.4 E24 solar emjoules per year[3]. Defined as what was previously required, the solar EMERGY is not changed as it accompanies the transformations along the chain. In that diagram the solar EMERGY flow is the same for each stage of energy flow. Another word for EMERGY flow is *empower*, defined as the EMERGY flow per unit time (Table 1).

### *Transformity*

Transformity of an energy flow or storage is defined as the EMERGY per unit energy. Solar transformity of something is its solar EMERGY divided by its energy. In Figure 3c the solar transformity rises sharply with each transformation (same EMERGY decreasing energy). The

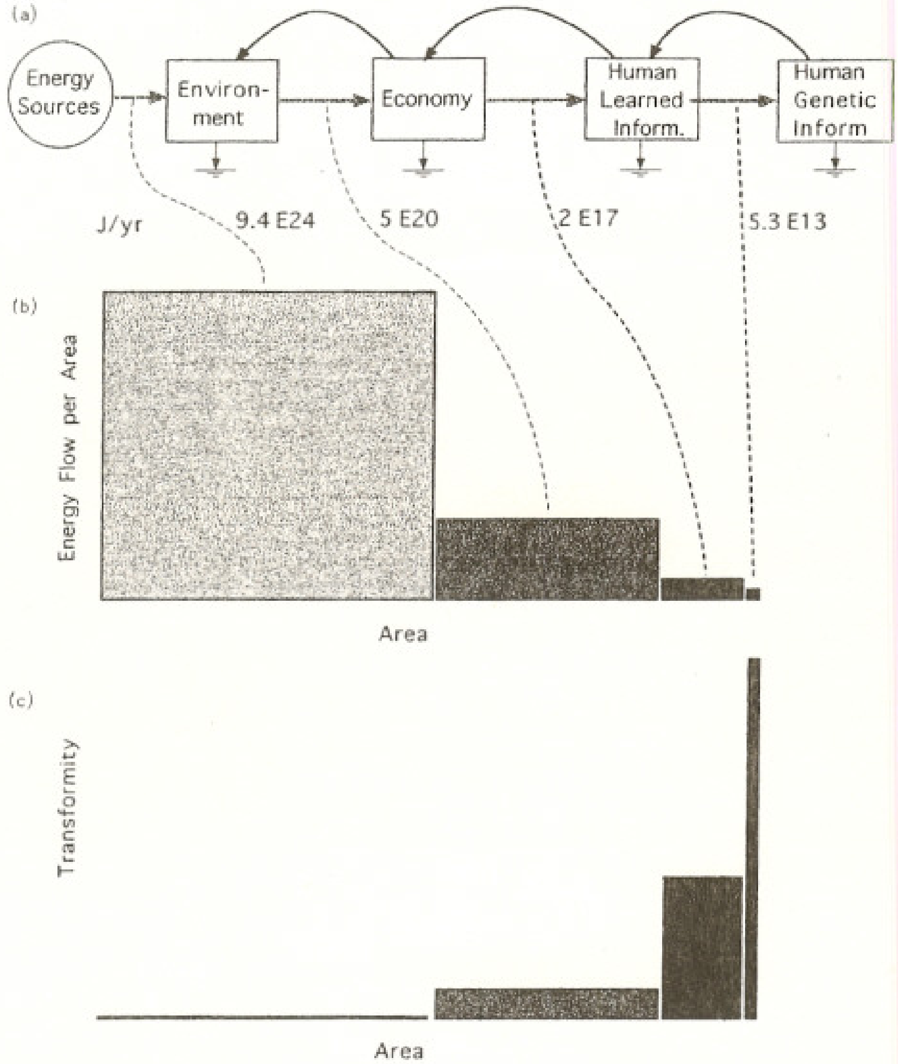


Fig. 3: Energy concepts and the basis for global information. (a) Simplified energy chain; (b) empower flow through the information chain; (c) transformities of stages in energy transformation chain (not drawn to scale).

transformity measures position in the energy hierarchy. It is a measure of energy quality. As Figure 3 shows, transformities for information are very high.

A plot of energy flow as a function of transformity is useful for relating transformities. Figure 4 is on a double log plot. The energy hierarchy is represented by a line from upper left to lower right, as energy remaining decreases and transformity increases.

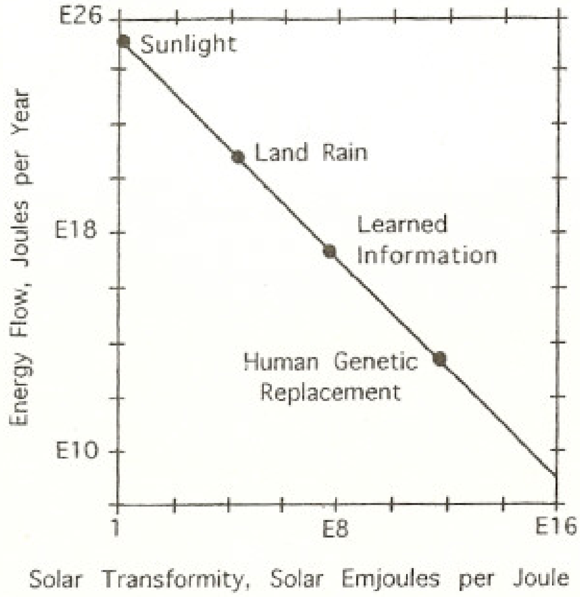


Fig. 4: Graph of empower as a function of transformity on double logarithmic plot (energy quantity and quality). Points are from four levels in the energy chain in Figure 3.

Points #1 Sunlight and #2 Rain from Odum (1996).

Point #3 Learned information: Assume 1% of the human energy flow;
Global EMERGY flow 9.44 E24 sej/yr
Energy flow in human learned information processing calculated:
(5.2 E9 people)(2500 kcal/d)(365 d/yr)(4186 J/kcal) (0.01)
= 1.98 E17 J/yr
Transformity calculated:
(9.44 E24 sej/yr)/(1.98 E17 J/yr) = 4.76 E7 sej/J

Point #4 Human genetic information for replacement time of one year;
DNA per person: 2.1 mg/g Canoy (1970) or 28.6 g DNA/150 pound person
DNA Energy flow calculated:
(28.6 g DNA/person)(5 kcal/g)(4186 J/kcal)(5.2 E9 people)/(60 yr)
= 5.28 E13 J DNA/yr

### *Emdollars*

Emdollars are the part of the gross economic product of an area due to an EMERGY contribution (Table 1). From an analysis of the total empower use by a nation, the ratio of EMERGY to money flow may be calculated. For the United States in 1996 it was about 1.3 solar emjoules per dollar. To calculate the emdollar value of something, divide its EMERGY content by the EMERGY/money ratio (emjoules/dollars) for that year.

## THE EMERGY OF INFORMATION

Using traditional concepts, information was defined as

*the components and configuration of a system (real or imagined).*

Information may take the form of words, codes, formulas, diagrams or art. Information can be measured quantitatively as the EMERGY required for the development and maintenance of their configurations[4]. For these purposes several levels of information are assembled as Table 2.

| Table 2: Kinds of Information in Order of Increasing Transformity |
| --- |
| An Untested Configuration |
| Useful Configuration in an Operation |
| Extracted Configuration |
| A Copy |
| Copies Distributed for Sharing |
| Copies Put into Shared Use |
| Item Sustained by an Information Circle |
| Emergent Item with Innovations |
| First or Last copy of a Proven Item |

It takes very little EMERGY to assemble a set of parts and connections that can't do anything. Much more EMERGY is required to develop useful information capable of doing something. Information is useful if it feeds back as an amplifier contributing to maximum empower (Figure 1a). Information can be useful by helping operate other information. For example, art may help people function.

### *Information in Operation and Extracted Information*

The same information can be embedded in a system that the information is operating, or extracted in a systems language as dormant information. If the extracted information is complete and without serious error, the extracted information can be used to restore and operate a real system again.

[4] EMERGY in information and biodiversity (Odum, 1987, 1988a and b, 1994a and b, 1996).

For example, the details of an operating radio can be written down on paper, including a wiring diagram, specification of parts, connections, and numerical properties. The plan can be used to build another radio to run again.

Another example is the configuration of DNA (genetic matter in living cells) which is shared by all the cells operating a tree, but which may be extracted separately and stored in dormant form in a seed. The seed can be used to grow a tree again.

Another example is the set of species operating an ecosystem adapted to an environmental condition. Representatives of these species can be isolated from that system as we observe in botanical gardens and zoos. The ecosystem can be restored to that same environmental condition by recombining the set of species and allowing self organization to develop.

Another example is the cultural knowledge in human heads which adapts a group of people to operate a society in a region, but may be extracted into memory by an elder or in book form by an anthropologist. In simpler times, cultures were often reestablished from the knowledge of a few colonizing migrants.

### *Depreciation and the Energy Content of Information*

Information requires a carrier, either the operating system or the material of the extract such as the paper, seed, books, computer disk, sound waves, and mental structure. There is a small amount of available energy in all information (in the information carrier). The letters on a page are away from thermodynamic equilibrium and thus can depreciate, losing their form. Information cannot be stored without a tiny available energy in the carrier, and thus can't be stored without spontaneous depreciation, which develops errors and information loss. Therefore, information cannot be sustained except by continual replacement and correcting of errors.

### *A Discriminating Distinction Between Information and Other Things*

What makes information configurations different from other storages is that :

*Information is something more easily copied than regenerated anew.*

With its intricate detail, information is normally corrected by discard and replacement. Copying information to replace lost copies is pictured in Figure 5b, for comparison with ordinary storage of energy and materials and their replacement in Figure 5a. A storage of sugar is replaced by an inflowing supply, but information has to be duplicated from templates. Information can only be efficiently preserved by building a template and maintaining an unbroken sequence of copying and correcting it.

### *Information Copies*

Very little EMERGY is required to make a copy (Figure 5b). Copying of a page on a copying machine is cheap. Little of a tree's EMERGY goes into the making a copy of a tree's genetic template that goes into a seed.

### *Sharing Information*

Arranging for information to be shared over an area takes more resources. The copies have to be made, then distributed, and means found for the copies to be accepted into storage or use. Shared information has more EMERGY.

### *Transformity and Rarity, Archaeology*

As the number of copies decreases and thus the energy of the carrier is less, the transformity increases. An example from archaeology is the preservation of information of past human societies. As time goes by, the number of tablets with inscriptions remaining gets less and less, whereas the EMERGY is that of the original information at the start plus the contributions of the environment during preservation. The transformity increases.

### *Restarting Operation from Extracted Information*

Returning dormant information into operation requires the plan and a source of empower for reconstruction of the system and its operation.

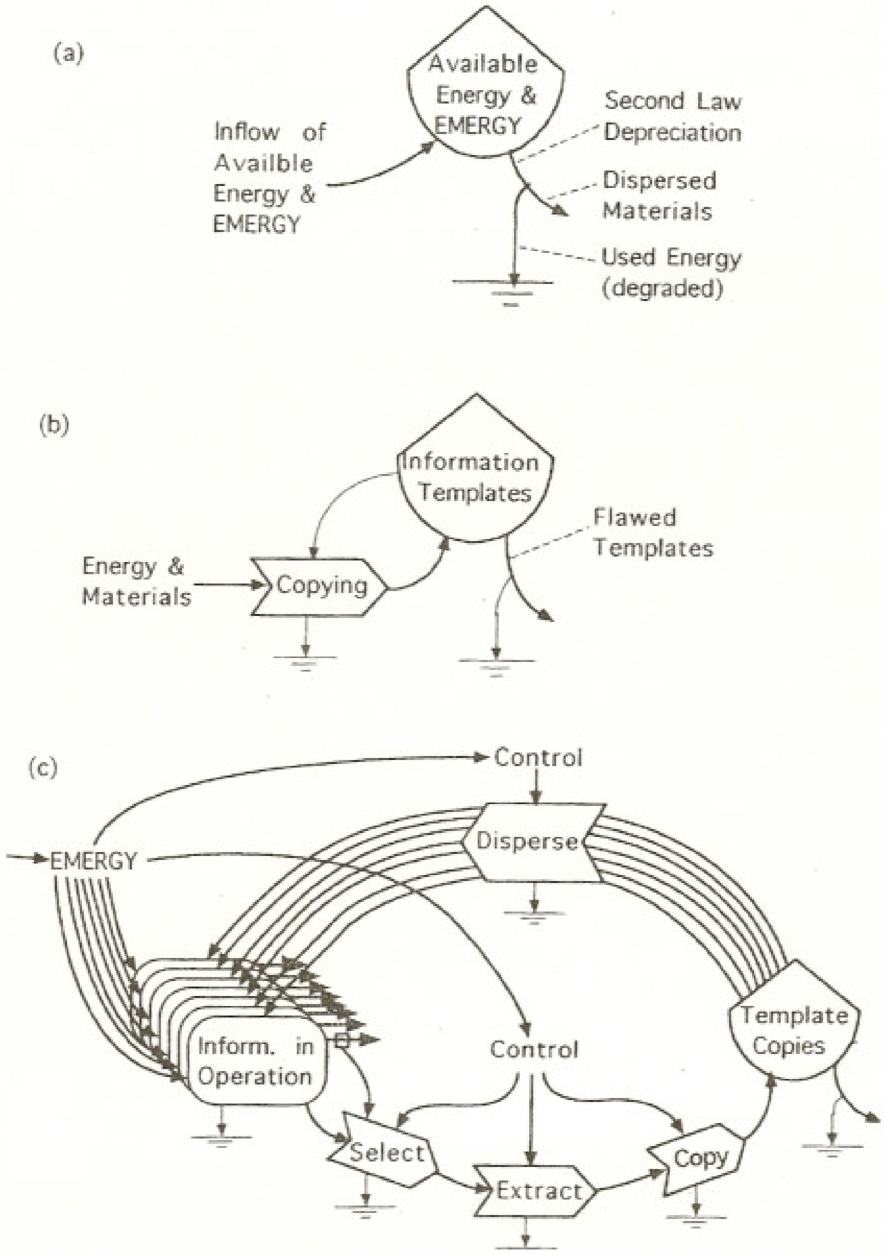


Fig. 5: The depreciation and replacement of information. (a) Typical storage of available energy or concentrated materials; (b) storage of information being replaced in the short term by simple copying of the template; (c) long term maintenance of useful maintenance using an information circle.

### *Maintaining Information With a Circle*

The information maintenance arrangement in Figure 5b requires duplicating from a unit without error, but all units eventually develop errors (second law depreciation). Simple copying is not long sustainable since there are no easy ways to correct a complex template. Therefore there has to be copying and testing on a larger scale using a *circle of information*[4]. The essential parts of an information maintenance circle include copying, distributing, testing in real systems operation, and selecting for best performance (Figure 5c). In poorly organized systems there can be *self selection* by that operation that competes better. Better developed systems have *organized selectors* such as markets or hawks. Then the circle runs again. The long term maintenance of useful information requires extensive empower to sustain the necessary populations and processes in its processing circle (Figure 5c).

### *Innovation*

The information circle can innovate useful information capable of doing something new when more choices and selection are provided than necessary to maintain existing information. Where more EMERGY is available, more innovation can result.

## INFORMATION, SPATIAL CONCENTRATION, AND PULSING

In many sciences it is useful to place phenomena on the scale of size and time. Molecules and micro-organisms have small territories and turn over rapidly, whereas large animals and geological events have larger scales and slow turnover times. Small items have rapid oscillations, whereas the larger scale units have slower oscillations. Transformity also measures scale with small values for small rapid processes and large values for the large slow ones. In Figure 4 items are arranged from left to right in order of increasing scale. On these scales, information is to the right of supporting environmental and economic processes which that information controls when operating (Figure 1a).

Kinds of information can be placed on a transformity scale also. A rainforest example of the several levels of information which we distinguished for EMERGY evaluation purposes (Table 2) is arranged from

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[5] DNA in ecosystems was reviewed and compared by Canoy (1970).

left to right in Figure 6. With each transformation the energy decreases, the transformity increases, and the territorial area required increases. Note the trivial requirements of copies, but much larger requirements to maintain the information cycle of a population necessary to select--duplicate-distribute-operate--select again (Figure 5c). If the information is lost there is an even larger requirement to regenerate it anew from whatever remaining information is most similar. The highest transformity is that of the last copy available. Its energy is tiny and its EMERGY is that of the inputs to the original cumulative development. Example of evolving a species is included in Figure 6.

Most species develop locally, their populations have small territories, and on an evolutionary time scale they are transient. Having many continents and islands allows more kinds of species to develop and coexist without competing. Local species (S's) are on the left in Figure 7. When innovations develop among species, the new genes may spread and displace others, eventually becoming a mainstream of other evolution with a large territory and longer turnover time. The innovative shared characteristics (Sh's) become part of the larger scale shared by many species. That information has a higher transformity.

### *Spatial Hierarchy Required for Maximum Reinforcement*

Consider the universal energy hierarchy to account for the spatial centers of concentration of cities and environment (Figure 8). With energy decreasing through the energy transformations of the energy hierarchy, the energy available to feed back and reinforce the productive basis of the chain gets less and less. To have the effect necessary to reinforce the chain, it has to concentrate its transformations feeding back into a small center. We observe this in the formation of cities and within cities in the central district of information processing and communication. Leaves and roots converge to the trunks of trees. In animals the organism operates a territory by moving around. For example, the spider carries the information center of the web. Where structures are massive, animal cities develop, such as oyster reefs and coral reefs. The information and managerial center is in the reef's higher animals (fishes). Figure 8 has the results of calculating what the spatial concentration in an energy chain has to be for reinforcement where there is a 10% transformation for each level of hierarchy. At the end of the chain the area occupied is a small percentage of the territory from which the center draws resources and delivers controls.

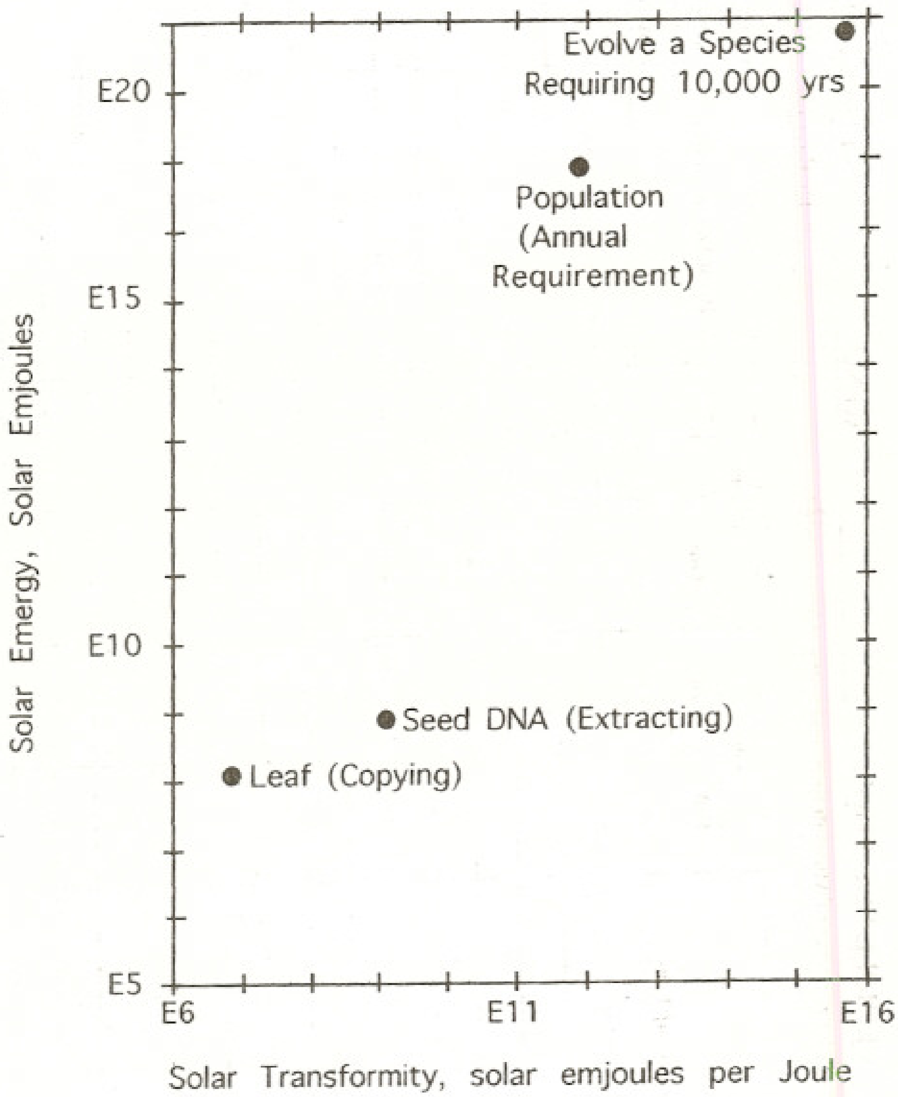


Fig. 6: Levels of information in rainforest trees plotted on a graph of EMERGY and transformity.

Point #1 Leaf (copying): EMERGY flow per area (6.0 E14 sej/ha/yr) and transformity(7.0 E6 sej/J) from Odum (1996); EMERGY per leaf calculated: (6.0 E14 sej/ha/yr)(1 E4 $m^2$/ha)/(5.0 layers/$m^2$)/(100 leaves/$m^2$) = 1.28 E8 sej/leaf.

Point #2 Fruit (Transmitting information): Fruitfall 68.4 fruits/$m^2$/yr from Pinto (1970); fruitfall: 292 J/$m^2$/day (Odum, 1970); DNA content from Canoy (1970). Fruit DNA calculated: (292 J/$m^2$/d)(365 d/yr)(5E-4 fraction as DNA)/(68.4 fruits) = 0.83 joules DNA/fruit Fruit EMERGY calculated: (6.0E14 sej/ha/yr)/(1 E4 $m^2$/ha)/(68.4 fruits/$m^2$/yr) = 8.78 E8 sej/fruit

Fruit transformity: (8.78 E8 sej/fruit)/(0.83 J DNA/fruit) = 1.06 E9 sej/J Points #3 and #4 Values from Table 12.1 in Odum (1996).

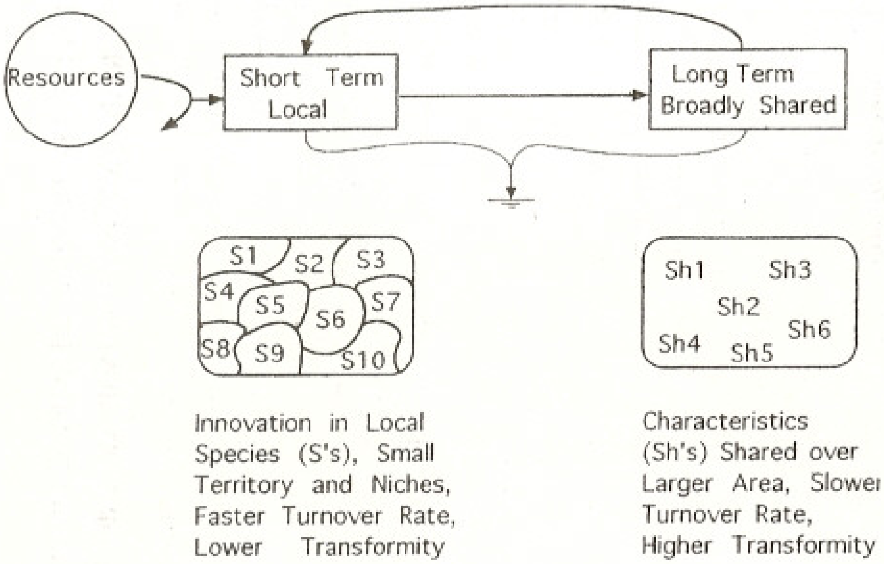


Fig. 7: Model of global biodiversity with species occupying local and short term memory contributing to and controlled by the higher transformity information shared among higher taxa.

## *Night Lights*

All this shows up in the night lights of cities, where EMERGY goes into concentrating the information processing by getting more out of a day. This could be one reason for the luminescence in the sea. By providing light at night, luminescence allows more hours of useful work. For example, in phosphorescent bays of the Caribbean Islands any movements of animals jostle the microscopic dinoflagellates, marking their position with a lighted outline.

## *EMERGY and Pulsing*

That all systems and scales apparently accumulate storages followed by a sharp pulsed consumption and material recycle is one statement of the *Pulsing Paradigm* (Figure 9). By now it is pretty universal as the view of environmental scientists for their various systems. See our papers on this starting in 1980's[6]. It is a paradigm because it replaces the idea of

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[6] Our papers on pulsing and hierarchical levels: Richardson and Odum, 1981; Campbell, 1984; Odum, 1982, 1983, 1988a and b, 1994a and b, 1995; W.E. Odum et al., 1995.

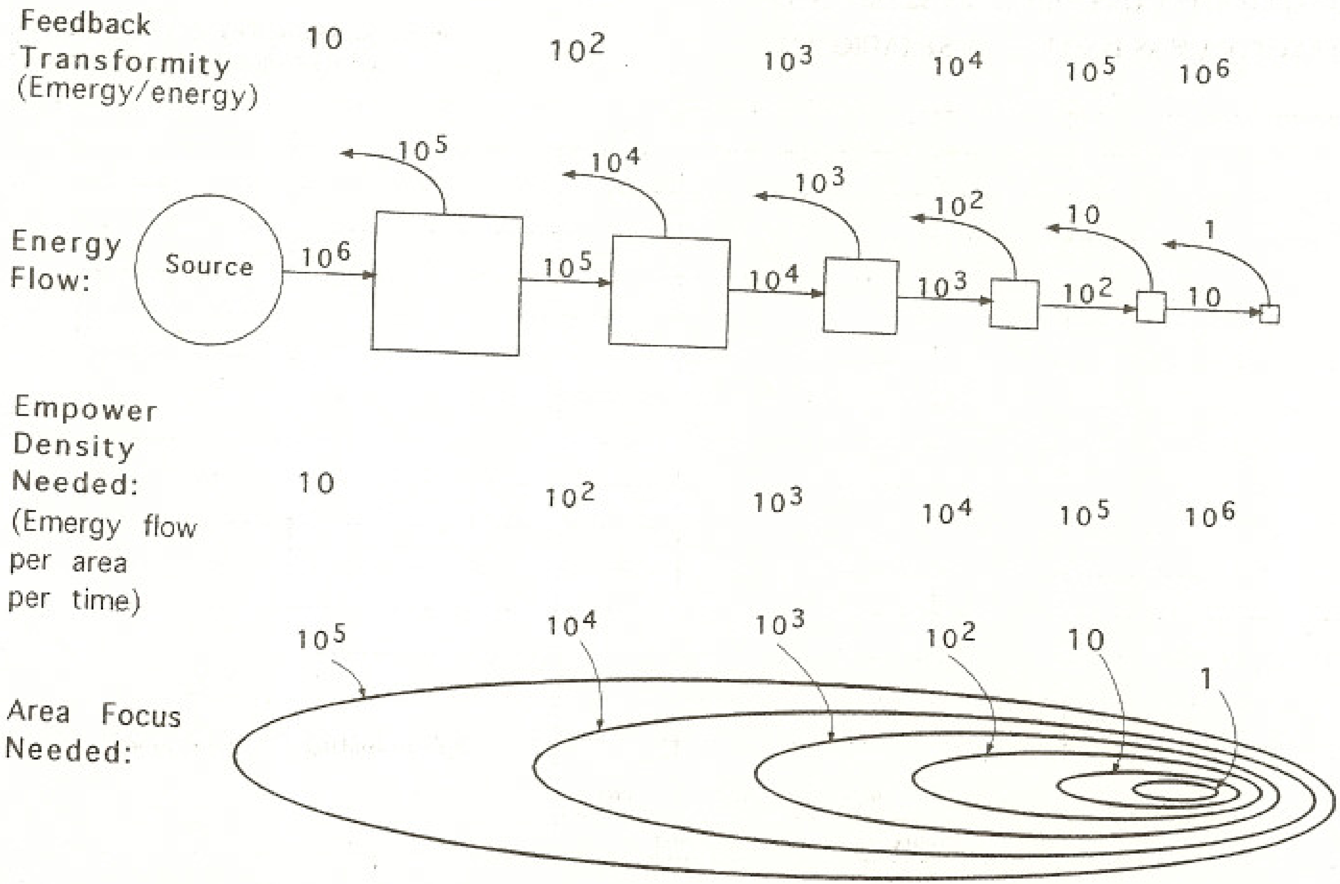


Fig. 8: Idealized energy transformation chain that converts 10% of the input energy per step. Calculations show the necessary area of concentration for each energy stage to maintain a feedback reinforcement commensurate with what was required (Empower density of feedback is related to the transformity).

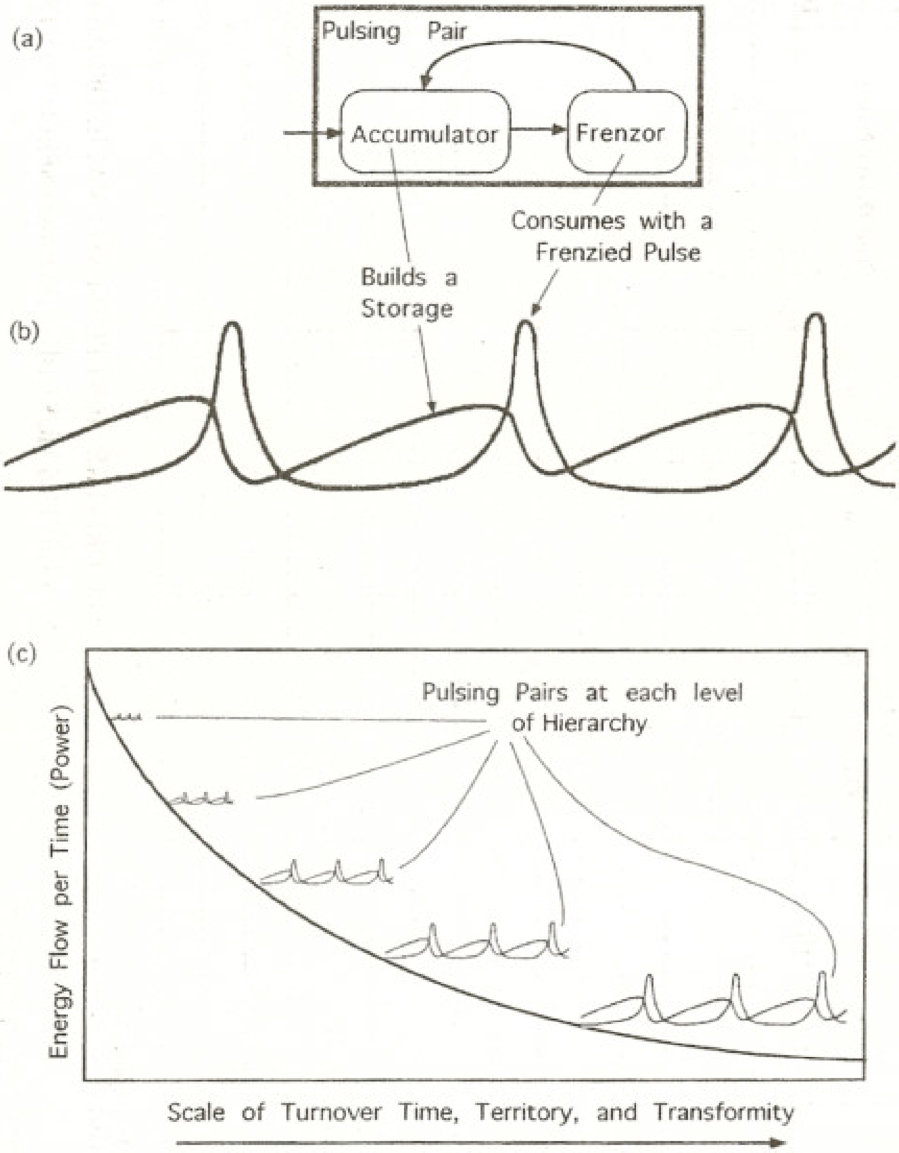


Fig. 9: Concept of pulsing by paired units. (a) Energy accumulator and pulsed consumer; (b) pulsing pattern generated by one class of simulation models; (c) increase in pulsed interval and concentration with hierarchical scale.

growth followed by steady sustainability. Apparently at all scales there are pairs of units with at least two hierarchical levels, one accumulating, reaching some thresholds at which the higher member operates a frenzied consumption. This consumption autocatalytically builds temporary high-level structures and information of high transformity and concentration. Suggested names are *accumulator* and *frenzor* (Figure 9). The pulses with time were generated from a general minimodel for two levels[7].

*Transformity and Holling's Figure Eight*

Holling[8] described ecosystems as passing through a circular process in four stages: (1) exploiting resources, (2) conserving resources at climax, (3) creatively destroying, and (4) starting over with released materials. This was illustrated with an ice skater's "figure eight" diagram (Figure 10a).

In Figure 10b this figure is compared with a basic energy systems diagram for a two level hierarchy (primary production (P) and secondary consumption (C)). The cycle in the ecosystem produces a surge in the units of the material cycle passing around the loop as a wave one after another: Stage 1 is production exploiting the materials excess; stage 2 is production of climax capital storage; stage 3 is the pulse of consumption; and stage 4 is restart with a full tank of materials again.

By translating the cycle to energy systems language, the position in energy hierarchy is seen from left to right with increasing transformity (Figure 10b). The consumer pulse is the highest quality operation (highest transformity) because large EMERGY goes into temporary achievements of information and diversity. Dispersed materials after a consumption pulse are ready to be reaccumulated by application of new energy sources, but are at a low transformity state. Perhaps natural capital is not an appropriate term for dispersed materials.

The stages of the figure eight cycle are clear when applied to the oscillation of one level (for example, one population). However, it takes at least two coupled levels for a dynamic model to pulse, each out of phase with the other. On any scale of conceptual aggregation there are two or more levels present. Assigning stage numbers in the pulse graphs of two levels in Figure 10c puts the numbers at different times. In a two level system information and diversity can occur at two or more levels (example: plants and animals).

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[7] Trace of simulation used in Figures 7, 8 and 10 is from simulating the Alexander model (1978), since used in many papers, theses and dissertations to represent temporal relationships for systems aggregated in two levels.

[8] Holling (1986).

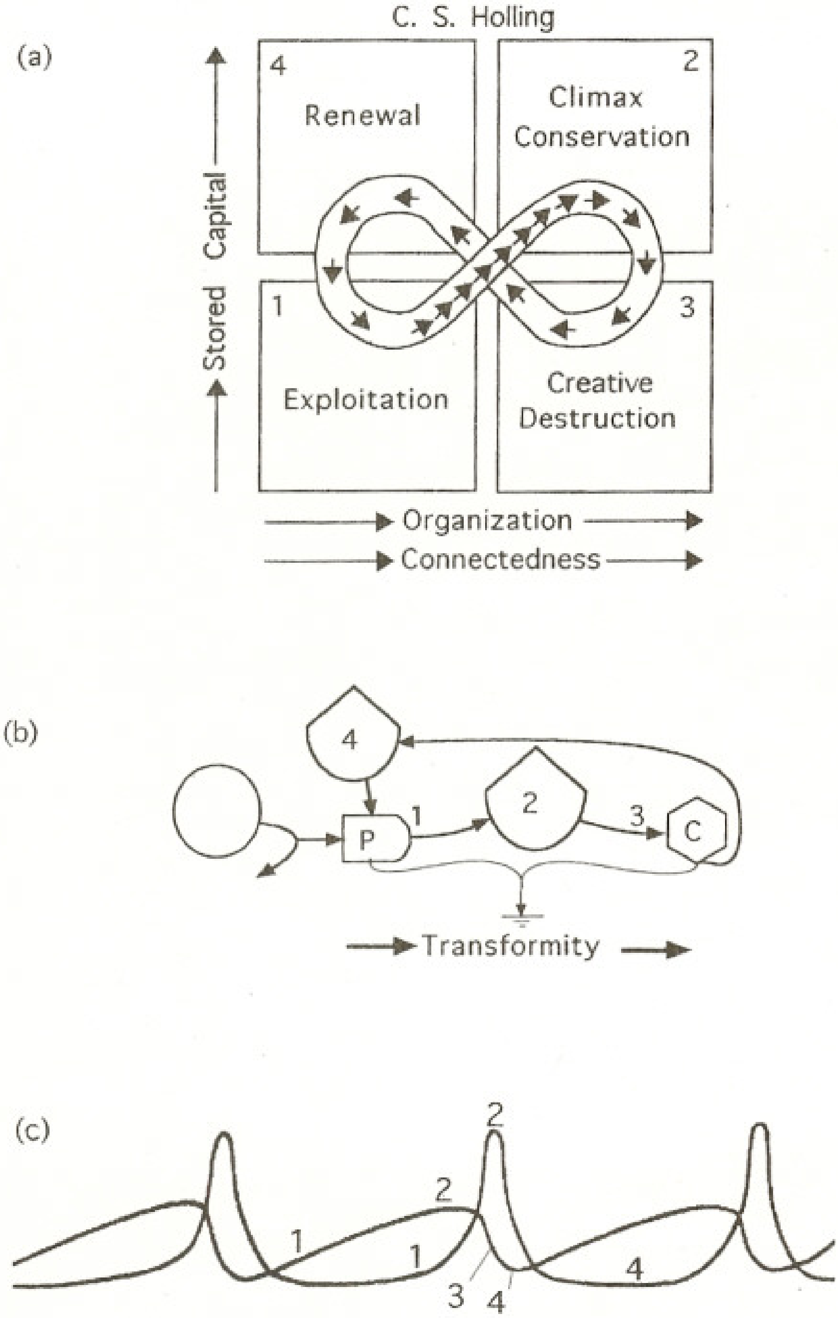



Fig. 10: Suggested relationship of Holling's diagram of an ecosystem cycle to energy systems hierarchy. (a) Figure "eight" diagram; (b) energy systems diagram of basic production-consumption-recycle system with Holling's stage numbers in the part of the system that is large at each stage; (c) graphs of pulsing pair (support capital and consumer achievement) with stage numbers appropriate for each.

The real world is an energy hierarchy of many levels, with many alternative species in parallel with opportunity to dominate the pulsing at their level. In current research Daesook Kang[9] succeeded in getting a three level dynamic model to oscillate with 3 different frequencies. However, pulsing at several levels was achieved more easily with pulsing pairs (Figure 9). The diversity of species supplies many choices that can become a pulsing pair appropriate for any particular conditions. Similarly, the diversity of business firms supplies many choices that can become a predominating pulsing pair for particular conditions in the economy.

### *Longer Intervals and Sharper Pulses of Higher Levels*

Recall the discussion about concentrating EMERGY *spatially* in order to reinforce effectively discussed with Figure 8. There is a similar need to concentrate reinforcing feedbacks in a short *time* as a pulse. The higher the level in hierarchy the less energy there is and the more time has to elapse to get a concentration with enough zip to reinforce with an effect commensurate with what was consumed. The higher the level the sharper the pulse (short duration) required to do more with less. A sample calculation is given in Figure 11 for an idealized web with 10% energy transformation per step. Empower delivered during the pulse (pulse empower) was made proportional to what was required to develop the transformity at that level.

In the environmental realms populations oscillate, a few year classes of fish populations predominate, and there are economic cycles in capital financing of fishing boats. There are familiar examples in the information surges in television, politics, and advertising fads that store and surge.

### *The Shape of Descent*

In relating aggregate minimodels to the observed pulsing of the real world, an important clue is the shape of the curve of decline. If the unit is consumed by the pulsing consumption of the next level, its decline curve is sharp. If, however, a unit declines with its own depreciation rate and occupies a high level position, then its depreciation turnover time is

[9] Kang (1998).

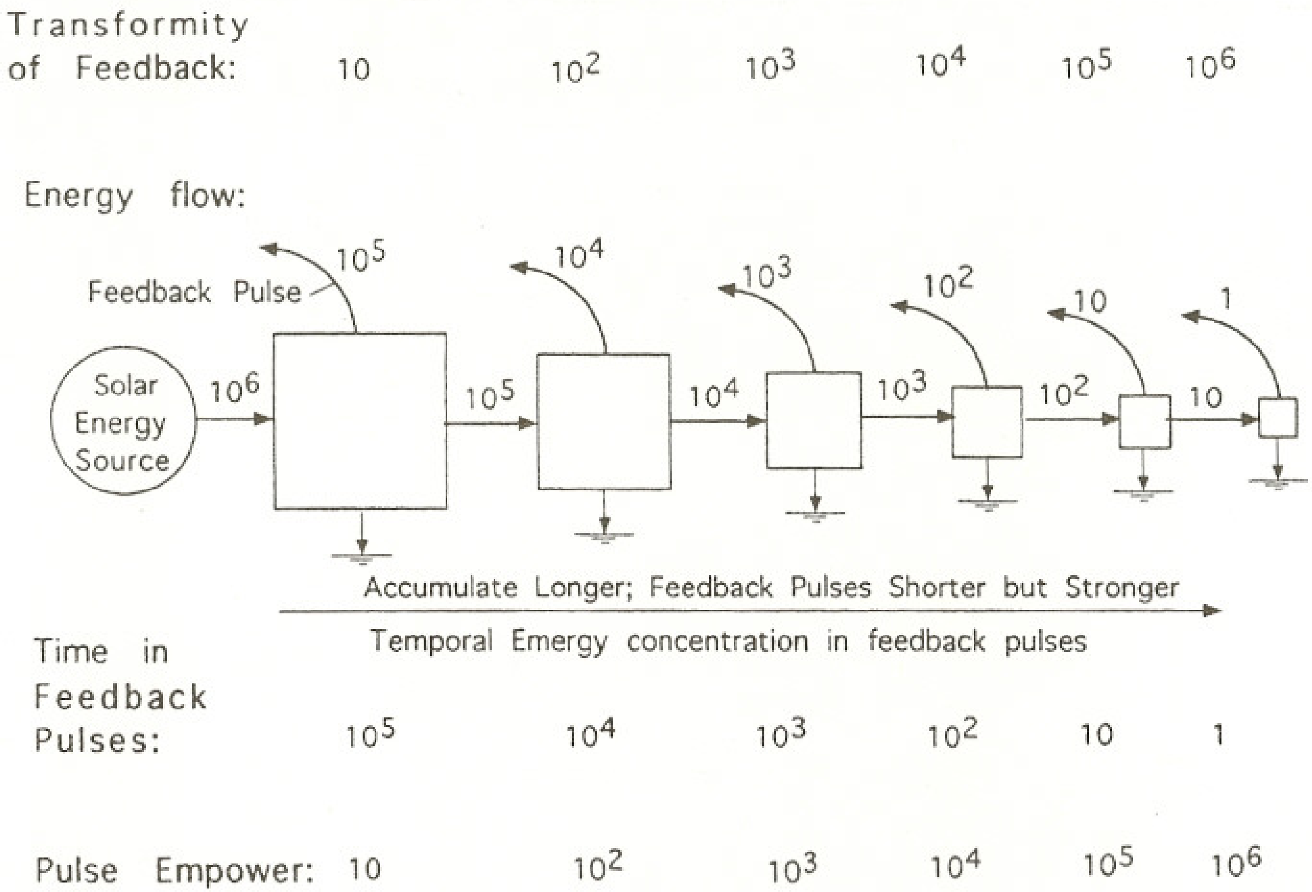



Fig. 11: Concentration of pulse required to maintain a constant temporal concentration of energy reinforcement in an energy transformation series that converts 10% of the input energy in each step.

large and the decline curve is more gradual. The ultimate question for the future is the shape of the decline curve of the pulse of our own civilization (fossil fuel driven). Will it be sharp, pulled down by some larger scale consumption or declining with the slow decay that comes from high EMERGY storages globally shared?

## Combining Factors Affecting Diversity

To understand and anticipate future diversity and information in ecosystems or in economic society we have to utilize several principles together: (1) The quadratic resource requirement of complexity; (2) the effect of resource excess in minimizing diversity; (3) the maturation of efficient recycle that maximizes diversity; (4) the development of information in pulses; (5) the organization of information territories with centers; and (6) the selection of appropriate scales for short term and long term memory.

### *(1) Quadratic Resource Requirement for Diversity*

We describe as complex the more parts there are to a system or to its extracted information. More kinds of parts means more EMERGY for its support, but the requirement is not linear, because the possible interrelationships increase much faster than the number of types. The kinds of units in the ecosystems are the species. The word biodiversity commonly refers to the kinds of living units in a system including that within each organism and in the kinds of organisms. The more species there are, the more EMERGY is required to relate one to another (for example competing or preventing competition).

The more kinds there are to a system, the more inter-unit pathways there can be and usually are (connectedness). With one pathway between each part and one within the part, the pathways increase as the square of the number of parts as shown with the system diagram in Figure 12. For an operational system each of these possible pathways either has to be provided, provision made to prevent the possible pathway from interfering, or provision made to correct more possible errors. Thus resource limits to operational information are reached quickly with increases in complexity. However, as tropical rainforests studies suggest, a large number of species in small numbers can be sustained as a contingency gene pool without any prominent role in the main operations and structure.

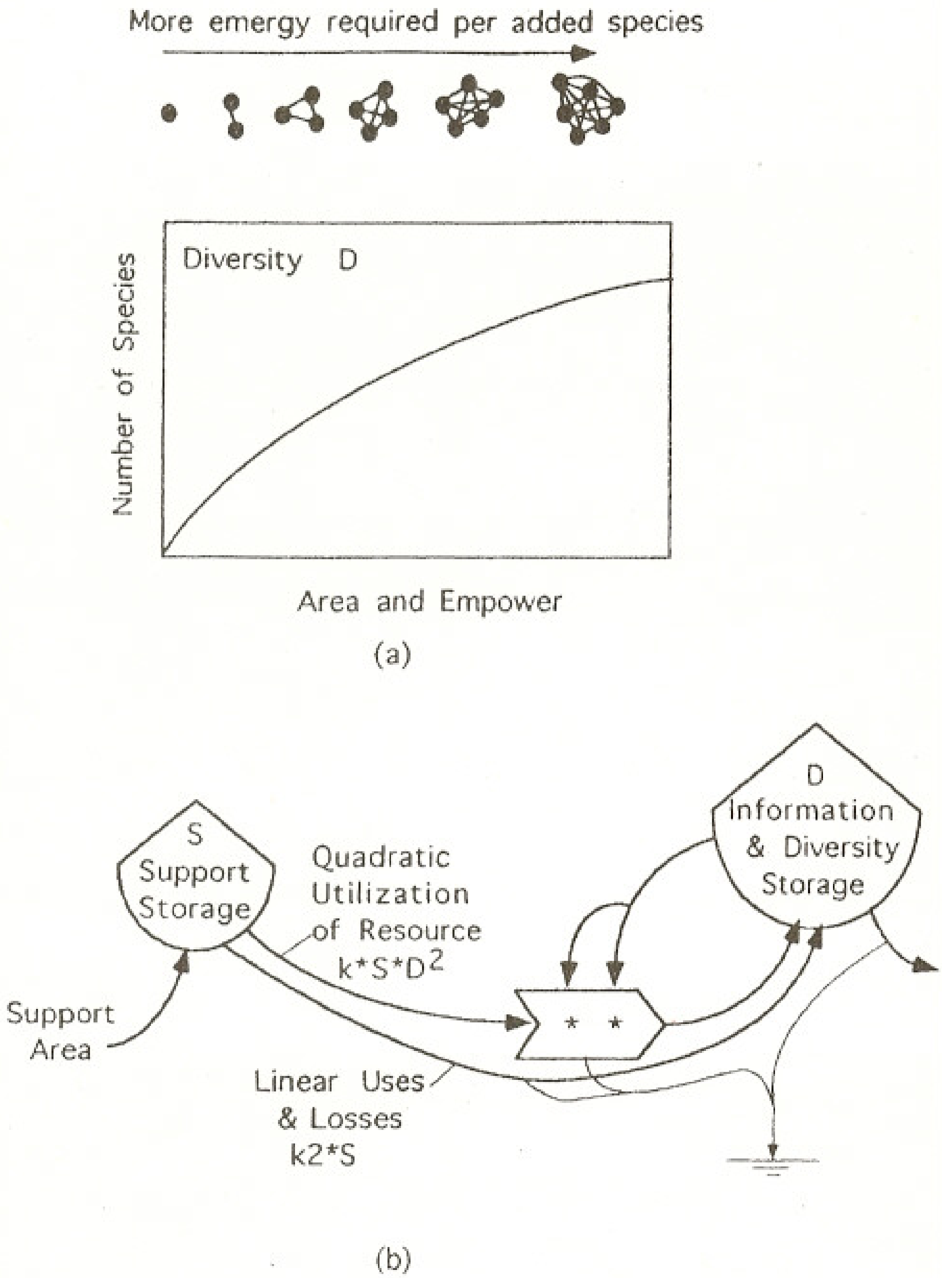



Fig. 12: Effect of increasing network complexity on the diversity. (a) Graph showing the increased resource area necessary to add species interactions; (b) system configuration showing the quadratic increase of resource use by increased diversity.

Apparently the resources required by information also apply to the kinds of information units in technological realms. The more kinds of computers, soft-ware programs, and types of inter-connections, the greater the EMERGY for support with the requirement increasing with the possible interconnections, perhaps as the square. The more kinds of human occupational specialists there are, the more EMERGY requirements are possible for interaction.

Early in the history of ecology, graphs of species found were plotted as a function of the area examined. Also graphs of species found were plotted as a function of the individual organisms counted. These curves had the shape of diminishing returns in accumulating species with increased resource area (Figure 13a). Observations show less diversity where areas are interrupted by development. On a semi-logarithmic plot these curves are straighter, and may curve upward to the left with larger samples. The shapes are consistent with the quadratic theory of increased resource requirement for supporting greater complexity (Figure 12)[10]. Raynor (1994), studying genetic strains in soil fungi, plotted the cumulative phenotypic differences as a function of the number of strains examined, finding curves of genetic diversity analogous and with similar shape to those of species versus individuals.

*EMERGY per bit*

Sometimes the complexity of components and parts is measured in the number of decisions required to duplicate them, where one yes-no decision is a bit. The same complexity is involved obtaining and arranging toy cars on a table as arranging real cars outdoors. However, it takes much less EMERGY for the toys compared to the large cars. Adding complexity requires more EMERGY as the scale increases. For the same EMERGY, the possible complexity decreases with size. Where high complexity is needed, it is achieved with miniaturization as in living genes and microchips. However, if the system or its representation is too small, the errors increase due to noise of molecular motions. There is a lower size limit for storing information.

Higher transformities accompany the same complexity at higher levels of hierarchy. Complexity in hawks takes more EMERGY than the same complexity in leaves. EMERGY per bit increases from left to right with position in the energy hierarchy scale (Figures 4, 6 and 7).

[10] Species area theory and simulations (Odum, 1970, 1983, and Beyers and Odum, 1996)

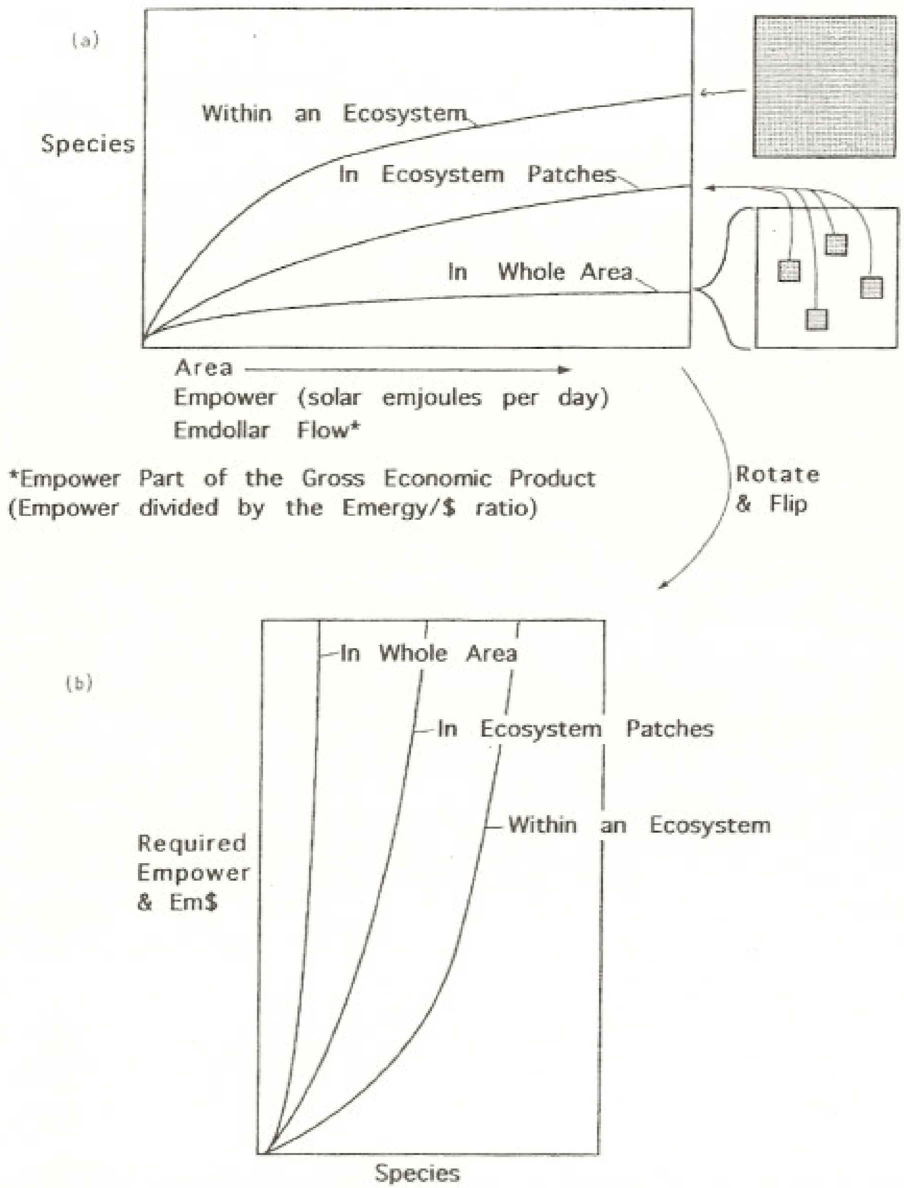



Fig. 13: Diversity as a function of EMERGY of support. (a) The traditional curve of species found versus area examined; (b) same with Y and X axis swapped.

*Diversity Sustainable per Area*

Where area is a measure of resource, graphs of species increase with supporting area (Figure 12a). In forests, for example, resource inputs of sunlight, rain, and earth are supplied in proportion to area. These graphs provide a practical way to determine the EMERGY required for diversity. As shown in Figure 13b, swap x and y axis. Then the resource area required can be visualized as a dependent function of the number of species to be supported. Graphs of kinds versus number of individuals counted can be used in a similar way if the resource required is in proportion to the quantity of individuals.

### *(2) The Effect of Resource Excess in Minimizing Biodiversity*

When there is an excess of unutilized resource such as light, nutrients, or organic matter, empower is maximized by one species expanding its population quickly to bring that resource into use. For example, weeds in a fertilized field tend to overgrow everything else. One species of microorganism will cover an agar plate quickly if the nutrients are rich. Especially in aquatic ecosystems and wetlands, excess resource situations are said to be culturally eutrophic. Empower is maximized at this stage by the species adapted to outgrow others, thus getting resources into use most rapidly. Competitive exclusion operates at this stage with a few species overgrowing others. Biodiversity is reduced.

### *(3) Maturation of Efficient Recycle that Maximizes Diversity*

If there are no unutilized resources (little inflow that passes out unused and no excess storages which could be used), then the maximum production and use are achieved with a division of labor which is provided by a high diversity in the operating system. Materials are captured and recycled better, and the total gross production based on the renewable flows is greater. Biodiversity and information are large.

Figure 14 shows the diversity accompanying the stages of a pulse of growth and succession that starts with excess resource (energy and/or materials). Overgrowth, rapid net production, and low diversity is represented by the systems view of pioneer species in Figure 14a. At the climax of the pulse there is high diversity, more information and efficient recycle (Figure 14b). However there is little net production because most of the production goes into the consumption to operate the high diversity and information. In ecosystems some of the consumption functions are in adaptations of plants for long life and some in the animals and microorganisms.

Regulating biodiversity means controlling input and output of resources and resource reserves. Keep excess resources away from areas

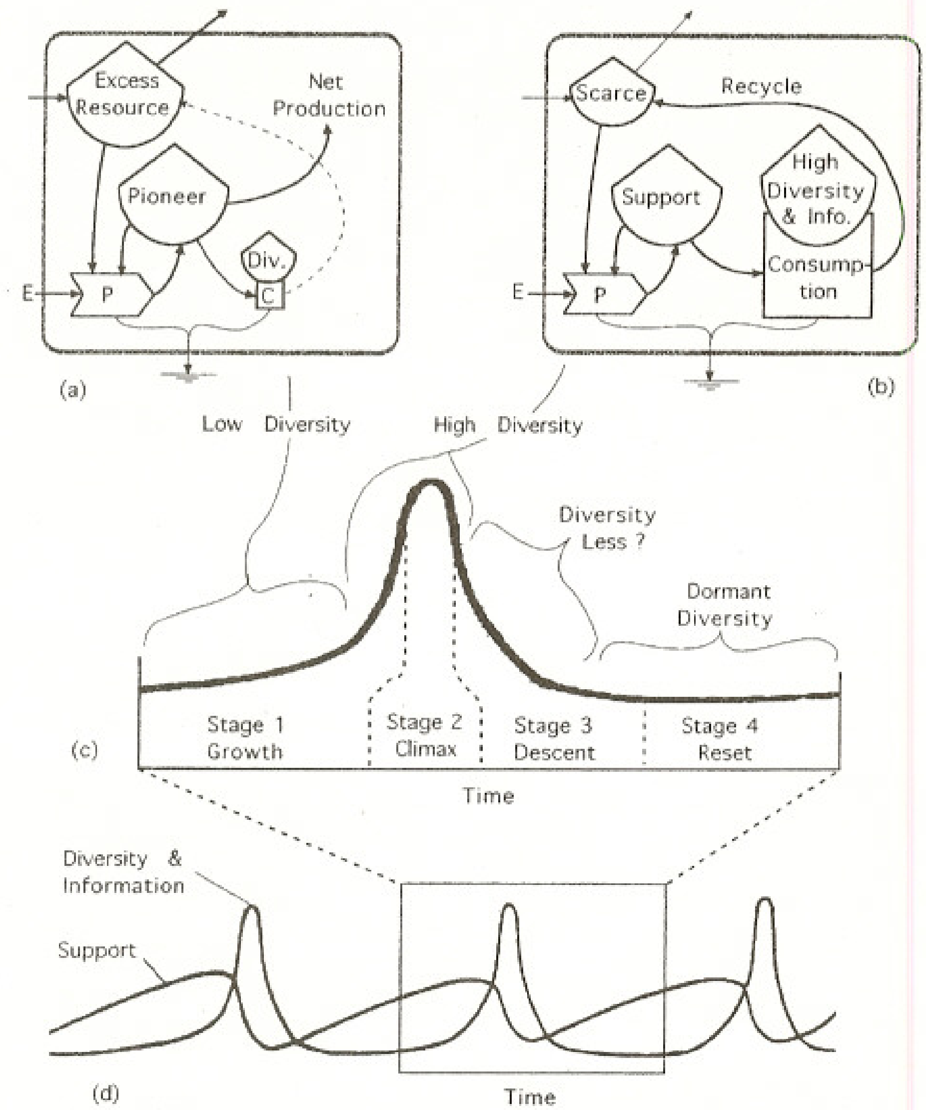



Fig. 14: Effect of resource on diversity and maximum empower. (a) Low diversity maximizing empower by competitive overgrowing; (b) high diversity maximizing empower by diversity and cooperation; (c) diversity expected in four stages of the pulse cycle; (d) oscillation of support and diversity.

### *(4) Development of Information in Pulses*

In aggregate overview diversity and information can be regarded collectively as the top member (frenzor) of a pulsing pair, accumulating structure and diversity. Pulses of diversity are shown alternating with the accumulations of support (Figure 14d). Margalef (1958) found pulses of biodiversity in plankton, representing temporary maturity. Four stages of the pulsing cycle are suggested (Figure 14c) with accompanying diversity. This model is appropriate for the diversity of species in ecosystems and for the information and occupational diversity in the economy.

The pulsing of parts of the economy on various time scales is familiar in economics. The pulse of the whole global economy of the entire civilization is part of the larger scale accumulation and concentrated use of the mineral-fuel resources. Predicting diversity and information means predicting where an area (or the whole earth) is in its pulsing cycle.

### *(5) The Organization of Information Territories with Centers*

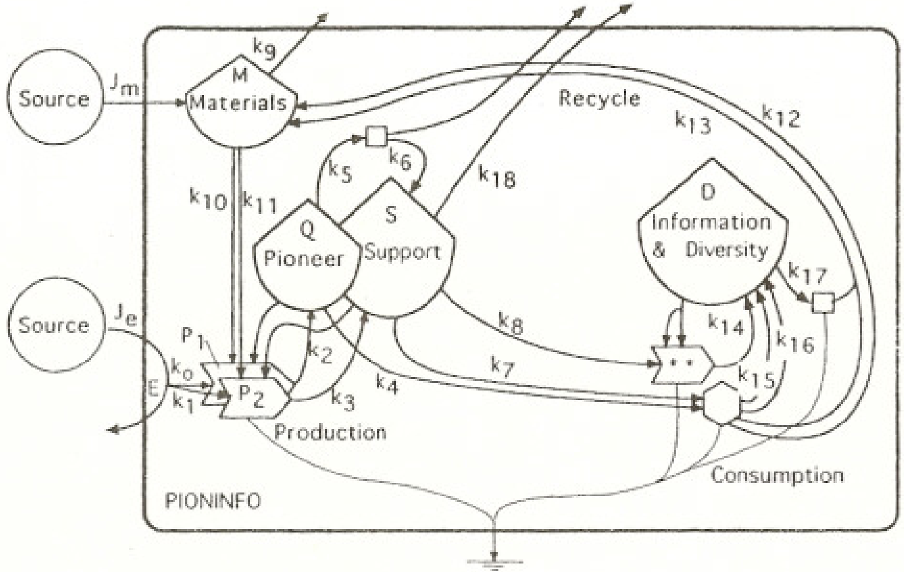
As we discussed with Figure 8, the top unit of a hierarchy is concentrated in a small central area even though its support and influence is from a large territory. If information-diversity is the top unit, it is to be found concentrated in small centers, as we observe in cities and in ecosystems (in animals).

### *(6) Selection of Appropriate Scales for Short Term and Long Term Memory*

The growth of new temporary species during succession is analogous to short term, local memory in the brain. Territory is small and turnover rapid. Later in succession, high biodiversity climax is analogous to long term memory in the brain with larger territory of shared information and slow turnover.

*A Minimodel Simulation of Diversity in the Pulsing paradigm*

One kind of modeling that we do attempts to capture the essence of principles, clarify concepts, and test the consistency of the human verbal ideas with quantitative simulation. A minimodel PIONINFO (Figure 15a) combines the aforementioned principles affecting diversi-




$$E = J_e - k_o{*}E{*}M{*}Q - k_1{*}E{*}M{*}S \quad \text{Therefore } E = J_e / (1 + k_o{*}M{*}Q + k_1{*}M{*}S)$$

$$P = P_1 + P_2 \text{ where } P_1 = k_2{*}E{*}M{*}Q \text{ and } P_2 = k_3{*}E{*}M{*}S$$

$$C = k_4{*}Q + k_7{*}S + k_8{*}S{*}D{*}D \qquad P_{net} = P - C$$

$$dQ = P_1 - k_4{*}Q - k_5{*}Q$$

$$dS = P_2 + k_6{*}Q - k_7{*}S - k_8{*}S{*}D{*}D - k_{18}{*}S$$

$$dM = J_m + k_{12}{*}Q + k_{13}{*}S - k_9{*}M - k_{10}{*}E{*}M{*}Q - k_{11}{*}E{*}M{*}S$$

$$dD = k_{14}{*}S{*}D{*}D + k_{15}{*}S + k_{16}{*}Q - k_{17}{*}D$$

(a)

Fig. 15: Simulation model PIONINFO with production, consumption, recycle, and diversity. (a) Systems diagram and equations.

ty. A pioneer unit (Q) incorporates materials into production for its own storage and with a net production that contributes to another unit (S). The support unit accumulates stores that are transformed by a high level consumer unit D to generate and sustain diversity-information. The higher level production function (k14) draws resource S in proportion to the square of the kinds of units, thus representing the high requirements for sustaining complexity. All of the consumption is placed on the right side of the diagram (D in Figure 14a) and the consumer by-product materials are recycled and dispersed back to a dilute environmental state (M).

The simulation was arranged to graph the total gross production (P) on the left and total consumption (C), the sum of 3 processes, on the right (C = sum of k4, k7, k8). The first run with coefficients as calibrated shows a short pioneer stage followed by build up of the support unit and then consumption-diversity-information (Figure 15b).

Then if the coefficient of accumulation (k8) is reduced, the effect is to increase the efficiency of developing diversity, allowing growth of storage and a regular pulsing (Figure 15c). The growth of pioneers alternates with accumulation of support, consumer pulse and biodiversity.

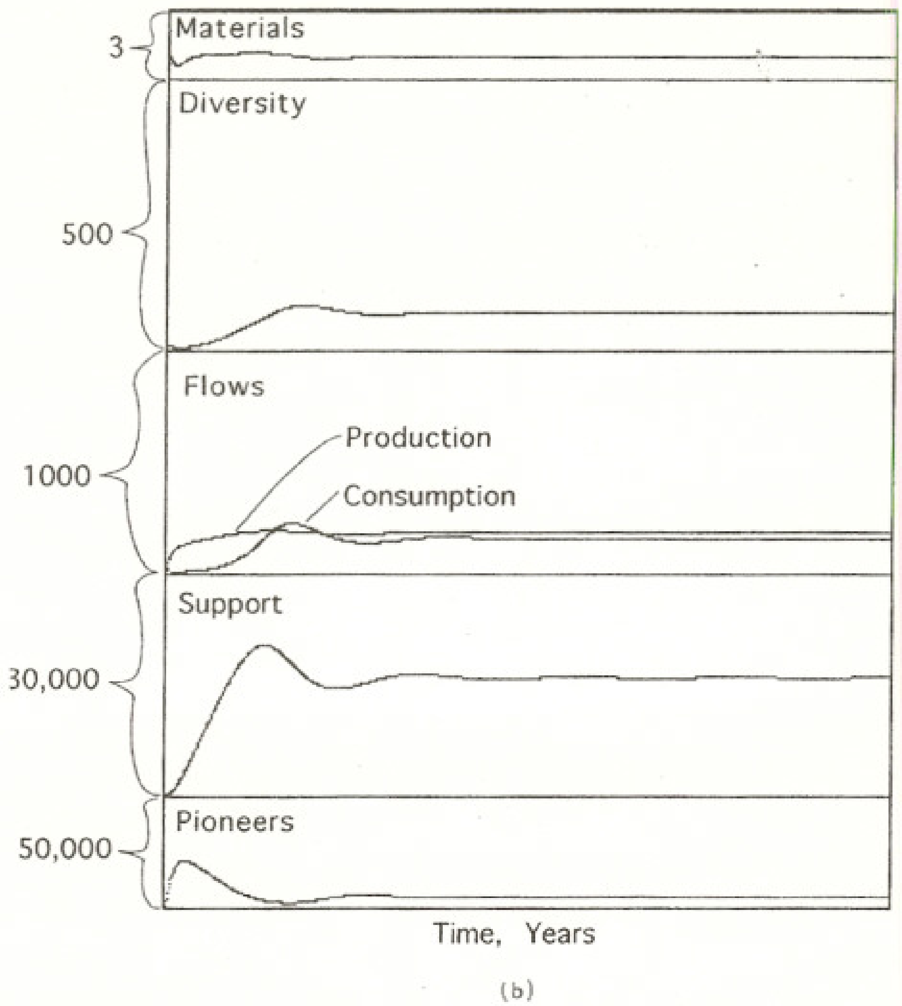



Fig. 15: Simulation model PIONINFO with production, consumption, recycle, and diversity. (b) simulation as calibrated.

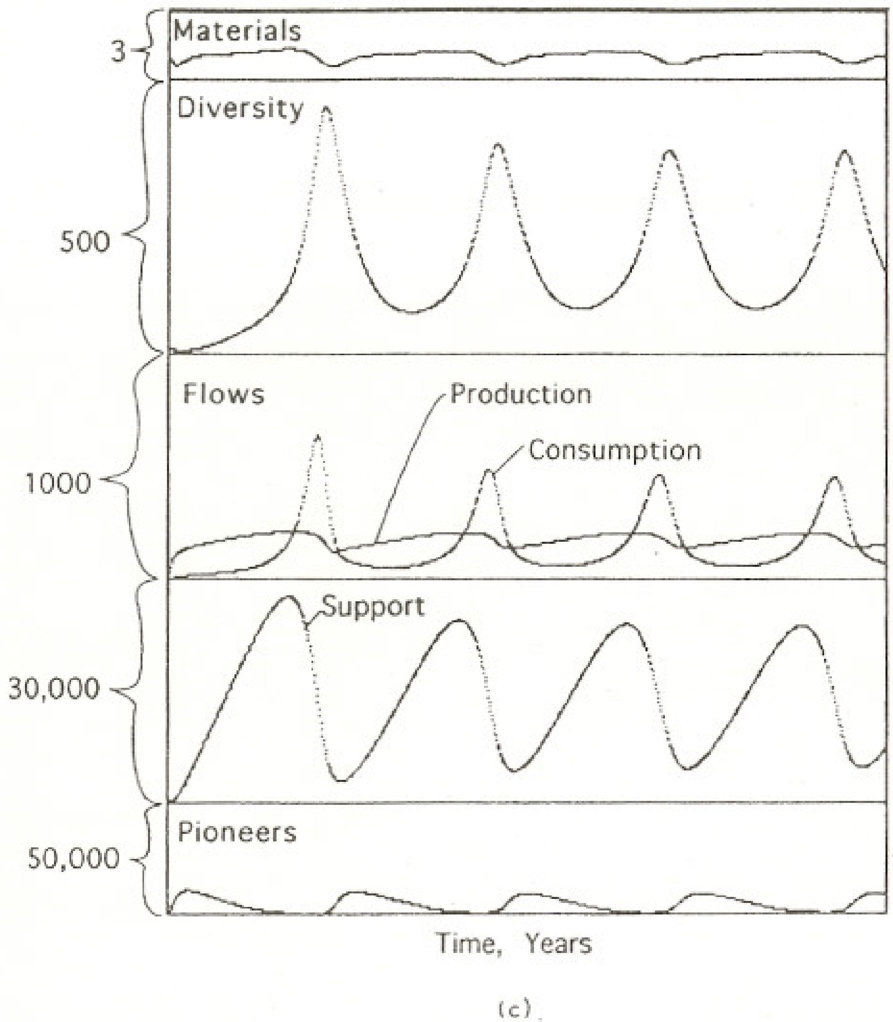



Fig. 15: Simulation model PIONINFO with production, consumption, recycle, and diversity. (c) simulation with smaller coefficient k8 (less use of support and higher efficiency of generating diversity).

## Comparisons with Evolution

The concepts of information hierarchy and pulsing seem to fit biological evolution. At times when new resources are available, there are new innovations which spread with low diversity at first. The emergent innovations overgrow and cause extinction of other species. Later, a more efficient diversity could develop, described by paleontologists as "adaptive radiation".

There appear to be parallels with the evolution of the computer technology. Giant corporations are restricting diversity while in accelerated growth. However, once the growth potential is exhausted there may be a greater diversity of hardware and software types, generating more efficiency and less waste.

In evolution orthogenesis refers to evolution that continues a pattern of change past the point where it is competitive. For example, the idea of orthogenesis has been applied to the Irish elk that evolved larger and larger antlers, finally going extinct, possibly because they were too large. Perhaps there is orthogenesis in the computer software industry.

The process of evolution is often described as a micro-evolutionary speciation process with many choices and variations tested in the short run and over a small territory. These are analogous to short term memory. Those genetic combinations surviving the selection process carry emergent new characteristics, are spread over a larger territory, and last longer. The longer-lasting and wider influencing characteristics become a higher taxonomic category as longer term memory.

The hierarchy in the taxonomic classification system of organisms from small to large is variety, species, genus, family, order, class, and phylum. Each of these represents longer time in development, longer persisting and larger territory of development and influence than the one below in the series (Figure 16). Moving up the hierarchy is another way of stating the old zoogeographic concept of age correlated with area. Each has a higher transformity than the one before. If the general theory is correct, then each taxonomic level is the stored basis for a higher level pulse (new taxon) which consumes and clears "memory" while developing something special at the higher level. Gradual development of information can begin at that level again, using the pulses of input from the level lower down. The pulsed-consumption dumps a shorter term memory for the next one higher.

## Future of Information and Diversity

In the human economy as in the ecosystem, colonization and expansion occurs when there are unutilized inflows or storages of resources. The U.S. economy in the 19th century was an example. There was a low diversity as only a few overgrowing business competitors prevailed. Later, when the economy did not have as many unutilized resources (land, waters, minerals, fuels), diversity and division of labor increased. Consumption and material recycling increased. There was a flowering of information.

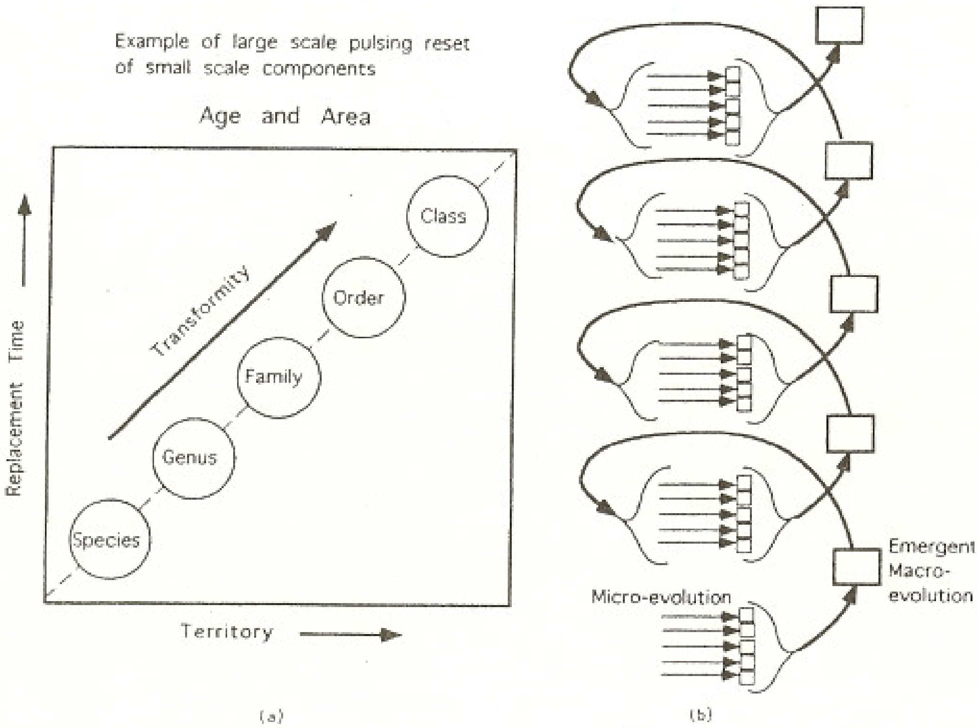



Fig. 16: Evolution and scale. (a) Taxonomic divisions according to territory, replacement time and transformity (age and area); (b) alternation of microevolution accumulating a stored basis used by a pulse of macroevolution which replaces previous kinds.

Those measuring information in the systems of self organization without humans can observe the limits to information in the ancient processes of nature. The DNA per area of land and water is fairly uniform[11] and the diversity of species does not exceed about 100 species in a thousand individual organisms counted. In Figure 17 species area plots of data from islands are extended to the area of the globe. These lines suggest limits for a world dissected into patches of biodiversity refuge. An emdollar scale is included to suggest the very high values of biodiversity to the economy of humanity and nature.

The present surge of global human economic development is based on the previous accumulation of earth fuel resources. The surge of

[11] DNA in Ecosystems from Canoy (1970).

information is based on the accumulation of the economic assets. Perhaps the information can have a long range future like that in the simulation (Figure 15c). Because of its long turnover time, considerable diversity-information was carried over from one pulse to the next.

### *Interaction of Society Information and Ecological Biodiversity*

Consider the relationships of the information of the ecological system information and that of the system of society, similar phenomena but on different scales. Both cycle between the four stages of Figure 14: low diversity net growth, high diversity climax, low diversity net decline and moderate diversity between pulses. All too familiar is the way the pulse of global economic growth drains and reduces ecological biodiversity. The ecosystems are lower in the energy hierarchy on a smaller scale and are reset by the pulses of the economy and its information.

An economic turndown with population still increasing may strip biodiversity. But if the population and resource processing decrease

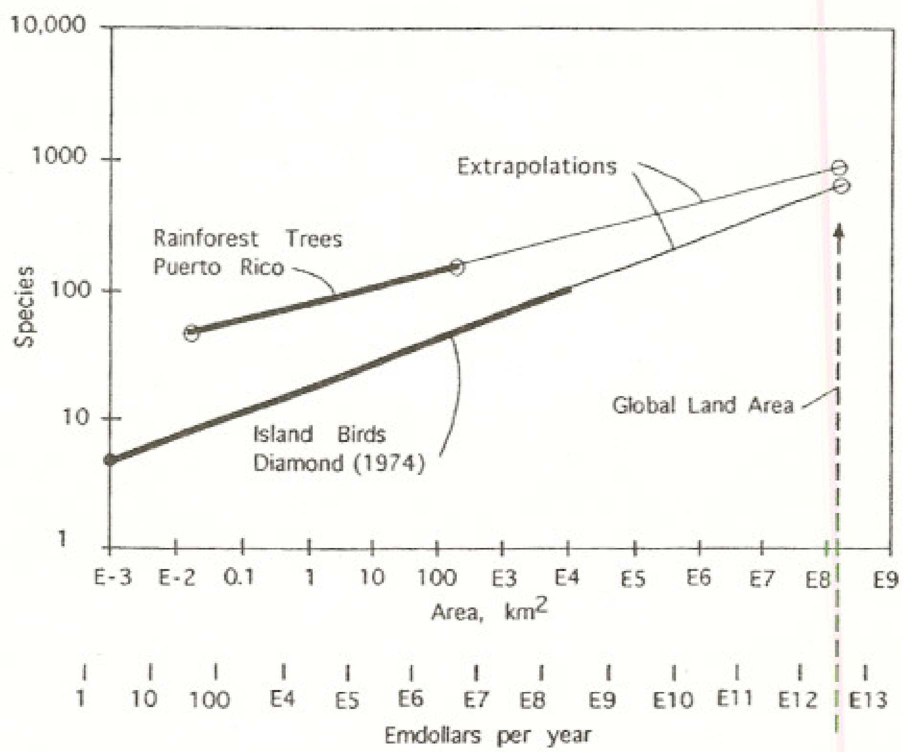



Fig. 17: Species-area data from islands on double log plot extrapolated to the global land area.

together, environmental systems can rebound again. Small scale oscillations of biodiversity can be in different phases of cycles in different places.

One tenet of the theory of maximum empower is that items of high transformity contribute most by interacting and amplifying more abundant items of lower transformity. The human economic assets and diversity are shown interacting and mutually amplifying the ecological biodiversity in Figure 18b. As the model suggests, maximum productivity of the combined system of environment and economy requires both information components interacting. People depend on the biodiversity of their life support system, and to sustain it they have to reinforce with feedbacks (Figure 18a). Since biodiversity is essential for life support of the higher levels in hierarchy, human flexibility can and probably will adapt a conservation role increasingly protective of its own basis. In practice this means maintaining ecosystem refuge areas during the zenith of human population density and learned information fervor. While the fossil fuel pulse is ascending there may be some substitution of learned information for biodiversity along the isoquant line in Figure 18c. Then biodiversity could become limiting to global life support.

### *Genetic and Cultural Diversity of Humanity*

Recent history records the mainstream of human cultures and religions focused on power seeking, resource exploitation, population maximizing, and competitive overgrowing with low diversity. In the hundred thousand or more years of *Homo sapiens*, high diversity, efficient, climax societies were mostly shredded and displaced in the main surge of population overgrowth. The genetics, physiology, and reproductive prowess of *our species* is very good at being a low diversity, net growth weed. Learned information and culture of the global society based on the invention of capitalism made amazing global supergrowth of economic structure. The diversity of modern human society is shown in the graph of occupations found as a function of number of entries in the yellow pages of a city directory (Figure 19). More than 300 occupations were found for 1000 entries. This diversity is higher than the biodiversity, perhaps to be expected in a time when very high levels of support emergy are available.

As we move to a situation without the resources for further net growth, how will the genetic biodiversity of *Homo sapiens* and the cultural biodiversity be changed? To reduce excess reproduction, sexual

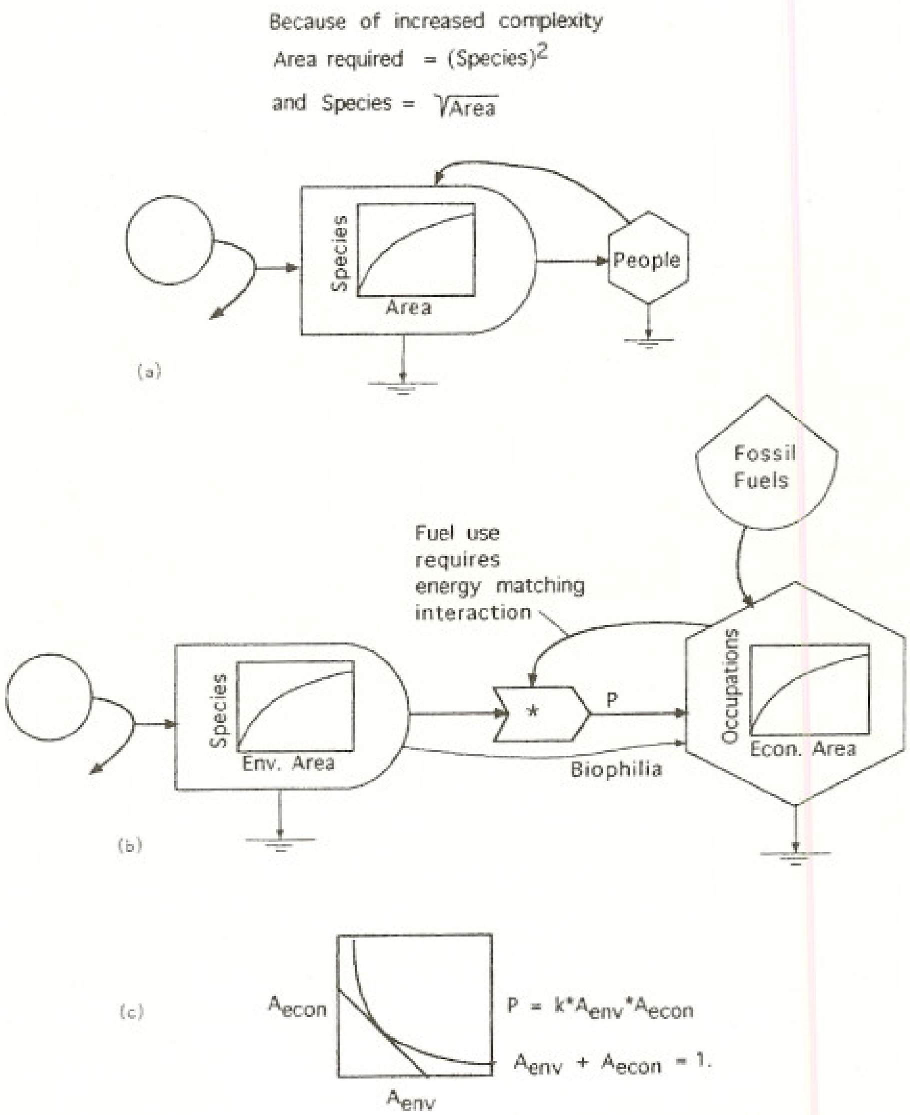



Fig. 18: Interactions of Information of society with biodiversity of the environment. (a) Species dependence on area resources and the symbiotic reinforcement needed from people; (b) interaction of two kinds of information in system production; (c) isoquant substitution of economic diversity and environmental biodiversity.

energies may have to be diverted away from reproduction, perhaps by cultural change. Or the changes may require a human being that is genetically better adapted to no-growth periods. Can the information prowess of the society survive its own pulse and redeploy for a lower stage? We already see the way pluralism is displacing the competing monotypes of a century ago.

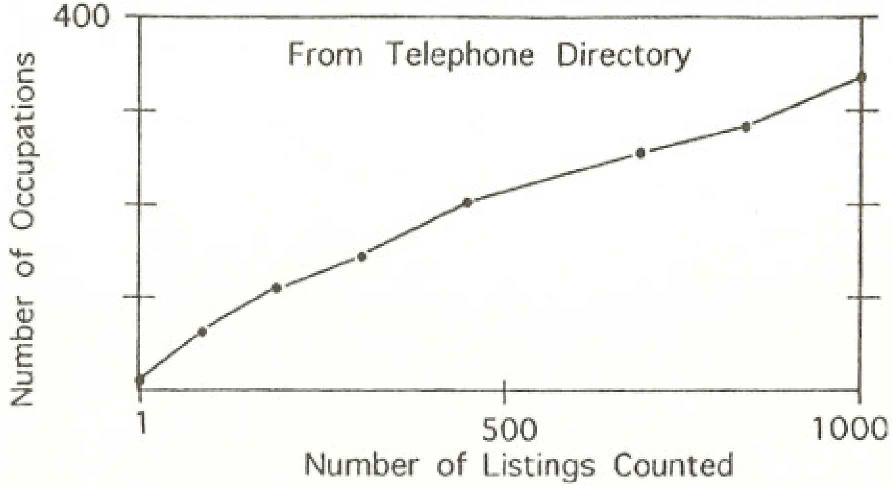



Fig. 19: Cumulative number of occupations found in counting entries in the city directory of Gainesville, Florida, in 1997.

*Hierarchy of Information Processing and Memory*

The processing of information by the human mind has short term and long term memory. Much more information is processed for a short time in the short term memory, saving only a few items for long term memory. A gradual accumulation at one memory level supports the pulse of something more important into the next level. And in the process the lower level memory is cleared. Learning what to dump and save well takes a third of a human life in growing up and being educated. A hierarchy of time and space is implied. This property of information processing along a hierarchy may be a general guideline for the future. Memories of different type are shown on a scale diagram of time, space, and transformity in Figure 20.

Information processing is accelerated when miniaturized as in brain cells and computer chips, but information storage in long term memory requires the opposite, a sharing over a large territory and slow turnover (Figure 20). We have to learn to consolidate and dump, selecting the most essential knowledge for long term maintenance. Something like this seems to be operating in the way society filters consensus from the daily news.

The internet is for information processing and its memory is short term. There is some danger that the emphasis now on information processing gets confused with the more important need for long term

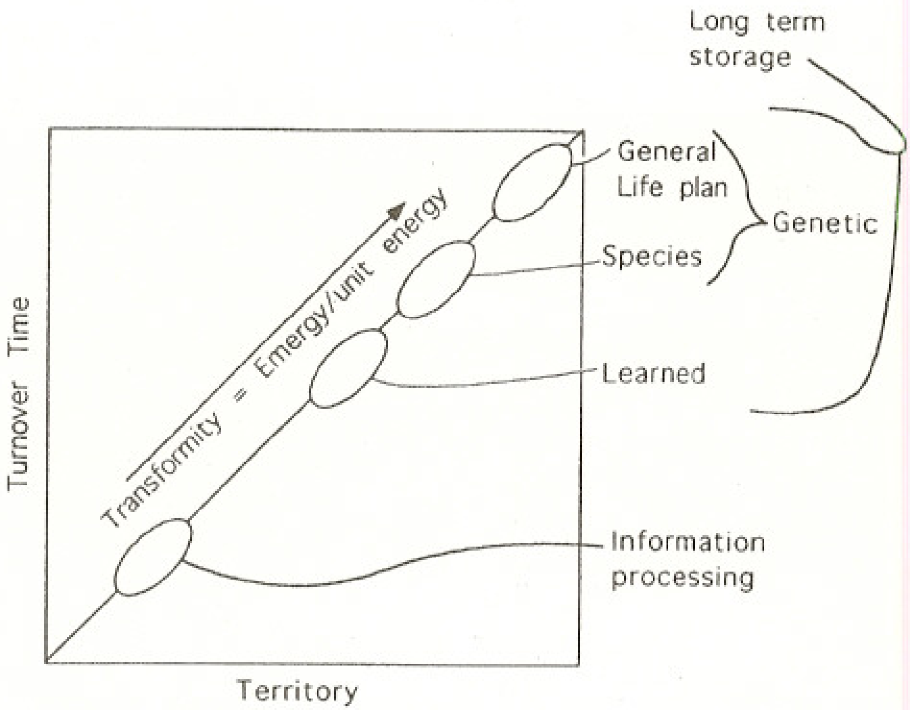



Fig. 20: Kinds of information processing and storage on a scale diagram of territory and replacement time.

information storage. Of course it is the ease of processing that helps to distribute more copies which can become long term storage if they are saved. It is not yet clear if CD's or other new technology will replace books and universities as the long range, broadly shared, memory of society's learned information.

### *Global Information Limits*

As Figure 5 suggests, the amount of information that can be sustained depends on the rate at which the sources supply EMERGY to run the information maintenance system. The limits are not unlike anything else whose existence is away from equilibrium with losses according to the second thermodynamic law. Many in our world in responsible leaderships are among those going berserk with fantasies about what can be done with information to replace the environmental, agricultural, and industrial support systems. However, information that works and is continued has high EMERGY requirements for operation and long term storage, especially because of the quadratic cost effect (Figure 12). In other words, there are limits to information.

## Summary

The earth is unique because of its genetic information, ecosystem biodiversity, and learned information of society. In this essay we try to understand information, its relationship to a universal energy hierarchy, and our current information frenzy. EMERGY (spelled with an "m") and transformity were used to measure kinds of information and to identify relationships.

Information occurs as a pulsed storage in oscillations. Numerical calculations of feedback reinforcement help explain the concentration of information in centers and pulses. Sustaining information requires a population of units operating a circle of copying and testing. For environment and economy, prevalence of pulsing pairs (an accumulator and a pulsing frenzor) is suggested as a general mechanism of self organization. On an evolutionary scale, pulses of macroevolution are based on the accumulations of microevolution. As a consequence of evolution, taxonomic categories form a series on the scale of age, area, and transformity.

The biodiversity information of life and the learned information of the human economy seem to follow similar concepts. Both are explained as the interplay of six principles: (1) the quadratic resource requirement of diversity; (2) the effect of resource excess in minimizing diversity; (3) the maturation of efficient recycle that maximizes diversity; (4) the development of information in pulses; (5) the organizing of information territories with centers; and (6) the selection of appropriate scales for short term and long term memory. To demonstrate how these factors might be combined, a minimodel was simulated which generated a pulsing oscillation.

Species area curves are comparable to curves of occupational diversity, their human equivalent. However, ecological biodiversity and human learned information are on different scales. Self organization may be developing a new symbiotic interaction of human learned information and genetic biodiversity in the global production of the biosphere. Because of the quadratic increase of resource requirement for sustaining more kinds of units, there are limits to the complexity and information that can be sustained in ecosystems and in society. Determining the area required for species and information is suggested as a practical method for determining the EMERGY and emdollar value of levels of biodiversity.

## REFERENCES

ALEXANDER, J. (1978): Energy Basis of Disasters and Cycles of Order and Disorder. Ph. D. Dissertation, Environmental Engineering Sciences, Univ. of Florida, Gainesville.

BEYERS, R. J., and ODUM, H. T. (1994): Ecological Microcosms. Springer-Verlag, New York.

CAMPBELL, D. E. (1984): Energy Filter Properties of Ecosystems. Ph. D. Dissertation, Environmental Engineering Sciences, Univ. of Florida, Gainesville.

CANOY, M. (1970): Desoxyribonucleic Acid in Ecosystems. Ph. D. Dissertation, Dept. of Zoology, Univ. of North Carolina, Chapel Hill.

DIAMOND, J. M. (1974): Colonization of exploded volcanic islands by birds, their supertramp strategy. Science 184:803–806.

HOLLING, C. S. (1986): The resilience of terrestrial ecosystems: local surprise and global change. Chap. 10, pp. 292–317 in Sustainable Development of the Biosphere, ed. by R. E. Munn. Cambridge Univ. Press, U. K.

KANG, D. (1998): Pulsing and self organization. Ph. D. Dissertation. Environmental Engineering Sciences, Univ. of Florida, Gainesville, 275 pp.

MARGALEF, R. (1958): Temporal succession and spatial heterogeneity in phytoplankton. pp. 323-348 in Perspectives in Marine Biology, ed. by A. A. Buzzati-Traverso, Univ. of California Press, Berkeley.

ODUM, H. T. (1962): Man and the Ecosystem. Proceedings of the Lockwood Conference on the Suburban Forest and Ecology. Connecticut Agricultural Experiment Station Bulletin 652:57-75.

ODUM, H. T. (1970): Summary: an emerging view of the ecological system at El Verde. Chap. 1–10, pp. 1191–1289 in A Tropical Rain Forest, ed. by H. T. Odum and R. Pigeon. Division of Technical Information, US Atomic Energy Commission, TID 2470.

ODUM, H. T. (1982): Pulsing, Power and Hierarchy. pp. 33–59 in Energetics and Systems, W. J. Mitsch, R. K. Ragade, R. W. Bosserman and J. A. Dillon, Jr., eds. Ann Arbor Science, Ann Arbor, MI.

ODUM, H. T. (1983): Systems Ecology. J. Wiley, NY.

ODUM, H. T. (1988a): Self organization, transformity, and information. Science 242 (Nov. 25, 1988):1132–1139.

ODUM, H. T. (1988b): Living with complexity. pp. 19–85 in The Crafoord Prize in the Biosciences, 1987, Lectures. Royal Swedish Academy of Sciences, Stockholm, Sweden.

ODUM, H. T. (1989): Emergy and evolution. pp. 10-18. in 33rd Annual Meeting of the International Society for the Systems Sciences, Vol. III, P. W. J. Ledington, ed. Edinburgh, Scotland.

ODUM, H. T. (1994a): Ecological and General Systems, revised ed. of Systems Ecology. Univ. Press of Colorado, Niwot.

ODUM, H. T. (1994b): The EMERGY of natural capital. Chap. 12, pp. 200–214 in Investing in Natural Capital: The Ecological Economics Approach to Sustainability, A. M. Jansson, M. Hammer, C. Falke and R. Costanza, eds. Island Press, Covelo, CA.

ODUM, H. T. (1995): Systems of Tropical Forest and Economic Use, Chap. 14 in Tropical Forests, ed. by A. E. Lugo. Centennial Volume, Tropical Forestry Institute, U.S. Forest Service, Rio Piedras, P.R.

ODUM, H. T. (1996): Environmental Accounting: EMERGY and Environnmental Decision Making. John Wiley, New York.

ODUM, H. T. (1997): EMERGY evaluation of biodiversity for ecological engineering. Chap. 18, pp. 330-359 in Biodiversity and Landscapes: A Paradox of Humanity, ed. by K. C. Kim and R. D. Weaver. Cambridge Univ. Press, New York.

ODUM, H. T., ODUM, E. C., and BROWN, M. T. (1997): Environment and Society in Florida. St. Lucie Press, Boca Raton, FL.

ODUM, W.E., ODUM, E. P., and ODUM, H. T. (1995): Nature's Pulsing Paradigm. Estuaries 18(4):547–555.

RAYNOR, A. D. M. (1994): Pattern-generating processes in fungal communities. Chap. 25, pp. 47 in Beyond the Biomass, ed. by K. Ritz, J. Dighton and K. E. Giller. Wiley, New York.

RICHARDSON, J. R. (1988): Spatial Patterns and Maximum Power in Ecosystems. Ph. D. Dissertation, Environmental Engineering Sciences, Univ. of Florida, Gainesville.

RICHARDSON, J. R., and ODUM, H. T. (1981): Power and a pulsing production model. pp. 641–648 in Energy and Ecological Modeling, W. J. Mitsch, ed., Elsevier, Amsterdam.

# INHALTSVERZEICHNIS



## I. TEIL
## SOZIALPOLITIK FÜR DAS 21. JAHRHUNDERT IN ÖSTERREICH



## ROUND-TABLE-GESPRÄCH
*„Pensions- und Pensionistenpolitik für das 21. Jahrhundert"*



## II. TEIL
## ÖKOLOGIE UND SOZIOÖKONOMISCHE ENTWICKLUNG