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GENETIC ENGINEERING WITHIN THE BIOSPHERE: HIERARCHICAL LEVELS AND VALUES

by

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INTRODUCTION

The ethical problems presented by genetic engineering will be considered in terms of human alteration of the biophysical capital of our planet. This means that the risks introduced by this new technology will not be considered in terms of the possible release of virulent organisms into the environment. In fact, human alteration of the genetic resources of the biosphere can imply, even without the occurence of heretofore unknown epidemic diseases, the destruction of a capital of information which has been accumulated over a million years of coevolution of physical and biological processes of self-organization. Unfortunately, science today is unable to fully assess the value of such a biophysical capital, and therefore, to fully assess the consequences implied by a massive alteration of the existent genetic resources. Serious ethical questions, thus, are posed by the dramatic development of new scientific disciplines such as genetic egineering, that are able to affect in the short/medium term the structure/function of the entire biosphere.

What kind of risks can recombinant DNA technology induce in the biophysical capital of the biosphere? What costs/benefits are currently considered when decisions in this field are taken? Who will pay if something goes wrong ?

The paper is divided into two parts :

PART I - a theoretical framework is provided to describe the problem of risk assessment of genetic engineering. Information or better complexity is defined by using the thermodynamic of non-equilibrium approach. Different hierarchical levels, at which technological activity can be assessed, are distinguished. Each of these levels implies a different space-time scale of risk assessment and a different goal definition for the system.

PART II - the ethical issues of genetic engineering are discussed, using the approach presented in part I.

I - THEORETICAL FRAMEWORK

Genetic engineering means the manipulation of information already available in biological systems at DNA level (e.g. in form of genes), in order to produce new biological structures and/or functions which are "more convenient" according to the human point of view. Clearly, any alteration of an existing pattern of organization aimed at obtaining a "better pattern" implies costs, benefits, and risks that, in order to be compared, need to be defined and in some way assessed. Considering changes in the biosphere structure it is difficult to define in an objective way the concept of "better" organizational pattern and to reach an acceptable accuracy in the assessement of costs, benefits and risks induced by human alteration.

The interaction between humans and biophysical systems can be described using energetic models (1,2,3). In this way, a non-biased ("man-centered") frame can be adopted to analyze the terms of the ethical problem generated by human exploitation of natural resources (4). In particular, an approach based on the thermodynamics of non equilibrium can be used to describe the process of human exploitation of biophysical capital and to define costs, benefits and risks (5,6).

1.1 Defining complexity for biological systems

The complexity of a biological system can be analysed using the thermodynamics of non-equilibrium approach, and in particular, the dissipative structure theory (7,8,9).

A dissipative structure is defined as an open system, not in thermodynamic equilibrium, in which matter flows in an organized pattern that represents the structure of that system (6). In dissipative structures, the work of self-organization transforms a flow of energy-matter input into the maintenance of a defined structure/function of the system. In other words, a dissipative structure, when stabilized in time, makes probable a distribution of gradients in space and in time that is improbable according to the classic laws of thermodynamics. For example, the most probable temperature of the human body is around 37°C in spite of external fluctuations in the ambient temperature as well as the streets of the center of a city are likely to be illuminated at night in spite of the natural external darkness. Plants, humans, ecosystems, societies, and the entire biosphere are all examples of dissipative structures (5,6). At biosphere level, biophysical processes, based on the dissipation of solar energy, sustain bio-geo-chemical cycles of matter, whose organizational pattern represents the biosphere function/structure.

Biological structures have developed the capacity to accumulate information into a DNA code. The genetic pool of a species (= the genetic resources referring to a single species) represents the physical structure where this information is stored. However, adopting the expression introduced by Prigogine (10) for thermodynamic systems in non-equilibrium, genes and genetic pools are "becoming systems", this means that the confinement of a defined distribution of genes within a genetic pool (which originates a species) is the result of a dynamic equilibrium between the becoming process of genes in different populations of the same species which undergo different selective pressures.

Moreover, the process sustaining the ecosystem's structure/function is based on matter loops, generated by energy dissipation which results from the interaction of many species (**Fig. 1.1a**). This suggests that the entire web of interrelationships among the species that compose the ecosystem must be considered in determining this dynamic equilibrium. "The plant compartment, utilizing solar energy, provides negative entropy for heterotrophs in the form of reduced organic compounds, and a stable environment. Heterotrophs, in turn, recycle carbon dioxide and other nutrients and with their activity regulate the distribution of plant genetic material in space and in time. The result of this interaction among components increases the quantity of solar energy captured and dissipated by the ecosystem as a whole"(5). Put in another way, the final structure of the ecosystem and therefore its stability depends on a dynamic equilibrium among the species composing it, as well as the definition of a genetic pool of a species and its stability depends on the dynamic equilibrium among the becoming genes composing it.

As a consequence of this, it can be seen that in our biosphere, a single species, even a plant, cannot survive by itself in steady state: sooner or later it would consume the stock of input on which it feeds and would be affected by the negative accumulation of its by-products. A change in the density of one species is only possible if there is a rearrangement in the biota of the whole ecosystem. For example, a dramatic improvement in the ability to catch flies in a population of spiders could lead to a temporary increase in their number - i.e. their density in the ecosystem. However, this new density is sustainable only if the density of all the species, directly or indirectly related to the spider population, is changed as well. This requires a dramatic change in the system's boundaries if the feasibility of such a sudden change is to be assessed (not only the reach of the spider activity has to be considered, but also the reach of flies, plants, the water cycle feeding the plants, etc.).

Clearly DNA-manipulated organisms would generate the same problem: dramatic changes in the activity of a single species, generate a perturbation and instability in the whole system. This is clearly illustrated, at the level of the biosphere, by the anomalous increase in the density of the species *Homo Sapiens*. As noted earlier, the actual configuration of a single genetic pool is dependent on the genetic pools of the other species living in the same ecosystem with which it is in dynamic equilibrium. Consequently, the distribution of information among the genetic pools of all the different species is related to the dynamics of their interaction.

In conclusion, the hierarchical level at which a biological system should be analysed to assess changes in its complexity is the ecosystem or biosphere level.

1.2 Hierarchical structures

The concept of hierarchical levels of organization is quite easy to illustrate: cells, tissues, organs, individual organisms, populations, species, ecosystems, and biosphere are all different hierarchical levels at which biological processes can be analysed. However, it is difficult to deal with multi-level hierarchical systems in scientific terms. In fact, when we switch from one particular level of description to another we have to change the assumptions about the boundary conditions (4) : for example, studying the physiology of a mammalian cell means assuming the environment as stable, while studying the physiology of a mammalian organism means assuming variable environmental conditions. "Parameters that are independent at one level (stability of atmospheric composition in plant physiology) may become dependent variable at another level (atmosphere composition in biosphere physiology). Components at a lower level (individual organisms) may be aggregateed into an average value (size of population) at higher level". (4)

Changing the hierarchical level means changing our perception and therefore the focus of the description of a system or a process. Such a change implies loss of information and of accuracy in the description of one aspect of the system, and a gain in another aspect; moreover, such a change implies also the need for a different space-time scale of assessment. Moving down the hierarchy, one reduces the space-time scale of the process analyzed, while moving up the hierarchy one enlarges the spatial-time description of the organizational process (2).

For example, to describe the behaviour of a gas at molecular level the variables to use are the position and the trajectory of all the gas molecules (space-time scale referring to Amstrongs and fractions of seconds). Clearly, a barrier created by the quantity of information which must be processed makes it impossible to use this approach to describe the behavior of a gas on a macroscopic scale (kg, m, hours) (9); not even the largest existing computer could handle the problem of describing the behaviour of the molecules present in a mole of gas (10^{23}) on a macroscopic scale, describing all the interactions occurring among the components. However, by adopting a higher hierarchical level we can describe the behaviour of the same gas in its interaction with its environment with a very simple and practical equation (PV =nRT). "Understanding the hierarchical structure means to be able to describe the system using less variables" (11). On the other hand, as noted before, this switch of level implies that we can no longer know about the position and speed of a single molecule.

H.T. Odum (2, 12) studied extensively the formation of hierarchical structures in biological systems and human societies, describing them as a network of components linked by flows of energy and matter, and controlled by feed-back mechanisms (**Fig. 1.1 a/ b**). Within these systems, the switch to a higher level of organization implies an increase in the space-time scale at which the functions and goals of the interactions are analyzed.

1.3 Hierarchical levels and the Definition of Values in the Management of Natural Resources

Dealing with human activity, at least three hierarchical levels can be distinguished to analyze technological efficiency (**Fig. 1.2**) (4):

1. Global level; the society is viewed as a part of the whole biosphere.

This is the ecological level at which efficiency refers to the entire system "human society + ecosystem". This system has a defined boundary represented by the physical structure of the biosphere. At this level a major concern is represented by the sustainability of human activity.

2. Societal level; the society is viewed as interacting with an environment composed of natural ecosystems and other societies. At this level (which we can define as the economic point of view) the constraints imposed by the availability of natural resources are obscured by two factors : (i) the short time scale of economic

processes, which prevents a complete assessment of the stock depletion of natural resources (because of the difference in time scale, the economic discounting of natural stocks of resources is very difficult - (13); (ii) the effect of trade, providing in embodied form the activity of ecosystems far away in space (imports of goods) and in time (imports of fossil energy) (5). This means that efficiency, assessed at this level, generally refers to the society's ability to consume resources, and to exchange goods and services with other societies via the price mechanism. The effects of the economic activity on the part outside the societal boundary are not clearly defined.
3. Individual level; at which a new set of ethical values is introduced in an independent way. For example, despite the fact that slavery and euthanasia could prove convenient in boosting the economy or in reducing the pressure on the environment, their application is ethically questionable, on the basis of concerns detectable only at individual level. In the same way, personal interests, defined at this level, can conflict with communal interests defined at the societal level (e.g. when filling in a tax declaration).

Despite the possibility of defining independently-formulated values, it should be noted that these hierarchical levels, at which human activity can be analysed, are far from independent. A decision made on one level invariably affects the fullfillment of objectives on the other levels (4).

1.4 Limits of scientific cost/benefit assessment and ethical values

The information accumulated in genetic resources should be considered a part of the biophysical capital of the planet Earth. Incorrect management of these genetic resources can lead to the destruction of this capital, as is already happening to other components of the biosphere's capital (loss of soil fertility, greenhouse effect, ozone layer thinning). Optimizing strategies based on economic assessments, with their rather short time scale (10-30 years), tend to optimize only the human returns without considering the depletion of biophysical capital. In other words, these strategies are formulated adopting the second hierarchical level presented. For example, economics aims at maximizing agricultural yields by using monoculture, pesticides, and fertilizers, an approach which seems to ignore the long term consequences of these technologies such as loss of biodiversity, development of pest resistence and soil erosion.

Ecological assessments on the other hand, deal with long term cost/benefit analyses for the biosphere's equilibria. Unfortunately, this time scale appears to be too long to allow an economic "translation" of the depletion of natural resources in monetary terms (e.g. the problem of discounting the value of natural resources in a time period of more than fifty years may prove insoluble) (14).

The consequence of this time-scale difference in hierarchical levels is that economic assessments have proved unable to assess the impact of human activity on the stability of the biosphere; long term cost/benefit analyses are not possible using economic indicators. In other words, *human capital* - considered to be composed of only humans and their technology - is generally considered independent from *natural capital* - composed of natural cycles that provide environmental stability, and inputs to the human society (6). Because of this, the economic approach is leading mankind to a too rapid technological evolution that is not in harmony with the evolution of natural systems. A more holistic approach is needed, combining the assessment of short term economic returns with the long term returns of ecology, an approach that defines harmony with natural processes as an intrinsic value, to be used in the assessment of technological changes (13). This would imply the ability to compare different, contrasting optimizing factors defined on different hierarchical levels (4).

Unfortunately, a serious problem exists in extrapolating the description of a system from a particular level to another, because of the differences in space-time scales which are used to describe the same phenomenon at different hierarchical levels. Analyses referring to biological systems at different hierarchical levels use space or time scale that can differ up to 12 orders of magnitude (e.g. micron versus thousands of miles; second versus millions of years) Fig. 1.3. "Molecular biology dealing with distances of 10^{-6} m and masses of fractions of grammes has too long way to bridge to arrive at the ecological level where measures are in the order of 10^{12} m and massess in the order of a million kg". (4).
The high level of scientific accuracy in describing cause and effect at one particular hierarchical level is obtained only because of the simplifications adopted and therefore cannot be maintained when crossing to a different level.

This observation propose the fundamental role of ethics in the process of decision making about the management of natural resources: making decisions with regard to societal development today means dealing with uncertainty. "Assessing the costs and benefits within a hierarchical level is a scientific job; evaluating the costs and benefits among different hierarchical levels is also an ethical and a political job. The human community has to decide what is to be gained, and what has to be lost, evaluating parameters that are, in scientific terms, difficult to compare: economic development versus environmental stability; biodiversisty versus hunger, safety for the future generation versus present quality of life" (4).

1.5 Assessing genetic engineering : the danger of the "one problem, one solution" approach

The danger of the "one problem, one solution" approach can be illustrated by the problem of development of resistence by pests to plant toxins. Approximately 10,000 chemical compounds produced by plants for defence are known (15): these toxic chemicals are used along with other factors (e.g. physical factors such as hairiness, and thorniness) to reduce herbivore attack. However, "the cost of developing and maintaining defensive characters prevents the host from accumulating a sufficient level of resistant characters to eliminate completely herbivores populations - optimal fitness results from a trade-off of the benefits and costs" (15). The fact that the defense of a plant is based on the combination of a wide range of defensive characters has a very important significance. Variety in defense mechanisms means to "retard or prevent evolution in the herbivores and other parasites to overcome host resistance" (15); in this way the plant buys time to develop new defensive characters as the predator develops more capability of attacking. "When a house fly population was exposed to 6 diverse chemicals for 32 generations . . . the population did not evolve resistance to any of the chemicals. However, when individual house fly populations were exposed to any one chemical alone, each population evolved substantial resistance to the chemical within 8 to 10 generations" (16). "A diverse set of resistant factors may have distinct advantages. For instance, combinations of 14 phenolic compounds at low concentrations were found to have a greater deterrent effect upon a locust (*Locusta migratoria*) than a high concentration of any single phenol"(17).

Genetic engineering often aims to transfer chemical resistence from one plant species to another. However, this can imply, in the medium/long term, the complete loss of the complex and dynamic equilibrium between predators (herbivores) and prey (plants). Such an alteration of the natural use of these chemicals by the genetic structure of the plant population, can induce an enhancement in the development of chemical resistence in pests. When it has the possibility to fight one chemical defense at a time, taken out from the natural pattern of the plant's defensive strategy, the pest may become able to accumulate genes of resistence to single toxic compounds and to share them with other insect populations. This process is described by a Roman legend: after a long and inconclusive war with a neighbouring city, a fight was arranged between three Roman warriors (Orazi) and three enemy warriors (Curiazi) to decide the final outcome of the war. Very soon two of the Romans were killed and the last was left no option but flight, hunted by the three enemies. However, because of the different speeds of which the three hunters were capable, the last Roman managed to face them one at a time, and to kill each of them.

Applying the "one problem, one solution" approach to genetic engineering, humans can destroy in a few decades huge quantities of valuable information that natural evolution has accumulated in the ecosystem's network of interactions over millions of years. The predator-prey equilibrium is a dynamical equilibrium sustained by a network of flows of energy and matter throughout the whole ecosystem. As noted earlier, the stabilization of a pattern of gene distribution among species is the result of a dynamic equilibrium due to their interaction in the ecosystem. Thus, the ability to reach such a dynamical equilibrium between predator and prey should be considered a valuable capital of information, which can be destroyed because of human intervention. This means that a new mechanism of control among species distribution will have to be developed to reach a new equilibrium required by a sustainable structure of ecosystem. Since humans do not even know how many species exist on their planet, and seem to have a very poor understanding of the processes sustaining the biosphere structure/function, it seems very improbable that this regulation will be provided, at world level, in the medium term by human bio-technology.

In conclusion, a species (or better the genetic pool of a species) can be viewed as a cluster of becoming genes - isolated from other genes via different mechanisms- selected with respect to their ability to express structures/functions that stabilize the work of self-organization of the related populations interacting with environmental processes. Therefore, the actual configuration of an ecosystem (form and distribution of genes among interacting species) is the result of a process of coevolution that has taken place over millions of years. For this reason, the capital of genetic resource *is not only* defined by the information coded in genes on DNA, *but also* by the particular pattern of distribution of this genetic information reached at equilibrium (abundance, diversity, different frequences of alleles among populations of the same species living in different areas). More in general this capital of information can be referred to the distribution of genetic resources among different species and ecotypes around the world. This means that any genetic manipulation which uses "technical solutions" coded on single genes (transferring genes among organisms) without considering at the same time the wider dynamic equilibrium existent between interacting species within the biosphere can result in a destructive use of such a capital of genetic information.

II THE ETHICS OF PATENTING ANIMALS AND OTHER FORMS OF LIFE

2.1. <u>The responsability of managing natural resources.</u>

Centuries ago, humans were too few in number and technology was not sufficiently developed to endanger natural processes. Constraints referring to the hierarchical level of the biosphere equilibrium were imposed on human society. With the discovery of exosomatic energy chains (engines fed by fossil energy) this situation has changed; humans manage to consume resources at a rate far higher than that at which resources are generated. This means that we can no longer afford to allow the economic mechanism (the human point of view) to decide how to use our natural resources to maximize human profit; today, human activity is able to alter the biosphere equilibria in an irreversible way.

When disturbed, dynamical systems can show resilience for a while, but if the stress is too great, the system will collapse and the capital information stored in the system will be lost for ever (e.g. the death of a living being). This suggests that a high level of caution should be adopted in the process capable of directly altering natural ecosystems. "Human societies and the biosphere are regulated by the catastrophy theory, which makes the "learning by doing approach" inappropriate for their management. Like the human body, these systems tend to keep their functions (e.g. breathing, temperature control) until the last second before collapsing. If our choices for the management of biophysical capital turn out to be wrong (collapse of the system), we will not have a second chance!" (4).

The genetic recombination can be seen as a way to dramatically increase the speed at which new biological structures can be generated, short-cutting the fastest biological process selected by nature for generating variability for evoluted organisms: sexual reproduction. However, sexual reproduction guaranteed that the variability of new "biological solutions" was always mediated by the clustering effect of patterns of genes within species. Genetic engineering represents " a radical break from evolutionary story . . . nature's wisdom setted boundaries between species, offspring were not biologically possible. Now molecular biologists . . . making an end run around nature's restrictions . . . are mixing genes from many distantly related species of organisms to produce progeny that nature would never allow" (25). The evident ethical concerns generated by this activity - "The simple act of biting into a ham sandwich may soon qualify as cannibalism . . . pigs whose chromosomes have been spliced with human genes may be on the market in less than ten years"(25) - seems to imply that a more holistic judgement (a larger horizon in the assessment) is still provided by traditional culture than by advanced science.

New forms of organisms, resulting from genetic engineering, are artificially generated by the manipulation of genetic resources; these organisms did not go through the long and patient process of natural evolution, and their compatibility with the existing biophysical capital is not proved. This phenomenon is analogous to the emission of man-made chemical compounds into the environment: man-made compounds are not compatible with the natural processes of the biosphere because they did not evolve together. Some chemicals require centuries, nuclear wastes thousands of years, before being changed into a form compatible with the environment. Moreover, when dealing with dynamical systems, non-linear effects may occur, such as biological amplification of pollutants in animals on the top of the food chain, as in the case of DDT (3). If the risk of ecosystem contamination with chemicals can still not be completely assessed, the level of ignorance about the risks of contaminating the ecosystem with "transgenic organisms" will be even higher (18).

2.2 Ethics of gambling

Altering the information content (DNA) of a single species without being able to forecast its possible consequences on the entire ecosystem is equivalent to gambling : increasing the human return (looking for a larger capital), by risking the existent capital of the system. I do not intend to discuss the ethics of gambling in absolute terms (the discussion would be biased by personal beliefs), but I do want to make two statements that can be agreed on by most people:

(1) Before deciding how to gamble (what, when, where), one should be able to assess the consequences of the possible gain and loss.

(2) The person making the decision to gamble should be the same as the one paying for the gamble.

Unfortunately, neither of these conditions is respected in the case of genetic engineering. Regarding the first point, I have already mentioned that today we are not able to assess the consequences of this form of gambling : we do not have a good understanding of the processes guaranteeing the stability of our ecosystems and therefore nobody can forecast the final consequences of the perturbations induced by human activity. The second point - who gains by and who pays for this gamble - will be briefly discussed below.

At global level : the developing world seems to be the most affected when consequences have to be paid for gambling. Developing countries generally have little access to technological resources (low consumption of fossil energy, low technological capital) and therefore rely heavily on natural resources generated by biophysical processes. A deterioration of natural cycles and local collapses of natural ecosystems represent a major threat for these developing societies.

On the other hand, the decisions about genetic engineering are taken in the developed world, that is at the same time the more likely end of possible gains. Developed countries based on technological processes and trade can afford this gamble, and clearly take advantage from it (the terms of trade are continually in favor of the developed world). Ironically, genetic resources used to prepare new engineered organisms are often taken from developing countries for free !

Despite the continuous production of technological devices capable of altering in a more decisive way the natural patterns of primary productivity within ecosystems, the long term trend within developed countries seems, paradoxically, to be toward more respect for natural processes. The green movements and the consumers' concern for the environment seem to be pushing technological development in agriculture within the developed countries toward more sustainable forms of production, and more respect for local natural equilibria (preservation of wild life, organic agriculture, etc). The less developed world, thus, seems to be the place where the use of bio-technologies is more likely to face lower control and therefore where the risk is higher (19).

In this respect, the lack of a holistic vision (lack of respect for the biospheric hierarchical level) has already brought the population of many areas of the developing world above the carrying capacity of local ecosystems (e.g. increases in population from 11 to 50 millions in Egypt in the last 80 years- 26) due to the careless application of modern technologies capable of temporary boosting agricultural productivity, such as the green revolution. Today, the consequences of these choices are becoming more and more evident: environmental degradation in the form of loss of biodiversity, loss of soil fertility, and contamination and lowering of water tables are problems widespread throughout the world. The dynamical equilibrium between humans and natural processes has been broken, and overpopulation implies destructive technologies of exploitation. In this framework, genetic engineering risks providing another short term remedy to sustain, if not increase, human activity - temporarily hiding the non sustainability of the size of the human population and its level of consumption - and allowing an increase in the withdrawal from biophysical capital at a speed not compatible with its preservation (5).

At societal level : "this technology probably has for the first time in the history of science, excited many academic scientists to become involved in business . . . many scientists working in this area are reading financial papers, and many investment analysts are reading scientific journals . . . to take advantages of the limited numbers of expert available, industrial firms are beginning to provide long-term support for basic research on genetic engineering in the universisties, in exchange for first right of licensing"(20). This development in genetic engineering can imply also a conflict of interests between the individual and societal points of view, as mentioned in section 1.3. This conflict can be amplified by the large quantity of money involved (due to the plundering of the genetic treasure) and the intrinsic difficulty of assessing long term risks and benefits. "It is no longer possible to believe that science can, or should, banish uncertainty in the new environmental problems. The technological processes are too novel, the interactions in Nature are too complex, and the human consequences are too subtle to permit anything like textbook exercises or lab experiments to be adequate" (21). After all, who can control the scientists but themselves ?

The suspicion of a possible 'collusion' between scientific and economic powers tends to exasperate the apprehension of a public which has already started to fear biotechnology after the loss of scientific credibility due to the recent nuclear disasters (22). "The complexity and novelty of a fully developed biotechnology in the industrial and agricultural sectors seems likely to exceed that of nuclear power, particularly in regard of its hazards" (21)

Conclusions

So far a very critical approach has been presented toward genetic engineering. Clearly, it is not the intention of this paper to question the potential of this new technology, which is immense; major breakthroughs, capable of solving many of the problems of mankind can be imagined using this powerful tool. The aim of this paper is to express concern, not about the technique of recombinant DNA in itself, but rather about the possible use that humans can make of it. In particular, the activity of patenting animals and other forms of life implies that an economic level of assessment has been chosen for an activity with important possible consequences on the ecological level.

Human technology has become so powerful that it has escaped the feed back control provided by natural, regulative processes. For this reason, a huge dose of caution is needed when altering the biophysical world, especially considering our unbelievable state of ignorance about the ecology of our biosphere. Due to this general ignorance of the dynamics of environmental equilibria (scientists do not even agree on the order of magnitude of the number of species present on Earth!) a dramatic change in the biosphere composition toward a sustainable structure based on lower biodiversity, after a man-made selection of useful biota, appears to be very improbable in the short-medium term. Moreover, the regulative effect of the economic market mechanism has proved not to work well where depletion of natural resources is concerned. It follows, that if human activity is regulated only by economic laws, human ingenuity can overcome the feedback regulation provided by natural processes until it is too late. Although, we do not know enough about greenhouse effect, ozone layer thinning, consequences of massive deforestation, the effect of an increasing charge of pollution in the environment, all the activities responsible for these facts are performed and regulated by laws; this means that we already are forced to make choices, without fully forecasting the consequences (23).

Before starting another major wave of man-made perturbations - a release of a massive flow of new organisms, not proved to be compatible with their environment, into the delicate and precarious equilibrium of our biosphere - a better understanding of this equilibrium should be achieved. Research referring to the stability of such equilibria should have top priority even over biotechnological research. Unfortunately, the lack of economic return of the former kind of research compared with the high possible economic return of the latter, can generate a distortion in the allocation of research funds between these two areas.

The economic assumption that natural resources are infinite and natural processes are not affected by human behaviour can no longer be held. Humans are already exploiting their ecosystem in a non-sustainable way, and this means that we are already gambling. Biotechnology can improve this situation, but at the same time will raise the stakes and the risk. If an ethical problem is definitely inherent in careless behaviour of genetic engineering scientists, a more important ethical problem is posed by the way decisions are made about problems which directly affect the resilience of our biosphere and therefore the safety of mankind. To provide an example, world conferences on the ozone layer, after acknowledging the responsability of CFC chemical products in the deterioration of the ozone layer, have decided a gradual banning of these chemicals starting in the year 2 000! Priority has been given to the preservation of industrial investments (where the economic costs are clearly determinable). What about the environmental costs? Nobody can forecast the behavior of ozone holes, we don't know if a sudden collapse of this layer might occur in the near future. We are not able to diagnose the symptoms of ozone layer illness, or to cure it, because we do not even know the ozone layer's physiology. Nevertheless, priority has been given to industrial investment (gambling on the lives of many, gain in the pockets of a few). The fear is that a boom of genetic engineering industries could repeat this process again and again with amplified effects.

We are entering a new era in which the scientific role has to be reconsidered; the enlarging and the mixing of hierarchical levels at which problems have to be considered, generate an enlargement and a mixture of space and time scales of the processes to assess. This implies that individual scientific disciplines can no longer provide scientific answers (**Fig. 2.1**). "Facts are uncertain, values are in dispute, stakes high and decisions urgent . . . for coping with the irremediable uncertainties of the problems, there must be an 'extended peer community' . . . the facts relevant cannot be restricted to those produced in the (scientific) research itself" (21). It is time to work on a new science in which harmony between peoples is obtained through harmony with nature.

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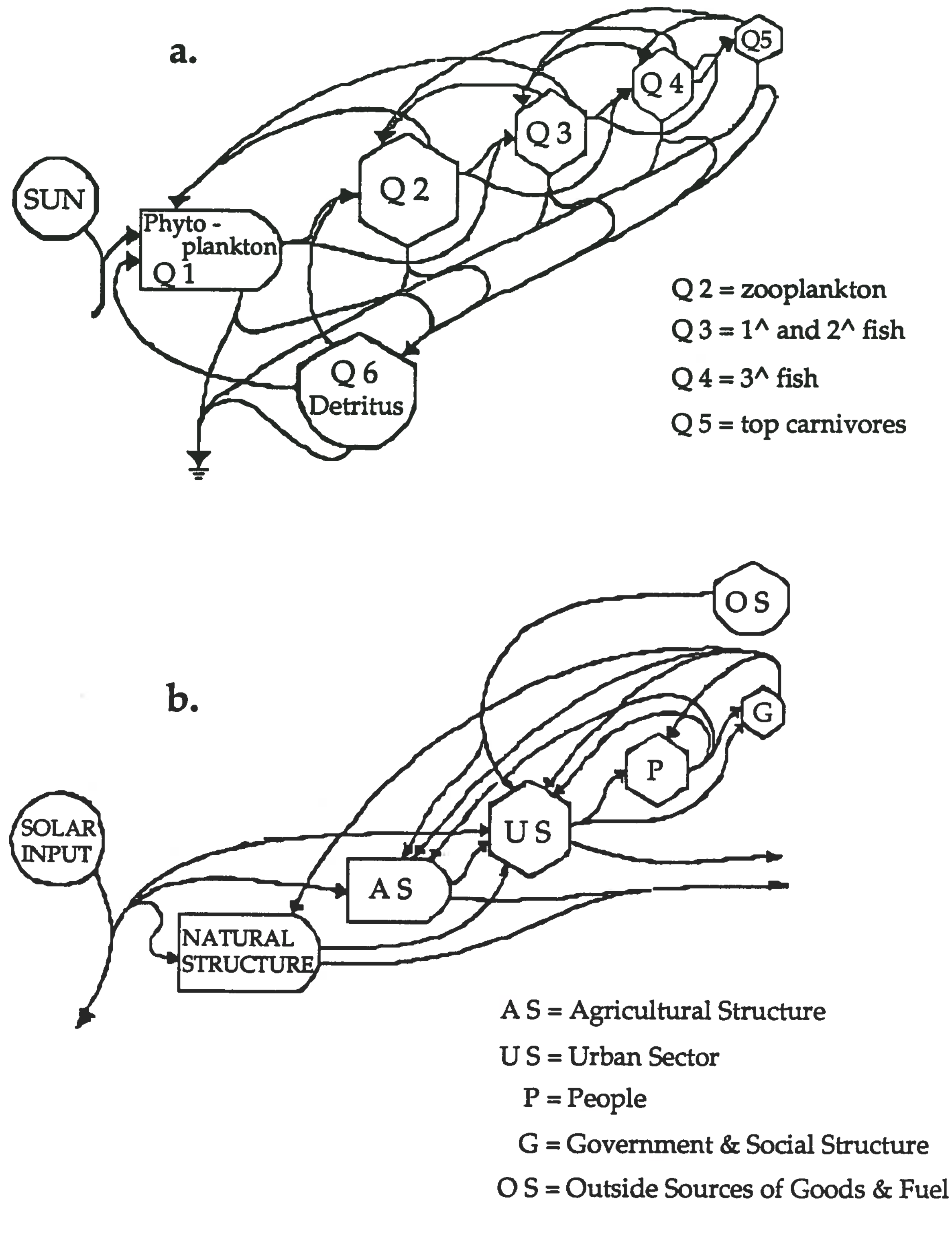


Fig. 1.1 Hierarchical structures in ecosystem and human society based on energy flows, after H.T. Odum.

Fig.1.2 Different hierarchical levels at which technological efficiency can be assessed

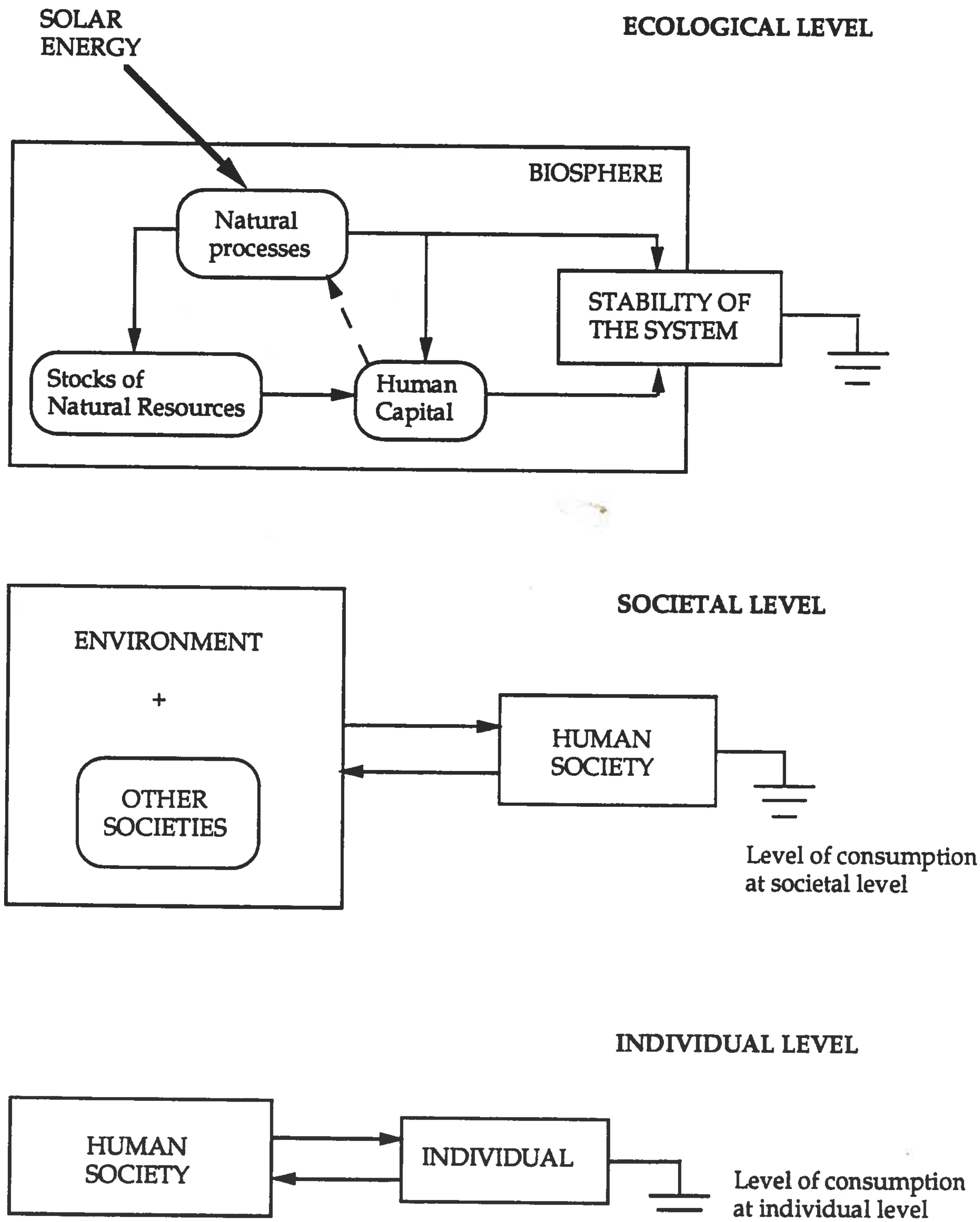
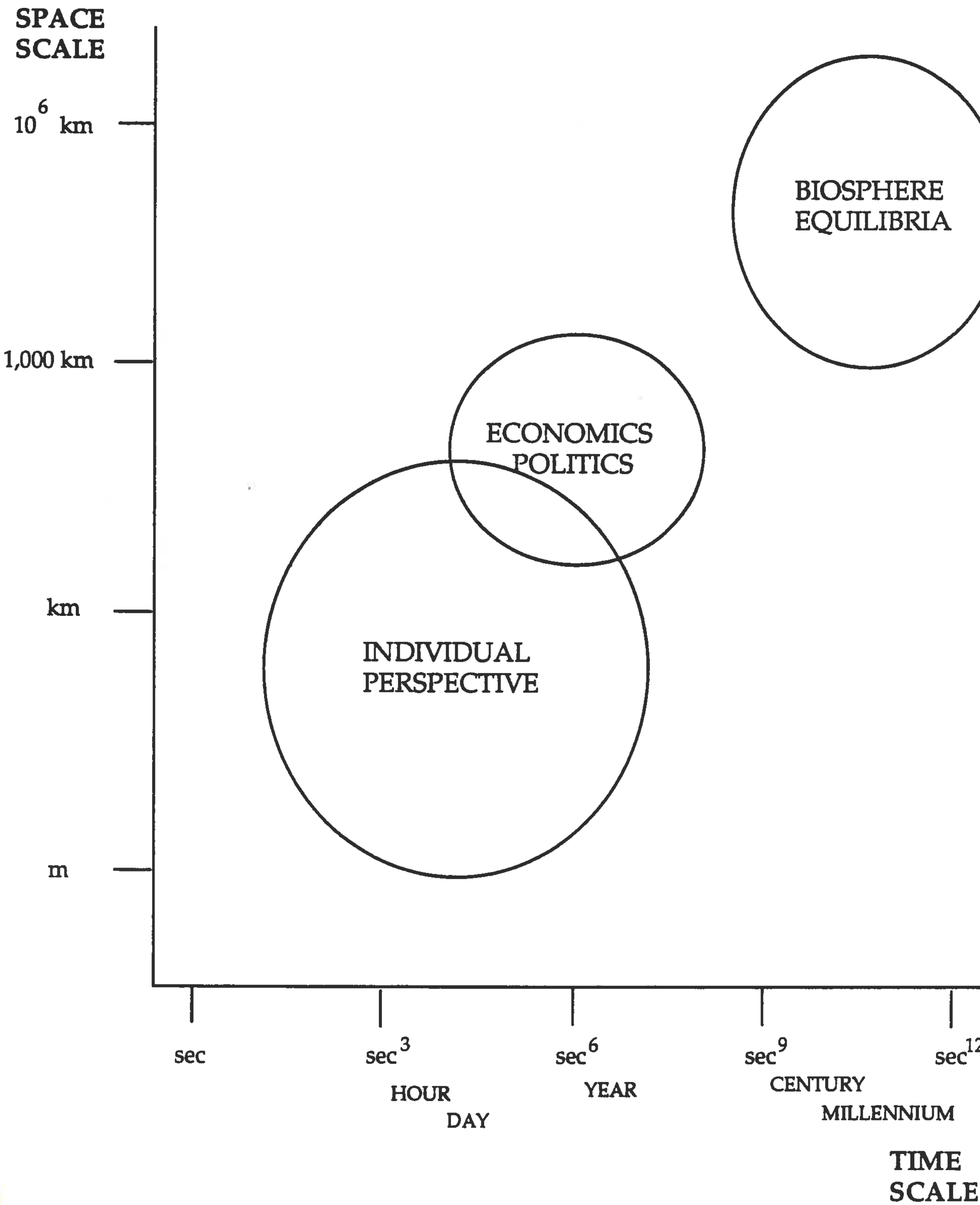


Fig. 1.3 Different hierarchical levels imply different space-time scales



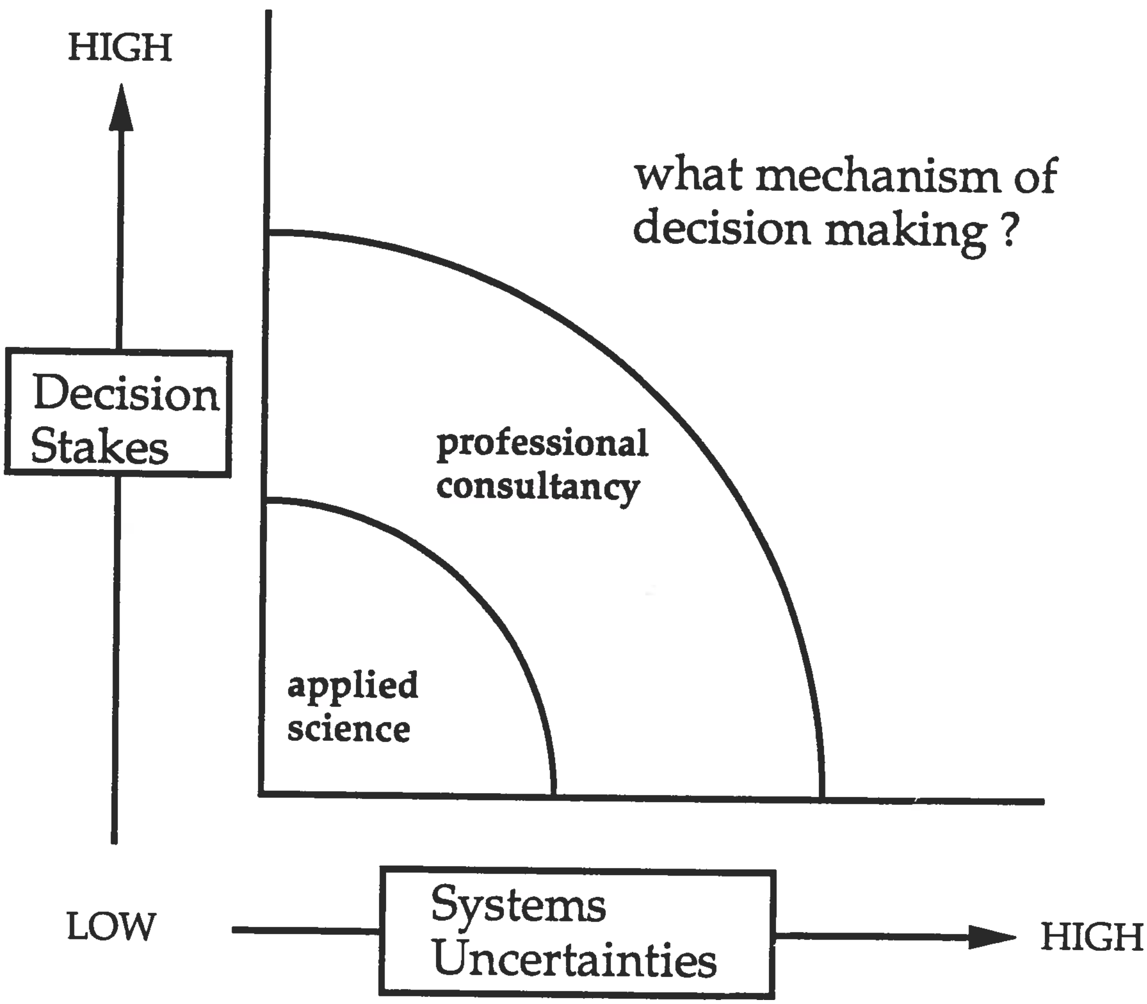


Fig. 2.1 A new science for new times
after : Funtowicz, S. and Ravetz, J.R. 1990. (24)