THE ENVIRONMENT: QUESTIONS AND PROSPECTS FOR RESEARCH

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Research on Environment involves a great number of questions which have extremely varied contents and which deal with numerous subjects concerning almost every major area of research. This characteristic leads us – or even obliges – to wonder about the way to imagine research programming in these fields.

Indeed, until the recent past, the approach was rather pragmatic: research operations have been launched on precise subjects as soon as they were identified. Numerous reports made since the beginning of the seventies have contributed to this identification of general problems [1] as well as specific ones (studies of various pollutions, in particular of the air and the water, effects of fallout of atmospheric pollutants, the evolution of various environments and ecosystems, the future of the stratospheric ozone layer, ...) [2]. The running of these multidisciplinary operations often amounted to a juxtaposition of monodisciplinary work. In this way, Research on Environment was and remains a matter for a list of more or less organized themes and not for a constructed and consistent unity. Little by little, groupings were made which enabled the launching of great international scientific programmes such as "Man and Biosphere" (MAB), "the International Geosphere-Biosphere Programme" (PIGB) or national programmes such as, in France, "the National Programme for Climate Study" (PNEDC) or "the Interdisciplinary Programme of Research on Environment" (PIREN) of the CNRS. The emergence of these programmes and the results they found, leads us to wonder whether today it is possible to suggest a coherent presentation of a scientific programme dealing with all sides of the Environment or even with the aspects which should be at the concern of a definition of Environment and Research on Environment admitted by everybody. That's what the Environment Programme of the CNRS tried in its very early months in 1990 and in particular on the grounds of the experience accumulated during the eleven years' work of the PIREN. The present text [3] lies within a continuity existing since that time.

Thus, we suggest focusing on the six following questions:

1 - Is it necessary – or are we able - to delimit a specific research field on Environment ? If the answer is "Yes", which definition can the field use as a paradigm ?

2 - Into which major areas could this field be organized ?

Summary

Problems of definitions

For example, in the "Petit Robert" dictionary (1979) we find: "Environment, n. (1300, "outline", from surrounding). • 1° Action of surrounding; its result. • 2° Way, Enclosure; surroundings of a place. • 3° Ling. immediate context. • 4° (1964 from the am. environment). Whole of natural conditions (physical, chemical, biological) and cultural conditions (sociological) able to act on the living bodies and the human activities. See Atmosphere, circle, surroundings. Protection, politics, quality of the Environment. See also Ecology. Rural, urban Environment. Space, acoustical and thermal Environment. Environment and Life quality and defense versus pollution and disturbances. • By ext. External conditions able to act on the functionning of a system, of a device.

For example, we will remember a part of the very behaviourist definition suggested by the encyclopaedic dictionary Larousse (1979): "whole of the elements of an Environment that an animal can detect. Progress in animal physiology and ethology sometimes enables us to know better in which sensorial universe of vibrations, of radiations, and chemical messages the various animal races are living. This universe is their Environment. The animals react with adapted behaviours: attacks, flights, immobilizations, conduct of court, feeding of the Young, ... Contrary to which is an objective reality including the temperature, CO2 content, illumination, food resources, the Environment is a subjective reality only made out of realities known by the animal. So, the plants have a surroundings but no or nearly no Environment. The study of the urban Environment holds the attention of urbanists and sociologists (see ecology)". In the same dictionary, we find under ecology: "... there also exists a human ecology which analyses Man's action on his Environment and the action of the Environment on Man...".

The present notion of Environment is really far from this "ethological" conception and is closer to the first definition (for the time being, the Petit Robert dictionary has the edge on the Larousse dictionary !) Nevertheless, this diversity of opinion reflects well the polysemy of the terme Environment.

3 - What are the particular theoretical and methodological problems set by research on Environment ?

4 - What are the effects of research on Environment on the various disciplines involved ? How can Environment problems direct or modify their problematics, their processes, their goals ?

5 - Which factors are to be taken into account in choosing a research strategy and therefore which strategy can be adopted ? Which priorities must be chosen and why ?

6 - Considering the characteristics of the Environment as a research field, which kinds of actions are to be implemented in the scope of this strategy ?

1. The Environment as a field for scientific Research

Research on Environment comes from a double questionning: the first from social origin, the second from scientific origin. The term "Environment" itself as it is accepted today, is new. This term has been added to the words: nature, milieu and in a sense has generalized them.

The social origin of the Environment problem dates from about the sixties with the awareness of a certain number of issues set out by the development of our societies: pollution, damage to areas, the limitation of natural resources, badly made or even chaotic accelerated urbanization, the global view of disturbance from anthropogenic origin...

Since the beginning of the seventies, this social awareness has lead to the writing of a great amount of reports – mentionned above – whose purpose was essentially to make the necessary assessment; to make some important urgent questions emerge and to make immediate recommandations to political powers.

The scientific origin is older and comes from the apprehension of nature, of "the natural surroundings". It also comes from the identification and study of its components, that is problems on which scientific disciplines have been built up. However, the evolution of problematics in each discipline could have taken them away from initial questions provided that these questions had been explained clearly. Nevertheless, we will remember that some up-to-date questions have been clarified for a long time. So, remember that:

– in 1824, J. Fourier was wondering about "the forming and the progress of human societies", "natural forces" and their respective effects at the global level of the Planet,

– a century ago Arrhenius was asking the question of the great balances of the Planet and in particular the question of the influence of CO_2 accumulation in the atmosphere,

– hygienist movements of the XVIII th century raised the question of the living environment and Health,

– during the XIX th century, the organizations managing natural resources were wondering about their exhaustion – for example: fishing – but saying that they were inexhaustible !

Today it is a matter of crucial questions because the expansion, the generalization of problems and the awareness of their interdependence are emerging more and more distinctly.

The stakes are very important and may be decisive to the future of human societies or even of man himself as a biological race living on the Planet. Maybe everything is to be thought again, to be reinvented but not to be done again: we must lean on the mass

Nature, Surroundings, Environment

The term "nature" has some mythical consonances; in fact as a scientific object , it is all that surrounds us excluding man and which obeys its own dynamics.

A surroundings is a local vision. This is what surrounds an object of study, or even what is internal to it (the "internal surroundings" Cl. Bernard). A surroundings is characterized by its physical and chemical properties and components; on the contrary there is no real reference to a space structure. In the biological sciences, the surroundings sets aside the human components. Conversely, in human and social sciences, the surroundings characterize the social surroundings, hence referring to a human group.

of learnings and know-hows accumulated; we must also base ourselves on an identification, a definition as precise as possible to the research subject: what do we mean exactly by Environment ? Can the Research on Environment be simplified to disciplinary problematics or, on the contrary, are we able to identify a specific interdisciplinary research field. After a stage, which was inevitably pragmatic, is it still possible to suggest a research orientation based on a strong logic ?

● 1.1. The difficulty to imagine the Environment as a scientific object

What do we mean exactly by Environment ? Although dictionaries tried – and that is their purpose – to give a definition; the scientific object, the term itself, keep giving rise to confusion. Why ?

For every one of us – and that is a first naïve and intuitive definition – Environment is what surrounds us as human beings, at a set time and in a given place. In fact, this notion of Environment is hard to understand, indeed:

• It is relative to a central object. This object depends on the point of view, on the centre of interest of the scientific work and it differs according to each discipline. For a population biologist, the central object is the population he studies and the Environment is what surrounds this population.

For a physiologist, the central subject is an organ or organism and the Environment is what surrounds this organism i.e "the ambiant environment" or what surrounds the organ i.e "the internal environment".

For a molecularist, the central object is a molecule, a macromolecule and the Environment is the "cellular environment".

For a sociologist, the Environment can be the family environment, the social class, the working environment, the living environment...

• It is complex. Three levels of complexity can be identified. Both "logical complexity and random complexity" are linked with the Environment itself. The third is from methodological nature: as we have already mentioned; in a naïve sense the Environment components have been the initial elements of scientific thought and of the identification of disciplines. It was a matter of isolating them in order to study them better and to develop a methodological, technical and theoretical assortment dealing with the study.

But today, it is a question of examining the whole: besides the examining of interrelations between the Environment components, we must design new techniques, we must deepen the methodological aspects and tackle theoretical structures in the scope of true interdisciplinary work. And that is probably a necessary condition for a better comprehension and control of environmental problems.

• It is polysemic. For example, some scientific and technological areas have taken it with different meanings. So we are talking about Environment in computer science in order to mark out all the devices and the application programmings which are essential to effect some tasks and in particular some high level ones.

• It is recent. The Environment as a subject for studies was only identified as a result of the problems asked by the human activity and because the Buffon's assertion: "Nature works to restore what man does not stop to destroy" doesn't seem to be true anylonger. The demographic and technological acceleration have had a revealing effect.

• It is changeable in time and space. A move can lead to a change of environment. In a given place, the components and structure of the Environment change with time.

• It involves some phenomenon with characteristics which are scientifically and technically hard to define, identify and estimate:

– The weakness of causes compared with effects and the weakness of some effects, in their first stage at least, make some of them virtually not perceptible. Then causes become uncertain and effects are disputed.

– The difficulty to distinguish natural fluctuations and the variability of effects which are induced by human activity.

– The multiplicity of time and space scales and also of organization levels of living systems; levels at which these phenomenon occur: from local to global, from a second to the geological era, from the macromolecule to eco-

The complexity

The notion of the complexity has often been disputed and today. Further to the work of the logician Bennett, we can distinguish two kinds of complexity:

– The "uncertain" complexity according to Chaitin and Kolmogorov: what is long to write is complex. So, a chain of uncertain symbols can only be described by this chain itself, for example it is not reducible to a recurrent formula with a smaller number of symbols, so it shows a maximum level of uncertain complexity. We can join to this notion the intuitive one of complexity linked with the number of components of a system and with the number of interactions between these components: a system is said to be complex if it has numerous components and/or numerous interactions between these components (it is "long" to describe);

– Organized complexity corresponds to an object, for example an image, a picture composed from a multiple association of elementary symbols but according to a rigorous diagram. Fractal objects are good examples of it as are the pictures of Escher. They are closely linked to the notion of recursiveness. C. Bennett has just given a good definition of this complexity, he talks about logical complexity. The measure of this complexity is linked with time to produce the object we are interested in. With this notion we find complexity linked with the linear or non-linear nature of the interactions between the components of a system.

A system like the atmosphere is complex. The physical laws which govern its evolution, even in the short run, lead to sophisticated models and algorithms. This is a system with a strong complexity which is both considered as "uncertain" and "logical". The ecosphere in its whole is of course a superior complexity.

This definition of the complexity is, of course, in reality reducing and it may not cover all the acceptances of this term. But there is one thing to its credit: it exists and everybody must experience it in its intervention area [4].

systems, to landscapes or even to the biosphere as a whole.

– The diversity and importance of the effects of human activity through a quadruple intervention: the diffusion or concentration of Environment components leads to: a modification of their spacial distribution (true for mineral resources and living resources), to the synthesis of new "products", of new races or even " species" which are not natural (chemistry of synthesis products, radioactive elements, new animal and plant varieties, genetically modified bacteria, ...), voluntary or involuntary destruction of some ecosystems that leads to a reduction of biological diversity at least locally and that leads to a major modification of the living conditions of human populations who live on these ecosystems.

Which point of view is to be adopted ? It is desirable to look at this with a double perspective : on one hand from an heuristic point of view and on the other from an active point of view, including both scientific action and action in the field. To this end, and as already mentioned, it is first essential to agree on the notion of Environment itself and then to explain what will be the particular characteristics of Research on Environment, characteristics which will be the consequence of this definition.

● 1.2. Problems of definition

It appears clearly that, as social individual, as citizen and as scientist, we are worrying about the Environment. The changes which endanger the blooming of human beings are worrying us. We would wish to understand the processes which are conditioning the state of this Environment in order better to forecast and control its evolution. We already know that this Environment is the result of processes of "natural" origin and of anthropogenic actions. We know that the latter are of paramount importance. At least in the short and middle-term, they interact so much with natural processes that they may change some of their deep trends.

Our purpose is not to suggest strictly a definition of the Environment, as we understand it, but rather to show how to delimit progressively a scientific object. To this end, we begin with a simple definition suggested in the middle of the seventies, then we will try to give a more recent version based on the central idea that the Environment we are interested in, is that of human beings, of human societies.

• Initial definition

"The Environment is the whole of physical, chemical and biological agents and the whole of social factors which are able to have a direct or indirect effect, immediatly or in the long run, on living people and on human activities" (International Committee for the French Language).

We can explain this definition with a diagram in order to make the thought easier (Figure 1).

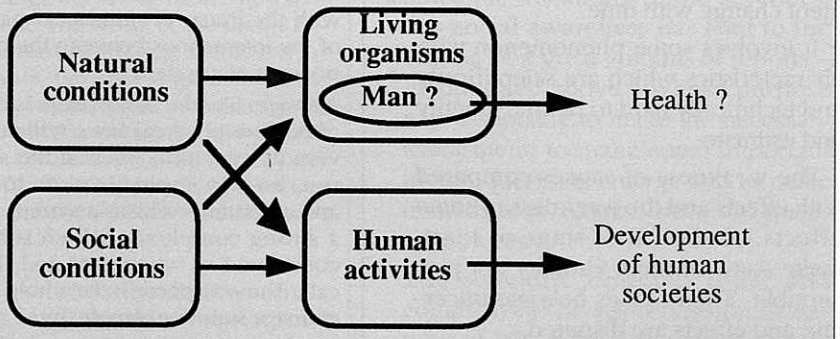


Figure 1 - The Environment – left part of the diagram – involves effects on living bodies – including man ? – and on human activities. We will note the divisions between "natural" conditions (agents) which are of bio-physico-chemical order and what belongs to man. Then we'll note the lack of reference to feedbacks essentially linked with human activities. There is no reference to the influence of natural conditions on social conditions.

• A more precise definition

In a first stage, we can suggest bringing back the notion of Environment on Man and human societies and then we can make clear the notion of ecosphere and the factors acting on it:

– the natural factors whose dynamic is not linked with Man – at least at first sight –

– the factors of anthropogenic origin.

The changes of this ecosphere act back on Man (in particular on health and on the development of human societies).

The introduction of the notion of ecosphere leads to a globalizing view,which is scientifically useful, of the Environment notion. As far as we are concerned here, we will keep the simple definition of the ecosphere that follows: "whole of biological (biosphere) and physicochemical components interacting with the biological systems (atmosphere, pedosphere, hydrosphere)". For greater convenience we will remember here the term ecosphere rather than the one of biosphere without ignoring the discussions on both terms [5].

• Definition given for discussion

In a second stage, we extend this global point of view of the ecosystem, first by including man and the human societies; then by specifying not only its biological and physicochemical components but also the processes which make these components change in time and space (Figure 3).

So, we suggest the following definition:

The Environment is the whole of natural or artificially made environments of the ecosphere, on which man settled, which he exploits and which he develops ; it is the whole of non-anthropised environments which are essential for its survival. These environments are characterized by:

– their geometry; their physical, chemical, biological and human components and the space distribution of these components,

– the process of change, action or interaction which imply these components by altering them in space and time,

– their numerous dependencies preceeding man's actions

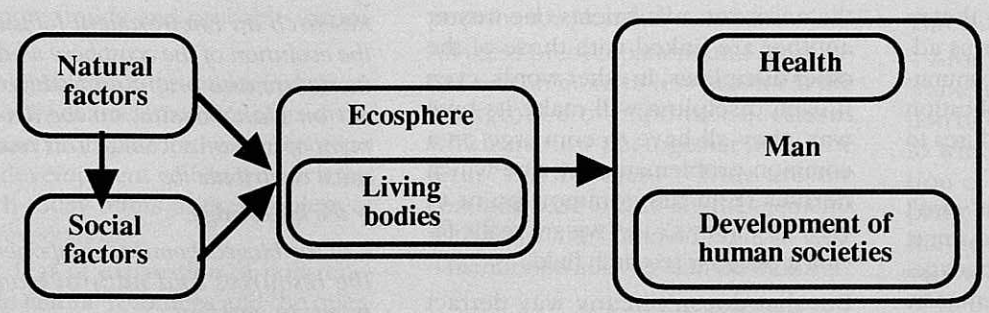


Figure 2 - To a centering on Man and human societies: the effects are centered on the ecosphere and this involves consequences on Man and the development of human societies.

– their importance for the development of human societies.

Some of the components are resources used by Man, we will talk about natural resources. They can be necessary to Man's survival and thus irreplaceable (like the air or the water) or alternates (most foods and vegetables). The renewal of these resources, in a state compatible with Man's health, can influence the dependence of other components and of "key" process of the environment (for example the chlorophyllous vegetables and photosynthesis).

In fact, this definition is only the realization, the formalization of a widespread point of view. However, how to deduce a research field from this definition ? In order to make it efficient, there is good reason for specifying the position of scientific disciplines with respect to the Environment and the situation of the Environment as an object for study in the present division of the scientific work.

● 1.3. The Environment in the social division of work

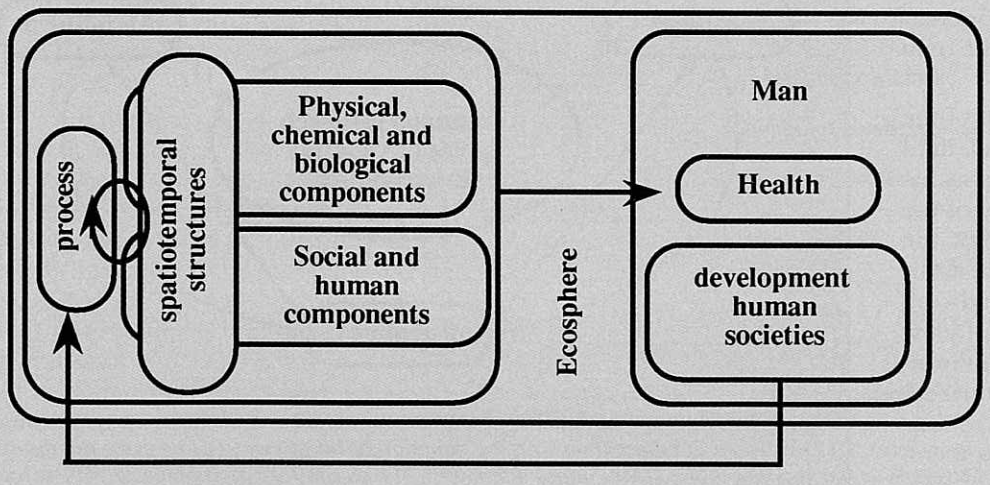
One can support the idea – and it has been done – that the questions asked of Research in the field of the Environment refer to problems which were amply treated by the disciplines we use, in other words that reference to the "Environment" is just another way to point out some areas and research subjects that have already been identified and studied. Then the Environment appears either as a simple application field of acquired knowledge or as a new opportunity to increase the research effort on problems already thought of as being fundamental and having priority in research.

In this perspective, the disciplines are taken as providers of services (and this may arouse some reluctance among researchers) or on the contrary as only rightfully in charge of Research on Environment. We consider that these disciplines are the only ones which are able to express the relevant scientific problematics in order to tackle strictly the questions asked by the Environment – and this laying on their own research process.

This way of thinking leans on arguments which are worth taking into account: the problems named Environment problems involve biological, physical or chemical processes which are known by biologists, ecologists, physicists, hydrologists, chemists, etc. These processes refer to economic and social problems ; the various sciences of Man and society acquired a real know-how in the analysis of these problems. This nearness between questions related to Environment and Research in some disciplines or special fields is all the more important as some environmental questions are directly derived from research (it is true, for example, for all that deal with the changes of chemical structure of the atmosphere).

But it is a way of thinking which is too narrow and too static. Science cannot answer questions which are external to it and so unfamiliar. From this point of view, it is not satisfying or it might be perilous to put forward "the social request" in order to legitimate a re-

Figue 3 - This diagram illustrates the temporary definition of the Environment notion.



search orientation. In fact, the questions asked for a scientific approach are required to be pertinent, that is they must be formulated in terms admissible by a given scientific community and which enable the application of clear and measurable procedures to them.

The "questions on Environment" don't elude this necessity. At least they must be set out in an appropriate language. And this implies a work of semantic and practical reassignment of these questions by the various scientific communities concerned.

This necessity of an internal logic in a scientific approach is useful for a justification – mentioned above – of the assertion of the favoured role of the different disciplines in the development and expression of scientific problematics linked with Environment. The fundamental problem which occurs here, is to know how to reconcile this actual requirement with the obligation, which is not less justified, to respect the possible originality of the questions raised by the Environment problems whether they are thematic, methodological or theoretical. Bringing back the Environment questions to problems, methods or well-known processes, is making the historically and epistemologically indefensible assumption that the knowledge acquired in a discipline is independent of the goals pursued. So, we will admit, at least as an hypothesis, that the given point of view when we tackle the Environment problems is new, compared to those possibly derivative, which contributed to lay the basis of the various disciplines concerned, to define their own fields of competence and their favoured research orientations, and to give them their own know-hows.

We will endeavour in the rest of the text – and mainly in the second, third and fourth questions – to specify what globally makes the originality of the Research on Environment. For the moment, we will only note that if this originality – as we have just said – results from a particular point of view then the research field on Environment in its whole is characterized. This means that all disciplines concerned don't have only to define themselves in relation to this point of view – and each discipline will make it with its own characteristic – but as they have this point of view in common, the necessary adjustments one way or another are linked with those of the other disciplines. In other words, even if each discipline will make its own way, they all have to converge on a common problematic: the one which derives from the common point of view. So, in this case, we are really facing a peculiar research field.

But that doesn't in any way detract from the relevance of the arguments on the role of the disciplines, on the use of the knowledge and the abilities acquired by each discipline. In fact, we set this work which is centered on the disciplines, in a vaster framework. This scope is organized with a triple set of concerns: between each discipline and the common point of view; between the different disciplines compared to this common point of view and lastly between this common point of view and the whole of the reconstruction processes provoked by this point of view and which leads continuously to its reconsideration and its redefinition (Figure 4). These tensions play an integrating and dynamic role. They give therefore a principle of internal creativity to the research field on Environment, and so give to it a real particular research field.

From these remarks, we suggest, at least for the time being and particularly to clarify one's ideas, to limit this research field as below, according to the given definition of the Environment:

Research on Environment focuses on the evolution of the ecosphere whatever its nature and origin and which may act on Man's health, on the development of human societies. This research must contribute to:

- *the knowledge:*

– of the biogeochemical components of the resources and natural environments in question,

– of the factors and processes of their change whether from natural or human origin,

– of the effects of these changes on Man's health and the living conditions of Man on earth.

- *the definition of actions which are able to regulate or modify the processes in question.*

2. The various sides of the research field on Environment

● 2.1. An heritage of elementary questions

Research on Environment takes place at the converging point of numerous trends of preoccupations from various origins. In fact, there is a lack of global history of questions which today are put together under this term and which form what we can call "The question of Environment". Without

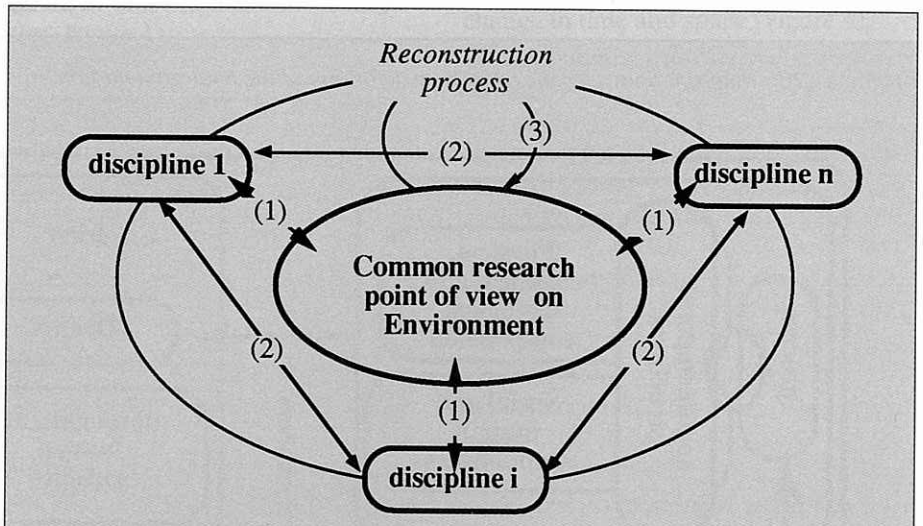


Figure 4 - The scope of Research on Environment results from a triple set of concerns: (1) between the disciplines and the common point of view; (2) between the disciplines compared to the common point of view; (3) between the common point of view and the processes which lead to its reconsideration and redefinition.

this history and for information only, we suggest the following listing which is rough, untidy and probably incomplete:

– the problem of the biological diversity, of its characterization, of its dynamic and of its part in the preservation and development of human societies which today refers to the problem of its preservation [6],

– the fear of exhaustion of non-renewable natural resources and the questioning of the modes of industrial development,

– preoccupations concerning the "management" of renewable natural resources,

– anxieties over civilian and military uses of nuclear power,

– problems of Hunger and under-development in the world,

– preoccupations related to thestate of the stratospheric change of atmospheric composition (ozone layer, accumulation of gazes),

– preoccupations related to climate change,

– health problems linked with working conditions,

– health problems linked with the living environment (in particular the urban one),

– health problems linked with water and air,

– problems of diseases and social hygiene,

– health problems linked with food,

– desires for the improvement of the living environment and taste for "nature",

– problems of the diversity of human cultures and preservation of the cultural heritage,

– new questions on artificial Environments asked by space research,

– natural risks, ...

For some authors there is an Environment problem when Man can with his action either worsen the risks themselves (for example, the weakening of sensitive environments with a deforestation which may lead to risks of falls or landslides), or worsen the consequences (for example, buildings on areas with seismic risks). So, there is an Environment problem when we can attribute a personal or a collective responsability [7]. This point of view clearly sets aside risks with global effects like the great volcanic eruptions (independent of anthropogenic action) which can disturb, at least temporarily, the global climate [8].

All these preoccupations and sensitivities remain more or less present at the background of important questions which are now put together under the term "Environment". They are the common base and so are the elements with which the common point of view – mentioned above – can be built.

● 2.2. An implicit structuring of the field

In fact, the common point of view is built with an ensemble of relations, crossings and interfertilizations between these different questions at first deeply or even totally disconnected. Here again, a subtle analysis with an historical dimension would be essential to follow precisely these progressions in order to clarify the presuppositions on which the recent scientific process are based. As we don't have this analysis, we can nonetheless outline in a rough way a diagram of progressive approach which nowadays structures the research field.

Three distinct elements occur:

– Around the "management of renewable natural resources". It is a question of ecological and economic origin to which we can add the recent question of biological diversity. For one part of these resources, we can insert the usage notion and deal with the very recent problematic: "the dynamic of resources and uses".

– Around the major balances of the planet coming mainly from the universe sciences: analysis of the great biogeochemical cycles, study of energy balance, consequences on the evolution of climates and more recently intervention and reaction of living people.

– A vaguer and more heterogeneous unity: the quality of the environment and living conditions and the consequences on health (or more globally the relations health-Environment), mainly defined by medicine, public health and town planners.

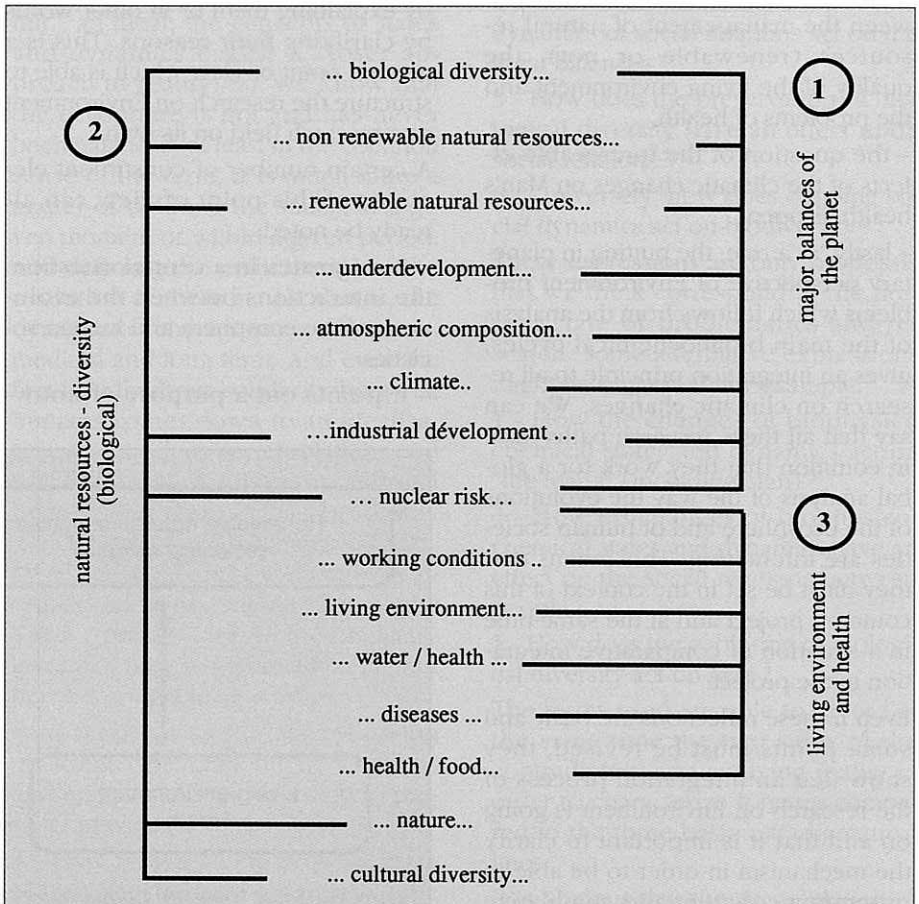


Figure 5 - First moving-closer of the questions as they come from concrete problems. Three groups of questions can be identified; the problems of the development of human societies are at the background of these questions.

The three questions recall another general question which in a way incorporates them: the development of human societies. This question occurs today in the industrial societies and also in societies which are said to be less developed or underdeveloped. It is a matter of economic development but also of social development. This problem was clearly raised in the Brundtland report (op. cit.) which suggested the term: satisfactory development or lasting development.

● 2.3. Second stage of integration

Some links appear progressively between these three subsets:

– the management of renewable resources seems to be integrated above and below every analysis of fundamental cycles which ensure the major biogeochemical balances of the planet,

– with notions such as the landscape studied in problems of local pollution (like those of water and of the atmosphere), lead to define a junction between the management of natural resources (renewable or not), the quality of the living environment and the problems of health,

– the question of the foreseeable effects of the climatic changes on Man's health, is open,

– lastly, as a rule, the putting in planetary perspective of Environment problems which follows from the analysis of the main biogeochemical cycles, gives an integration principle to all research on climatic changes. We can say that all these research paths have in common that they work for a global analysis of the way the evolutions of the ecosphere and of human societies are interacting. This means that they must be set in the context of this common project and at the same time in a situation of comparative integration in the project.

Even if these reflections are basic and some points must be revised, they show that an integration process of the research on Environment is going on and that it is important to clarify the mechanism in order to be able to program a coherent and cumulative research project. Figure 6 illustrates the relations between the three main categories of problems. However, we note that the themes which appear during this integration stage are still mainly more centered on the observation of the state of the problems than on the analysis of the processes and of the dynamic which lead to these states. It is still a static point of view, more synchronic than diachronic.

● 2.4. To a unifying point of view

We mentioned before (cf. 1.2.) the question of a possible point of view which would be able to build a research field dealing with the Environment. We have also seen that some integration processes between the different major "inputs" in Environment problems have taken place and progressively have provoked some cross-checks and in turn ordered the arrival of cross questions. In particular, we have seen that putting Environment problems in planetary perspective may provide an integration principle to the whole of research on Environment. This point is important because it incorporates all the others by explaining them or in other words by clarifying their reasons. This is a general point of view which is able to structure the research on Environment as a research field on its own.

A certain number of constituent elements of this point of view can already be noted:

– It originates in a central question: the interactions between the evolutions of the ecosphere and human societies.

– It points out a purpose of knowledge very precise which is part of the former exposition: it is a matter of studying the reciprocal actions of the ecosphere. Moreover, as these interactions happen necessarily in time or even in sequences, it is really a question of analysing how they jointly develop.

– It is global for two reasons: first it contemplates the ecosphere as a whole, that is as a unity of flows, transfers, transport, processes (of accumulation, change, growth and so on...) which are acting on the physical, chemical, biological and social components (previously, man and human societies kept a particular status outside of the ecosphere, as quote above in the two first items). Secondly, it takes the ecosphere at the highest possible level of integration: the planetary level.

– The choice of the integration level specifies the goal: the level chosen corresponds to the one where we bring to the fore what causes a problem, that is to say an alteration of the biological, physical or chemical parameters able to have effects on Man's health and on the conditions of settlement on the planet. This specifies and limits the field of the "interactions" and the "joint evolutions" which are part of the questions on Environment.

It is important to note that these elements of definition bring us back to research on climatic changes. Although on most points, a generalization to the whole of research on Environment is possible, there is a point – and not the least – which raises a pro-

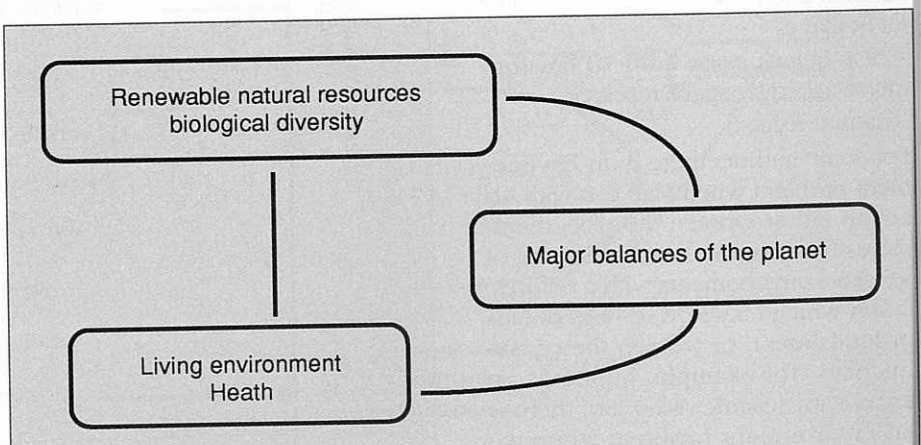


Figure 6 - Some links are taking place progressively between the three main groups of questions and contribute to the emergence of a common project. One of the questions which rules over the development of these links, is precisely that of the development of human societies.

blem: the choice of the planetary level as "input" level and as reference. The management of natural resources – renewable or not – and the quality of the living environment can be put into this perspective, but they cannot be totally subject to this choice; as is the case when we work on the high layers of the atmosphere, for example on the stratospheric ozone. The Environment problems (as explained before) related to handling of the biomass, soils, water... in order to produce or to develop, generally appear on a local or regional scale: so, all the space scales and all the integration levels can have their pertinence according to the problem studied. We will mention this important question further on. This kind of thought has lead the Environment Programme to prefer a "functional" input compared to a global point of view which, nevertheless, is mentioned in the different themes proposed.

However, it is not arbitrary to consider that these situated researches are influenced by a triple planetary reference: first reference to biological diversity (and its essential management or preservation), then reference to a human right to well-being and to an interdependent destiny of humanity.

So, "the question of Environment" could be imagined as the result of the implementation of three paradigms:

– planetary states and dynamics,

– biological diversity,

– mutual dependence upon humans.

The unity of the research field would lie in the permanent validation and comparison of these three paradigms. The aims of research should be:

• to make a constant revaluation of their inner pertinence, particularly with the appraisal of the operating concepts beyond these paradigms. The latter represent limit-notions as points of reference. They are out of place when we must show some states which are the temporary product (at a more or less long time scale) of dynamic processes.

More precisely, at least in a first stage we may keep the notion of biological diversity as it is expressed but examining all its sides: not only the biological one (from the gene to the structural and functional ecosystem) but also the social one (particularly through

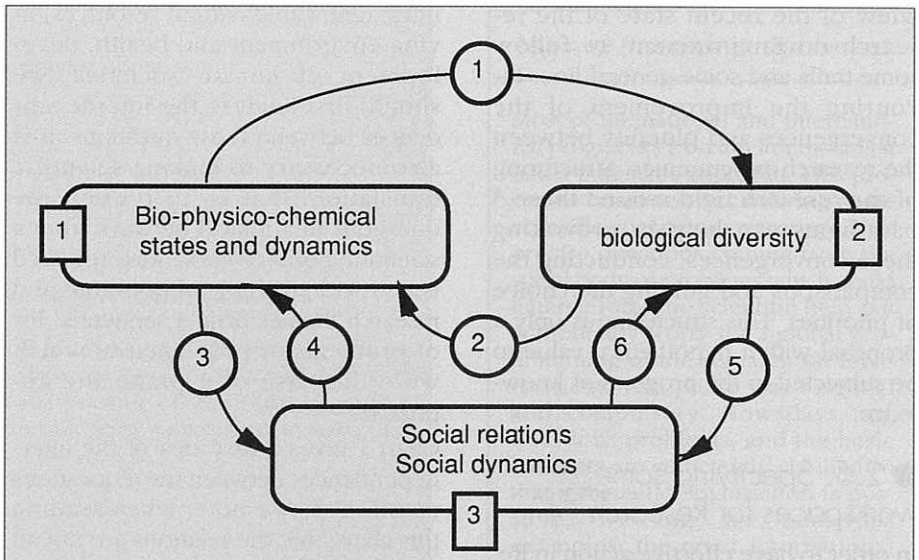


Figure 7 - Realization of the paradigms through notions more rapidly operational. Three possible groups of questions emerge from this diagram when these new concepts are linked in pairs.

the notions of the perception and the use of this biodiversity) and putting it in a dynamic and developing perspective (appearance and disappearance, birth and extinction, Life and death). Conversely the balance notion is a "limit", an ideal; the concepts of states and dynamics enable a closer approach to reality. So, we know that the ecosphere is not and has never been balanced, at least in the common sense of the term, it is much more a matter of defining the states, at a given moment or within a given period, and defining the main trends of the evolution of these states, that is, the dynamics of the system on the short, medium and long term. And even the fact to talk about solidarity between humans comes down to an idealization; to introduce social relations and social dynamics is more operational because they represent in a better way the involved social mechanism. Lastly, these new concepts are effective at all scales and especially at the spacial scale: from the local to the planetary level. So, they have the advantage of not favouring a level *a priori*.

• to respond to the six following questions which link the new notions and reexpress them according to present knowledge:

1 - How do the changes of the main biophysicochemical balances of the planet act on biological diversity ?

2 - Conversely, how do the alteration and the reduction of the biological diversity act on the major planetary biophysicochemical balances ?

3 - How do the changes of these great balances have repercussions on the social relations between people ?

4 - Conversely, how does the recent dynamics of social relations act on the great balances ?

5 - How does the preservation of biological diversity have an effect upon social relations ?

6 - Conversely, how does ongoing social dynamics act on biodiversity ?

These expressions are only proposals that we think correspond to the present state of problematics and research. Some alternative expressions might be suggested, for example:

1 - How the changes of biophysico chemical states and dynamics act on "the living" (including Man) ?

3 - How do changes of biophysicochemical states and dynamics have an effect on the social relations between people ?

5 - How does the evolution of biological diversity act on Man ?

The terms used are able to record at the same time the two sides of the contradictory and evolving reality in order to characterize it better compared to the three basic paradigmatical lines.

It is obvious that the accumulation of knowledge clarifying these questions will use various and much more precise means but itmay be useful in

wiew of the recent state of the research on Environment, to follow some trails and some general lines favouring the improvement of the convergences and plurality between the research programmes. Structuring of the research field around these 3 paradigms can help in provoking these convergences, conducting the comparisons and guiding the choice of priorities. This structuring is only a proposal with a hypothetical value to be subjected to the progress of knowledge.

● 2.5. Specifying some workspaces for Research

In order to have effective action in Research, it is essential:

- to define some pertinent fields for scientific research based on the definition of the Environment and of the scope suggested; and this according to the origins of the Environment question;
- to call out and to interest the scientific disciplines then to assess the consequences of their implication in research on Environment for their own development;
- to develop an activity of necessarily interdisciplinary nature;
- to equip oneself with a substantial methodological and theorical assortment of tools.

If we summarize the major questions identified: planetary states and dynamics, renewable natural resources, living environment and health, development of human societies; we should first analyze the interdependences between these questions. It is also necessary to make a scientific translation, that is, to present the questions in a logical network from a scientific point of view. Also required is a structured whole of questions and research themes from a sequential list of problems or problematics which were the base of a pragmatic approach.

Chart 1 gives a first idea of the interdependences between the 4 questions mentioned. We note, when reading this chart, that the relations are not all symetrical (i.e x → y does not imply y → x) and that the transition from a question to another can be made through one or two questions (without a secure transitivity). This narrow interdependence explains the difficulty of creating a scientific programme.

At least, Chart 1 enables us to illustrate the interdependence of the questions. It is not possible to answer only one of them without taking the others into account. For example, we cannot set aside the use of natural resources and the problems linked with development when considering global problems (first column). Nor can problems linked with development be ignored when considering global problems (first column). Conversely, the problems linked with the natural resources, development possibilities, living environment and sanitary state surely depend on planetary dynamics. The effects can be direct or indirect.

One of the ways to prepare programme, is to take an input point and to deduce the others from it; for example the International Geosphere Biosphere Programme (IGBP) chooses SPD as input point. Then the risk is to favour one input, that is, to orient the research, results and consequences according to this input, and so either to ignore the others or to imagine their study only according to this input.

So, the main concern is to be able to tackle a specific question while never losing perspective on the whole problematic in which the problems have a sense. Chart 2 constructed with this wiew point, gives a non-exhaustive list of subfields, or aspects of the four great questions. We remark also that questions are posed in dynamic terms, which implies the study of involved processes.

With the help of this kind of structuring, we are able to sharpen the definition of scientific actions insofar as we identify more precisely the object of studies and the scientific problematics.

The "Text of Scientific Orientation and Programming" of the Environment Programme (December 1990) was elaborated from this angle. Five input points can be distinguished in it (Table 3).

This is a first stage elaborated at the beginning of the Environment Programme. It is not perfect, but it enables us to delimit the priority actions to be undertaken in a pursuing of fundamental research.

	(1) SPD States and Planetary Dynamics	(2) RNR Renewable Natural Resources	(3) LEH Living Environment and Health	(4) DHS Development of Human Societies
(1) SPD		1 → 2	1 → 3 1 → 2 → 3	1 → 4 1 → 2 → 4 1 → 3 → 4 1 → 2 → 3 → 4
(2) RNR	2 → 1 2 → 4 → 1		2 → 3 2 → 1 → 3 2 → 4 → 3	2 → 4 2 → 1 → 4 ?
(3) LEH	3 → 1 ? 3 → 4 → 1 ?	3 → 4 → 2 ?		3 → 4
(4) DHS	4 → 1 4 → 2 → 1	4 → 2 4 → 3 → 2	4 → 3	

Chart 1 - Bringing to the fore of interdependences between questions in form of relations. The latter are not necessarily causal in mechanistic sense, x → y: x is contributing to y, or x must be taken into account to explain y..., the departure points are the lines and the arrivals are the columns. This table has not the pretension to be exhaustive.

3. Specific theoretical methodological and technological issues

The preceeding developments already evoke the theoretical problems raised by any attempt to base the research on Environment on a single research field. We will not mention them again.

Simply, we would like to identify the major theoretical and methodological problems which follow from the above.

I Planetary states and dynamics
(functioning of the biosphere-geosphere-atmosphere system).
- the major ecological systems
- the major biogeochemical cycles
- the great transfer processes of energy and matter
- the main changes of anthropogenic origin: pollutions, physical, chemical and biological changes of environments
- the climate; its evolution
- the consequences of – and – on demographic and economic development

II Renewable natural resources, the dynamics of resources and uses
- water, soil, air
- living resources; biological diversity and richness, the various expression levels and the dynamics of this diversity (from molecular to biosphere level)
- evolution, damage, development and restoration of ecological systems
- processes endogenous to ecological systems and exogenous ones, in particular of anthropogenic origin
- reversibility and the irreversibility of the processes
- pollution and its effects on renewable natural ressources
- consequences at various scales

III Living environment and health; the dynamics and pathologies of landscapes
- protection, development and management of Environments
- Environment changes and effects on health
- pollution and waste
- human activities and the living environment

IV The development of human societies
- processes of concentration and artificialization (the dynamics of less anthropogenic systems, evolution of rural and urban systems)
- long-term development; lasting development
- the Environment and demographic and economic developments; local, regional, global aspects
- technological aspects
- processes of urbanization and their consequences.

Chart 2 – Here are the four major questions dealing with Environment as we can express them and some of their main sides today. This chart is not exhaustive but illustrates the major themes suggested. Some technological approaches such as work on artificial ecological systems, are not mentioned. First developed for space research, these approaches are nevertheless quite interesting, in particular at the level of basic research for the analysis and the understanding of fundamental mecanisms.

1 - Water, Soil, Atmosphere, Biomass: media and transfers.
2 - Functioning, disruptions, regulations.
3 - Ecological systems and human action.
4 - Genesis and components of the Environment and of regulating actions.
5 - Methods, models and theories for Research on Environment.

Chart 3 - Here are the themes identified in the text of scientific orientation and programming of the Environment Programme. This classification is oriented more to the study of fundamental processes than the former charts.

In a first analysis we can distinguish four problems:
– analysis of the relations between different integration levels of space and time,
– the systemic approach,
– the method of models
– devices and experimental design
– interdisciplinarity, particularly between the natural sciences and the social sciences.

● 3.1. Organization levels and analysis of the relations between different integration levels of space and time

As we have seen, the planetary level has a central place in the unifying process of Research on Environment. And thus, we can interpret the fact that the term "global change" at the international level has progressively replaced the term "Environment" in the language of the scientific community. This change in vocabulary, which doesn't alter anything in all the above developments, has in his favour the cleary statement of the question – mentioned above (cf. 2.2.) – of the pertinent levels of research on Environment. It is at the base of the misunderstandings between the three great fields of knowledge concerned: the sciences of the universe, the life sciences and the social sciences. Some very quick changes calling this problem into question are happening in the research processes without the effort of theorizing always following the daily pragmatism. But in fact, this question often lies on a confused insufficiently clarified vocabulary.

Without pretending to be able to treat here the whole of this question since it would involve very long developments, we can evoke, as an example, the concept of the organization level as it is used by the life sciences. One may wonder about the interest of this concept for interdisciplinary research on Environment; and notably on the possibilities to apply it to other fields.

So, the concept of organization level

Logic of research programmes.

Most of the national and international programmes on Environment first had a pragmatic approach. This processes consisted in clarifying some scientific operations answering either precise questions coming from the social body or problems which could emerge form the scientific field but without any worry for a global programming of the research on Environment. This phase was essential and compulsory. Nowadays, the questions problems, and the basic concepts are sufficiently clarified so that a thematic organisation is possible. We can see numerous examples: the great international programmes like IGBP or more modestly "the Scientifix Organisation and Programming Text" of the Environment Programme (op. cit.). We will also refer, for the global aspects and an always pragmatic approach, to the comment by M.J. Grubb *et al.* [9] which sums up the present debates on the special measures which should be taken at the Earth Summit in Rio, June 1992.

comes essentially from life sciences but it can be applied to other subjects of study. It results from the observation of the organization of living systems, which leads to identifiable and observable entities (molecules, macromolecules, cells, organisms, populations, communities, ecosystems...). Each level corresponds to a series of entities, of systems, of functionnal units linked, whose smallest element – the individual – is the entity of the inferior level (for example, groups of people such as tribes in the population). One of the greatest difficulties is to define precisely a functional unit, particularly when the space limits are not obvious.

Some properties can be directly explained by the structure and behaviour of objects from inferior levels (for example, phenotypic properties which are seen at the organism level, are the direct consequences of the structure of a gene and its expression). Moreover, properties emerge at each level and new concepts which have no sense at the inferior level (for example, self-replication of macromolecules, cell division for a macromolecule, sexual reproduction of organisms...): a group of elements from the living world is not a simple statistical collection of these elements as they exhibit strong interactions between themselves [10].

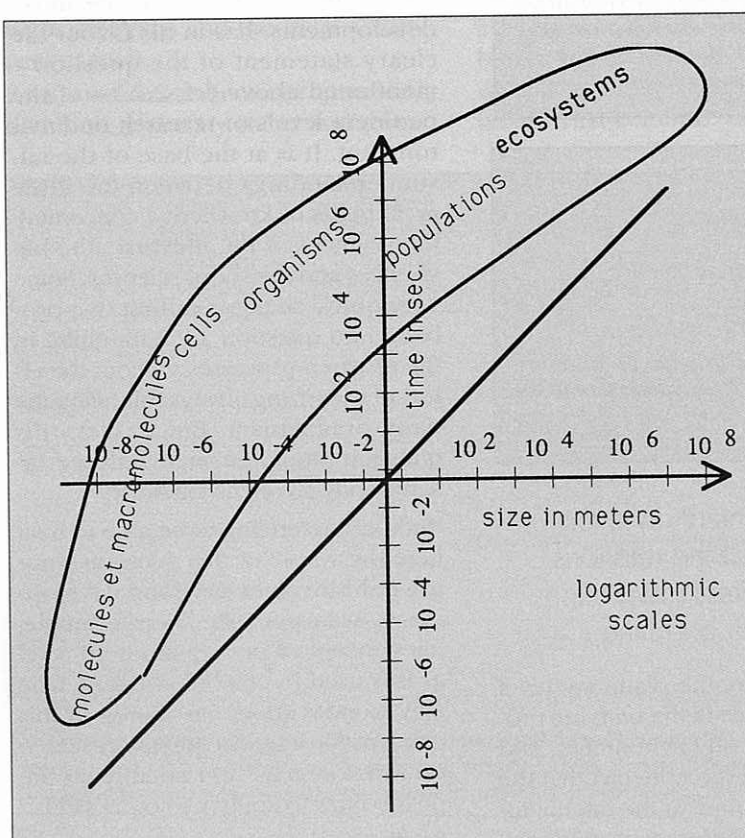
All this evokes the double problem of the identification of organization levels on one hand and of the relations between levels on the other.

In terms of research, this is shown by the choice of scales for making the observations or by the definition of pertinent functionnal units according to the phenomenon to be observed. This choice, of course, brings us back to concrete space structure but it also involves the identification of temporal sequences which enable one to see the processes at work, that is, to describe them in a spatiotemporal context: so a tiny link is to be made between space and time. Lastly, the space structure is not necessary static and particularly the functional units which rapidly change in space (case of migratory populations, or transported matter). So the fit of spatiotemporal scales of observation is difficult, and all the more as we have to deal with numerous interlockings.

For the Research on Environment, the favoured reference at the planetary level may be reducing if it becomes a rule according to which any question must be reverted to a single level or originated in it only. That amounts either to denying any existence and any judgment at the other levels, or purely and simply to subjugating all of them to the superior level in a downward hierarchised diagram. This way of thinking has two drawbacks:

- Obviously, it suffers from its reductant nature which leads to eclipsing the whole complexity of the interactions between the different integration levels in the ecosphere. If we want to understand this complexity, we must take into account at the same time the processes involved, the spaces in which these interactions take place and the time which punctuates them.

- Moreover, this point of view can easily take a purely normative nature and if the domination of the superior level is accompanied by a standard then the ideological drift happens immediatly. As the process uses a notion of order and must obey an order: we go necessarily from the "ecological order", which is law, to the "social order" that we must establish so that it can rule. But here again, this sets aside the complexity of the mediations between the ecosphere and the



We know there exists a certain link between space and time, the units of large space dimensions often have time constants which are higher than those of smaller units. But this is not absolute; for example it is less obvious when we compare systems of "large dimension" of different sizes (for example a geological system and an ecological system).

We also note that there exists a link between time scale and space on one hand and level of biological organization on the other. For example, molecular interactions implement time scales greatly inferior to the second. Protein synthesis requires a few seconds to a few minutes and a bacterium like *E. Coli* can have a generation time of about 20 minutes. On the contrary, for Man it is about 25 years: establishing a big ecological system takes several centuries. However, the time may be shorter than what we formerly thought (it is likely that the big Amazonian forest system we know today, is much more recent than we thought a few years ago).

Lastly, this is not absolute and for example, can depend on the nature of the size or of the relation studied. So a molecule can have a longer life span than a big ecological system.

This figure illustrates very roughly the relations between the space and time scales on one hand, and the levels of biological organization on the other. (The space unit chosen only permits finding one's bearings and may be taken as "the biggest of the space dimensions").

social systems and particularly this neglects that the questions raised by the references to the Environment entering the field of numerous social stakes (the distribution of riches, underdevelopment, the problem of security and defense, the political system, etc.) on which the answers largely depend. Here again, we are facing complex processes linked with the nature of the stakes, with the power relations they bring into play, with spaces concerned and the time they need for social contradictions to come to a compromise *i.e.* a provisory stage which prepares another stage.

Further to these first developments, we can conclude that while situating us in the planetary scope which gives them their final reason, Research on Environment must take as a goal the reporting of the extreme diversity of cases and particularly of the organization levels and different scales of space and time produced by the various questions. In fact, the understanding of the phenomenon which occur at inferior levels, is part of a better knowledge of processes at the planetary level.

● 3.2. The analysis of systems

For a long time the approach of objects, phenomenon and "complex" systems raised questions of methods to the scientific world, especially because the classical reductionism and analytic method were incapable of solving a great number of problems raised by these objects, to describe them and to explain their behaviour. The Environment, obviously a complex object of study, even in a naïve sense, was not an exception.

Holism's goal was to be a different school of thought, but although it seemed interesting and sympathetic it was ineffectual in practice: "everything is in everything and vice versa". However, without doubt this idea has contributed to the emergence of the much more operational notion of system. Nevertheless, we will remember that some apriorisms are disputable: so, the holistic approach postulates that a system is more than the sum of its parts. It can be more but also less or even equal without losing its nature of system. In fact, the holism is like a reaction which is quite justified compared to a pure and hard reductionism but has an imprecise, vague or even sometimes poor scientific outline.

The analysis of systems has completely changed the classical way of thinking. In order to understand better, it has enabled us to represent the structured wholes made up of organized and interacting elements, that is, systems. Moreover, the integration of modelling and the experimental process in a systemic perspective make this analysis a great operational approach. Although it is simple in its fundamental ideas, it has been the subject of "theoretical" developments which were not always of great interest: numerous concepts with uncertain utility, abundance of vocabulary from certain systemic schools. Neverthless, it has stood up very well to these "metascientific" processes; it has become one of the elements of the scientific method.

The most determining and operational contributions were without doubt those of people working in automation, thanks to their intensive use of the mathematical modelling. Physiology and especially ecology (for example the study of ecosystems) were disciplines in which the concept of system was very well used and developed. This is also true in some areas of the human and social sciences.

The Environment as an object, a complex and diversified system, is a selected base on which these schools were in confrontation. There is no doubt that the analytic method on one hand and systemic analysis on the other, furnish determining results. Besides they are not contradictory, they are even complementary and effective if they are used well and if we avoid their "perversions".

Contrary to what is sometimes said, it is useful to recall that the systemic approach does not challenge the outline of causality. Indeed, if it is true that in a complex object the scheme "one cause → one effect" is too simplistic; we do obtain a perfectly operating development in the current state of our knowledge if we accept to complete this scheme with multiple cause effects, the causal strings and loops of retrospective effect.

The holism in question

In a sense, holism occurs in contemporary thought and we could almost say that it prefigured it: this is a thought which is incapable or has not the will to tackle the present problems and which takes globalizing and additioning turns that are often not rigorous and consequently less or not operating. Again, as for holism, we will make our motto the remark of M. Minsky on this subject [11]: We often hear say that some wholes are "more than the sum of their parts". This beautiful statement often goes along with impressive words like "holistic" or "gestalt", whose solemnty lets us think that they make an allusion to real clear ideas. In my opinion, I suspect that these terms are used for covering up a certain ignorance. We are talking about "gestalt" when things combined in a way we are not able to explain and we qualify as "holistic" the events that are surprising us and about which we realize that we are not understanding them as well as we think.

● 3.3. The method of patterns

We have seen that a certain number of fundamental problems dealing with Environment are to be solved (complexity, diversity of components involving an interdisciplinary approach, non linearity, multiplicity of causes and effects...). What can be the contribution of modelling to the solution of these problems ? First, it is useful to state again what we mean by modelling today, what its scientific status is notably in an interdisciplinary context in which different notions may emerge and play a unifying role.

It is useful to re-formulate a few questions, again without pretending to be exhaustive, with their translation in terms of modelling; and finally while using the unifying idea of model and modelling, it is useful to examine their possible contribution to a theoretical elaboration of Environment problems.

• The methodological status of modelling

Modelling, that is, the building, study and use of models, and mainly of mathematical models, has acquired a status of method. This status is recent. In fact, if for more than thirty years, the notion of model has been established and accepted as one of the basic tools

of scientific research [12]. Conversely, reference to the method has been hardly popularized in the last ten years and it is not yet know in everiday language (for example, if it does not appear in the 1990 edition of the Petit Robert french dictionary, it appears in classical Webster english dictionnary under the word model(l)ing).

In a way this methodological elaboration has happened apart from the "classical" developments of the physical sciences, even if there were punctually some convergences. In fact, some scientific areas are appearing clearly in which the use of mathematical language merges into the tradition of scientific speech (this is the case for many fields of Physics) and some areas where this introduction is newer, essentially because the problems are of a new nature (for example, dealing with structured and organized systems, with "noisy" systems...). This leads to different practices, then to the development of specific processes and tools. And so, modelization in a given discipline field tends to become a special field.

To day modelization presents several facets:

– use of the model as an element of language, and of scientific thought. It is the object and the tool of conceptual thought;

– extension of the notion of models to representations other than mathematical or numerical (formalism of databases, of artificial intelligence, of various forms of representation such as thematic cards, schemas in "boxes and arrows" of models with compartments or of Forrester diagrams ...);

– integration of the model in the experimental approach, that is the implementation of a dialectic model-experience, (cf. for example, the contribution of Legay [12]),

– speculative use *i.e.* the analysis of properties of mathematical formal objects and the interpretation of the latter as the possible behaviours of real objects. Then it is a matter of an analogical approach, the model serves as a paradigm,

– use of models to define regulating actions (controls). So, J.L. Lions (op. cit.) [13] suggests the three terms of what he calls "the Universal Tool" *i.e.* modelling, analysis (of the model) and the control.

Finally, computer science makes the elaboration, study and use of models easier. It has contributed largely to the implementation of more and more complicated models, thanks in particular to "Super Computers". It has enabled us to popularize the method and also to increase by feedback, the culture, notably mathematical culture, of the greatest number of people. Nevertheless, although the results are already impressive, there is still a lot of work in the field of the integration of tools, methods and process at the computer level. This problem is linked mainly with the development of new softwares.

• Possible contributions to research on Environment

If we admit the scientific and epistemological status of the model and modelling as explained above, it is clear that these objects and processes must be key-elements of the research on Environment. But, it must be sure also that if the model, and modelling can be mediators in interdisciplinary approaches, they also can be tension objects in so far, as we have mentioned, different practices can be identified according to scientific area.

After having specified this, we note some methodological progress to be made on the fundamental problems mentioned above. So, there is cause for:

• First specifying the relations between the models, the experimentation, the observation and the instrumentation (for example, data acquisition and processing in the goal of model identification or validation).

• Specifying the process and tools to be used for the building and elaboration of models (for example, to specify the elementary models of fundamental processes and combining rules of these elementary model to obtain a model of a system).

• Defining well the links between the models and the concepts of organization level, scale, space and temporal integration. For example, are we able to imagine how to represent the global behaviour of a system with simple models or even simpler than the list of individual models which describes the elements and the interactions between these elements ? Experimentally we know that it is possible and effective; can we have some demonstrations of it in other cases than those of statistical collections ? Likewise, is the long-term dynamics of a system able to express, in its main lines, in a simplier way the effects of short-term dynamics (for example, are the models of climatic evolution compelled to be based on the models of atmospheric dynamics used in meteorology or on the contrary do they have to be elaborated on the basis of another expression which would be adapted to the possible time scale ?).

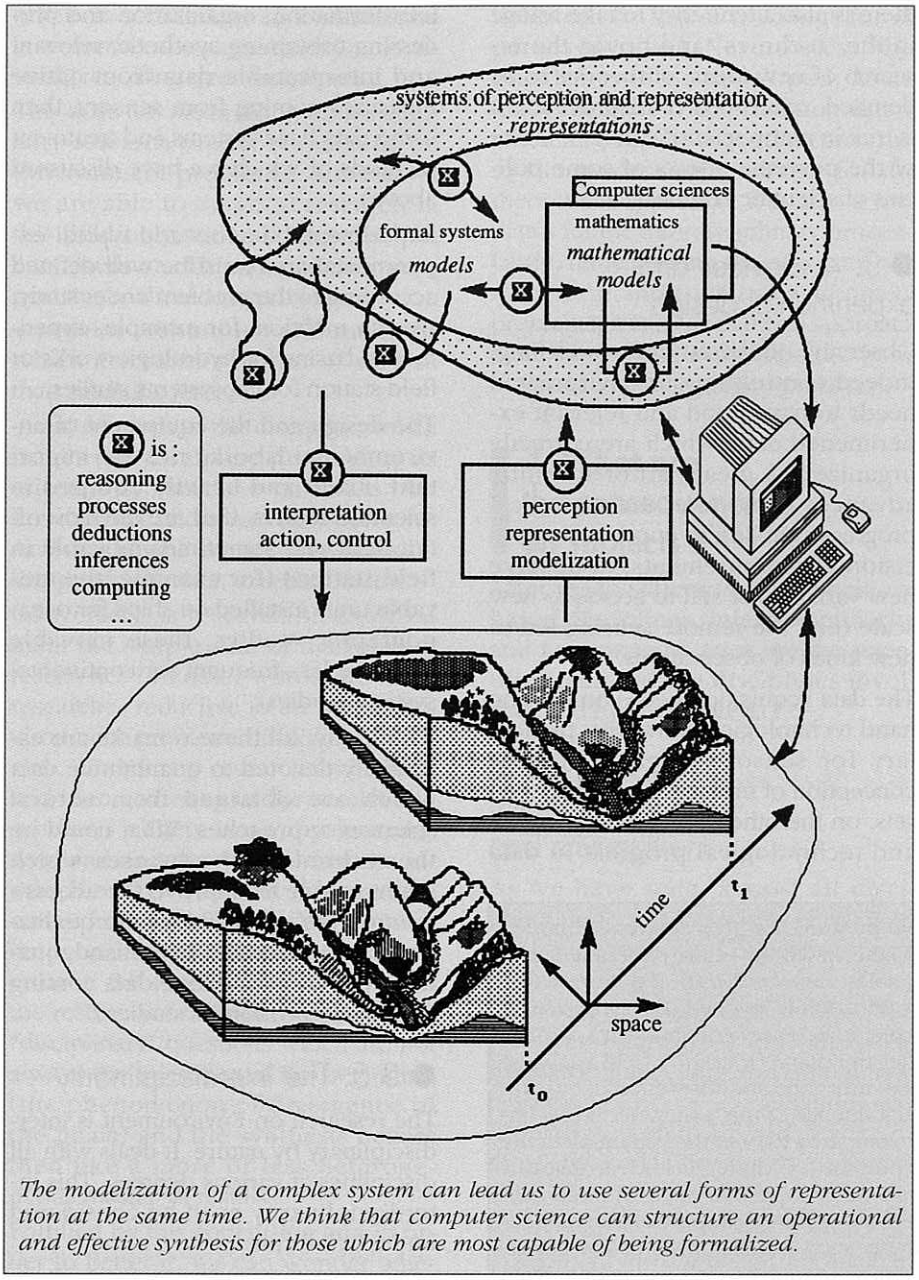
• Studying the extension of the notion and practice of models to other formalisms than the mathematical ones (for example, the formalism of the logic of computer science: programming languages, logic, functional and oriented objects, simulation systems, database systems, systems of artificial intelligence...).

• Developing the systems with databases or knowledge bases.

The systems with knowledge bases are a generalization which enables us to introduce some techniques dealing with artificial intelligence. To day, there is a trend to bring together the classical notions of data base and the more recent one of knowledge base (new formalisms as "object-centered" ones which are used in the both domains enable this rapprochement).

Finally, the processing of geographical information has required large efforts for about ten years. The GIS (Geographic Information Systems) interfacing the management system of relational databases with the software level of the handling of spacialized data has been created. These systems which are of great utility remain in the field of the specialist [14]. In the near future, we will discover systems linking the techniques of artificial intelligence with those of GIS and integrating dynamic models [15].

• Considering the consequences of what we call particularly the "non-linearity" of phenomena. This concept which comes directly from mathematics, shows that a phenomenon, the behaviour of an object, of a system subjected to actions, to disruptions, to controls, ..., to variable parameters, in



The modelization of a complex system can lead us to use several forms of representation at the same time. We think that computer science can structure an operational and effective synthesis for those which are most capable of being formalized.

short to causal variables, can have a response which is not in proportion to the value of these variables. So, we can observe sudden modifications of the behaviour (transfer from a balanced state to an oscillating state then to a chaotic system, or a brutal transfer like a catastrophe from one balanced state to another). Numerous non-natural or natural phenomena, seem to have equivalent behaviours to those of the mathematical objects which are said to be non-linear. Thus, on one hand the extension of the use of the term and on the other the awareness that some actions, which seem to be minor, may have considerable consequences. So, if some changes in our Environment, for example the climate, are governed by non-linear phenomena, then the hypothesis of brutal transition is not to be set aside. In this case, we can ask the question of the forecast of such "risks": it is easy to show, in the case of simple models, that the approach of such a remarkable event may be accompanied by an increase in the variability of the phenomenon (for example, is a rise in climatic variability, at least at a certain scale which must be determined, capable of predicting a brutal transition ?).

• Considering the socio-economic aspects. Although they were introduced into numerical models only at the beginning of the seventies in the United-States and at the IIASA (for instance in the models of Mesarovics & Pastel); they had limited success. Today, we can see some computer models emerge, relying, for example, on techniques of artificial intelligence which integrate the behaviour of human actors, the dynamics of resources, environmental problems and economical aspects (ORSTOM, in France, currently makes such attempts). This type of highly interdisciplinary approach is really promising and may be more effective than the numerical attempts of the seventies. In fact, a large effort of modelization must be made but on more and more convincing bases [16].

In order to answer these questions, first we must rely on what already exists in the various disciplines: on their methods and models, but also on their theories. It must be done not only with the disciplines which are already involved, but also with others like mathematics which can help a great deal. Conversely, by supplying new problematics, research on Environment can contribute to the methodological and theoretical development of these disciplines and maybe this is the essential condition for the lasting contribution of their researchers.

• To a theoretical approach ?

Without having the immoderate ambition to seek a "global" theory of the Environment and in order to cope with an explosion of the number of cases to be studied, it is necessary to adopt the principle of conceptual thought, of a theoretical approach which will enable us to rely on the dialectic "theory-experience". So, which contribution can have the construction of models in an interdisciplinary context in the goal of elaborating theoretical view of environmental problems ?

Despite the problems we raised which belong at the same time to the varying status of the model in the different disciplines and to the practices involved; the modelling can also facilitate the interdisciplinary dialogue. It also seems reasonable to think that it is with this intermediary that a theoretical approach to the Environment may be outlined. For example, we can think about global models which should introduce not only the models

of the Physics or the Chemistry of the atmosphere, oceans and continents but also models of the evolution of terrestrial and underwater ecosystems and then models which describe the activity and action of human societies [17]. We note, at small scales, that some biological and human components are already in practice in some laboratories. These attemps are, of course, to be encouraged.

Finally, it is necessary to underline the possible risks or "perversions" of the method of models. In fact, it is dangerous to take refuge in the building and the study of models apart from reality and of a doubtful concrete utility, even paradigmatical. For exemple, we have seen in Ecology, in Economics or in several other fields, some developments more centered on the solution of mathematical problems than on the implementation of models. When it is a matter of good mathematicians, of good Mathematics, then the discipline is progressing but in a great number of cases the work are useless from both points of view. More generally, there is also a tendency to take refuge in the "technics" and not in the research of new ideas, of theories to be denyied, reinforced or disproved... It is true in many scientific field, it is one of the perverse effects of some policies of scientific edition.

● 3. 4. Devices and experimental design

Observing, understanding, modelling, indeed controlling our environment needs to have good and relevant experimental data, which are correctly organized. A great part of scientific advances came after technological progress enabling to improve the precision of measurements, to observe new variables or still to access to new scale (e.g. the remote sensing led to new kinds of observations.

The data acquisition needs on the one hand technological advances, particulary for sensor design or for the conception of measurement integrated sets, on the other hand metodological and technological progress in data transformation, organisation and processing (obtaining synthetic, relevant and interpretable data from native measures coming from sensors, then using data base systems and treatment methods of which we have discussed above).

Experimental devices and typical experimental area must be well defined according to the problem under study. we can mention, for example, experimental basins for hydrologic works or field station for ecosystems studies.

The design and the equipment of environmental laboratories are important. Fixed and heavily equiped in scientific centers, they are the most often light and sometimes movable in field stations (for example, the movable units installed on ships for oceanographic studies, these movable units are less frequent for continental systems studies).

Eventually, all these remarks are essentially devoted to quantitative data which are obtained from natural sciences approaches. What could be the technological advances which might enable to improve the acquisition, on the one hand, of the qualitative data and, on the other hand, qualitative and quantitative data coming from socio-economics studies ?

● 3.5. The interdisciplinarity

The research on Environment is interdisciplinary by nature. It deals with all disciplines at various degrees. This interdisciplinarity must be considered under two forms:

– as a participation of numerous disciplines in a common field of research,

– as a common research effort of several disciplines.

Above all and in all situations, the first terms of Environment problems call on several disciplines, especially since a scientific discipline focuses on one organization level (this is particularly true in the biological disciplines) whereas the problems raised deal with several levels. Later the conclusions expected are of the nature of a synthesis and they must combine harmoniously the results achieved by different teams during the research dealing with different disciplines. To define a common research field which is sufficiently precise so that each discipline will be able to be situated compared to the

A simple indicator for a sudden transition could be studied with a differential model: $dx/dt = \mu x\ e(t)$. x is the main tendency and e(t) the variability of the phenomenon to be studied (for example, expressed as a white noise then $x = dB/dt$). If $\mu <$ is a stable fixed point, $x = \infty$ is unstable, if $\mu > 0$ then the situation is inverted. If we consider μ as a parameter which varies in time (for example, it increases continuously), we can study the transition when μ crosses 0. Consider the plane (x, μ): the field is almost vertical when μ is very negative. In this case, any random difference is quickly brought to 0. When μ comes close to $\mu = 0$ the influence of this parameter is less important, then the effect of a random difference compared to 0, so the variability of the phenomenon tends to be more and more important (cf. chart). It is clear that this example is a simple illustration, it does not pretend to represent any real phenomenon. The mathematical object could be disputed, as well as its properties according to the modelization of noise. However, this example shows the heuristic power of mathematical objects. A more detailed study of this situation is worth examining, from the mathematical point of view as well as the practical point of view. For example we could imagine to approach the forecast of rapid changes – for example, climate changes – due to similar processes. In this case the examination of past-chronological data could be instructive.

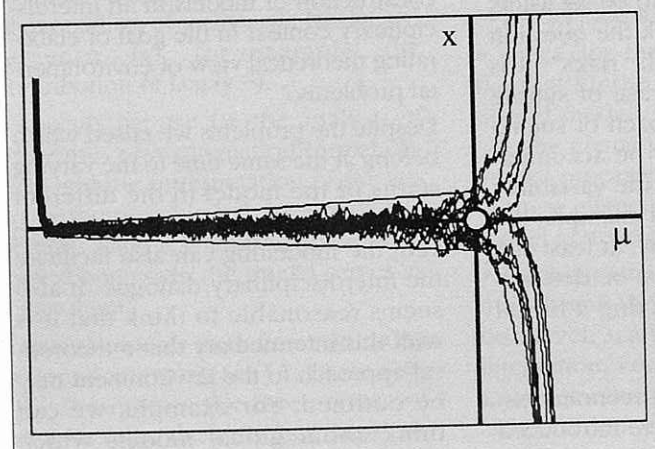


Illustration of the increase in the variability of a phenomenon (x) near a singular point depending on the parameter μ. Here, μ is supposed to vary in time (*i.e.* $d\mu;dt = 1$), so the dynamic of x can be observed. Oblique lines have been drawn to show the increase in variability.

others in a collective task whose aim is to answer the same question, is already requiring interdisciplinarity.

This does not mean that monodisciplinary research cannot be pursued on Environment problems. Nowadays, we are able to do good research in this field only with a strong disciplinary medium. This disciplinary support materializes at two levels:

– proven techniques and methods which are more a matter of service than scientific research,

– real research in the discipline which makes this discipline progress in its scientific dynamic or even breaks with this dynamic and opens new horizons. And that is why we are able to mobilize good scientists, excellent teams.

Conversely, is research on Environment the simple sum of disciplinary researches ? In other words, are these researches reducible to the series: Environment problem, disciplinary division, disciplinary research and results and then gathering of the results and synthesis ? There is no absolute answer, and an important part of the research on Environment more or less comes from this diagram. We know its limits and its difficulties and in particular at the level of the synthesis of the results: we often answer excellent "disciplinary" questions which are not always the questions of the beginning (the phenomenon of divergence of the goals) and the synthesis occurs then like a more or less heterogeneous mosaic of results.

Fortified by this conclusion and in order to better it, we can wonder whether interdisciplinary approach is possible in everyday practice. This practice involves making a division of the object of the research which is different from the sequential approach mentioned above: the interdisciplinary practice then leads to a quite permanent contact between the researchers of the various disciplines. There are several examples which show that this practice is possible and even that it is one of the major acquisitions of the preceeding years. However, it is sure that this practice is difficult, restraining and uncomfortable because it obliges us to understand, assess, and criticize process which are different from our own discipline and to review our own process. But, as is true for everybody, the interdisciplinary approach in the fields can be full of teachings for all parties involved. Nevertheless, this practice must be developed. As already mentioned, the common use of modelling can be a good means. Just as the model is a mediator for the theoretical approach, it is also a mediator for the interdisciplinary process. Lastly, remembering the necessity of a theoretical approach to Environment problems, it is clear that this approach can only be established on the basis of strong interdisciplinary practice.

4. What are the consequences on subjects ?

After these statements, on what are based disciplines, interdisciplinarity and Environment, what are the scientific areas and the disciplines involved, and by what criteria ?

● 4.1. Disciplines, interdisciplinarity and environment

As we have seen, almost all disciplines and specialities are called on to deal with research on Environment; the more disciplines and specialities involved, the more case studies. The problems of Environment can act on the disciplines either through a crystallization of research orientations and thematics which already exist, or through the modification of the hierarchies among the priorities, or through the setting-up of new specialities.

The sum of the impulses thus given to the research and the sum of their concrete effects on the research underway in the different disciplines, is the first sign of the existence of a research field on Environment, as it brings to the fore some common research questions and themes.

This community of problems constitutes what we call the first degree of interdisciplinarity, provided that it will be clarified and known by all those who must share it in their research process. Research on Environment can also act on the disciplines through the spreading of a scientific questioning from these common questions which each discipline can have – and effectively often has – a specific approach. Then progressively we go to the second degree of interdisciplinarity, that is, the work in common – and so the confrontation – between disciplines and this with all the difficulties of understanding and all the possible methodological problems.

As we have commented above about models, the methodological tools which are able to help fix the rules of these interdisciplinary confrontations, play here an essential role. The problems of Environment can still act on the disciplines beyond the modulations and thematic innovations they may involve, and this by adapting their processes to research procedures, to methods of data processing and to modelling processes which seem particularly adapted to the analysis of these problems.

In concrete terms, chemists, physicists, biologists and engineers of all disciplines are working more and more in common in the scope of the research on Environment. Although it remains necessary to go on favouring these cooperations, the major problem is to introduce not only the social sciences, which are not sufficiently involved in research on Environment, but also the mathematical sciences which can contribute greatly. As for human sciences (for example psychology), they are nearly absent.

● 4.2. The areas and disciplines involved

• The life sciences: ecology and biology

Among all the disciplines involved, ecology plays a particular part. First, for social reasons: the social groupings which intentionally raised the Environment problems are the groups of political ecologists. This was often done on anecdotal, local, emotional and less scientific bases, but they were nevertheless real, concrete and showed an intuitive comprehension of the great dangers of our society or even of humanity as a whole facing the changes and disruptions in our Environment.

This social and political appropriation of a scientific discipline has not facilitated things for the discipline. Another difficulty is directly linked to the content and the practice of ecology.

Indeed,

– ecology considers on one hand the relations between living people and on the other the relations of those people with the environment they live in. Its concepts, like the ecosystem, integrate the physical and biological environment and increasingly spatial structure (for example, the notion of landscape);

– ecology largely uses other disciplines to solve its own problems; so ecologists have the experience of interdisciplinarity;

– lastly, it is not sufficiently well known that ecology has a sound theoretical approach and large experience in modelling.

Thus, it tends to appropriate the research on Environment but now as a real scientific discipline [18]. Of course, this scientific discipline is deeply involved by the nature and the quality of its process and research; but it only focuses its view on the subject that we want to remain scientific, the Environment.

The other disciplines of the life sciences are also involved

If ecology is the first discipline to be implicated in the research on Environment, other disciplines are also concerned: systematic, animal and plant physiology, evolutionary biology, human biology, microbiology, molecular biology,... An important effort, dealing first with the Environment, must focus on the deciphering of the fundamental mecanisms which govern:

– the phenomenon of biological organization,

– the emergence of the organization levels and their properties,

– the definition of the functional units, of the origin, of the evolution and of the role of biodiversity. We can indicate the present thoughts on the subject which led the IUBS to suggest an international programme on the theme of biodiversity: "From Genes to Ecosystems, a research agenda for biodiversity" (op. cit.). The state of knowledge and the quality of the questions asked, provide an excellent basis for thought. One of the greatest features of this work is that it considers all levels of biological organization where biodiversity is expressed and it does not only consider it at the level of the species; as it is too often done.

In desert areas, here the Kyzylkoum desert (South-East of the Aral sea), human societies are present, particularly at the bottom of valleys where little rivers streams. These systems are fragile. Management errors can lead to "natural" and social catastrophes.

Moreover, the relations between organisms and the environment are very important to consider, for example:

– to sharpen the analysis of the contributions of humans to the great biogeochemical cycles and their reactions to alterations in the cycles.

– to study the relations health-Environment

– to forecast the behaviour of recombined and modified organisms in the Environment.

The questions related to photosynthesis and its fundamental mecanisms are topical questions for understanding the reactions of photosynthetic organisms to global modifications of the Environment.

Finally, the problems studied in the framework of "ecotoxicology" or "toxicology of the Environment" raise questions at all levels of organization and in particular at the cellular and molecular levels (for this last point, it seems important to develop everything that is linked with the genetic effects of pollutants: "genotoxicology").

• Chemistry at the parting of the ways

Chemistry is one of the disciplines most involved in Environment problems, and this for three reasons:

– The first from social origin put the chemistry if not in an accused position, at least in a suspicious one as it represents the origin of pollutions and thus it makes the odd mixture of a scientific discipline and its industrial use even if the development of the former was strongly influenced by the latter.

– The second reason, of economic origin, is given by the production sector: elaboration of new products which pollute very little or not at all and which are biodegradable..., study of cleaning problems in industrial and natural environment.

– The third is of scientific origin. For a long time the chemical synthesis has been more developed than analytic chemistry. We know its outstanding achievements. This is a chemistry of simplified environments (the number of reactions and of components is limited, the physical parameters are controlled) which is oriented to industrial processing. Nowadays, analytic chemistry may experience interesting and important new developments: the chemistry of compounds in traces; the chemistry of complex reaction systems in solid, liquid, gaseous phases, at the interfaces; dynamics of complex systems..., many problems for a new chemistry of "natural environments", which will surely have consequences on the Chemistry of synthesis.

To sum up, chemistry is one of the disciplines which may evolve very rapidly thanks to the Environment problems, chemical problematics will probably be fundamentally renewed.

• Engineering sciences: some lessons, tools and requirements

These sciences already bring much to the Environment (applications of hydrodynamics, acoustics, aerodynamics...). They participate largely in the elaboration of the Universal Tool based on the Trilogy "Model, Analysis, Control" (J.L. Lions op. cit.). The technological aspects and in particular the processing genius that they develop, are putting them on the first line for numerous industrial and environmental problems (new procedures linked with the technologies themselves, procedures for waste processing, restauration of the Environment, fight against noise...). Two fields which are not involved yet, computer science

and automation, should become rapidly involved in Environment problems:

– Computer science, as we have already mentioned, for the creation of new tools for the management of environmental data and for the development of possibilities of modelling and simulation (including new formalism and means such as artificial intelligence and all the possibilities of analysis and synthesis of images).

– Automation for its implication in the genius of processes dealing with Environment, in particular in processes with strong biological components, and for the diffusion of its knowledge, its theories of non-technological systems, especially to natural systems. And we recall its contribution – already mentioned – to the analysis and theory of systems.

In short, engineering sciences intervene largely already in Environment problems. A more and more important involvement of computer science and automation is not only to be foreseen but to be anticipated and solicited.

• The sciences of the Universe: necessary but not sufficient

The sciences of the Universe are "naturally" involved in the Environment problems. Nonetheless, their status must be brought closer to ecology. They also risk reducing Environment problems to their problematics. The astronomic sciences are less concerned by the Environment, at least in our sense (except however for evaluating some phenomenon like the effects of solar activity on our Environment, or studying other space Environments, enabling comparative studies). The other disciplines of the sciences of the Universe (Earth sciences, soil sciences, sciences of the atmosphere, oceanography...) are involved in the study of:

– the physical environment of our Planet (geosphere, hydrosphere and atmosphere); of its evolution and the consequences of this evolution. For example, it is clear that the sciences of the atmosphere are directly concerned with the study of the global climate and its spatiotemporal variability, that is by one of the main thematics related to "global changes"; it is also true for physical oceanography. Likewise, hydrologists and geologists are inevitably participating specialists, for example, in the current study of continental hydrosystems and, more globally, the study of the "water vector". The study of soils, which is essential to understanding numerous aspects of the biosphere's functioning, also fall under the sciences of the Universe, at least for the physicochemical part;

– some biological aspects, in particular in the marine environment, that is where the inner dynamics of the physical environment is fundamental. Indeed, the major part of marine biology is classically attached to the Sciences of the Universe;

– the past (paleontology, paleoclimatology, paleoenvironments, ...) which is historically linked to the Earth sciences, without citing the remarkable results given recently by the glaciologists. The research being done, brings not only a fundamental contribution to the knowledge of our past and future Environment, but also leads to instrumental and methodological developments which are important and usable by other disciplines. For example, we cannot deny the effort in the field of space and aerial remote detection, or in the modelling of numerous phenomena.

The research done are bringing not only a fundamental contribution to the knowledge of our past and present environment but they are also leading to methodological and instrumental developments which are important and usable by other disciplines. For example, we cannot deny the effort made in the field of the space and air remote detection or in the field of the modelization of numerous phenomenon.

We recall the deep integration of the contributions and the capabilities of the different disciplines in their participation in the Environment study. That is what we can call "local" interdisciplinarity.

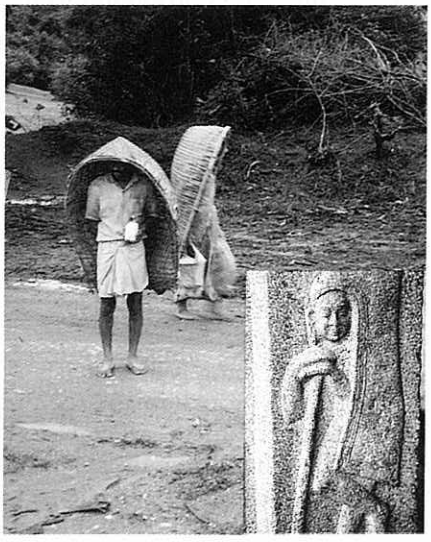
For all these reasons, their contributions to the knowledge of the Environment are essential and inevitable. However, as for ecology, there may be a perfectly understandable temptation for the appropriation of the research on Environment, all the more as French teams excel in many of the cited fields.

• Human sciences and sciences of society: the center of the debate

As we have seen, the human dimension has a central position, the notion of Environment on which we are working is related to Man and human societies. So it is clear that human sciences and sciences of society are directly in question. They took an interest in the Environment problem later than did the Earth sciences or Life sciences, at least in the "natural Environment", and so they are unequally and insufficiently involved. As for the "constructed Environment", human sciences and the social sciences conversely have taken precedence on the natural sciences (for exemple about urban affairs). A great number of disciplines are concerned.

– The first sollicited are in order economics, the law and sociology. They are the three disciplines in which research efforts are the most numerous and which have pushed to its furthest the problematics of the questions raised on the Environment, in the scope of their own processes. An opening should now occurs for political science.

– Geography and history are beginning to assert themselves in a very active way. They have a central part to



Human populations have adapted themselves to environment which they have settled. Original solutions have been found in the past and are always used. For example, in the South-India (Kerala) we can find today curious raincoats which were used in the past, as shown in the picture inserted (sculpture found in a temple of the country, built during the 14th Century).

play. The first because the Environment question fits with its founding "paradigm", the second because the economic and social history – and as a rule – time (from about the last glaciation, that is, since Man has marked the evolution of the ecosphere with his presence) plays an essential part in the processes at the background of Environment problems. Archaeology, paleontology, prehistory and historical anthropology are already strongly involved in the research on paleoenvironments.

– Philosophy has made a recent but immediatly effective entry in force in the field. Nevertheless, the field is vast and notably the epistemology which should play an important part because of the methodological problems raised by the research on Environment (particularly in their interdisciplinary dimension) remains out of play. Here the history of sciences and techniques is an essential link to be developed. Likewise the field of ethics cannot be ignored.

– Anthropology offers a back-ground of knowledge of an extreme richness for comprehension of the relations nature-culture. This material is largely unexploited in the perspective of Environment.

– Social psychology already brings a not insignificant contribution to the analysis of Environment representations. This is a field which will exprerience a considerable development. The place of psychology strictly speaking is more problematic and should be defined.

– Lastly, demography cannot be as absent as it is today. The relations between the growth of human populations and Environment problems are direct at all levels.

The important thing is to understand fundamentally how humans see the Environment according to their history and culture; how humans react towards the Environment, how they exploit it, disturb it or protect and manage it; what are the regulating actions humans can implement. All this must be examined in the context of social tensions and the evolution of human societies, but also of the evolution of the Environment itself, due in particular to the influence of damage to the environment, and of climatic changes and their consequences [19].

Urban systems lead to population concentrations. This kind of system is very artificial, though some ecological system are "naturally" installed in towns. The study of multiple aspects of urban systems (socio-economic, ecological, ...) is one of actual stakes for human societies.

• Mathematics and basic Physics: new ideas and new methods

Mathematics is still apparently less concerned by Environment problems, unless it is indirectly by the study of mathematical objects coming from disciplines involved in the study of Environment problems (for example, in the phase of mathematical and numerical analysis of models). Nevertheless, some original questions could be tackled in connection with:

– the emergence of properties in the organized systems (modelling and analyzing the organization process),

– the treating of problems of spatial and temporal scales, particularly qualitative behaviour with very different time constants, also the treating of the appearance of space structures at different scales,

– the analysis of mathematical objects with complex behaviours which enable us, for example, to represent systems with high "logical" complexity (*sensu* C. Bennett),

– the treating of uncertainty, for example, the theoretical study of decision process in an uncertain future,

– the definition of indicators able to announce sudden changes of state (behaviour of the trajectories of a dynamic system near a special point, with noise...),

– more generally, the properties of dynamic systems.

These themes are given only as examples: surely it would be easy to complete this list and to make it more precise and more attractive for the mathematical community.

This presentation shows the present range of disciplines or that potentially concerned by research on Environment: almost every sector of human knowledge is involved. This is one of the difficulties but also richnesses of the problem. So, it is not surprising that the question of interdisciplinarity expresses itself in a crucial way on the subject.

5. Which strategies of research ?

The field to be studied is vast and the forces are limited, so we must choose. In this context, the points to be debated are the following:

– Participation in the great international programmes: under which conditions ?

– National priorities: political priorities and scientific choices.

– Internal dynamics of the research field: priorities for knowledge.

– Good use of the national scientific potential and its enhancement.

● 5.1. Taking part in great international programmes: under which conditions ?

Two arguments militate in favour of a close participation in the great international programmes:

– the planetary dimension of the Environment problems,

– the necessity of maintaining the French scientific community at a world level of excellence, of clarifying the originality of the process and of assuring the quality of results.

As we have seen, the first of these arguments merits thought. We may question the scientific judiciousness of a too important exclusivity granted to a downward process originating at the planetary level and favoured to subordinate the other efforts. Here there is at least matter for profound discussion. This debate should deal with at least two groups of questions:

– How is the ecosphere conceived in the great international programmes ? Which analysis levels and which struc-

turings between levels are to be envisaged ? How are the relations between the ecosphere and the human societies conceived ? Is the idea of Environment at the basis of this process ? And how to understand the reasons for this conception ?

– What are the advantages and limits of such a process ? Which possible complementary processes or even contradictory ones could be envisaged ? On the basis of which arguments ?

As for the second point, it exists only if the first is justified. Conversely, it may be better to reach excellence at the international level by suggesting an alternate process to the dominant one than by fitting into the latter. To achieve that, of course, we must be able to show the limits of the suggested original process.

ARAT : Avion de Recherche Atmosphérique et de Télédétection (atmospheric and remote sensing research aircraft). The measure of major environmental parameters and variables can be obtained at different scales. The aerian measure campaigns enable to access to local and medium scales. Besides, the mobility of the aerian tool leads to a great flexibility in experimental design.

● 5.2. The national priorities: political priorities and scientific choices

It can lead to opportunistic choices and so to second rank choices to take into account national priorities either because a certain Environment problem is considered more important than another, or because France through its Environment problems, as through any others, must honour or preserve relations with other countries. Although we can honor these priorities, this should not prejudice the fundamental scientific choices which direct the scientific processes themselves.

● 5.3. The internal dynamics of the research field: priorities for knowledge

A research field limited by its monodisciplinary or interdisciplinary aspects must acquire its own dynamic. Such dynamics are governed by research on fundamental mechanisms which direct the evolution of the Environment and which must be the foundation of the definition of regulating actions enabling us to control this evolution. That is by emphasizing:

– the discovery and comprehension of the Environment changes linked to human activities;

– the bringing to the fore of global and local dangers to societies and the individuals, that is the relations between Environment and health;

– the research and the description of alternative, technological, socioeconomical and political solutions.

A constant reassessment of the goals and problems must go with these dynamics as we have tried to show in this text.

● 5.4. The right use of the national scientific potential and its enhancement value

Evidently, this problem must be put forward in close relation with the preceeding one. In this perspective, we must wonder about the abilities and sensitivities in French scientific communities that can be mobilized in the field of research on Environment. We must also understand what comes from their histories and their scientific and other cultures closely linked to those of the country itself. We must also understand how this enables them to make an original contribution to the "question of the Environment" and from this on to making a research field of.

To sum up, it is clear that the research on Environment must proceed from a synthesis perspective in order to avoid the accumulation of facts without global understanding. It is according to this point of view that a scientific programme can be and must be elaborated, according to the purposes and abilities which can be mobilized.

6. Which actions for which goals ?

In this defined context, what is the scientific policy, and what must be the principal lines of putting it into practice for a succesful scientific programming of the research on Environment ?

● 6.1. Objectives of the actions to be undertaken

Beside deciding on a scientific programme for the research on Environment and contributing financially to its realization, the Environment Programme must see to it that:

• the growing scientific problem solving should be done through constant re-explanation and re-examination from the founding point of view of the field of research on Environment, in order to be sure that the integrated process of this research field proceds in a controlled way,

• confrontation among disciplines and methods could develop. A particular effort must be made notably to test and validate the methods which are able to cope with the Environment problems,

• actions should be adjusted to the situation, the strategy and the means. In particular, an overall view of the research field and the state of advancement of the research should be updated regularly and serve as reference for the scientific programming and all the actions launched. Well-informed answers should be given to questions dealing with the positionning of the French research compared to the international research.

● 6.2. Forms of action

Among the possible forms which respect the knowledge dynamic and which follow traditional problem solving, we recall the necessity:

• First, as we have already said, to rely on an effort of a structured and constantly updated programming. This was the purpose for writing the "Scientific Orientation and Program-

ming Text" made by the Environment Programme. Let us remember that the text presents an approach which is essentially oriented towards knowledge of the great stages of the fundamental processes. This text puts forward a transverse approach of methodological and theoretical nature. The questions we evoked above are coupled with those raised in this "SOPT". So, this text has the authority to be reviewed and updated periodically.

- To launch incitative actions of programming as calls for proposals as exploratory phases before structuring the research effort.
- Then, to support actions of animation and thought on the research field which, beside the spreading of scientific information, will serve as basis for updating the research field of the scientific programme but also as support for the development of interdisciplinary practice.
- To structure the effort of research through initiatives which crystallize the various operations. We recall:

– the definition of research centres,

– the launching of research teams,

– the open question of the creation of true interdisciplinary laboratories of research on Environment,

– and last and above all, the integration of research in a inter-institutional and international activity.

● 6.3. Training problems

The development of research on Environment will not occur without the training of young researchers. The concrete implementation of the knowledge and technological developments must also have specialists, that is, engineers and technicians of the Environment. It also seems necessary to suggest an effort of consciousness-raising to Environment problems be instituted. How to promote training actions to meet this purpose ? We do not pretend to give an immediate answer, this is a question which is worth thought on what already exists either in the Environment field or in related fields such as health. Several preliminary thoughts neverthless can be suggested:

First we must agree on the following principle: the field is vast and the first danger is to dilute such training in too vast a generality, that is, to create generalists without real professional competence.

We suggest for the initial training to rely on a strong disciplinary content: first to train good mathematicians, physicists, chemists, geologists, pedologists, biologists, ecologists, sociologists, economists, ..., before plunging them into Environment problems. The specialization in Environment will happen at the end of the degree course – notably for engineers and technicians. The educational report orthogonal to the preceeding one, will be centered not on the discipline but on the object "Environment". So, from identified questions, it will be a matter for precising the spacialized contribution of his discipline to the solution of some of these questions and for presenting the point of view of other disciplines on this object "Environment" and their contributions to the answer to these questions.

We think that during the "classical" phase of a degree course centered on a discipline and in addition to the degree objective; the point of view on Environment problems of this discipline must be stated. For example for chemists trace molecule chemistry can be emphasized, as can heterogeneous reactions, atmospheric chemistry, ... For the biologist talking about ecology, ecotoxology, biological diversity, ..., would be heuristic.

But, it seems nevertheless desirable, as already mentioned, that an education oriented to consciousness-raising to Environment problems be proposed to the whole of young people in training. To this end, the approach at the global level, if we emphasize that it is not the only level, may be able to answer such concern. On a local scale, the study of concrete cases which are immediatly comprehensible may be used as a support, as a beginning to a more general coverage.

For the doctoral training, the diagram can be transposed. We think that doctoral training must first lie in a discipline and must specify the point of view of this discipline on the object of the study that is to say the Environment. So, we think it is better to see emerge subjects like "the chemistry for the Environment", "Environment sociology", and "Environment law", than those which specify only the term "Environment".

Lastly, what we say about research activity at the methodological level must be taken into account in the trainings actions; in particular we must introduce or develop the education of systems analysis and of modelling. Moreover, it also seems desirable that young researchers get very early into interdisciplinary practice (although this practice is not well structured yet, we must admit that it is true for numerous engineering courses but much less so in the academic cursus in Universities); particularly they must learn how to speak clearly about their discipline and how to read the results of other disciplines.

These several remarks were only mentioned to open the debate which should be situated, at a national level and this all the more as local initiatives multiply without any coordination or even a clear view of the means and the goals. For example, we could criticize weaknesses of the number of research subsidies which is dramatically low for subjects dealing with the Environment. Conversely, it is not always easy to find one's bearings in this "environmentalist" nebula and so to promote a serious and ambitious scientific training policy.

▮ By way of conclusion

The role that a research programme like the Environment Programme can play on one hand consists of ensuring the intellectual means, in assessing the needs and in distributing the material means which enable us to structure the research effort on Environment in France: geographical structuration (the poles), institutional and above all thematic structuration (research teams). On the other hand, this programme consists of participating in the effort of reflecting on the training and recruitement of young researchers. This programme will succeed the day he can disappear. At last, and as its subject deals with it, it can (it must ?) also contribute to the development of interdisciplinary practice or even to setting out the main methodological lines. So it has a double responsibility first toward the research subject, the Environment and then toward the scientific approach to the subject, interdisciplinarity.

Notes and references

1 For example, we can quote:

[1] Man's impacts on the global environment: Assessment and Recommendation. MIT, Cambridge (Mass.), 1970.

[2] The famous "Meadows' Rapport" (The limits to Growth, 1972).

[3] Development and Environment (preparatory report to the United Nations, June 1971).

[4] Use and preservation of the biosphere (UNESCO, 1970).

A synthetic presentation of the reports and of the state of Science at the end of the seventies can be found in:

[5] Environnement: problèmes, recherche, politiques (Antoine S. & Batisse M.) Encyclopaedia Universalis, 17 (Organum) 313-319, 1980.

More recently,

[6] The Brundtland report (1984).

[7] The "rapport sur la planète terre" (E. Goldsmith & N. Hildyard, Stock, 1990).

[8] Le rapport de conjoncture of the CNRS (1989).

[9] Images de l'Environnement. Ed. Aubry M., CNRS mail, 1983.

[10] Recherches sur l'environnement. Ed. Massoud Z. and Barbault R., CNRS mail, scientific reports, 1989.

[11] La Terre, de l'observation à la modélisation. Ed. TOAE/INSU, CNRS mail, scientific reports 1990.

[12] Environnement et gestion de la planète. Ed. Theys J. Cahiers français, la Documentation française, 250, 1991.

[13] L'effet de serre et ses conséquences climatiques – évaluation scientifique – Rapport à l'Académie des Sciences, 1990.

Lastly, some questions related to possible major disturbances like a nuclear conflict have troubled the scientific community these last years, cf, for example, the book:

[14] C. Sagan and R. Turco: l'hiver nucléaire. Seuil, Paris, 1990.

2 For example,

[15] La pollution de l'air en France (la documentation française, 1973).

or the reports of the programme DEFORPA which studies the effects of acid rain on the forests.

3 See also:

[16] Scientific Orientation and Programming Text, CNRS, Programme Environnement (December 1990).

[17]Preliminary tests of the days of the Environment Programme, Strasbourg, October 1990.

[18] Conclusions of the symposium of Strasbourg, CNRS Environment Programme, November 1990.

[19] Preparatory texts of the days of the Environment Programme, St Malo, October 1991, letter from the Environment Programme, CNRS, September 3, 1991

[20] Report of the days of St Malo, October 1991, letter of the Environment Programme, CNRS, December 3, 1991.

4 To consult:

[21] Perspectives on biological complexity. Ed. Solbrig O.T. & Nicolis G., IUBS monographs series, n°6, Paris, 1991.

Or the excellent popularization article:

[22] J.P. Delahaye. Complexités, la profondeur logique selon C. Bennett, Pour la science, 1991, 166, 102-104.

5 [23] N. Polunin et J. Grinevald. Vernadsky and Biosphere Ecology. Environmental Conservation, 15, 2, 117-122, 1988.

6 for a current view on the problem of biological diversity, see the collective book:

[24] From genes to ecosystems: a research agenda for biodiversity. Ed. Soldbrig O.T., IUBS Cambridge (Mass), 1991.

7 cf. Roqueplo's works.

8 On the influence of the volcanic eruptions on the global climate, we can consult the recent article:

[25] J.F. Luhr: Mount Pinatubo, volcanis shade causes cooling. Nature, 354, 6349, 1991, 104-105.

9 [26] JM.J. Grubb, D.G. Victor and C.W. Hope: Pragmatics in the greenhouse. Nature, 354, 1991; 348-350.

10 One of the best presentation of the notion of the organization level and of the properties which are emerginig at each level, can be found in the book:

[28] F. Jacobs: la logique du vivant. Gallimard, 1970.

We will also fing a synthetic presentation in the book:

[29] R. Barbault: Ecologie générale. Masson 1990.

Lastly, a recent theoretical reflection based on the analysis of the organisational behaviour of robot networks seems seducing as it examines organization phenomena in the light of the concepts of determinist chaos, see:

[30] S. Kauffman: Antichaos et adaptation. Pour la science, 168, 1991, 66-72.

11 Extract from:

[31] Marvin Minsky, La société de l'esprit. Inter Editions, 1988.

12 "with the practice of models, some of the more recent conditions of the building of the knowledge are arising: it shows the ways of the research and of the codification of the results, it puts in the light the main role of the figures and the signs in the institution of knowledge" . Extract from:

[32] N. Mouloud. Les modèles. Encycl. Univers. Ed. 1980

We can also consult:

[33] J.-M. Legay. La méthode des modèles, état actuel de la méthode expérimentale. Informatique et Biosphère, Paris, 1973.

13 [34] J.L. Lions. El planeta Tierra, el papel de las matematicas y de los super ordenadores. Instituto de España, 1990.

14 [35] Ashdown & Schaller S. GeographicInformation Systems and their applications in MAB-Projects. UNESCO. Man and Biosphere Program, German National Commiuttee, Bonn, 1990.

15 [36]Coulson R.N., Folse L.J., LOH D.R., Artificial Intelligence and Natural Resource. Management Science, 1987, 237, 262-267.

16 [37] Représentation, Modélisation, Développement. Actes de l'atelier "Recherche Opérationnelle et Développement – 1990" (Org. P. Matarasso). Centre d'Échotechnique du CNRS, 1991.

17 The idea of the "community model", which is discussed at present in the French scientific community interested in the climatic evolution, follows this approach. To consult:

[38] L'évolution du climat et de l'environnement global: le modèle communautaire français. Météo France, les Universités et le CNRS. Report by Cariolle D., February, 1991.

18 However we remark that in some recent work, the authors distinguish Ecology and the Environment, at least in terminology if not at the base. For example:

[41] Sharma P.D., Ecology and Environment. Rastogi Public Meerut (India), 1990.

19 For additional developments on the implications of Man sciences and of the sciences of the society, see:

[42] M. Jollivet. La prise en compte de la société dans les recherches sur l'environnement. Lettre du Programme Interdisciplinaire de Recherche sur l'Environnement, 4, 13-16, 1991.