Debates about Biodiversity: Scientific and Social Issues

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This text has been written to support conferences presented by the author in Australian Universities (Perth, Adelaide, Melbourne and Sydney), and French Alliances in Australia during may 2012. This conference, with some additional information, has been also presented in the framework of an Advanced Research Institute: the *Studium* (Orléans, France), at the beginning of January 2013. The author wishes to thank all colleagues for the splendid organization of conferences, their acute remarks, which permitted progressively to improve the text. An event occurred when I was in Australia: the message of 15 Academy of Sciences to G8 to alert about environmental major problems. Curiously Biodiversity was omitted. Maybe some aspects developed hereafter could give an explanation for this omission. When it has been published, I was travelling between Perth and Melbourne, and I had to take it into account in conferences, which followed the first release presented at the Western University at Perth. It was a real challenge. We have also to underline the actual work of the French Academy of Technologies on "Biodiversity and Territories Management", which will be published during 2014.

Summary

The word biodiversity is more and more used both by scientific community, by media, by politicians and by society. Progressively it has replaced the word nature with implicit cultural, ideological and sometimes religious background. A catastrophic discourse appeared since the first publication, which popularized the concept (1988): humans are suspected to destroy living things at global scale with possible catastrophic aftermaths. The purpose of this conference is not to deny the impact of human activities but to underline the uncertainties of evaluations, to recall the history of biodiversity at the geological scale, to give a concrete example of the dynamics of biodiversity within a large ecosystem, the Amazon Forest, and to replace biodiversity problematic in an evolutionary context. When analysing the scientific status of the research domain defined around biodiversity, we note that living sciences are not very implied apart ecology, but more and more other disciplines are interested, particularly in social sciences. At the end, we propose a rough draft of an epistemology of ecology, which is not monolithic: we can identify three main streams in this discipline, the first one more or less neo-fixist, the second one evolutionist, and the third one bio-geochemist. It could clarify the diverse sensitivities encountered in scientific publications, and maybe also the public interest, because ecology pose many questions about Mankind and its relations with Nature, with philosophical and political consequences.

Introduction

Biodiversity is a neologism appeared during the 1980's; it was popularized after the issue of the Wilson's book precisely entitled: "Biodiversity" (1988), and also after the Rio Conference

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(1992) on "Environment and Development" even if the convention proposed at the end of the conference has been called "Convention on Biological Diversity" (CBD) rather than "Convention on Biodiversity".

In fact, the problem of diversity of living things was one of the main problems in biological sciences and a major difficulty to understand the living world. Since Aristotle many scientists and philosophers have written about that. Before the appearance of the word "biodiversity", the expression "biological variability" was commonly used (expression chosen by Charles Darwin), then later "biological diversity" has been adopted. These expressions concern mainly diversity of species and the genetic differences between organisms. But what's new with "biodiversity"? Is there any difference between this word and the classical expression "biological diversity" or is it just a shorter word easier to use? How can we explain the "success story" of the new word, while "biological diversity" remains used?

We have also to point out that before the scientific concept, social organisations were devoted to nature and species protection. For example, protected areas, such as natural parks in USA, were created at the end of the XIXth century; Theodore Roosevelt was a traditional hunter but he was also engaged in the protection of species and nature; the Leagues for the Protection of Birds appeared at the beginning of the XXth century (1912 for the French one: "*ligue de protection des oiseaux*" (LPO)). On the other hand, politicians and managers were early concerned by the management of biological resources (e.g. In France the preoccupations of royal administration about the fisheries are relatively old, and dates back at least to the XVIIth century[2]). More generally, a lot of laws and rules were enacted along the history of our societies for the preservation of resources, and the protection of areas but, obviously, without explicit reference to biodiversity.

Recent history of the use of "biodiversity" and "biological diversity"

Already, the book edited by E.O. Wilson presented a wider point of view about the field of biodiversity, particularly by introducing questions on the relationships between humans and other living beings of the planet, including social and economical aspects. The book also warned about the threat of species disappearing, consequence of the human activities: the uses of biological resources and disturbance of natural ecosystems, particularly destruction of habitats. The titles of the chapters are illustrative: Challenges to the preservation of biodiversity, Human dependence on biological diversity, Diversity at risk: tropical forests, Diversity at risk: the global perspective, the value of biodiversity, How is biodiversity monitored and protected? Science and technology: how they can help? Restoration ecology: can we recover lost ground? Alternative to destruction, Policies to protect diversity, Present problems and future prospects, Ways of seeing: the biosphere.

A short time later, at the beginning of 1990's during a meeting organized by O.T. Solbrig at Harvard, an extension of the meaning of "biological diversity" was proposed: "from genes to ecosystems" but mainly restricted to a biological domain: the ecology[3]. During

[2] Cf. For example: Pavé M. « France's Atlantic Coastal Fisheries, c.1600-1850 ». In : STARKEY David, THOR Th. Jón, HEIDBRINK Ingo (eds). *A History of the North Atlantic Fisheries*, *volume 1 : From Early Times to the Mid-Nineteenth Century*, Bremerhaven : North Atlantic Fisheries History Association / Deutsches Shiffahrtmuseum, 2009, pp. 208-228.

[3] Solbrig O.T. From Genes to Ecosystems : a Research Agenda for Biodiversity. IUBS-SCOPE, UNESCO, 1991.

the 1990's, just after the Rio conference (Earth Summit), global problems concerning environment and development were clearly enounced: (1) Climate Change, (2) Threats on biodiversity and (3) development of human societies[4]. Moreover relationships between these problems were also identified: they are not independent but linked together. Nowadays it appears quite obvious, but at this epoch it was not the case. Anyway, a huge effort of scientific research was developed on these subjects after Rio Conference. However we have to note that at the beginning, in official vocabulary, "biological diversity" remains preferred rather than "biodiversity".

Figure 1. The cover of the book edited by Edward Osborn Wilson, in 1988[5] . It can be considered the first scientific document mediating the concept of biodiversity and which associates a scientific point of view, mainly ecological, with economic and social dimensions. It also warns about the threats on biodiversity, the disappearing of species, proved or assumed, the major risks for others species and afterwards consequences of these extinctions, particularly for the stability of ecosystems. A really interdisciplinary approach. Nevertheless a deep biological discussion on mechanisms of natural diversification and disappearance has to be developed. Today, this is always the case.

In the same time, public opinion was sensitised and mobilised by NGOs and political groups, defenders of ecology and environment. The economy was also early concerned; it was one of the main subjects during negotiation of the Convention on Biological Diversity, which was opened for signature at the Rio Earth Summit. The defenders of human communities living in huge diversified ecosystems were active to protect the traditional knowledge of these communities, their rights on territories and on local biodiversity, and their economical interests linked to the use of biodiversity. It was the aim of CBD. Talking of which, we have to underline that biodiversity covers one of the main economic sectors: agronomy, alimentation, drugs for a great part (nearly than half of active molecules comes from natural products), raw materials (e.g. wood and fibers such as cotton, wool or silk), energy production (classical use such as wood combustion, but also biofuel), without forgetting leisure, recreation and tourism.

The scientific use of the word

A manner to evaluate the importance of the concept is to look at the occurrence of the word in the scientific literature. As it is a relatively recent word and maybe a concept not still stabilized, its use during time can be informative about its scientific relevance. Rather than to investigate all the literature, we explore the database of the journal *Natur*e because it is easier

[4] Jollivet M., Pavé A. L'Environnement un champ de recherche en formation**.** *Natures, Sciences, Sociétés***,** 1993, 1 :1, 6-20. English and Portuguese (Brazilian) translations are available.

[5] Wilson O.E. (Ed). *Biodiversity.* National Academic Press, Washington D.C, 1988.

to see where the context lies than in general literature. We compare the respective occurrences of "biodiversity" and "biological diversity". We also explore the occurrences of another word, "bioinformatics", and a new expression, "bioinspired technologies", because they are somewhere connected to biodiversity (figure 2).

So, the increasing number of occurrences is significant of accepted concepts and of the emergence of a new domain: bioinspired technologies, which will probably follow a same type of trajectory in the next future.

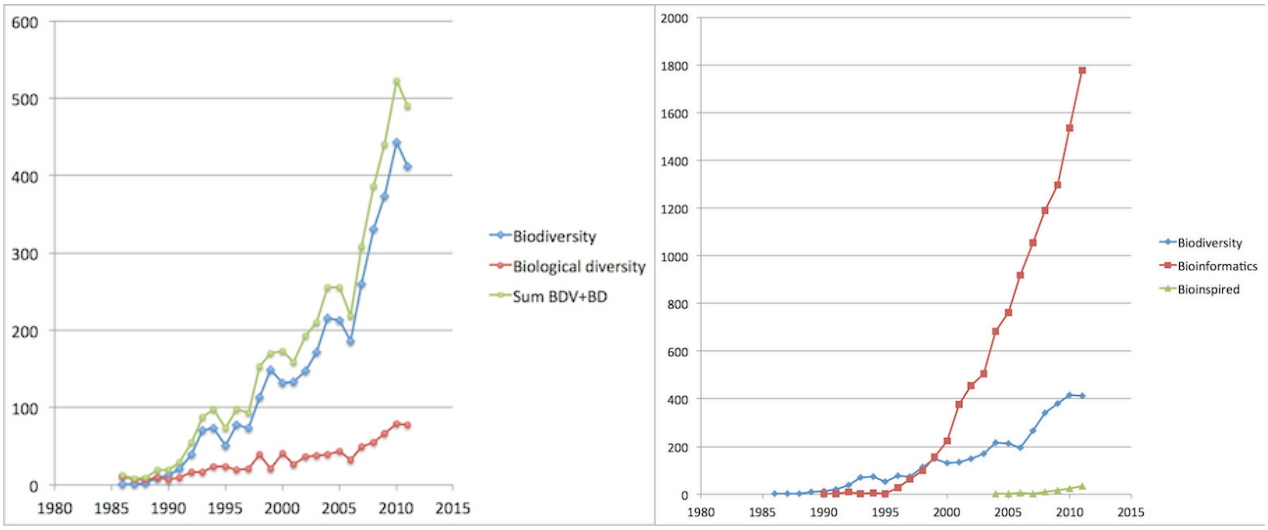

Figure 2. Left: occurrences of the word "biodiversity" and occurrences of the expression "biological diversity". Right: respective occurrences of the words "biodiversity", "bioinformatics" and "bioinspired". The last word is connected to Technologies. The statistics have been established between 1986, the year of the first appearance of the word "biodiversity", and 2011 (from Nature's database).

The figure 2 (left) shows the continuous increase of the scientific field devoted to diversity of living world since 1986. In average, it is quasi exponential. However the difference between "biodiversity" and "biological diversity" cannot be explained as a change in terminology, during time the first one don't replace the second one, but mainly by a preference in the practical use.

Neff and Corley denoted that biodiversity "*is a word that was invented to encapsulate a variety of other concepts* [than biological diversity] *and also ethical norms* […] *biodiversity as a concept within ecology marks one of the most significant trends in that field*." [6]

The polysemy of the word is richness and explains, at least for a part, the growth of its occurrences since 1986, but it is also a difficulty: at the risk to be not understandable, we have to specify the context in which this word is used.

Scientific, technological and socio-economics fields and thinking related to biodiversity

Physics, chemistry, life and environmental sciences centre their approaches on : (1) the origins (evolution, palaeontology), (2) evaluation (organismic and molecular taxonomy, phylogeny, biometry), (3) dynamics (diversification, decreasing, self-maintenance processes),

[6] Neff M.W., Corley E.A. 35 years and 160,000 articles : a bibliometric exploration of the evolution of ecology. *Scientometrics*, 80 :3, 2009, 657-682

(4) roles of biodiversity in ecosystems (e.g., resilience, ecosystem services), diversity of biological products, molecules and materials (chemistry of natural products, mechanics of materials), their ecological and biological action, effects of climate change on local, regional and global biodiversity. The modelling of the dynamics of biodiversity is also developing rapidly and implies mathematicians, statisticians and computer scientists.

The social sciences investigate relationships between human societies and living things and develop the economy of biodiversity (e.g., values and markets of biological products, of organisms and of ecosystems), ethic and cultural dimension, including religious aspects, policies and management, the perceptions and the representations of biodiversity, the uses of biological products (e.g., ethnopharmacology is interested by the uses of plants or animals in traditional medicine).

Apart technological applications coming from basic research (e.g., chemistry of drugs or mechanics of wood and fibers), specific fields have been developed (e.g. agronomy and alimentation). Traditionally living things are sources of inspiration for technicians, engineers and scientists for conception and control of machines or more generally of technical systems (e.g., planes was inspired from the flight of birds, regulating devices were also inspired from physiology[7]). The set of activities in this domain has been recently called "*bioinspired technologies*".

Social sensitivity to biodiversity

Human societies are sensitive to biodiversity but in a different manner of scientists and then not always connected to scientific dimensions. First, preoccupations concern mainly what we see, that is to say local biodiversity and what we like (symbolic species or ecosystems), what can be interesting in our everyday life, what our culture said to us what is good or what is bad, what is nice or what is ugly. Perceptions, representations, behaviours and therefore values attributed to biodiversity (not only monetary, but also moral and ethic) are conditioned by these human dimensions. They change during time and they are different in accordance with specific cultures and beliefs. For example, Amazonian forest was seen as "green hell" but has been recently idealized as "The Emerald Forest". I know rather well this kind of forest: it is not a hell, nor a paradise, it is simply a forest, an ecosystem rather disorganized than structured. The principal danger is to lost himself and not to be aggressed by animals or by wild people. Figure 3 shows examples of representations, which influences unconsciously our vision of nature and of biodiversity.

[7] Wiener N. *Cybernetics, or Control and Communication in the Animal and the Machine* (1948), The MIT Press (Cambridge, Mass.) et Wiley (New York).

Figure 3. How we see the biodiversity. (A) A prehistoric images painted on walls of a cave: very early, man represent living being, mainly animals (Lascaux, 18000 BP.). (B) Adam and Eve in the Garden of Eden (Jan Brueghel the Younger): in occidental Judeo-Christian culture the ideal nature corresponds to this mystic garden. (C) and (D): posters announcing movies show how our point of view can change during time : *Green Hell* by James Whale, 1940, and *The Emerald Forest* by John Boorman, 1988. (E) and (F) warning : to day wild animals are also idealized, don't forget that wolfs were and remain dangerous (a recent book written by a French historian explain the fight of our ancestors against wolfs), so are polar bears (shot taken in French Guyana, far from the pole, ... probably to keep smiling rather than a proof of an environmental activism!).

A manner to evaluate the impacts in the public opinion and its change during time is to examine the occurrences of keywords into the medias. We have chosen one of the most known French newspaper "*Le Monde*" (Figure 4).

The curve looks like that obtained from scientific data. It shows peaks, which are associated to international events, but the first occurrence of biodiversity is detected only in 1990 (vs 1986 in Nature). However, the newspaper reacts immediately to the events while their consequences in the scientific journal exhibit a kind of delay. It is astonishing to observe the weak consequence of the Johannesburg Conference (10 years after Rio) into scientific literature conversely of the increasing of publications after Rio.

Concerning the associated domains, biodiversity is mainly connected to forests and to farming, to climate change, to sea and ocean and to GMOs (following the number of co-occurrences).

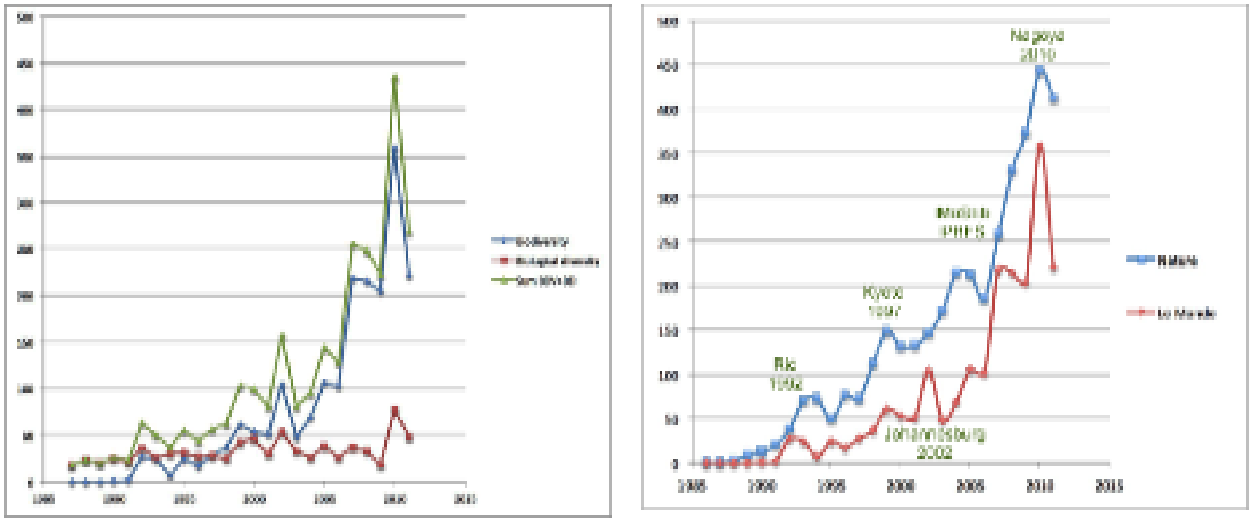

Figure 4. Left: Occurrences of keywords "Biodiversity", "Biological diversity" and the sum in the French newspaper "Le Monde" between 1987 and 2010. Right: comparison between occurrences of "biodiversity" in scientific journal (*Nature*) and the newspaper. The scientific community concerned by the biodiversity tried to organise itself like climate's one (IPCC: *International Panel on Climate Change*): IMoSEB (*International Mechanism of Scientific Expertise on Biodiversity*), at the end of an international conference of the Unesco (Paris, 2005); finally IPBES was created in 2010. To do that, the French Environmental Ministry plaid an important role to convince the international community.

When we examine developed topics, the catastrophic visions seem to be dominant (e.g. the concept of 6th extinction), and the permeability between social perception and scientific discourse is important. NGOs and associations are very present at the interface, particularly in medias. This is also the case for some scientists. The catastrophic point of view is associated to a systematic positive perception of biodiversity: it is good in itself. Is it a consequence of an idealistic view of nature (e.g. the lost Garden of Eden)? And when we have to consider negative aspects (e.g. biodiversity of pathogens), the point of view becomes a new time positive by considering that a high biodiversity gives a protection against pathogens. Thus decrease of biodiversity can pose problem and may be catastrophic because the consequence may be a proliferation of pathogens… That illustrates the loop between positive idealisation and catastrophic vision; somewhere they reinforce each other. But negative perception linked to decreasing of biodiversity remains dominant particularly in political ecology. Is it a concretisation of the Spinoza's thinking about "the merry passions and the sad passions"? Maybe because: "*Sadness will be any passion whatsoever which involves a diminution of my power of acting, and joy will be any passion involving an increase in my power of acting. This conception will allow Spinoza to become aware, for example, of a quite fundamental moral and political problem which will be his way of posing the political problem to himself: how does it happen that people who have power [pouvoir], in whatever domain, need to affect us in a sad way? The sad passions as necessary. Inspiring sad passions is necessary for the exercise of power. And Spinoza says, in the Theological-Political Treatise, that this is a profound point of connection between the despot and the priest—they*

both need the sadness of their subjects. "(Deleuze, 1978)[8]. The desire for power isn't it an incentive to create sad passions?

At the end, "biodiversity" remains one of the main important scientific and social concerns. Progressively and since 1980's, it replaces the word "nature". But somewhere the recurrent catastrophic view about it, based on some good data, but also on many uncertainties, may be a source of confusion in debates. Moreover, the ideological positions are often presents, sometimes explicit, but the most of time implicit, when it emerges from our deep historical and social culture. Another bias is to generalise local observations and to make confusions for instance between, on the one hand, symbolic endangered species and, on the other hand, the global ordinary biodiversity. The problem concerns also scientists who aren't free from such confusions and, even unconsciously, the most honourable of us.

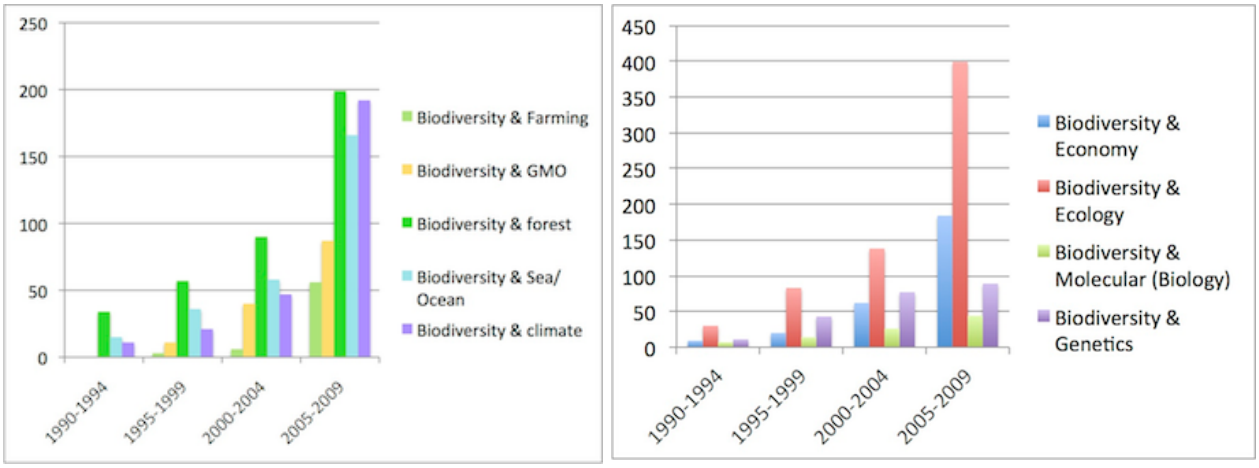

Figure 5. Co-occurrences of the word biodiversity with other topics (left) and some scientific disciplines (from *Le Monde*'s database; curiously, the *Nature*'s database doesn't enable to associate words…). In each case, the co-occurrences increase during time. There is no surprise, but the low involvement of molecular biology and also genetics may be underlined.

Science and biodiversity

Before the appearance of the word "biodiversity", scientists who were interested to "natural history" have tried to classify living things (C. von Linné, Jussieu, Buffon, etc.), then to understand how species appears (J.B. Lamark and mainly C. Darwin) and how variations occur (G. Mendel), how living things are organized (Haeckel). During the XXth century, we assisted to a huge development of living sciences. But biological diversity was more or less a decreasing topic up to the appearance of the concept of biodiversity (it was seen as a hobby of taxonomists).

Today biodiversity is mainly the affair of ecology. After we find in order of occurrences in databases: economy, sciences of evolution, legal studies, genetics, chemistry, geography, philosophy and the statistic. On the other hand, molecular biology (excluding

[8] Lectures at the university of Vincennes (English translation):
http://www.webdeleuze.com/php/texte.php?cle=14&groupe=Spinoza&langue=2

barcoding and molecular phylogeny), physiology and also, astonishingly taxonomy are weakly concerned[9].

Here we examine principally ecology and the changes, actual and future, in its approaches of biodiversity.

Evaluation

First we have to define the level of diversity, which interests us: the most often organisms, species, even if species has not functional properties. It is a taxonomical concept, but organisms classified in the same taxonomical box, a species, are very similar, they have also similar biological and ecological properties. It is also a very popular concept. So it can be a basic reference: but by this way genetic diversity is neglected despite it is the first step on which natural selection operates. Anyway, we refer to species and on the number of species to characterise biodiversity. The problem is the difficulties to obtain an evaluation. For example, if anyone looks at the literature on the subject, he or she will find a global evaluation ranging from some millions up to 30 millions different species on the Earth! At this subject some colleagues crossed the borders of a reasonable evaluation. For instance, Budiansky says that Wilson, himself, depending of the audience (scientists, politics, members of NGOs, other people), gives different values. His commitment to the cause has probably led to overestimate, for example, the rate of extinction of species. I've also a personal experience on this subject. So, if I discuss of the reliability of some estimations, on the basis of my statistical and modelling skill, but also biological one, it arrived to be literally aggressed by defenders of ecological organisations, because it might not be in accordance with the main stream of ideas.

No matter a paper, published in 2013, has proposed an evaluation by using reliable data and good statistical methods evaluate the number of species to be about 5 millions ± 3 millions of species on Earth, which is greatly lower than previous estimates[10]. Previously, another article proposed a greater evaluation, but it was mainly centred on biodiversity in Brazil (table 1) and the global evaluation was an addition in this article.

The problem concerning biodiversity is the relative abundance of data but, once again, their low reliability[11]. This is a drastic limit for modelling and the forecasting of the state of

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[9] In a recent book, I've tried to propose an integrated approach of biodiversity in life sciences « from gene to ecosystem » associated to an evolutionary point of view:
Pavé A. On the Origins and Dynamics of Biodiversity: the Role of Chance, Springer, New-York, 2010.
My colleague and friend Robert Barbault said in 1992 that biodiversity might be a domain, which could unify life sciences, it is not yet the case and my book is just a step in that direction. We have written together an article devoted to trends in ecology, particularly in France; the books he has written are also references in the domain. Today he is particularly interested by social and ecological interactions.
Barbault R., Pavé A. Écologie des territoires et territoires de l'écologie. Caseau P. (Ed.), Académie des Sciences, RST « *Études sur l'environnement. De l'échelle du territoire à celle du continent* », Lavoisier, Tech&Doc, 2003, 1-48.
Barbault R., Weber J. La vie quelle entreprise ! Seuil, Paris, 2010.
Barbault R. Un éléphant dans un jeu de quilles. L'homme et la biodiversité. Ed. Seuil, Paris, 2006.

[10] Costello M.J., May R.M., Stork N.E., Can We Name Earth's Species Before They Go Extinct ? Science, 339, 2013, 413-416.

[11] For example, data published by FAO about forests show great and astonishing differences in the recent history. For example, at the world scale, the areas covered by forests in 1990 was estimated to be 3,433 millions of ha (1995 report) and, in 2010, to be 4,033 millions of ha (2011 report); a curious increase when deforestation is at the foreground of discourses. But 2011 report gives another *a posteriori* evaluation for 1990 areas: 4,168 millions of ha. Now forests are considered as the main reserves of biodiversity, we can imagine the imprecision of its evaluation through forest areas.

biodiversity in the future. But molecular tools such as metagenome analysis will certainly be a good rapid and reliable solution. In fact, which is interesting is the dynamics of biodiversity and to point out that the biodiversity of tomorrow will be different of that of today, locally but also globally. Whatever we do. It is a lesson of the past and a result of our biological knowledge but also a manner to be not systematically pessimist.

	Number of species currently identified (estimations)	Actual biodiversity (estimation of the total number of species)
Brazil (mainly Amazonia)	190 500 ± 10%	1 800 000 ± 30%
World	1 750 000 ± 10%	13 600 000 ± 30%
% Brazil (Amazonia)	10,9	13,2

Table 1. Estimation of biodiversity with associated precision. Data coming from: Lewinsohn T.M., Prado P.I. How many species are there in Brazil? *Conserv. Biology*, 19, 2005, 619-624

C	Sites	No of core soil samples	No of plots	Sequencing platform	No of sequences analyzed	No of families identified
	Boreal (Varanger Fjord, Norway)	72	8	Roche 454 FLX	176 283	33
	Temperate (French Alps, France)	8	1	Illumina GA IIx	396 054	5
	Tropical (Nouragues Field Station, French Guiana)	49	1	Illumina GA IIx	1 636 455	34

Table 2. Results obtained from DNA analysis in soils. Results published in: Taberlet P. et al. Soil sampling and isolation of extracellular DNA from large amount of starting material suitable for metabarcoding studie*. Molecular Ecology*, 2012, 21,8, 1816-1820; and in : Yoccoz et al, DNA from soil mirrors plant taxonomic and growth form diversity. *Molecular Ecology*, 2012 (to be published, available on-line).

Another lesson is the permanence of diversification processes, not only at the evolution scale, but also at small scales in time and space: when a crop is left fallow, a large diversity of plants covers rapidly the field. The preceding crop disappears. The low biodiversity was maintained by human action, once it is suppressed, biodiversity recovers rapidly. Such an observation can be done by anyone. However, at the contrary, we have to be not blissfully optimist, there are many problems: invasive species, habitat destruction, we have to be attentive because they could induce ecosystem dysfunction and thus to disrupt the ecological services they ensure.

Biodiversity and ecosystems

The concept of ecosystem was invented by Arthur Tansley (1935)[12] and developed after by Eugene Odum particularly during the 1950's[13]. This concept is efficient when studying biochemical fluxes (cf. figure 5).

[12] Tansley A. G.. The Use and Abuse of Vegetational Concepts and Terms. *Ecology*, Vol. 16 : 3, 1935, 284-307.
[13] Cf., for example : Craige B.J. Eugene Odum Ecosystem Ecologist and Environmentalist. University of Georgia Press, 2002.

Progressively the idea emerged that an ecosystem is self-organised, a kind of a super-organism, according to Lovelock's Gaia Hypothesis (i.e., the biosphere being itself a super-organism, 1979)[14]. Previously Clements (1916) spoke also of super organism when considering communities[15]; but Gleason (1926) introduced a different point of view. For him a community is an association of individuals having similar requirements and tolerance with a non-organized spatial structure and where chance plays a particular role[16]. M. Begon et al.[17] and mainly Donald Worster[18] present clearly this debate. But the adoption of the concept of ecosystem, indirectly reactivated the ordered vision. Our experience is in favour to the Gleason's concept of plant association and not to the Clements' one, nor to the classical ecosystem one, at least for a part as we explain hereafter. The annex to this text is devoted to the Worster's analysis, completed by our own experience; it enlightens the historical and philosophical trends in Ecology.

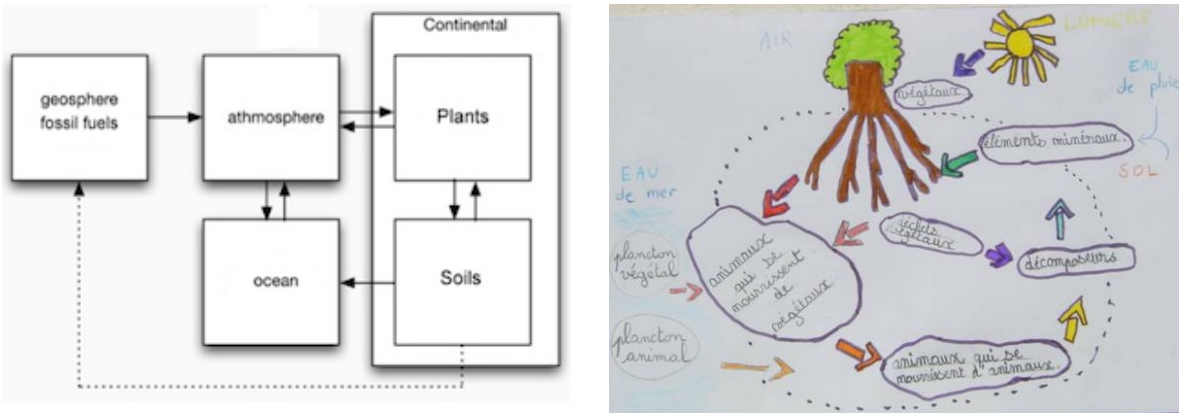

Figure 6. Representations of carbon fluxes at the global level (left) and of the functioning of an ecosystem (drawn by a pupil of a secondary school in French West Indies, right).

So if we look at the spatial structure of a natural old ecosystem, such as Amazonian forest, there is no apparent order. So during many years, researchers tried to find hidden structures. Of course, they find lightly aggregative ones, such as the relative abundance of trees of one species close to a seed tree of the same species, or that local biophysical constraints can be favourable to trees of peculiar species. But in general, we didn't yet find structures characteristic of a self-organised system.

On another hand, old tropical forests remain diversified on the very long term. But, if we consider the principle of competitive exclusion, they should be simpler. So there are mechanisms, which avoid this fatal convergence toward a poor biodiversity. To explain this "breach of the law" Hubbell proposed a new theory: the neutral theory of biodiversity. In this theory, populations of trees have approximately the same demographic parameters (equal in

[14] Lovelock J. Gaia a new look at life on Earth. Oxford university press, 1979.

[15] Clements F.E. Plant Succession : Analysis of the Development of Vegetation. Carnergie Institute of Washington Publication N° 242, 1916.

[16] Gleason H.A. The Individualistic Concept of the Plant Association. *Torrey Botanical Club Bulletin*, 53, 7-26.

[17] Begon M., Harper J.L. and Townsen J.R., Ecology, Blackwell science, 1996. Cf., section 17.3.3 p691-692.

[18] Worster D. The Wealth of Nature, Environmental History and the Ecological Imagination. Oxford University Press, 1993. Cf., Chapter 13 : The Ecology of Order and Chaos.

his model)[19]. So, selection by competitive mechanisms can't occur and biodiversity remains, at least in average, unchanged.

However, this theory doesn't explain the stochastic distribution of trees in the forest, nor the fact that local environmental conditions advantage some species amongst the large number of possible ones, but always with a great disorder in spatial distribution. Thus we have been led to complete the neutral theory by two mechanisms:

(1) the ecological production of a random noise, such as transportation of seeds by animals or by fluid turbulences (i.e., water and wind), largely stochastic and which explains the random distribution[20];

(2) the environmental filtering which selects a subset of possible species, locally more adapted than other;

(3) the establishment of ecological relationships locally between individuals depending of the context and during a period of time when there is not drastic change.

Thus we might speak of a system "self-disorganised" or of a "stochastic eco-network" or sill simply an "econetwork" or still "ecoweb". It would be more adapted than the word ecosystem, because the word "system" comes from the Greek representation of a cosmos, that is to say a set of elements strongly organised and interrelated, a kind of a big mechanical system (figure 7), which structure remains unchanged during time[21] (for more details, see annex). Nevertheless, as the word ecosystem is widely used, maybe we have to keep it.

Figure 7. Random structure of an equatorial forest (South of French Guyana). Left: even a non specialist can see the random structure and the diversity of trees (covered area about 60m x 40m). Right: a scheme representing a stochastic eco-network (species are coloured and ecological relationships are represented by dotted lines, they depend of local circumstances, in time and space, and they change during time).

[19] Hubbell S.P. *The Unified Neutral Theory of Biodiversity and Biogeography*. Princeton Univ. Press, 2001.
Jabot F., Chave J. Infering the parameters of the neutral theory of biodiversity using phylogenetic information and implications for tropical forests. *Ecology letters*, 2008, 12 : 1-10.

[20] Jabot F., Etienne R.S., Chave J., 2008, Reconciling neutral community models and environmental filtering: theory and an empirical test. *Oikos*, **117**, 1308–1320.

[21] This is the Parmenide's ontological legacy, while, today, the Heraclite's vision of a permanent changing word, more or less chaotic, seems to be more adapted to the ecological reality, and may be to our whole world itself.

Such a functioning, which leads to a random structure, has a major consequence: the self-maintenance of the biodiversity; thus we may say that the stochasticity ensures biodiversity and resilience of the system relatively to this criteria (figure 8). We know also that a diversified ecosystem is more productive than a simpler one (Hulot et al., 2000)[22]. And probably one of the best way to preserve biodiversity is effectively to let the spontaneous expression of biological and ecological processes and thus to manage specific areas for that. Bust what's new? Not the fact to create kinds of such areas, which already exist, but its scientific explanation and then to imagine such management, which can be not uniquely protected ones: directly or indirectly, human can be also actors of biological diversification.

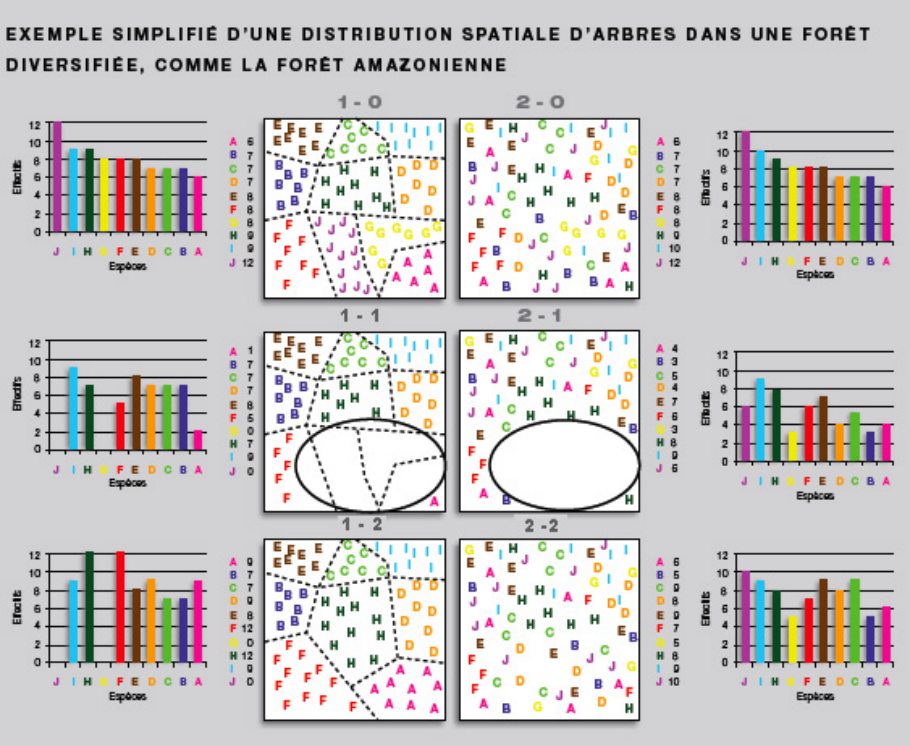

Figure 8. Distribution models of trees in tropical forests and sensitivities to environmental disturbances. The trees are marked with the coloured symbols (A, B, C, D, E, F, G, H, I, J); each of these corresponds to a species. For all practical purposes, in the immense majority of the cases, we run into a type (2-0) distribution (the individuals are either distributed randomly or in small groups, but these groups, on a large scale, are also distributed randomly). This is randomness, but it is not by chance. This distribution ensures the maintenance of a maximum number of species (2-2) - and, so, biodiversity - despite a major impact (2-1). Indeed, over a highly aggregated distribution (1-1), this same impact (1-2) results in the dying out, in the space being considered, of two species and thus a decrease in species diversity, even after the regeneration of the forest (1-2).

Palaeobiodiversity

The study of the past is also a good manner to better understand the present. It is the case for the biodiversity. Note that Australia is a rich country, where old fossils can be found; it is the kingdom of palaeontology. Here, we only present two examples, the first one concerns the

[22] Hulot F.D., Lacroix G., Lesher-Moutoué F., Loreau M., 2000, Functional diversity governs ecosystems response to nutrient enrichment. *Nature*, **405**, 340-344.

dynamics of biodiversity during the last 600 millions of years, and the second the dynamics of biodiversity in Amazonia during the Tertiary and the Quaternary.

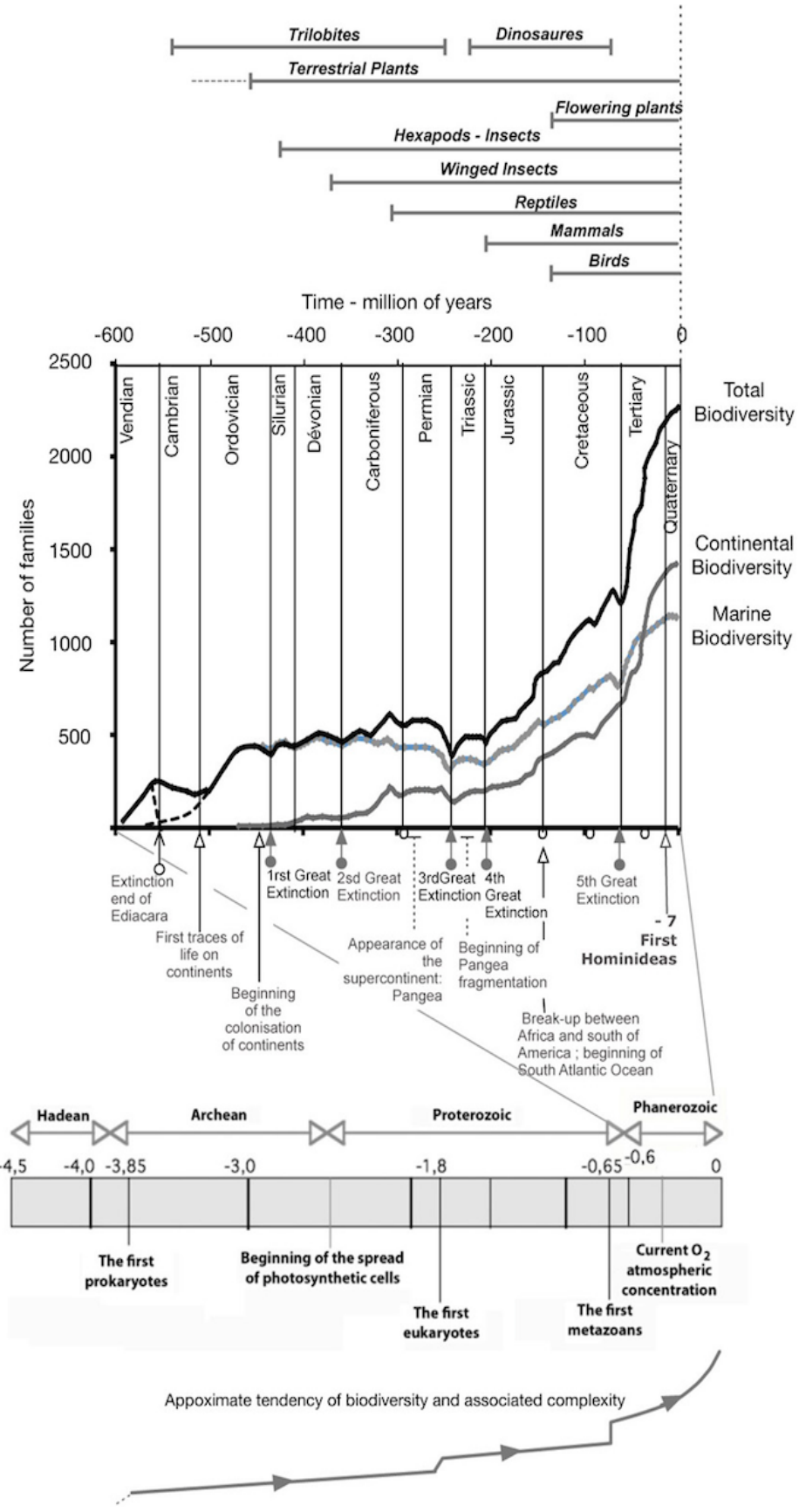

Figure 9. Dynamics of biodiversity at the geological scale shows that the history of biodiversity is not "a long quite river". But it is punctuated by drastic accidents called "great extinctions". In the classical literature 5 are mentioned, in fact the one, which has occurred at the end of the Ediacara period, is systemically forgotten.

From: :Benton M.J., 1995, Diversification and extinction in the history of life. Science, 268, 52–58.

And: Pavé (2010, *Op. Cit*: footnote 8). In this book models describing the dynamics of marine biodiversity from the Ordovician up today are proposed.

We can also refer to Benton's article cited above and to :

Courtillot V., Gaudemer Y., 1996, Effects of mass extinctions on biodiversity. *Nature*, 381, 146–148.

Pavé A., Hervé J.C., Schmidt-Lainé Cl., 2002, Mass extinctions, biodiversity explosions and ecological niches. *C. R. Biologies*, 325, 755–765.

In these publications, global models of biodiversity dynamics are proposed, based on a novel interpretation of the logistic law.

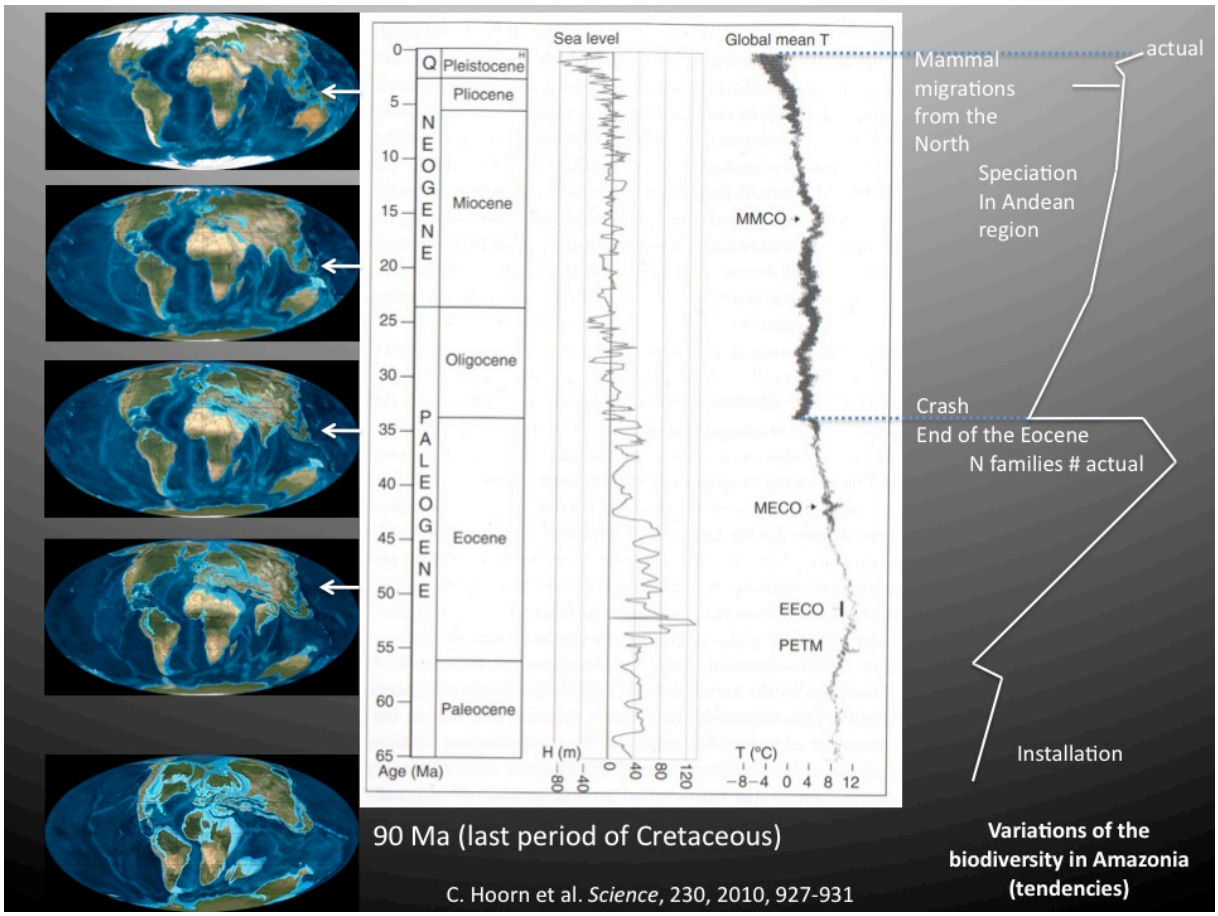

Figure 10. The history of biodiversity in Amazonia. It was at a maximum during the warm period of the Eocene (about 12°C above the actual). From : (1) Hoorn C. and Wesselingh F (Eds). Amazonia Lanscape and Evolution. A look into the past. Whiley-Blackwell, Oxford, UK, 2010, and (2) Hoorn C et al. Amazonia Through Time: Andean Uplift, Climate Change, Landscape Evolution, and Biodiversity. *Science*, 2010, 230, 927-931.

For Amazonia, we have also results during the Holocene, which exhibit large variations of the forest area probably consequences of drought periods. It seems that biological and ecological processes producing random events are important to be considered and studied to explain its global structure (cf. annex).

Obviously, if considering the past permits to relativise actual changes, it cannot be an excuse to do nothing facing to risks presented; particularly by climate change.

Biodiversity and biological active products

Animals, plants and microbes synthetise organic molecules for their own needs, particularly to resist to aggressors or for transmitting chemical messages. The case of antibiotics is well known, also that of pheromones. Classically, we search active molecules or mixtures of molecules by analysing traditional knowledge or by screening. Today we put together chemists, specialised in analysis and synthesis of natural molecules, and ecologists, specialised in chemical ecology. Then we try first to find what substances have specific biological and ecological effects *in natura* before the chemical identification and to do biological activity essays. This new way of research has been promoted in the framework of the interdisciplinary programme on Amazonia of the CNRS.

Biodiversity: an interdisciplinary field of research

As previously mentioned, if ecology is the main implicated discipline, which investigates the domain, many other disciplines are also concerned. More than a long explanation, a scheme proposed by the French Foundation for Research on Biodiversity is a good illustration (figure 11).

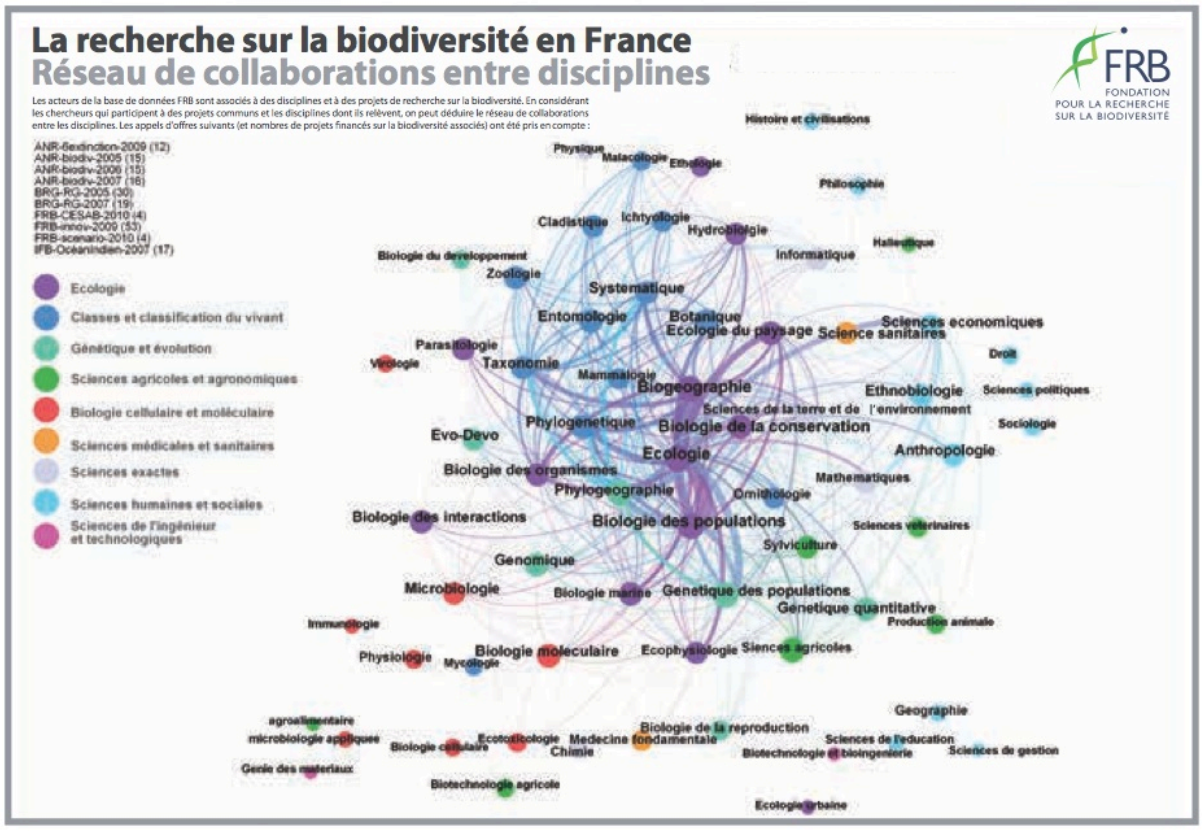

Figure 11. An illustration of the interdisciplinary research on biodiversity: the example of collaborations between scientific disciplines on this subject, today in France[23].

Conclusion

Biodiversity offers extraordinary opportunities to Ecology to develop[24]. That is clearly shown by the citations in literature, and also by the progresses accumulated for twenty years. It can be compared with molecular biology and with genomics, in biological sciences, or with the studies on climate, in geosciences. Recent and future developments will probably lead us to change our deterministic vision of ecosystems and maybe more generally of life world, following, at least for a part, the way depicted by D. Worster. Particularly, considering processes, which generate random events, govern mainly functioning of ecosystems (or econetworks) may be a kind of a "Copernician revolution" in ecology (i.e. to put chance at the heart of ecosystems). Endeavours can also be predicted in the acquisition and organisation of data. For example, after genomics, bioinformatics has to focus on ecology. Modelling is also

23 Rapport d'activité 2010-2011. Fondation pour la recherche sur la biodiversité, Paris, 2012, p. 37.

24 Biodiversity "is a word that was invented to encapsulate a variety of other concepts *and also ethical norms* [...] *biodiversity as a concept within ecology marks one of the most significant trends in that field.* " Neff M.W., Corley E.A. 35 years and 160,000 articles : a bibliometric exploration of the evolution of ecology. *Scientometrics*, 80 :3, 2009, 657-682

an important domain which has to progress. We can forecast that ecologists will be amongst the major users of sophisticated mathematical and statistical methods, and also of high performance computing. We have also to look more precisely at biological and ecological diversification processes, while disappearing ones are well identified and studied (e.g., overuse and overexploitation of biological resources, hunting, habitat destruction, climate changes, chemical pollutions, invasive species…). A new idea appears about the generality of Darwin's analysis "on the origin of species" during biological evolution, which can be applicable to many other cases in dynamics of biological and ecological systems, that is to say the succession of processes producing variability (*i.e.,* diversity) followed by natural selection. For example, in dynamics of tropical forests when we associate random dissemination of seeds (diversification) and environmental filtering (selection), we are typically in a Darwinian scheme.

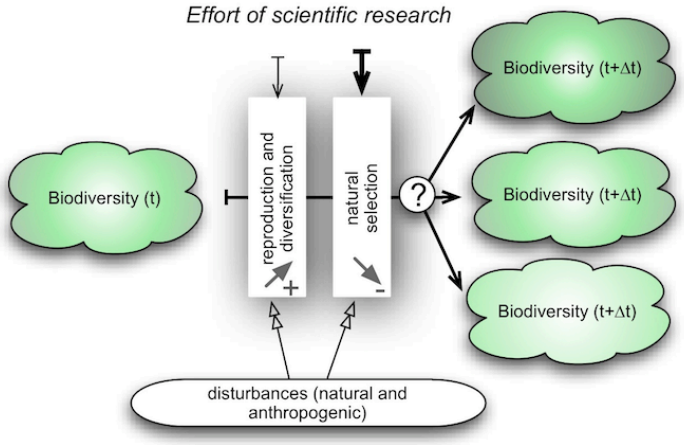

Figure 13. Dynamics of biodiversity analysed through a Darwinian scheme: the balance between, on the one hand, reproduction and diversification and, on the other, natural selection determines the increase or the decrease of biodiversity. The involved processes have an important random component. We have to point out that scientific researches are more oriented on studies of selection than of diversification. Perhaps, it is time to investigate deeply processes, which generate variability and thus diversification.

Eventually, "synthetic biology" begins to be developed at least "intellectually"; it is important to underline the necessity to take into account variability. Living things are not only defined by reproduction properties but also by capabilities to evolve, for which variability is essential. Therefore, to envisage the identification and the implementation of biological processes, which generate randomness, may be a keystone to reach such an objective.

Biodiversity has also an important echo in societies, which are anxious, face to actual changes. The political translation was to multiply laws and rules concerning particularly protected area, and to elaborate economical arguments about its monetary value[25]. All's said and done, it is none the less that this social sensitivity constitutes an asset for scientists but also a certain risk. Why a risk? Because it may lead to some confusion between scientific and politic discourses, even to introduce thoughtlessly ideology in scientific approach. That is not to say that scientists must not have a political even a religious thinking, or defend an ideology,

[25] Cf., for exemple : Aubertin C. (Ed). Protected Areas, Sustainable Land ? Ashgate and IRD Edition. 2011.

but we have to categorize them to avoid confusions. Conversely, other orders of thinking may enhance the scientific one and mainly the personal blossoming.

Scientists constitute also a social component, which has to deal with politics and economy. They are convinced of their role in social, in the well being of human societies. Doom and gloom is not a way of life: scientists are also able to offer a space of dream. So they consider their researches are important even critical for the future of humanity. This is particularly the case in ecology of biodiversity. Their questions about it are justified and the research relating to these questions also. But they need money to achieve that. So their arguments focus often on this goal to sensitize politicians and other actors of society, this explains they use sometimes catastrophic forecasting in the case of decrease of biodiversity and, on the other hand, they often present an idealistic picture of it. It is good for every one and every things. Moreover, if biodiversity is useful and becoming scarce, its value enhances and logically also the researches about it! This is not a negative criticism; many scientific communities use these kinds of mechanisms in the social debates, for example climate scientists. Biodiversity is the analogue for ecologists of climate for the community of geosciences. But, it doesn't mobilize the life sciences, which have other engines, particularly all which concern human health. In fact, as we already denoted, global problems are interrelated and need interdisciplinary approaches and collaboration between scientists from many disciplines. It is what we try to do, for example at the CNRS since about 35 years, it is not easy, but we have accumulated experience about it.

How is the debate organized? What is the role of media?

As we have emphasized, biodiversity is the subject of two debates, which concerns on the one hand scientific community and on the other society, with its multiple components. To better understand the ins and outs, it is useful to identify more precisely the actors. First, the scientific community, the more relevant is the fraction of ecology. Second, social actors are citizens generally receiving messages from various sources via the media, and mostly from advocates of biodiversity, they are involved in various associations of "conservation", which can also be called environmentalists. The economic world is not absent because biodiversity can be both object of benefits or of constraints. Managers circles the territories are at the forefront. Lawyers are both concerned in the establishment of laws and to decipher the jungle of rules and norms. Finally, the political world is actively involved in the debate, proactively through representative environmentalists parties, more or less positively or passively, depending on its perception of the impact of environmental discourse in the electorate.

The concert is orchestrated by the media, which obviously play their important information role, as we have seen with the example of the daily "Le Monde". However, they are also there enough to feed their business, which can influence the presentation of environmental issues in general and biodiversity in particular. General scientific journals are not immune to this observation.

We are already seeing the diversity of actors and motivations of each can contribute to complicate the debate. And so much more that one person may belong to several categories. An example: a scientist may be active in an association for the protection of nature, he can

participate in the media, newspapers and obviously scientific journals and he may also play a political role. Above all, we are all citizens and many are influenced by our cultural milieu. And even those who are not believers are impregnated with a religious order thinking. At the end: many sources of confusion.

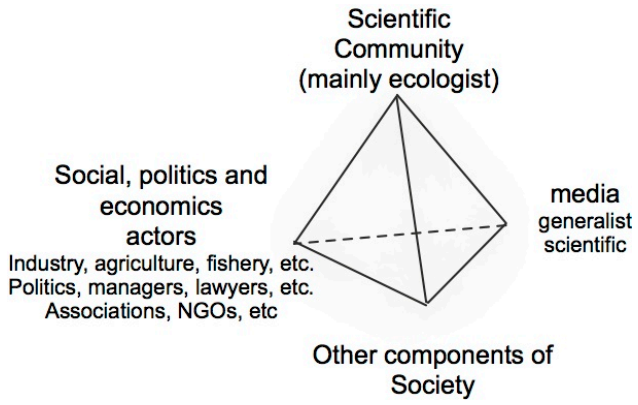

Figure 13. Principal social components in the debate about biodiversity

It is not our intention to analyse, even briefly, this complex situation. It's out of our jurisdiction, others will already occupy. But, to our knowledge, there is no general synthesis. We emphasize only how scientific journals play their role. Their role is to publish research results, results of peer-reviewed, as objective as possible. Many are also commercial and they have editorial lines. These editorial guidelines are also permeable to ideological positions. Catastrophic discourse may be indicative of such positions, or at least can we ask.

Take an example, not less. *Nature* magazine is considered a benchmark for scientific publication. Taking only two very recent publications can be cited:

– « *Approaching a state shift in Earth's biosphere* »[26], a large interesting survey of literature, but a surprising use of a geometric model (named a fold bifurcation, which looks like the section of a cusp, from Thom's catastrophe theory) which leads to assume a rapid change of state of biosphere (figure 2 of the article). It might lead us to implicit links to an apocalyptic view.

– "*Averting biodiversity collapse in tropical forest protected areas*"[27] presents these areas as a kind of Arks (*tropical reserves will function as 'arks' for biodiversity and natural ecosystem processes*) to save biodiversity and the risk to lost them associated to human activities. The short journalistic presentation emphasizes the biblical reference. However, it summarizes a large study of a great sample of protected areas.

Many other examples can be found in the literature. This is not a baseless accusation, it is indicative of our cultural representations that are expressed in both writing articles and editorial decisions. Anyway, the debate around biodiversity is very active. There are also

[26] Barnosky A.D. et al. Approaching a state shift in Earth's biosphere. *Nature*, 486, 2012, 52-58.

[27] Laurance W.F. et al. Averting biodiversity collapse in tropical forest protected areas. *Nature* 489, 2012, 290-294.

some articles, which reveal how diversity is maintained on the long term. An other article can also be cited, which concern polar bears[28]. The authors show how these bears can hybridize which brown bears during periods when the boreal lands lost their white snow cover, and conversely hybrids differentiate in brown and polar bears when snow cover extended a new time. When reading this article, we remind the classical example of the peppered moth (*Biston betularia*). This kind of result relativizes catastrophic discourses, but it is not a reason to ignore the anthropic pressure on biodiversity. It underlines the necessity to study processes, which governs its dynamics, but all of them: erosion ones but also, once again, maintenance and diversification processes.

Note. The reflections about ecology and biodiversity presented here and in other circumstances, can be found in diverse publications (articles and books). They are the results of our collective work, essentially accomplished in the framework of interdisciplinary research programmes of the CNRS (French National Centre for Scientific Research) and particularly the last I have managed: the "*Programme Amazonie*" (Analysis, modelling and engineering of Amazonian systems), between 2004 and 2011. In the future a book relating this experience will be published in English. Today we have already realized a "coffee-table book", smartly illustrated, but written in French : "*Amazonie, une aventure scientifique et humaine du CNRS*" (Authors: Alain Pavé and Gaëlle Fornet, Editor: Galaade Paris, 2010). Finally, the skill accumulated in mathematical modelling and in bioinformatics was also precious in this kind of scientific activity.

Personal information about many years devoted to scientific research and teaching can be found at: http://web.me.com/alain.pave/Site/ (still in French, but soon also in English).

This text has been written to be a guide for scientific conferences in Australia (May 2012), invited by the "*Alliance Française*". These conferences will be associated to the presentation of a movie devoted to Biodiversity and Aborigens' traditions in the West Region of Australia: *Goolarabooloo* (realization: Bruno and Sylvain Cedat, scientific advisor : Alain Pavé). The ideas presented here have already been presented in France in the framework of the "*Fondation Ecologie d'avenir*" (Paris, November 2011), and after during a debate at the National Academy of Technologies of France (Paris, March, 2012). At the beginning of 2013, at Orleans, in the context of the Studium, and advanced Research Institute, we presented a version entitled "Is Biodiversity a Strong Concept?". Finally, the actual version very similar to the first one was enriched with last data, particularly concerning the number of species on earth, and also a little change in epistemic analysis.

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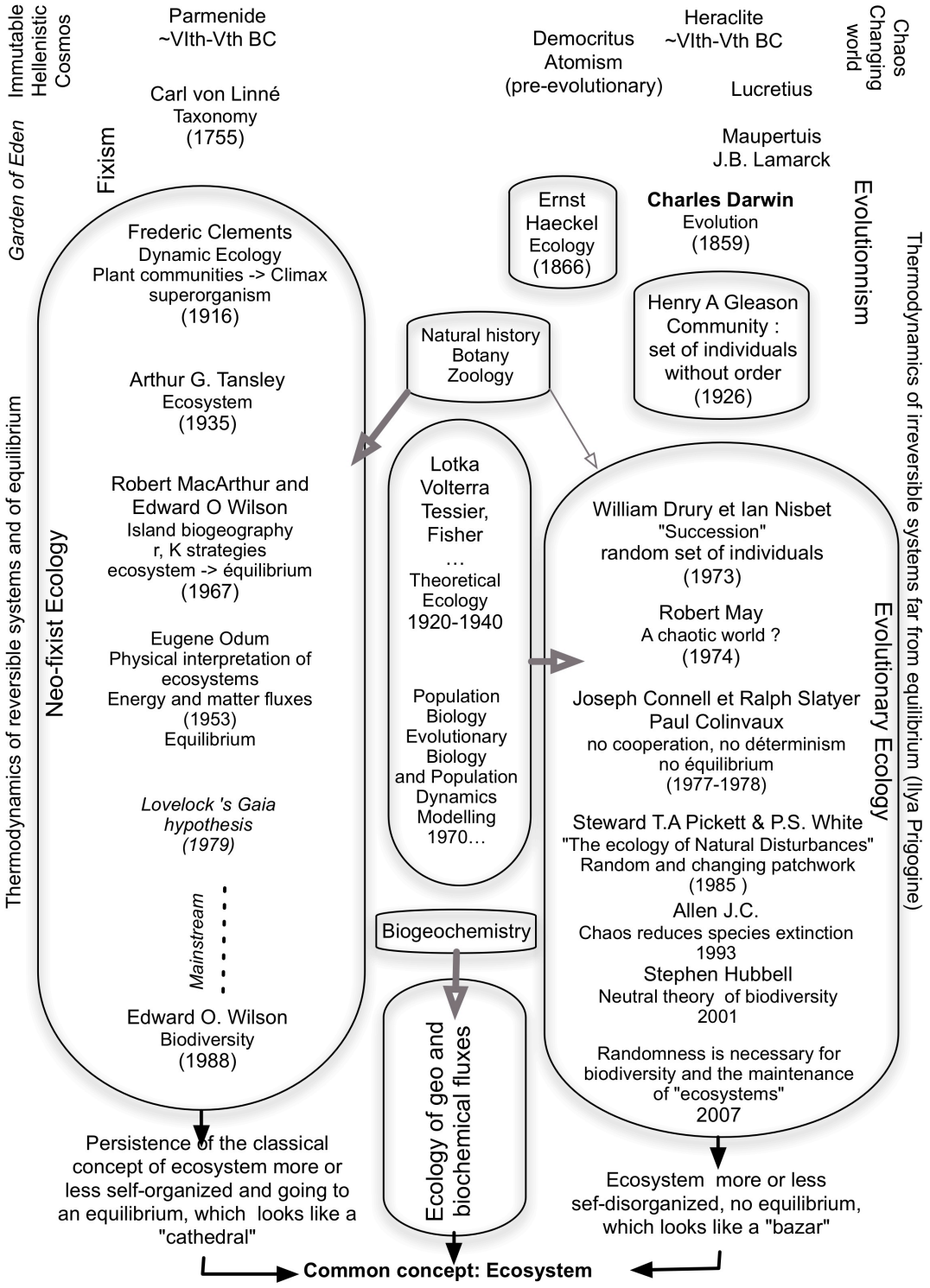
[28] Miller W. et al. Polar and brown bear genomes reveal ancient admixture and demographic footprints of past climate change. PNAS, 2012 : www.pnas.org/cgi/doi/10.1073/pnas.1210506109

Annex

Schematic view of history and epistemology of ecology



Evolution of concepts in Ecology mainly inspired by Donald Worster (1993).

At the left, the maturation of the ecosystem classical concept centred on the assumed tendency towards equilibrium, towards homeostasis and towards a superorganismic organization. More or less it can be named a *neo-fixist* ecology . At the right, we represent the lineage of ideas, which leads to a chaotic or stochastic interpretation of ecological processes, where natural disturbances play an important role and strongly related to evolutionism. We try to show the inheritance and origins of ideas and finally we found that they can be related to

an old debate between two Greek philosophers : Parmenide and Heraclite, between to visions of the world, immutable for the first one and continuously changing, even chaotic (or without an order a priori or even without a tendency to converge to an order), for the second one. Democritus plays a particular role in this scheme: evolution needs to be found on a kind of atomistic view. Representations, such as the Garden of Eden, which come from the Christian culture, are also present in our collective consciousness even into scientific community. For the scientist is important to know it to avoid confusions.

The role of population biologists to promote the stochastic vision is underlined by Donald Worster. He enhances also their ability to use and to develop quantitative approaches and mathematical modelling. The author is particularly sensitive to this explanation because it corresponds to his personal experience and has presented and developed this point, in association with French colleagues (Lévêque et al., 2010). In addition we show how ideologies influence scientific thinking. Moreover, today we try to depict the history of ideas before Clements, because we think that it is important to better understand the origins, which influence our approach of the real world and probably not only in Ecology.

Eventually, as we can see by looking to the scheme above, ecology is influenced by ideologies more than other domains of science. It could explain the importance of social debates and also why it has been translated in political discourses, parties and institutions, so the question posed by Christian Lévêque, a well-known French Ecologist, and the actual President of the Academy of Agriculture of France: Ecology is it still scientific?

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