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# ECOSYSTEM HEALTH: WHAT IS THE DEFINITION?

## LA SANTÉ DES ÉCOSYSTEMES : QUELLE DÉFINITION ?

By Patrick GIRAUDOUX\*

(Communication presented on February 3<sup>rd</sup>, 2022, manuscript accepted on March 16<sup>th</sup>, 2022)

This article is dedicated to the memory of Patrick Le Bail. He is, in fact, the co-author of the definition proposed here.

### ABSTRACT

*Ecosystem health is often presented as an emergent property relating to its 'proper functioning'. Following the French Veterinary Academy's declaration of the 17<sup>th</sup> of July 2021 on veterinary health, and the Academy's invitation, this article comments on the notion in the light of ecological knowledge and proposes a definition of ecosystem health: "The state of diversity or functioning of an ecosystem which, as an ecological unit within a defined space and time, is characterised by its physico-chemical and biological properties, including its robustness and resilience to external stresses. An ecosystem is therefore "healthy" if it preserves the maximum potential of its functions, dynamics and evolutionary capacities, as well as those of the systems it includes and which include it. The various states of possible deficit, or states of health, can be qualified on the basis of an (eco)epidemiological approach, which makes it possible to establish a diagnosis and prognosis, and to propose "therapeutic" paths, as in the medical and veterinary disciplines." The place of ecosystem health within the concept of "One Health" is then discussed.*

**Keywords:** one health, ecohealth, global health, planetary health

### RÉSUMÉ

La santé d'un écosystème est souvent présentée comme une propriété émergente relative à son « bon fonctionnement ». Suite à la déclaration de l'Académie vétérinaire de France du 17 juillet 2021 sur la santé publique vétérinaire, et à son invitation, le présent article commente la notion à la lumière des connaissances écologiques et propose une définition de la santé des écosystèmes : « État de diversité et de fonctionnement d'un écosystème qui, en tant qu'unité écologique située dans un cadre spatio-temporel délimité, se caractérise par ses propriétés physicochimiques et biologiques, dont sa robustesse et sa résilience, notamment au regard de stress extérieurs. Un écosystème est donc en « bonne santé » s'il préserve le maximum de ses fonctions, de ses dynamiques et de ses capacités évolutives potentielles, ainsi que celles des systèmes qu'il inclut et qui l'incluent. Les différents états de déficit éventuel, ou états de santé, peuvent être qualifiés sur la base d'une démarche (éco)épidémiologique, qui permet de poser un diagnostic, un pronostic, et de proposer des chemins « thérapeutiques », à l'instar des disciplines médicales et vétérinaires. » La place de la santé des écosystèmes au sein du concept « Une seule santé » est ensuite discutée.

**Mots-clés :** Une seule santé, écologie de la santé, santé globale, santé planétaire

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1- A major part of the proposed definition was worked on during July 2021 with Patrick Le Bail. Following the AVF statement of July 17, 2021 on veterinary public health, he had, with his usual modesty and in his own words, "ventured on this subject". He had then attended the seminars of "Penser la pandémie" (Thinking about the pandemic), a cycle at the University of Franche-Comté initiated by my philosopher colleague Arnaud Macé and myself, an ecologist. Patrick Le Bail had submitted to me for my opinion a first definition that was already very advanced and remarkably relevant. This was followed by stimulating exchanges that led to the addition of an evolutionary component, based on articles that I had previously published (opus cit.). The idea of defining ecosystem health as a fraction of achievement compared to a potential maximum came to me during the preparation of this article, following a seminar organised by Alain Brauman, an IRD researcher, on the subject of "soil health", organized by the Fédération Île-de-France de Recherche sur l'Environnement (FIRE) in January 2022. It then seemed necessary to me to insist more clearly on the temporal and multiscale dimensions of ecosystem health.



## INTRODUCTION

The health of an ecosystem is often presented as an emergent property, related to its "proper functioning". While the notion of "health" has received an official definition in human and animal health, this is not (yet) the case for ecosystem health. However, the use of the term has become popular in ecological engineering, with the creation of specialized journals such as *Ecosystem Health* (1997-2001), *Aquatic Ecosystem Health and management* (1998), *Ecosystem Health and Sustainability* (2015-), etc., and its integration is explicit in the One Health triptych combining human, animal and environmental health.

Supported by the journal *Ecohealth* (2004-), this triptych, historically derived from the Brundtland report on sustainable development (World Commission on Environment & Development, 1987 ; Patz *et al.* 2004), is now promoted jointly by the World Health Organization (WHO), the World Organization for Animal Health (OIE), the Food and Agriculture Organization of the United Nations (FAO) and the United Nation Environment Programme (UNEP) (OHHLEP, 2022). Criticism is often expressed that the concept of ecosystem health is only a metaphor applied to the knowledge and management of ecosystems, but that it does not provide, unlike other health, objective measures and methods to make it an operational management tool. It is true that without a clear and consensual definition of assessment targets allowing a health diagnosis and, if necessary, a healing target and engineering, as in other medicines, ecosystem health would be limited to its metaphorical virtue, and condemned to remain a vague and subjective notion in practice. It has become clear, however, that human and animal health depend to a large extent on the "proper functioning" of the ecosystems from which the populations concerned draw their resources, and that this "proper functioning" is being altered by multiple and interlinked causes such as innumerable pollutions, the collapse of biodiversity, global warming, etc., which compromise the habitability of the earth by humans and their domesticated animals, among others.

The French Veterinary Academy, in its declaration of July 17, 2021 on "veterinary public health"<sup>2</sup>, emphasizes the importance it attaches to human, animal and ecosystem health together, and thus to the implementation of the "One Health" concept. The purpose of this article is to clarify the concept of ecosystem health and to propose a definition that is as generic, objective and applicable as possible.

<sup>2</sup> <https://academie-veterinaire-defrance.org/actualites/communiqués-de-presse/communiqué-de-presse-2021-08-lacademie-veterinaire-de-france-revisite-la-definition-de-la-sante-publique-veterinaire>

## CAN ECOSYSTEM HEALTH BE THE ANALOGUE OF THE OTHER HEALTH?

Human health has been defined by the WHO since 1946 as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity". I have not found a specific definition of animal health at the OIE, but the notion of "animal welfare" is an important concern of this organization, which emphasizes, without giving an explicit definition, that it is "a complex, multifaceted subject with scientific, ethical, economic, cultural, social, religious and political dimensions". In all cases, it can be seen that the notion of health, presented as very close to that of well-being, is essentially based on a subjective feeling (well-being), that it is not reduced to the absence of disease, and that it must be considered not only in an individual "patient" approach, but also within the social norms of the population to which the patient-subject belongs. The disease itself is defined by the WHO as "a dysfunction of psychological, physical and/or social origin, which manifests itself in different forms". We could not be less precise, but the notion of dysfunction implicitly echoes that of "good functioning", which suggests deviations from a "good functioning" norm. If the notion of health remains rather vaguely defined, even in the highest authorities, it nevertheless exists, fortunately, in practice, doctors and veterinarians, have the daily task of ensuring the good health of their patients and populations. They do so, as an art based on science, and therefore on evidence, by making health diagnoses and, if necessary, providing remedial responses.

Table 1 is an attempt to draw parallels between what a medical or veterinary diagnosis is and what a diagnosis of ecosystem functioning might be. The first three lines of the table show that these parallels make superficial sense: the notion of robustness/resilience (we will come back to these notions later) at the scale of a community of populations of different species (the biocoenosis) in their biotope (the abiotic part; the whole biocoenosis and biotope constituting the ecosystem) can be considered equivalent to that of homeostasis at the scale of an individual. Metabolic constants follow in both cases, and deviations from norms are then symptoms. Individual capacities, which are not only based on metabolic constants, are also examined by the physician and the veterinarian. The ecologist will examine the capacities of the ecosystem in terms of ecosystem service (we will return to this notion later), and capacity or service deficiencies will also be considered as symptoms of dysfunction.

Medical and veterinary diagnostic criteria	Ecological diagnostic criteria
Homeostasy > equilibrium > <b>stability</b>	Robustness/resilience > equilibrium > <b>stability</b>
Metabolic constants > norms > <b>symptoms</b>	Metabolic constants > norms > <b>symptoms</b>
Capacities > norms > <b>symptoms</b>	Services > norms > <b>symptoms</b>
<b>BUT</b>	<b>BUT</b>
Ontogenesis	Ecological successions
Growth	Darwinian evolution
Handicap	Non-lethal modifications

Table 1: Comparison between medical and veterinary diagnostic criteria and ecological diagnostic criteria.

Beyond these similarities, there are "buts" in the picture regarding the subjects and processes being evaluated. The doctor and the veterinarian have to consider the ontogenetic and growth processes of the individuals they examine: an embryo, a young patient, are not adults in miniature, and a certain number of specific standards are applied to them; the doctor and the veterinarian also consider the fact that the equilibrium of the organism, like that of any living form, is the result of a continuous flow of matter and energy. It is therefore a dynamic equilibrium.

An ecosystem is also a flow of matter and energy, but it does not grow like an individual. An abiotic space (for example a just cooled lava flow) is colonized following an ecological succession, that is to say by the setting up of more and more complex ecosystems, over the long time, by mechanisms of colonization/extinction/reorganization of species populations, themselves in Darwinian evolution (Figure 1). If the norm is set at a stage of the succession, it will quickly become inappropriate because of the transient nature of the system's states. Moreover, if the terminal stage of the succession (the climax) is theoretically a

dynamic equilibrium with the climatic conditions that prevail at a given moment, the norm of this moment can quickly become inappropriate as a consequence of climatic changes and the Darwinian evolution of organisms. The forests of the dinosaurs are not the forests of the Anthropocene, and the forests of the Middle Ages are not the forests of today, which are themselves different from those that will adapt to ongoing climate change. Ecosystem disturbance (e.g. by fire, storms, floods, the action of certain species such as humans, beavers or elephants, etc.) is also part of the "proper functioning" of an ecosystem. What may be perceived as a local ecological catastrophe (by regression in the ecological succession, which is then thwarted) may be perceived as desirable on a larger spatial scale, one that maintains a metastable mosaic of ecosystems at all stages of the succession, and thus a greater overall biodiversity. On the long term, Darwinian evolution adds to this succession dynamic, as we shall see later. The duration to consider depends on the organisms: a few months for certain microorganisms, as shown by the succession of SARS-COV-2 variants, from a few years to several thousand years for more complex organisms, less

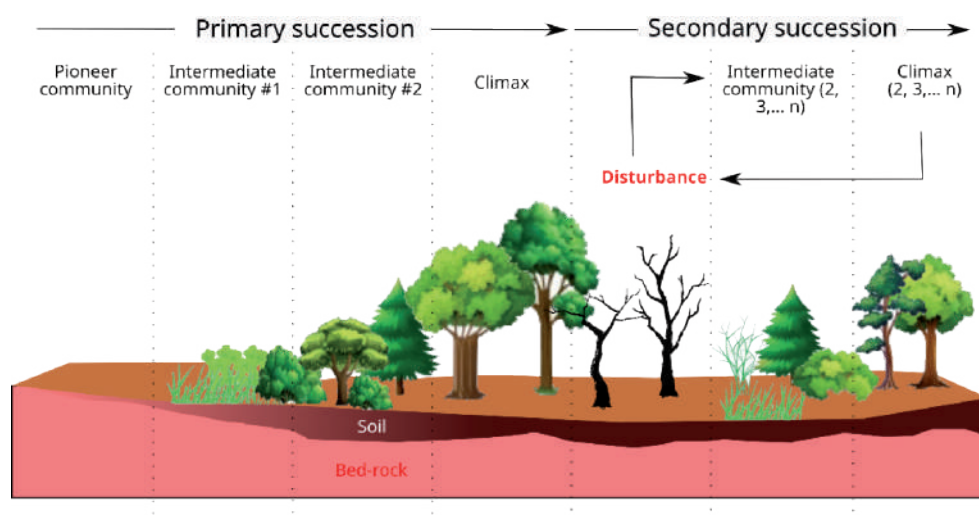


Figure 1 : Example of ecological succession, diagram inspired by Khanolkar et al. (2020). At each transitional stage of community successions, species reassortments occur with some degree of predictability (in its simplest and most obvious formulation, for example, trees succeed bushes, which in turn succeed grasses) but with varying degrees of stochasticity. The latter results from the chance occurrence of biotic interactions such as competition, predation, parasitism, mutualism, etc., and also from the intensity and frequency of disturbances such as fire, extreme meteors, the soil seed stock, the variable spatial arrangement of habitats-sources of individuals of various species around, etc. The ecosystems that emerge from these processes and follow one another, although ecologically functional (since the processes are maintained over time), predictable in their broad structural and functional features, but not in their details, are never completely identical to their predecessors.

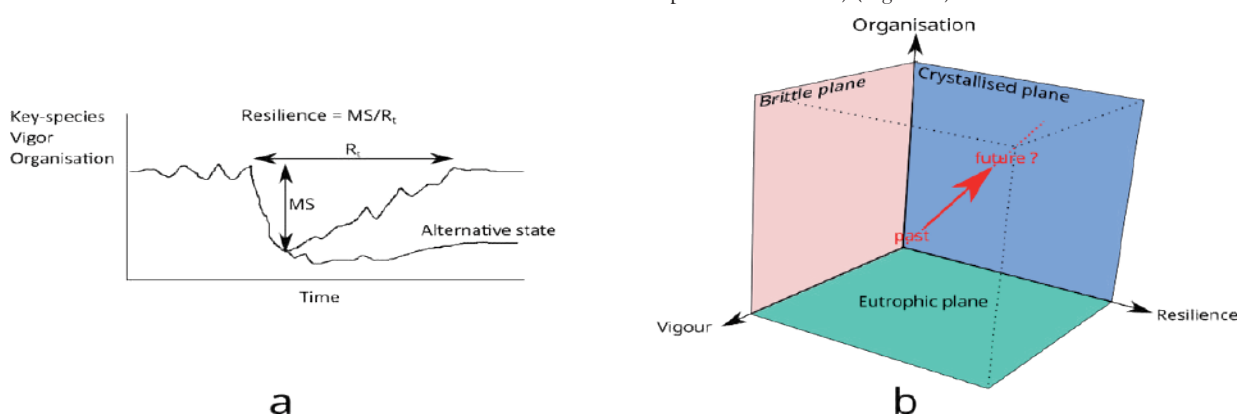


numerous and with slower generation (Giraudeau, 2021). Finally, the resilience of an ecosystem does not always allow it, after a disturbance, to return to its initial state. It can then remain for a time in a different state of dynamic equilibrium, with other species and other properties, and it is sometimes difficult to say, other than subjectively, whether it is better or worse than the previous one. Nevertheless, if the complexity of ecological processes makes it difficult to establish an indisputable definition of their "good functioning", if it is of course impossible to question an ecosystem like a patient, about its feelings and its "well-being", attempts have been made to define the "health" of ecosystems.

### HISTORICAL ATTEMPTS AT DEFINITION AND THEIR LIMITS

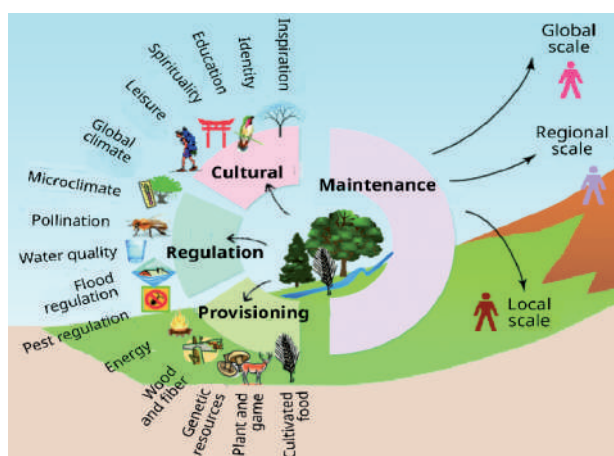
Robert Costanza is an environmental economist who, after graduate studies in architecture and urban planning, had the famous ecologist Eugene Odum (1913-2002) as his thesis

advisor. Prolific co-author of 22 books and more than 400 scientific publications, he is one of those who have promoted the concept of ecosystem health since the early 1990s, among others in his book *Ecosystem health: new goals for environmental management* (1992) and as president of the *International Society for Ecosystem Health*. He also put forward the notion of ecosystem services. This notion has still a strong influence on the way in which the functioning of ecosystems is evaluated in the political and economic spheres (Costanza et al. 1997 ; Millenium Ecosystem Assessment, 2004). In particular, Costanza et al. (1992) argue that "an ecosystem is healthy and free of the 'distress syndrome' if it is stable and sustainable, i.e. if it is active and maintains its organisation and autonomy over time, and if it is resistant to stress". In this regard, he proposes to measure the health of an ecosystem according to three criteria: its vigour (the measure of the ecosystem's activity, metabolism, primary productivity), its organisation (the number and diversity of interactions between components) and its resilience (its ability to maintain its structure [temporal and spatial, I add], and processes in the presence of stress) (Figure 2).



**Figure 2 :** Components of ecosystem health after Costanza and Mageau (1999) : a, two components of resilience: the return time  $R_t$  and the maximum stress. Beyond the maximum stress, the ecosystem cannot return to a state equivalent to the initial one over the time presented, and bifurcates towards an alternative dynamic; b, the three-dimensional space related to the health and organisation of ecosystems. A healthy ecosystem should move away from the 3 planes of this space (brittle, crystallised, eutrophic) where the value of one of the axes is zero. The red arrow, added by me, indicates a hypothetical "improvement" trajectory (cf. Figure 6 and corresponding paragraphs).

Costanza et al. (2012) later added, following the popularisation of the notion of ecosystem services (Costanza et al. 1997), that a healthy ecosystem 'must sustainably provide a range of ecosystem services', an anthropomorphic injunction to individual productivity that is very much in the air. This range of ecosystem services (Figure 3) was extensively described in the *Millennium Ecosystem Assessment*, a report commissioned by the United Nations to provide a science-based assessment of the extent and consequences of ecosystem change, as a continuation of the work of the IPCC (Intergovernmental Panel on Climate Change) and a precursor to the IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services).



**Figure 3 :** Examples of ecosystem services (provisioning, regulating and cultural) provided by the ecosystems of a territory to beneficiaries at different scales. Maintenance services are those that do not provide direct benefits to humanity, but are necessary for the sustainable functionality of ecosystems and the production of other services. Based on Locatelli et al. (2017), modified.

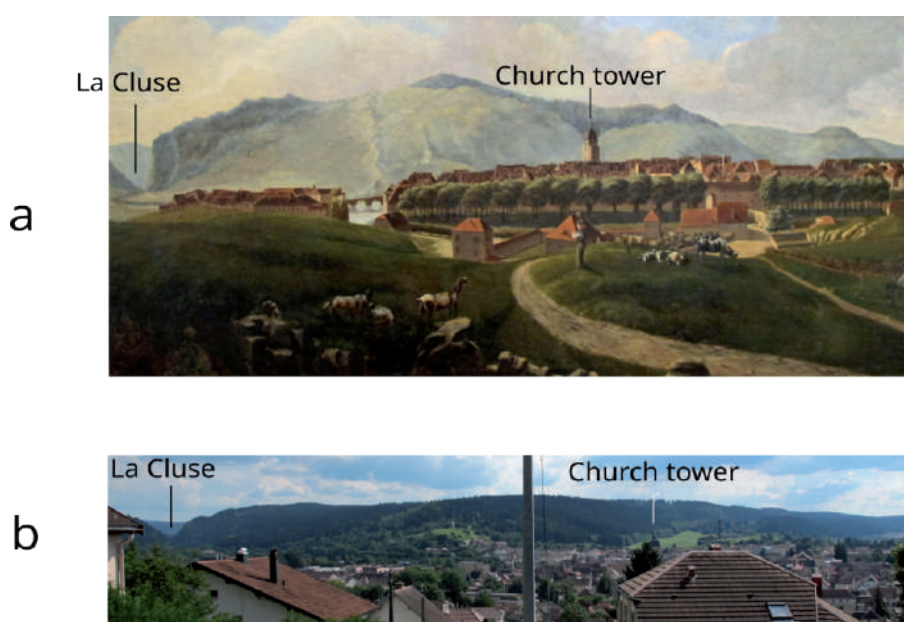


While the notion of ecosystem service has the merit of translating the intrinsic functional value of ecosystems into monetary value, in a language that economists and politicians can understand, it has the major drawback of reducing ecological processes to this value alone, estimated in terms of services rendered directly or indirectly to humanity. It could not be more reductionist and anthropocentric. In this framework, no place is really given to the long term, that of the Darwinian evolution of living beings (Evolution), which is nevertheless the essential engine underlying the functioning of an ecosystem. Costanza *et al.* (2012) explain, however, that 'a sustainable system is one that survives for a specific (non-infinite) time'. The difficult issue of quantifying this duration is however left to subjective judgement. The answer is indeed not obvious: an ecosystem is a dynamic system that is constantly evolving on several time scales.

The choice of a duration presupposes that a reference starting state has been defined and that useful variations linked to the functioning of the ecosystem have been defined around this state (e.g. seasonal, or spatial, such as the upstream-downstream gradient of a river). This is objectively impossible beyond a very short period of time (for example, one human generation): the obstacles come from the irreversible nature of the time's arrow. The first is that a healthy ecosystem, and the neighbouring ecosystems on which it may depend (e.g. a river and those of its catchment area), undergoes disturbances, including the most extreme ones, which contribute to its functioning (within certain limits, cf. Figure 2a). Its resilience normally allows a certain number of altered functions, ideally all of them, to be rehabilitated within a few months, years, tens or hundreds of years. But, as mentioned above in relation to secondary successions, ecosystems that derive from each other are rarely exact replicas of the previous ecosystems (stochastic loss and reassortment of species, relative abundances, etc.).

The second obstacle, which is even more complex to grasp, refers to longer time scales (Giraudoux, 2014). Current life

forms represent only 4-6% of the species that have existed since the appearance of life nearly 4 billion years ago (Mace *et al.*, 2005). A large number of ecosystems have succeeded each other since then, some of which are still recorded in the geological layers. Each ecosystem, over a long time scale, has inevitably been replaced by a different ecosystem with different species or combinations of species, and rearranged interactions and regulatory mechanisms, even after the five known major extinction crises. Changes, however, can be much faster. For example, in the Holocene, large post-glacial forest formations were progressively replaced by agricultural landscapes, by successive deforestation of the most favourable lands for agriculture and livestock, optimising the resources available to humanity under the constraints of landforms and geology, and creating species assemblages and interactions that *de facto* constitute new ecosystems. The importance of the human impact on nature in the evolution of these Anthropocene ecosystems is highlighted by the term "socio-ecosystems" sometimes used for them (Collins *et al.* 2011; Bretagnolle *et al.* 2019 ; Giraudoux, 2022b). All current landscapes, often described as "natural" because they are green or uninhabited, are in fact socio-ecosystems, the result of compromises between human exploitation of resources and local biological and geological potential. The 'natural' is only pretended to be so: it is only qualified as such in opposition to the urban and the 'concrete'. It should more sensibly be called rural, and at most 'green' on a gradient that goes from the grey of urban concrete to the green of the vegetation of a meadow or a production forest (Giraudoux & Lebreton, 2018; Giraudoux, 2020). Moreover, these socio-ecosystems are no more stable over time than others. The realistic painting allows us to measure an example of a century-long trajectory (Figure 4): the grassy slopes above the town of Pontarlier in the Jura massif, which were devoted to livestock farming, were covered with predominantly coniferous forest during the 20<sup>th</sup> century, leading to a different type of socio-ecosystem.



**Figure 4 :** Evolution of the forest cover to the south-west of Pontarlier, seen from the same vantage point. a, in the 19<sup>th</sup> century (anonymous painting made between 1838 and 1865, collection of the Pontarlier municipal museum); b, in August 2013 (photo P. Giraudoux).

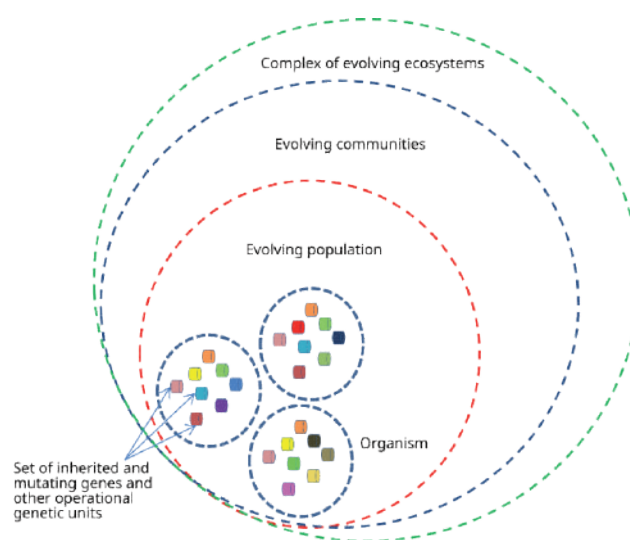
The agricultural changes of the 1960s also led, on the high plateaus of the Jura, to the virtual abandonment of crops and the extension of permanent grassland 2 to 5 times more productive, with the consequence of triggering cyclic regional population outbreaks of voles from the 1970s onwards, outbreaks which favour the transmission of a parasite, *Echinococcus multilocularis* responsible for Human Alveolar Echinococcosis, a rare but severe parasitic disease (Giraudoux, 2022b). Can we say that the extension of forests or these vole outbreaks reveal a dysfunction of the ecosystem? Absolutely not: this is the normal response of fully functional ecosystems to changes in anthropogenic constraints, even if the "disservice" rendered to farmers by the outbreaks poses an economic and health problem. In the same way, the great storms of late December 1999 due to the Lothar and Martin depressions, which caused hundreds of thousands of trees to fall in French forests, were not an ecological disaster, contrary to what was claimed at the time, but possibly an economic disaster for the timber industry. These reorganisations of ecosystems can also be observed in the microbial world (Karimi *et al.* 2017; Villette, 2018).

The difficult question of justifying a choice of normative reference state thus stumbles on the indivisible continuity and dynamics of ecosystem successions: why one stage rather than another, how can we justify blocking (even mentally) a process in its course? Within an ecosystem, it also comes up against the 'shifting baseline syndrome'. It was pointed out by Pauly (1995) in relation to the assessment of marine fish stocks: « Essentially, this syndrome has arisen because each generation of fisheries scientists accepts as a baseline the stock size and species composition that occurred at the beginning of their careers, and uses this to evaluate changes. When the next generation starts its career, the stocks have further declined, but it is the stocks at that time that serve as a new baseline. The result obviously is a gradual shift of the baseline, a gradual accommodation of the creeping disappearance of resource species, and inappropriate reference points for evaluating economic losses resulting from overfishing, or for identifying targets for rehabilitation measures ». The title and content of an article on birds in metropolitan France, "What are the baselines of bird populations in France: don't lose your memory" (Barbraud & Barbraud, 2019), testifies to its existence in ecosystems other than marine.

In addition, Evolution, which is essential in ecology for long-term management, does not seem to be taken into account in the concept of ecosystem services (but see, for examples, Faith *et al.* (2010) and Sarrazin & Lecomte (2016)). This is not to say that research on ecosystem services and ecosystem health denies the existence of Evolution, but in practice it is placed in a short- or medium-term context where Darwinian evolution acts less

quickly macroscopically than the dynamics of ecosystems under the effect of anthropic pressure. But isn't the evolution of living organisms central when questions of duration and sustainability are considered as a priority? In other words, can we think about duration without thinking about the processes that prevail in this duration? (Giraudoux & Lebreton, 2018). We can therefore understand the inadequacy of an assessment of the health of an ecosystem if it refers to quasi-fixist concepts, concerning short-term functionality, or recent generational references, assuming a form of immutability of species and current ecosystems, "without the full awareness" of a manager who knows however, at least in theory, the processes of Darwinian dynamics and evolution.

A health practice in terms of ecosystems, like a medical practice, must consider and accompany the evolution of the "patient" in the hierarchy of relevant time scales. This implies knowing the trajectory of this evolution on all scales, including the long term (over several human generations). The first difficulty lies in the unpredictability of these trajectories, due to the complexity of evolving systems, which are riddled with organisation hierarchies, each level having its own processes (Figure 5), non-linearities, threshold effects, and sensitivities to 'initial' conditions (Steffen *et al.* 2015). In other words, although ecologists, like climatologists, are quite good at explaining what has happened *a posteriori*, they also have difficulty predicting the future in detail, and sometimes even in outline.



**Figure 5:** *Mobilis in mobile: nested hierarchy of the organisation of living organisms (interactions are specific to each level), which are constantly evolving, according to Giraudoux (2014). All these diversities at each level, to which we should add cultural diversity for certain species, constitute biodiversity. It is the result of innumerable underlying processes from which it emerges.*

However, it is interesting to note that nucleic acids such as DNA have become more complex over evolutionary time (Figure 6a) and that, despite the jolts of at least five mass extinction events over geological time, biodiversity has increased at each resumption (Figure 6b), albeit with very profound reassortments of taxa. The disappearance of dinosaurs in favour of mammals is one of the most striking examples.

To sum up, a definition of ecosystem health seems to have to combine dynamics on several time scales:

- The short term (a few decades) of functional characteristics that maintain the integrity of ecosystem processes ensuring the sustainability of its identity, an identity characterised by the diversity of living forms (biodiversity) that make it up and their functional relationships, at several relevant levels of organisation of the living (genetic, population, community, cultural, etc.);
- The medium term (a few hundred years), which preserves its potential in terms of ecological succession and ecosystem diversity;
- The long term, in terms of Darwinian evolution, the notion of the long term being adapted to each organism (evolutionary time is not the same for all living forms, even if it takes place in the same chronological time for all).

The "health" of the ecosystem should then be assessed by measuring the difference between what it achieves in terms of biodiversity, processes and services, and what it could potentially achieve if the stress that causes it to be considered "unhealthy" was removed (Figure 7).

$$\text{Health} = \frac{R}{Q}$$

Potential quality (Q)

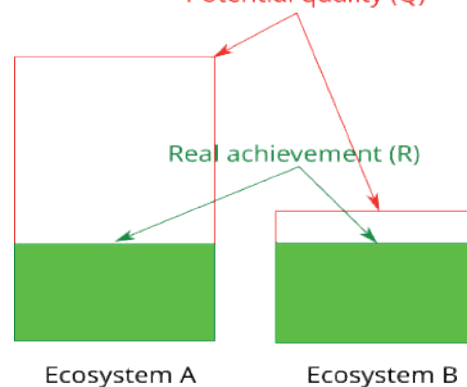
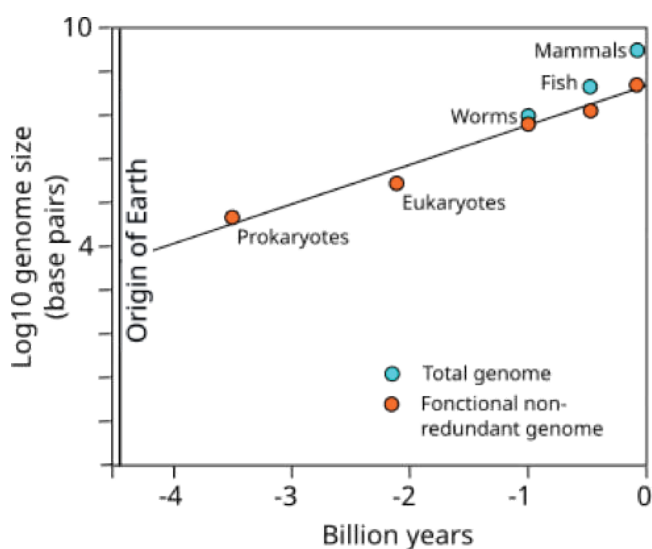
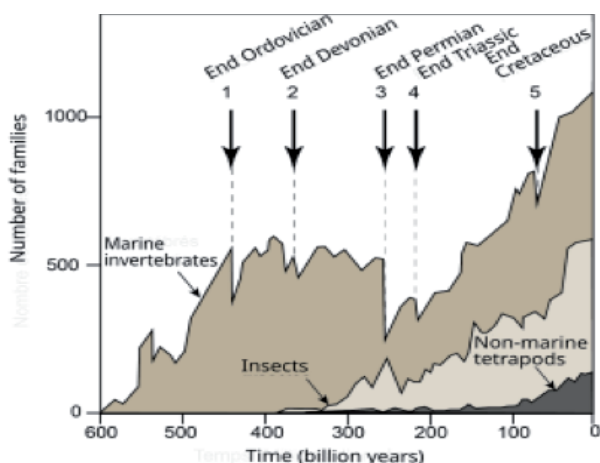


Figure 7: The health of an ecosystem can be assessed by measuring the difference between a potential quality and its realisation. For example, here, if we take the number of species as the estimator, ecosystem B would be healthier than ecosystem A, although it has the same number of species, because it realises a much larger fraction of its potential. Based on Kibblewhite (2008) and Alain Brauman about soil healths, modified.



a



b

Figure 6. a: according to Sharov and Gordon (2013), in the course of evolution, the genome of organisms follows an empirical Moore's conjecture (increasing complexity);

b: biodiversity trends for marine invertebrates, insects and non-marine tetrapods, after Benton (2001), infography Ruaut-Djerrab. The five 'major' extinctions are indicated by the arrows. The robustness of considering taxa only at the level of families does not allow us to highlight the possible bushiness within these groups, at lower taxonomic levels.

Patrick Le Bail (pers. comm.) thought that 'the various intermediate states could be qualified according to an epidemiological and prognostic approach, following the example of medical and veterinary disciplines'. This observational approach to the evolution of the health of an ecosystem can certainly inherit and benefit from the eco-epidemiological approach named and promoted by Jean-Antoine Rioux (1925-2017) in his pioneering studies of leishmaniasis, bilharzioses and mosquito control, and pursued after him by others in various fields, including the ecology of the transmission of pathogenic organisms, the management of agricultural pests and biological conservation (Houin et al. 2018; Giraudoux, 2022b).





## DEFINITION PROPOSAL

Given the considerations listed above, a robust definition of ecosystem health might be as follows:

« The state of diversity or functioning of an ecosystem which, as an ecological unit within a defined space and time, is characterised by its physico-chemical and biological properties, including its robustness and resilience to external stresses. An ecosystem is therefore "healthy" if it preserves the maximum potential of its functions, dynamics and evolutionary capacities, as well as those of the systems it includes and which include it. The various states of possible deficit, or states of health, can be qualified on the basis of an (eco)epidemiological approach, which makes it possible to establish a diagnosis and prognosis, and to propose "therapeutic" paths, as in the medical and veterinary disciplines. »

## ONE HEALTH AND ECOSYSTEM HEALTH

"One Health" is a concept that has been promoted for more than twenty years under this term, which combines human, animal and environmental health (Figure 8). As the links between ecological and climatic alterations, the emergence of pathogenic organisms and epidemics of all kinds have become clear (Morand, 2020; Mendenhall, 2020), governments and scientists around the world have recognised that greater interdisciplinary collaboration is needed to prevent and control zoonotic diseases, but not only zoonotic diseases, and that this collaboration needs to include not only medical doctors and veterinarians, but also wildlife ecologists, environmentalists, anthropologists, economists and social scientists (Gibbs, 2014; Destoumieux-Garzón *et al.* 2018).

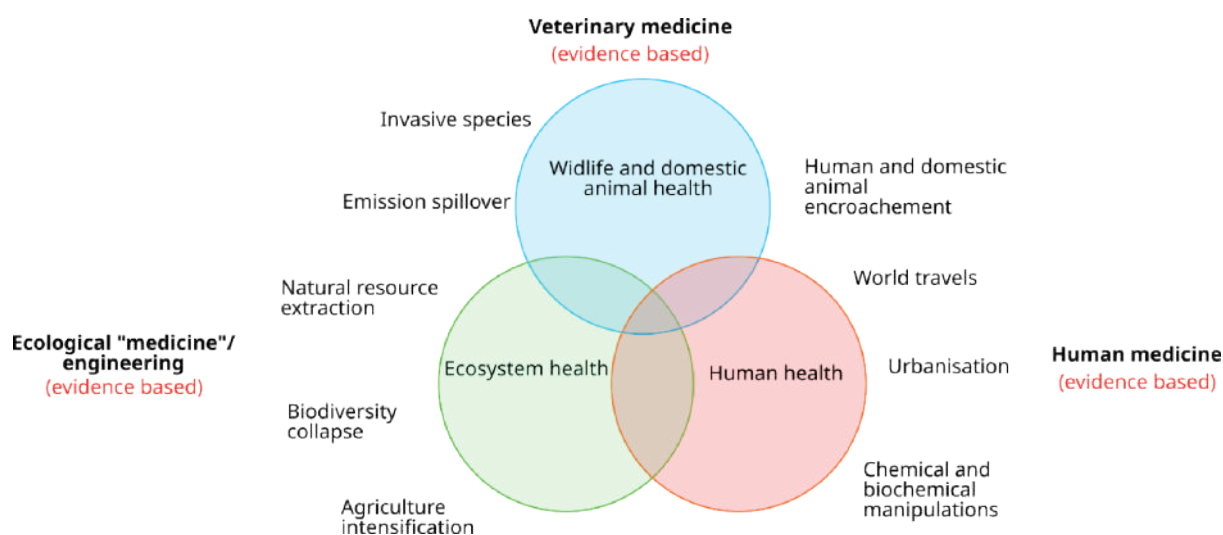


Figure 8 : . The 'One Health' triptych, based on Patz *et al.* (2004), modified.

This integrative concept is accompanied by related concepts such as Ecohealth or Global or Planetary health (Lerner & Berg, 2017). In fact, it is often a question of rehabilitating and broadening the focus of public and veterinary health that is concerned with prevention. Curative medicine has shown its incredible performance for the global minority who can afford its cost and benefit from its technological prowess, but, not being designed for anticipation and prevention, it most often intervenes too late and partially from an epidemiological point of view, when the fire is already in the roof of the common house. Two thousand four hundred years after the Hippocratic treatise "of air, water and place", and after the more recent hygienist approaches of the great Pastorian era, it appears (again) that the functioning of socio-ecosystems at all scales is a determining factor in the emergence of epidemics. It is therefore logical to combine animal and human health with ecosystems in an integrative whole, and to translate this desire for integration into practice (Giraudoux, 2019). However, it must be acknowledged that there is still a long way to go to achieve fully functional integration (Destou-

mieux-Garzón *et al.* 2018; Morand *et al.* 2020; Giraudoux, 2022a). The study of ecosystem health, like that of human and animal health, requires a material and human investment that is far from being made. For example, the investment in research on the Ebola and Marburg viruses between 1997 and 2015 is estimated at US\$1,035 million, of which 61.3% was allocated to research into vaccines, 29.2% into new therapeutics, and 9.5% into diagnostic kits (Fitchett *et al.* 2016). I have not been able to find any figures estimating the investment in ecological and anthropological research on socio-ecosystems and animal population dynamics in the areas affected by these viruses. Nor am I aware of any ongoing ecological studies at appropriate spatial and temporal scales. At most, when health crises force public opinion, viruses and their barcodes are fished out of ecosystems where the ecology of host communities is virtually unknown at the appropriate scales and levels of biological organisation (Wu *et al.* 2021; Giraudoux, 2022a). One can only deplore this and the consequences, which mean that the tripod of One Health currently works, at best, only on the two feet of human and veterinary health but exceptionally on the three supports judiciously

claimed (Giraudoux, 2022b). I have no doubt that climate emergencies, together with those posed by the collapse of biodiversity and the emergence of zoonoses, are leading to a stronger desire to better integrate the medical, veterinary and ecological dimensions in order to analyse and understand the

origins of health crises, by exploring the upstream stages of the emergence of infectious agents. The French Veterinary Academy has demonstrated its interest in this integration in its declaration of 17 July 2021 on veterinary public health, which explicitly mentions ecosystem health.

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