BIODIVERSITY AND HEALTH: PERSPECTIVES FOR THE FUTURE

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The workshop chair, Eric Cornut, President of the pharmaceutical manufacturer Novartis (France), which produces, among other things, anti-malarial medicines derived from artemisinin, reminded us of the scourge that so many infectious and parasitic diseases still represent in our today, especially in the countries of the South. While calling for increased international efforts to combat communicable diseases, Eric Cornut emphasised the role which manufacturers should be playing in the area of sustainable development.

The workshop began with an introductory lecture by Professor Paul Epstein, entitled, "Climate Instability: Consequences for Health, Biodiversity and the Global Economy". Natural systems are made up of functional groups, or guilds, which all play an essential role in maintaining and regulating opportunistic organisms such as destructive plant pests or micro-organisms which are pathogenic for the hosts they invade. The speaker also recalled that the biological diversity of species and the multitude of mechanisms upon which this diversity rests can act as barriers against biological invasions. In the same way, the heterogeneity of habitats acts as an often infallible defence system against invasions by pests or opportunistic micro-organisms.

Due to the alterations they bring about in the dynamic equilibrium of ecosystems, environmental changes are contributing in a major way to the emergence or resurgence of pests and pathogenic micro-organisms. Since their effects can be felt at a global level, emergent and resurgent diseases are an integral and far from negligible part of global change: by destroying crops or affecting human populations, they can place economies in jeopardy, as witnessed in Southern countries. Paul Epstein recalled that climate change is currently acting in a very serious way on species dynamics, especially that of disease vectors and reservoirs, and on the characteristics of biotopes.

Jonathan Patz, in a talk entitled, "Tropical Deforestation and Malaria: the role of Landscape Ecology—a Trans-disciplinary Approach", discussed the biotic integrity of ecosystems. Changes to vegetation cover, e.g. deforestation and habitat fragmentation, caused by human activity, are well-known examples of how environmental disturbances have a harmful effect on the health of animal and/or human populations. Alterations to the ecological context and its dynamic balances can lead to the resurgence of certain host populations capable of triggering an epizoonotic disease. Deforestation, the settlement of human populations in new territories, industrial development, road building such as that in Amazonia, hydraulic and hydro-electric installations and climate change have all provoked the appearance of new pathogens and the growth of many others which, already well-established, have found the new conditions favourable to their development.

Malaria is the world's most prevalent vector-borne disease, causing between one and two million deaths per year, mainly among children. Recent studies show that ecological upheaval has led to a resurgence of the disease, as in the northern Amazonian region of Peru, where Jonathan Patz' team is currently developing a research programme. In this region of South America, the deforestation of the primary forests for agricultural development and livestock raising has undeniably produced an increase in living standards, but populations have also paid a high price in a serious increase in the incidence of malaria. Between 1987 and 1997, the incidence of malaria has increased by 50% and the region has seen the invasion of the Anopheles darlingi mosquito, known to be the main vector of malaria in Latin America. Jonathan Patz compared four types of habitat which have been penetrated by humans to varying degrees, in order to estimate the impact of deforestation on the local resurgence of malaria, and the results confirm that there is a strong link between the level of deforestation and the abundance of A. darlingi vectors, with the formation of clearings and felled wood producing larval habitats for the mosquito. This research clearly has implications in terms of land management and planning, biological

1. All the speakers whose name is put into brackets equally contributed to writing this resumé. Their addresses appear on the DVD.

conservation and public health. It is also necessary to continue taking these types of measures in order to persuade political decision-makers and planners of the importance of considering the direct and indirect consequences which these activities can cause.

Jonathan Patz made it clear that more beneficial solutions could easily be found by taking greater account of the links between ecology and the health of populations and at the same time considering the compromises which can be reached between short-term economic benefits and long-term harmful consequences for ecology and health. It is also necessary for political decision-makers to focus on sustainable development in taking these steps, on, in other words to think in the long term for all socio-economic measures.

In analysing the close relationships which exist between biological diversity and pathogens, in his talk entitled, "Biodiversity and Disease Risk: the Case of Lyme Disease", Richard Ostfeld demonstrated the importance of biological diversity as an "ecosystem service" which serves to keep in check the proliferation of a pathogenic agent in the environment.

Most of the current emerging diseases are of zoonotic origin, in other words they come from a host animal which is often the natural reservoir of the causative agent. Lyme disease is one of the emerging diseases in Western Countries. In the USA, where the disease is in major resurgence, the principal natural reservoir of the bacterial agent which causes the disease is the white-footed mouse, a very prolific type of small rodent which is resistant to any degradations or alteration to its environment. Ticks which feed by biting these small mammals act as vectors for transmitting the disease to human populations. In the same way, the West Nile Virus, which has recently been introduced into the USA, uses as its primary reservoirs common bird species such as starlings, sparrows and crows, which then infect the mosquitoes that feed on their blood, thus increasing the risk of transmission to humans wherever these vectors are anthropophilous.

Research has also shown that in local communities that are rich in species of vertebrates, human populations are at a lesser risk from these two diseases. A greater specific diversity of reservoir animals has the dual effect of also reducing the proportion and density in the environment of infected vectors and therefore of "diluting" the impact of the primary reservoir species in the transmission of a disease to target populations. In the case of Lyme disease, forest patches of less than two hectares which harbour both a poor biological diversity and a high density of infected ticks make the risk of human exposure to the disease greater than in larger forest patches. In the case of the West Nile virus, we note that the federal states which are home to a rich variety of major bird species are also those which have had lower incidences of the disease over the last few years. This phenomenon, christened the "dilution effect", represents a previously underestimated ecological service provided by biological diversity against the persistence and transmission of zoonotic infectious diseases.

The presentation given by Christian Lannou and Marie-Laurie Desprez-Loustau, entitled "An Ecosystem Approach to Epidemiology for Sustainable Management in Forestry and Agriculture", is slightly different in that it focuses on the interactions between biodiversity and plant health. Their oral presentation opened up a view of agricultural and agronomic methods which would be planned to take better account of the links between ecosystem dynamics and the health/quality of plants. Plants are crucial elements in human survival and well-being, carrying out ecological functions in forests which are of prime importance, such as climate control, water cycle regulation, maintenance of the diversity of the associated flora and fauna: plants produce benefits which are essential for human health and comfort. However, these functions depend directly on the health of the plants and their capacity to grow and reproduce in the face of threats from numerous pests and parasites.

Of the wide diversity of plant species a small number have been domesticated and their genetic diversity considerably reduced, for the purpose of more intensive and rationalised production. This relates particularly to plants used for food, but also some forest species used in plantations. This decrease in diversity in intensive production systems, whilst assuring increased returns and uniformity of quality, has gone hand–in–hand with side effects which have been most unfavourable in terms of the impact on disease. Genetic modification for resistance to disease, in relying on the use of a very small number of genes, has proved generally ineffective, as the parasites have managed to overcome the resistance. Theory and observation show that resistance to disease should not actually be viewed only on an individual level (one resistant genotype), but as a property of the population within its environment, the diversity of resistance factors being an important component of stability. This diversity is manifested at different levels: (1) diversity in genetic resistance: partial resistance and tolerance; (2) local resistance: a mix of species, spatial arrangement/distribution of populations; (3) diversity on a landscape scale: parcel plan, movement of parasites between wild and cultivated compartments. The speakers concluded that by reintroducing a functional biodiversity which is perfectly compatible with current production aims, it is possible to reconcile modern agricultural and forestry production methods with the sustainable preservation of our environment and our quality of life.

Introducing the second part of this workshop, Pejman Rohani gave a concise presentation entitled, 'The Mechanisms Underlying Infectious Disease Dynamics', on recent developments in theoretical concepts and

mathematical modelling of infectious diseases. Pejman Rohani demonstrated how the joint use of mathematical modelling and statistical time-series case analysis has enriched our understanding of the mechanisms involved in the genesis of epidemics. During the 1920s, mathematical theory predicted continuous incidences of measles, whereas actual observation of the illness revealed the occurrence of epidemics of greater or lesser proportion in multi-annual cycles. In 1926, for example, Soper showed that outbreaks of measles were more prevalent during the autumn and winter months, which led people to contemplate whether the missing ingredient in the mathematical models that had been hitherto created was a parameter reflecting the seasonality of school time and holiday periods. Current mathematical models are highly effective in explaining epidemics of measles in contrasting environmental conditions such as Europe and the USA, and even in Africa, as in Senegal for example.

In a second part to his presentation, Pejman Rohani looked at the question of the continuing presence of measles, using well-documented studies carried out in Great Britain. In spite of vaccination campaigns aimed at eliminating the disease, measles continues to be present in British populations, as of course in other regions worldwide. With the help of statistical analysis of case reports the speaker demonstrated that the persistence of the disease is essentially due to one consequence of vaccination, which has been to considerably reduce the synchronisation of epidemics among British towns, thus ensuring that some contagious cases are always present, ready to transmit new infections. This major change in the spatial distribution of measles epidemics following vaccination campaigns prompts us now to contemplate alternative vaccination methods which take account of this new knowledge, such as pulsed vaccination. At the end of his presentation, Pejman Rohani spoke in support of developing a new epidemiological theory based on a greater knowledge of the incubation periods and infectiousness of diseases, which are crucial elements for devising effective models. This new direction is particularly needed in the case of emerging diseases, for which we have little data on which to base predictive models.

Jean-François Guégan presented a contribution entitled, “The Macro-Ecology of Infectious Diseases: Links between Spatial Distribution and Ecological Mechanisms”, bringing a biogeographical dimension to the subjects expounded by Pejman Rohani. After a brief reminder of the historic reasons for the absence of biogeographical perspectives in epidemiology, the speaker presented the results of some recent research on the spatial distribution of nearly 400 infectious and parasitic agents affecting human populations, arguing that simple ecological and bio-geographical laws can explain most of these distributions. Focusing on two specific diseases, the presentation showed that in the case of whooping cough, the almost four-yearly cycle observed in outbreaks of epidemics was universal and that within the worldwide metapopulation system, they are transmitted as waves of epidemics between populations which have some degree of contact between each other. A series of whooping cough cases over a rural region of Senegal, studied in the speaker’s laboratory, shows no significant difference from series of cases of the same disease from Western Countries. The same observation is made in the case of measles. The global nature of the dynamics of whooping cough should be taken into account in planning vaccination campaigns, since the disease can only be properly controlled at a planetary level.

The second example of an illness, cholera, displays a very different spatial dynamic, since the causative bacterial agent of the pathology is a micro-organism which exists naturally in the aquatic environment. The population dynamics of cholera cases tend to be cyclical and to appear in two different modes, one biennial and the other every four to five years, in the countries of the intertropical band from West Africa to South-East Asia. Climatic variations caused by ENSO perturbations, particularly those observed since 1986, appear to be partly responsible for these recurrent cholera epidemics in human populations. It is noted that cholera epidemics can exist outside the intertropical band, but these are rare. Jean-Francois Guégan concluded his oral presentation by calling for the development of epidemiology research which is more integrated and more quantitative, based on the analysis and modelling of temporal and spatial case series. The creation of health observatories in various regions must be an international priority if we are to gain a better understanding and hence better control over the development of these infectious diseases.

The final presentation of this workshop by Jean-Paul Gonzalez and Jean-Pierre Hugot, entitled, “Principles and Territorial areas of Emergence”, considered, with the aid of illustrative examples, the problem of the emergence of infectious diseases of zoonotic origin. Health managers have, for about fifty years now, been confronted with a growing number of new epidemic phenomena, which have given rise to the concept of emerging diseases. This concept applies to a wide variety of infectious diseases associated with new germs (“emergence” in the strictest sense), or “resurgent” germs, where diseases suddenly appear in populations or areas which have hitherto been unaffected. The concept of emergence is provoking research into factors and indicators which can enable us to model and predict the outbreak and spread of the diseases. The need for systems in place to respond to the epidemics has led to the development of strategies for early detection and rapid identification of the pathogens involved. Moreover, the possible spread of certain pathogens on a

planetary scale, due to the development and growing speed of transport, means that these strategies must be coordinated at a worldwide level.

In their exposé, Jean-Paul Gonzalez and Jean-Pierre Hugot demonstrated that these "diseases" can be traced to living organisms acting within complex systems of relationships. Study of them necessarily involves a consideration of the interactions between pathogens, reservoirs, hosts and, where applicable, vectors. This makes it important to be able to precisely identify the organisms present, which must be distinguishable from those non-pathogenic organisms, non-reservoirs or non-vectors which resemble them most closely. The fight against and control and prevention of these diseases need monitoring structures in place which bring together researchers from the medical world and those from related disciplines which are in a position to put complex analysis and modelling methods into practice. Jean-Paul Gonzalez and Jean-Pierre Hugot came to the conclusion that it would be desirable to build a network of observations at a national or supranational level (e.g. Europe), a regional level (South America, South-East Asia) and an international level (WHO, FAO, OIE), using coordinated methods for investigating and using data.

At the end of these seven general presentations, a two-hour long debate followed, between a large number of the workshop participants. Everybody recognised the importance of de-compartmentalising the different disciplines. Another area on which participants were unanimous was the importance of long-term monitoring of infectious and parasitic diseases, through observation networks similar to those used by scientists in earth sciences. Such observation networks, which would be coordinated and organised amongst themselves both in their monitoring and sampling protocols and in their administrative management, are the only instruments available today for understanding the causes of the emergence and spread of infectious diseases.