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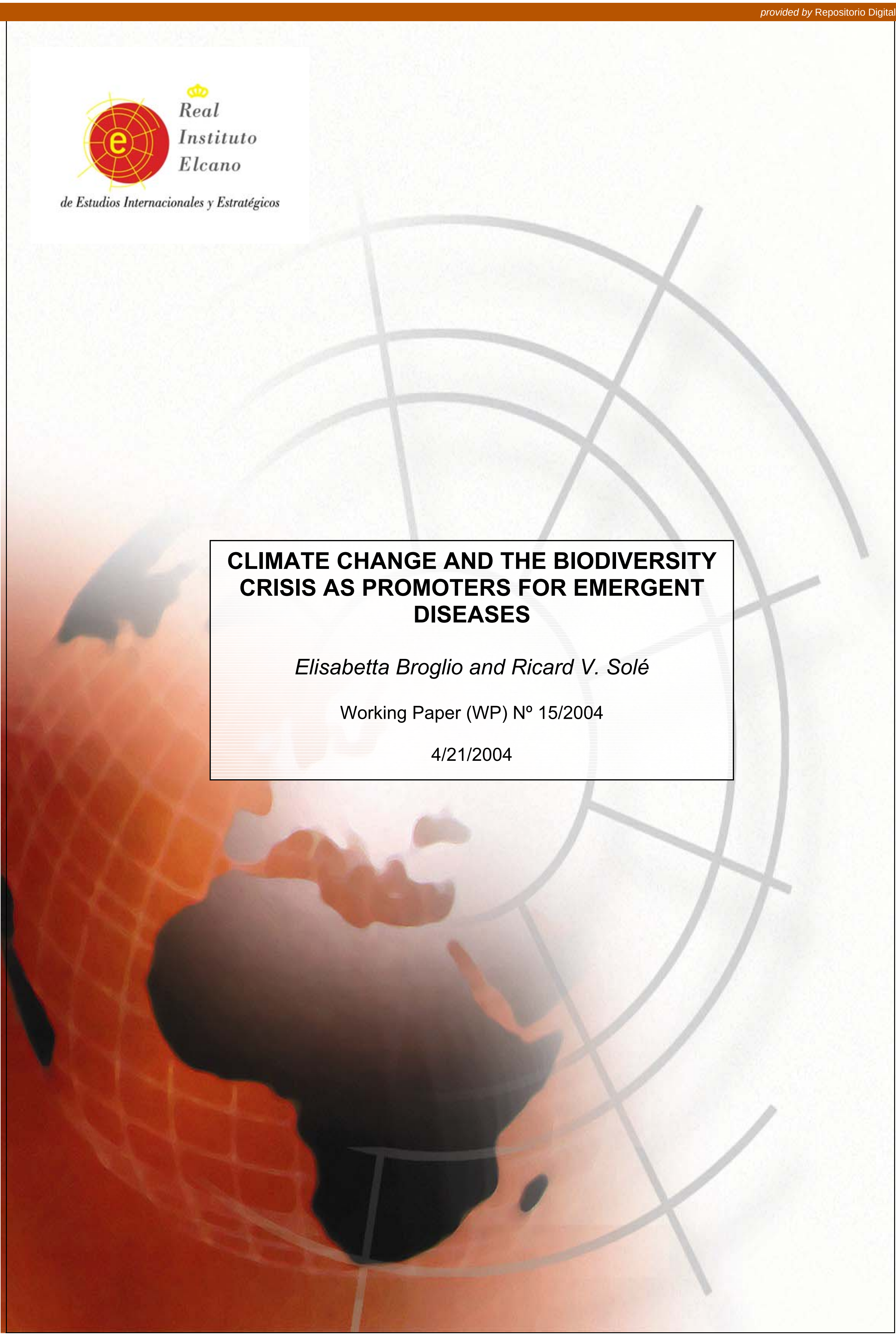

CLIMATE CHANGE AND THE BIODIVERSITY CRISIS AS PROMOTERS FOR EMERGENT DISEASES

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Climate change and the biodiversity crisis as promoters for emergent diseases

Elisabetta Broglio and Ricard V. Solé *

Introduction

Looking at our biosphere, we see a planet that is out of balance. At the start of the twenty-first century, we can clearly see the widespread degradation of the world's ecosystems. Many plant and animal species are being driven to extinction, habitats are undergoing extensive degradation from indiscriminate logging, uncontrolled hunting and over-fishing, the introduction of exotic species, global warming, mining and urban growth. All these processes have altered the balance of ecosystems and, in many cases, it is too late to turn the clock back (Terborgh, 1999). Furthermore, the accelerated depletion of some of the Earth's key resources is a direct result of the rapid growth of the world's human population (currently at 6 billion, compared with just 1.5 billion at the beginning of the twentieth century). Many scientists believe that the global changes brought about by the above-mentioned processes could seriously endanger mankind's future. What are the possible effects of the ecosystem degradation being driven by human activity? While not easy to predict, some of these consequences are becoming evident, as is the case with the emergence and spread of new diseases.

As we shall see below, some of today's notable epidemic diseases could have originated from the ecological imbalance induced, whether directly or indirectly, by human activity. The worldwide exploitation of ecosystems by man has effectively diminished the habitat available in many areas and, since many species, particularly top predators, have minimum-habitat-size requirements, they rarely survive once their habitat shrinks to below this level. The *main* consequence is that changes caused by human activity are driving certain species to extinction, which, in turn, can result in other closely related species becoming extinct –ie, the process triggers an 'extinction cascade'–. However, how can habitat fragmentation and species extinction endanger human health? To answer this question, we will look at how other characteristics of ecosystem organisation, such as the species interaction chain, can affect the spread of infectious agents.

As an example, we shall consider severely stressed habitats, where the loss of a large part of the native species can trigger population outbreaks of opportunistic species. Such opportunists, which can coexist inside or near human settlements, often carry pathogens that can eventually be transferred to human beings, representing an important reservoir for emergent diseases.

Furthermore, we also analyse the effects of habitat variations due to climate change, which could prompt the spread of microbes and, thus, of diseases. We shall see how changes in both air and water average temperatures can foster the spread of certain illnesses, favouring microbe growth or expanding their habitats. In fact, although climate change is difficult to associate with human activities, greater human involvement could probably help in the control of some of the factors associated to the process.

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New Diseases Emerging from Ecosystem Degradation: Some Examples

A good example of emergent diseases linked to the breakdown of the equilibrium between a species and its habitat are those transmitted by the so-called Hanta or Arena viruses. Hanta and Arena viruses are zoonotic RNA viruses that are transmitted from rodents (essentially mice and rats) to human beings. These rodents are merely a step in the transmission chain between the virus and humans. This is a typical case of commensalism (a relation involving two different kinds of organisms, which benefits one and does not harm the other), with the rodents acting as the reservoir host and being unaffected by the virus. Although direct transmission of the virus (ie, through bites) is uncommon, infection can occur as a result of eating contaminated food, or touching the mouth or nose after handling a contaminated surface, or even by airborne transmission of the aerosol particles released by the rodents with their saliva.

Infection with Hanta or Arena viruses can cause quite serious diseases: Hanta virus infection can cause Haemorrhagic Fever with Renal Syndrome (HFRS) or Pulmonary Syndrome (HPS), the latter being very serious and actually fatal in about half the reported cases. Scientists have demonstrated that habitat destruction and climate change can increase the possibility of Hantaor Arena virus infection in human populations. The question is how and through what mechanisms?

It is well known that rodents can thrive in a wide range of habitats, from forest to grassland, canyons and deserts. They can survive in any dry land habitat and invade and exploit disturbed areas. The deer mouse, in particular, is one of the most common transmitters of Hanta viruses to human beings; it is extremely common in areas affected by flooding, fire, avalanches, and mining or construction works. Rodents are omnivores and store food for winter consumption, making human-occupied areas especially attractive given the supply of acorns, nuts, insects, other small invertebrates and various plant parts that rodents need to survive.

Therefore, habitat destruction in the vicinity of suburban areas furnishes an attractive environment to these animals, triggering sizeable population outbreaks.

These outbreaks are regulated in part by climate change, since variations in temperature and/or rainfall patterns influence rodent populations given the indirect impact on both the total nutritional biomass available (plants, fruits and invertebrates) and animal reproductive processes (eg, reproductive seasons or gravidity rates).

Hanta and Arena viruses are clearly linked directly to ecosystem degradation: changes in habitat or climate have a direct impact on rodent populations and, therefore, eventually cause the emergence of viruses. Nature, however, is not always so evident in terms of cause and effect. As mentioned above, we can expect an extinction cascade to result in the collapse of an ecosystem. As a collateral effect we are also likely to see new species playing an important role in the altered ecosystem, as well as the interaction of new species (and/or habits), thereby opening the door to significant expansion of infectious agents. A clear exampleis *Lyme disease,* which was first detected in 1975 in a small town, located near a wooded area, in Connecticut.

Understanding the mechanisms associated with *Lyme disease* took some time. At first, the patients affected developed a rash (*Erythema migrans*) that spread and looked like an insect bite. However, they soon began to show other symptoms such as aching joints, chills, fever and arthritis. Scientists determined that the infection, which affects the human immune system, was due to a tick-borne bacterium –the spirochete *Borrelia burdoferi*–. Since this species of tick –*Ixodes dammini*– was known to feed preferably on the blood of deer, a very common animal in American woodland, scientists concluded that by eliminating the deer they could effectively stop the infection. However, removing the deer did not prevent the disease from spreading. Scientists subsequently discovered that a species of mouse –*Peromyscus leucopus*– rather than the tick was the bacteria's natural host. They also determined that deer ticks need to consume blood to progress to each successive stage of their life cycle and that, in their development from larvae to adult, they pass through different hosts, such as mice, deer, cats, dogs and human beings. In principle, the infection is not congenital in deer tick larvae, so they cannot transmit *Lyme disease* to human beings. Rather, reservoir hosts, the above-mentioned mice, can infect tick larvae. The mice themselves are merely carriers, which do no contract the disease, although the bacteria reproduce in their blood. When mice and deer, which share the same brush habitat, come into contact, infected ticks can take the opportunity to change host, an essential stage of their life cycle. Finally, contact with humans occurs when deer enter suburban yards.

The emergence of *Lyme disease* is a clear consequence of human manipulation of an ecosystem. The original woodland where this disease first emerged was actually destroyed during the late 18th century, when the iron industry became the area's most important source of money and work. Forests were depleted to supply fuel for iron smelting and to build housing. The indigenous trees –oak and larch– disappeared, as did the area's carnivorous animals due to both natural (loss of habitat) and unnatural (human aggression) reasons. However, new plants and fauna started to re-populate the woodland and, as is often the case in denuded habitats, aggressors replaced the original species. Deer, rodents and ticks started a new coexistence and the deer population grew significantly. This surge in the deer population was also helped by the lack of natural predators, such as wolves, cougars and coyotes, as these had been exterminated by human beings in order to protect their farms and houses. Hungry and freed of their natural predators, the deer were forced to explore new habitats in search of food. Deer started to appear in suburban storage areas and in places where azaleas and pasture were cultivated, thereby facilitating access to humans for the above-mentioned ticks and, therefore, the pathogen bacteria.

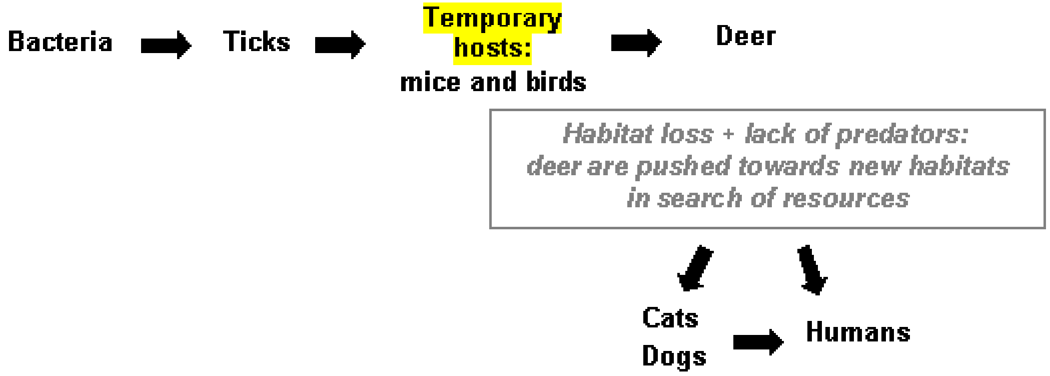

Figure 1. Animals involved in the transmission chain for *Lyme disease*. Bacteria infect deer ticks, then tick larvae wait at ground level until they can jump onto small mammals (mice) or birds to feed on their blood. When tick larvae moult or transform into the next life stage (nymphs, then adults), they usually change host. At this stage, they inhabit stalks of grass to reach deer or other larger mammals.

Thus, *Lyme disease* seems to be caused by both forest devastation (and the subsequent human occupation of new environments) and the collapse of the natural species' organisation, leading to new species dynamics and habit arrangements. In this case, although rodents were the fundamental reservoir for the microbe, they were not the only species involved, as a complex network of organisms participated in infecting humans. If the species involved had not been, directly or indirectly, pushed into contact, the likelihood of the microbes infecting humans would have been much lower.

Apart from rodents, other animals also transmit pathogens to humans. Insects such as mosquitoes can be highly dangerous to human health, transmitting illnesses like yellow fever and malaria. We are currently witnessing the expansion of some of these diseases, which seems to be linked to climate change, forest devastation and the occupation of new environments by humans –all determining factors in the modification of mosquito feeding patterns–. In fact, these diseases were originally limited to areas where mosquitoes fed on mammals other than humans (eg, monkeys and marmosets). It might not be easy to visualise how forest devastation and habitat manipulation can transform a region into an excellent habitat for mosquitoes. However, it has been demonstrated that the large-scale felling can destroy nature's fragile system of defence against the damage caused by torrential rains. Trees provide a twofold protection against destructive precipitation: their foliage moderates the strength of downpours, while their roots form a supportive network that helps minimise erosion. A series of hydro-geological disorders might lead to the formation of stagnant puddles, nourishing paludism and boosting mosquito populations, thereby increasing the incidence of related diseases. Climate change is also having a major impact on the spatial and temporal distribution of many groups of organisms. The geographical range of insects is likely to expand, with them moving into new areas with similar temperature and precipitation patterns. Small changes in atmospheric temperature (1º-2ºC) have been proved to determine changes in insects' diffusion range, reproduction rate and activity.

Global warming is also affecting the temperature of seawater. Biologists have discovered that bacteria and viruses can live inside algal cells and that, given their seasonal nature, they are most abundant when temperatures are warmest. Microbes are very resistant and can survive inside dormant algae, so they can move around the world dragged on marine currents or in boats until better conditions (ie, in terms of nutrients, temperature and salinity) wake the algae from their dormant state, permit them to spread. This spreading mechanism might explain how the same strain of *Vibrio cholera* that hit Asia in the late 1960s provoked an emergence of cholera in Peru during the 1990s. The bacteria probably travelled, in a dormant state inside algae, in cargo ships moving between Asia and Peru. On reaching harbour, a series of coincidental factors could have facilitated the spread of cholera. One of this factors was the especially warm water off Peru in summer 1991, given the effect of *El Niño* (a disruption of the ocean-atmosphere system in the tropical Pacific, provoking a periodic increase in surface water temperature), which was probably responsible, at least in part, for the algae waking from their dormant state. Once the bacteria started growing in the new environment, they started to reproduce exponentially and contaminated the food chain, reaching humans (see Figure 2). Access to humans was even easier for the bacteria in Peru, where poverty, inadequate health conditions and the lack of effective water disinfection increased the probability of infection. The lack of adequate water treatment was a key factor in spreading the disease, as it permitted the transmission of cholera via drinking water. This, in conjunction with the strain's resistance to certain antibiotics, was determinant in the onset of a devastating pandemic.

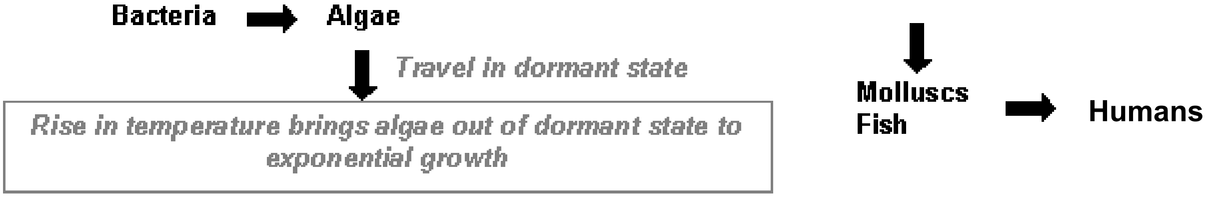

Figure 2. The processes and chains involved in spreading cholera.

Biodiversity Loss and Climate Change: Trends for the Near Future *Loss of Biodiversity*

There is evidence that habitat loss and fragmentation represent the main threat to biodiversity in the near future. Human-driven exploitation of ecosystems worldwide has effectively reduced the available habitat in many places. Figure 3 is just an example, but the same picture, except for the spatial and temporal scales, could be drawn in many other places in the world: whole countries are affected and the sequence shown in Figure 3 takes place over a period of just a few decades.

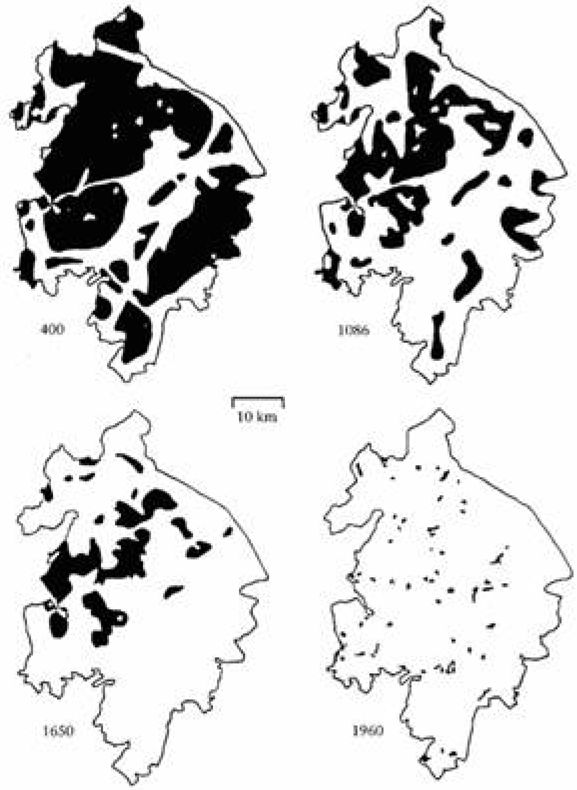

Figure 3. Habitat fragmentation in current ecosystems. In this example, corresponding to a small area in England, the amount of available, non-disturbed habitat is shown in black. Since the year 400, the habitat has declined until only a small set of tiny patches is left (1960).

This process can be harmful at two different levels. Firstly, it involves direct habitat reduction, and many species (especially top predators) rarely survive once their habitat shrinks below their minimum habitat size requirements. Secondly, this habitat destruction typically involves fragmentation (loggers fell trees in different places, creating a spatial pattern of disconnected patches). This leads to sudden transitions, which are highly prejudicial for the survival of species.

A model habitat can be used to illustrate the impact of the local, random elimination of the large areas available to a species (see Figure 4). Imagine a given habitat as a square lattice: each site in this lattice would be an area of habitat of a specific size (say 100 x 100 metres or more). For the sake of simplicity, we assume that such patches can either be healthy (white squares) or destroyed (black squares). The first type can be occupied by a given species, whereas the second cannot. Next, we proceed to destroy patches at random, by removing the plants and fertile soil. There are other possibilities, such as intermediate degrees of destruction, but the current picture is the most appropriate in our context. The fraction of habitat destroyed –D– ranges from 0 (all patches preserved) to 1 (all destroyed).

Since we are concerned with the impact of this process on the survival of existing species, we are interested in the effect of eliminating patches on the available, connected areas. Specifically, if individuals of a given species can move from patch to patch through local migration, we have a situation were movement is restricted to one of the four closest sites in the lattice. Two patches are *connected* if they can be reached in this way. But what happens in the case of random habitat destruction? One would expect the linear, gradual decrease in the size of the largest piece of habitat. However, as shown in Figure 4 (bottom picture) this is certainly NOT the case. Initially, the largest area shrinks in line with D (D = habitat destruction rate), as expected. However, the available area suddenly becomes so small that it might endanger the survival of a species with reasonable habitat requirements. Once this level is reached, the largest patch becomes fragmented. This process –known as *percolation*– has existed in the field of physics for years. Beyond the percolation point, ecosystem collapse can occur, and many other factors contribute to the decline of a species, including the loss of keystone species (those particularly relevant in maintaining ecosystem functions), increased susceptibility to invader species, the loss of water and nutrients associated to vegetation decay, etc.

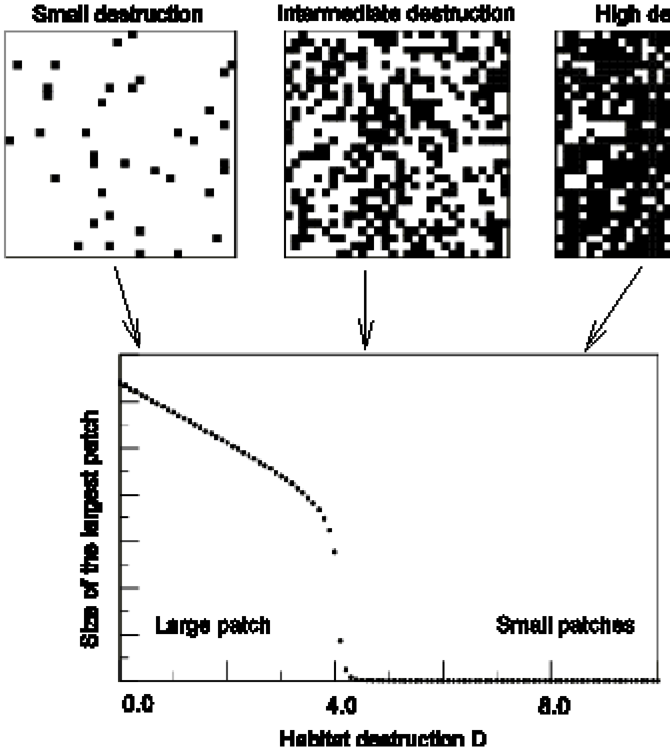

Figure 4. Habitat destruction and sudden transitions in ecosystem organisation. The top three squares show examples of habitat loss in a square lattice, with black squares indicating destroyed habitat. The bottom graph shows the size of the largest connected patch (here a given patch is only connected to its four nearest neighbours). For small amounts of habitat destruction (D < 4), the size of the largest connected area decreases linearly and smoothly. However, once we reach a critical point, D = 0.41, a sharp reduction is observed and the largest patch is fragmented into many disconnected pieces.

The main conclusion to be drawn from the example above is that our intuition might fail when considering space realistically. Species (particularly plant species) compete and interact with their local neighbours, exploiting and moving through space locally. Consequently, if the available space becomes highly fragmented, many species will be unable to move from patch to patch, and will thus be confined to sub-requirement patches, endangering their survival. In many places around the world the situation has already gone beyond the critical point, although it is not always easy to see. It takes some time for a species to disappear completely, making it difficult to recognise that the process towards extinction is underway. There is no time for adaptation, as the changes introduced by humans trigger the extinction of a species over a timeframe of years or a few decades, whereas adaptation to changing conditions through evolution requires centuries. As shown in Figure 5, habitat destruction is the main cause of extinction for plants and animals, now that hunting and the introduction external species is largely controlled by law.

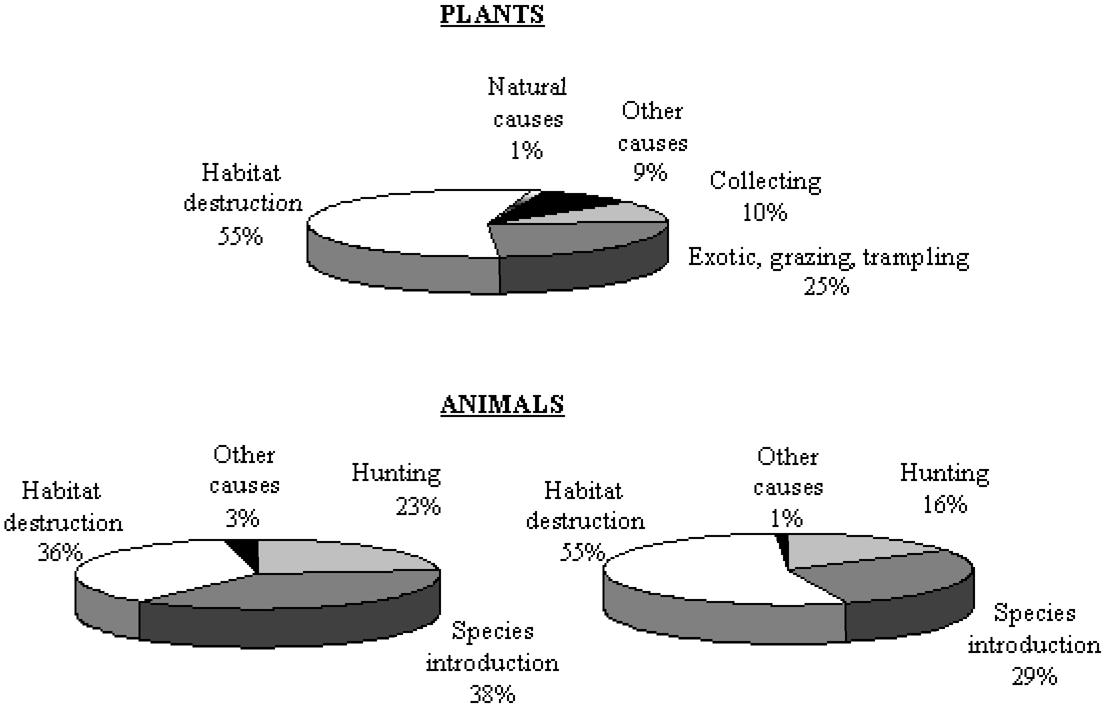

Figure 5. Causes of extinction. Plants: this specific pie chart illustrates the causes of endangerment in the United States, but is probably representative of many other areas around the world. Animals: the pie charts illustrate both historical causes of extinction (left) and current causes of endangerment (right). Over time, habitat destruction has become the first cause of extinction, ahead of hunting and species introduction.

In addition to the aforementioned non-linear effects of habitat loss and fragmentation, we have seen that other characteristics of ecosystem organisation, such as the network of species interactions, could affect the outcome of this process. The increase in populations of herbivores, rodents and other small mammals, potentially carrying emergent viruses, after a habitat has been destroyed and/or degraded also follows threshold patterns.

Perhaps the clearest feature observed in ecosystem degradation by habitat destruction is the loss of top predators. As demonstrated by the ecologist John Terborgh, under such stressful conditions ecosystems follow a well-defined pattern of declining biodiversity. First, top predators and other large mammals disappear, creating the conditions for the so-called ‘empty forest effect’ (Terborgh, 1999) in which vegetation patterns are conserved in terms of diversity, but there is a lack of large mammals. This is followed by a major imbalance in the abundance of herbivores and other species freed from the related top predators. As a result, the absence of predators gives rise to population outbreaks, facilitating the emergence of new pathogens.

The Role of Governance

The preceding examples offer some perspective and raise the issue of the link between the emergence of a new pathogen and the deterioration of biodiversity. This is a complex issue, since different factors (including both biological factors and political decisions) are involved.

A recent study illustrated that most of the current biodiversity loss takes place in countries characterised by high levels of political corruption (Smith *et al.*, 2003). These countries are highly dependent on external aid to preserve their biodiversity resources. Defining appropriate governance scores reflected the close correlation between the key components of biodiversity (eg, total forest cover) and national governance and other relevant socio-economic measures.

Corruption is known to be a major obstacle to both economic and social development, and has been shown to negatively influence foreign investment and government implication in public services. Not surprisingly, improved governance has become a common demand as a precondition for successful funding measures. Over the last few decades, mounting pressure has been brought to increase the foreign effort to minimise the loss of biodiversity by fostering appropriate conservation policies. In this context, the usually external nature of the funds, together with their short timescale, increase the possibility that conservation projects will be affected by corruption (Smith *et al.*, 2003).

In order to properly assess the impact of governance on biodiversity parameters, it is important to provide a quantitative measurement of such policies. Such scores (see method section in Smith *et al.*, 2003), weighing a number of socio-economic factors, are based on the Corruption Perception Index (CPI) defined by Transparency International (2002). An example of the correlations identified is shown in Figure 6, where the change in forest cover is plotted against the governance score.

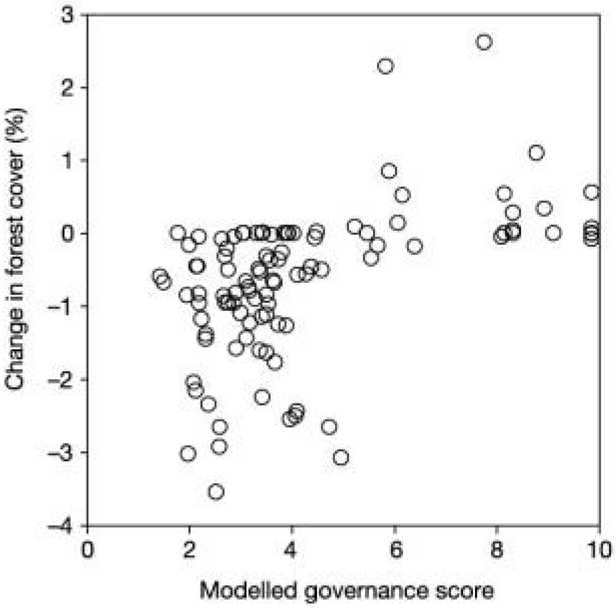

Figure 6. Changes in total forest cover considering a survey of 83 different countries (circles) against their governance scores. Note that most of the circles are located below the zero level.

Countries with low scores (implying a high level of corruption) typically reflect deterioration in forest cover (ie, net loss of cover area), whereas those with the highest scores either show no loss or reflect gains. This simple picture provides a clear insight into the problem of widespread illegal logging.

Another example of this correlation is given in Figure 7, where we can see that, to a large extent, those countries with low CPI scores present a rich biodiversity, while its impoverishment is greatest in those places with high CPI scores. This clearly indicates that conservation policies need to be defined at both scientific and political levels in order to be effective. As explained below, in the decades ahead we will face a major threat from the rapid decline of biodiversity, ecosystem functioning and resilience – likely to result in the emergence of new pathogens and the re-emergence of old ones.

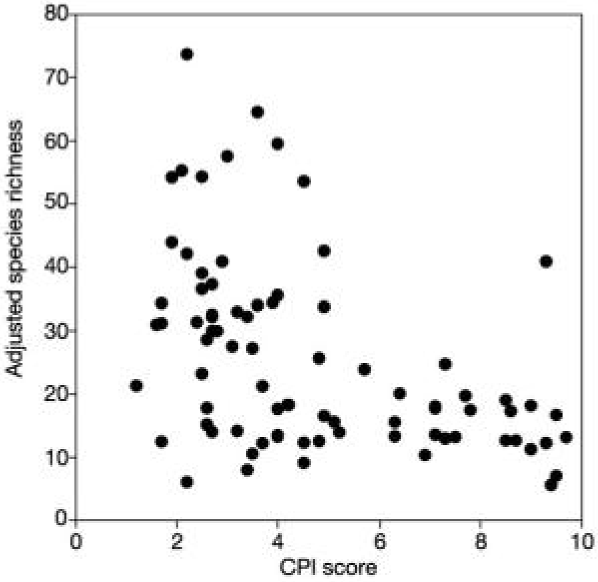

Figure 7. Negative correlation between species richness and CPI score for a survey of 83 countries. High corruption is clearly associated with low species richness.

Climate Change

Apart from biodiversity loss, climate change is also associated with emergent diseases. Evidence points to a trend of rising temperatures since the late 19th century, with this warming process a fact in both the northern and southern hemispheres, and the oceans. Global mean surface temperatures have increased by 0.2º-0.5°C, the snow cover in the northern hemisphere and the floating ice in the Arctic Ocean have been depleted, while the global sea level has risen by 10-20cm. Worldwide precipitation over land has also increased by about 1%, as has the frequency of episodes of extreme rainfall and other extreme phenomena (eg, droughts, hurricanes or extended hot periods), which have intensified locally.

There is no doubt that CO_2 concentration has increased (mainly due to fossil fuel consumption and forest burning) as a result of human activity. Moreover, numerous studies report the negative effects on the atmosphere of this gas, in conjunction with others derived from the breakdown of plastics, pesticides, detergents, etc (greenhouse gases). Scientists have demonstrated that these emissions play an important role in global warming. The analysis of fossils and deep glacial ores indicates that there have been other episodes of global warming in the Earth's past, suggesting that part of the climate change could be inherent in the historic cycle of the planet. However, it is clear that emissions related to human activity do not help to stop this process.

The question of whether of not humans are the sole cause of global warming remains under discussion. However, many scientists are convinced that rising temperatures could also affect human health, as they create a suitable environment for microbial growth and reproduction. The above example of the expansion of cholera in Peru could become a generalised trend if temperatures continue to rise. Furthermore, since there is evidence that variations in precipitation rates affect rodent population densities (ie, relatively wet years bring suitable conditions for an increase in rodent populations), changes in precipitation patterns could play a major role in the propagation of the Hanta virus. More recent episodes are currently in process, as is the case of the West Nile virus, which has spread through North America, due in part to the warmer climate favouring the life cycle of mosquitoes.

Another key but lesser known factor in this context, involves fluctuations rather than average quantities. In addition to rising levels of CO_2 and temperature in the 20th century, many different parts of the world have reported a rapid increase in the frequency of episodes of extreme weather. Although average values have so far risen gradually over time, fluctuations are increasing at a very rapid rate. Human populations have adapted to a wide range of climatic conditions, but the available resources and their appropriate exploitation are largely subject to the assumption of a reasonable degree of predictability. Weather extremes can penalise economic stability and health heavily in the near future, with the poorest communities being the most vulnerable (95% of deaths associated to natural disasters are estimated to occur in poor countries).

Since weather extremes occur over short periods of time and are typically unpredictable, their impact on local economies, and globally in the long run, is huge. Rapid changes cause human and animal deaths, crops are either destroyed or severely damaged, and health infrastructures are often seriously jeopardised. As an example of the latter, we have seen heat waves causing respiratory syndromes that affect elderly people in particular.

Climate change has been mentioned as a source of species loss, as well as of widespread changes in species abundance and geographical distribution. But how fast does it occur? Do climate properties have critical points too, given their highly non-linear character? Once again, the answer is yes. One of the past few decades' most interesting, albeit depressing, discoveries in the field of large-scale climate dynamics is that our climate has actually changed on numerous occasions over the last 100,000 years (as determined by studies of ice cores). Contrary to previously held opinion, these changes occur frequently and rapidly, meaning that sharp variations in surface temperatures (10º C or more) can take place in less than one decade.

The reason for such rapid variations can be found in the interaction between ocean and atmospheric circulation. As suggested in the early 1960s, the interplay between the effects of salinity and temperature can lead to changes in ocean circulation. The amount of fresh water injected into the Nordic seas (from the ice cap) is an important factor in the process. Ocean circulation in the North Atlantic is largely governed by water density, which in turn depends on both temperature and salinity.

The North Atlantic circulation is currently active, and surface air temperatures are 5º-7ºC warmer than those at the same latitude in the Pacific. Global circulation is largely dependent on water masses sinking in the North Atlantic thanks to their high salinity content. What about the consequences of the increase observed in freshwater inflows as a result of the ice sheet melting? Climate models clearly indicate that a rapid shift will occur if the current trend persists (Ganopolsky & Rahmstorf, 2001).

Consequently, a likely future climate-change scenario might reflect a sharp departure from the current trend, as a gradual increase in temperatures due to the accumulation of greenhouse gases could be followed by a rapid, widespread and catastrophic shift towards a cooler planet (see Figure 8). The implications of this scenario are clear, since many key nodes of the economic network depend on the stability of many primary resources. This stability might be jeopardised beyond the economy's resilience point, although no strategic responses seem to be in the pipeline at present.

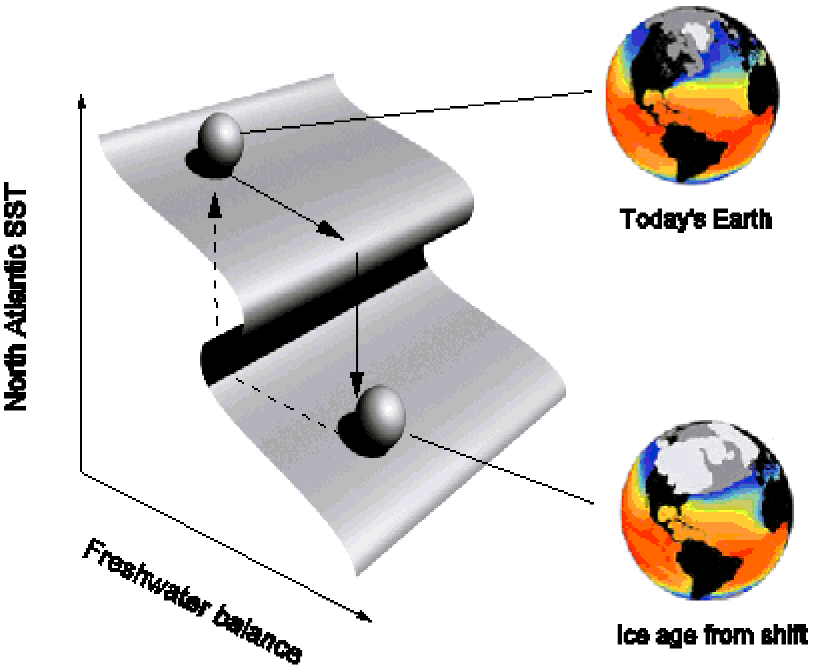

Figure 8. Sudden shifts in climate dynamics. Mounting evidence shows that increasing inflows of freshwater (from melting ice) into the North Atlantic will trigger a sudden change in ocean circulation, eventually modifying local temperatures in northern areas. We could see a drop of over 10º in less than a decade.

Discussion

Emergent diseases represent a serious, ongoing threat to human populations. Although for decades developed countries have successfully eradicated old pathogens, this success is being challenged on two fronts. First, consider the increasing resistance of known bacterial strains and the changes in the geographical range of many others. Secondly, we should look at the emergence of new pathogens, to a large extent associated to the human-induced changes that are rapidly modifying existing ecosystems. The lessons to be learnt from AIDS, Hanta and Arena viruses (as well as from more recent episodes related to new strains of flu) are clear: the rapid degradation of complex ecosystems, together with the explosive increase of human settlements nearby, is creating the conditions for the transfer of unknown pathogens from their natural reservoir (mainly, but not exclusively, mammals) to human beings.

Biodiversity depletion is followed by certain predictable, medium-term changes in the composition of species. Habitat destruction and hunting lead to declining predator populations, which is indirectly responsible for the further breakdown of ecological networks and chains. Population outbreaks, in the absence of the natural control provided by top predators, represent an intermediate step in this process. These outbreaks are usually seen in herbivores and rodents, many of which carry transmissible diseases that can easily gain access to human settlements.

In line with other reports concerning the significance of these factors, we believe that the non-linear character of both climate dynamics and ecosystem responses to external perturbations could result in significant variations from current forecasts, as follows:

(1) The rapid decline in biodiversity due to sudden changes in habitat structure derived from continuous fragmentation. This impoverishment can be catastrophic and lead to species-poor communities that are especially vulnerable to invasion by exotics. Reversing this situation would require extremely costly measures and very long periods of time, which are virtually impossible for under-developed countries, where the richest biodiversity is concentrated.

(2) The collapse of food chains as a result of synergies between habitat loss and hunting. The loss of top predators and other large mammals triggers ecosystem breakdown. If this situation becomes widespread, it means that mechanisms to restore the ecosystem would not be easily available (ie, via the immigration of other species to replace those lost), giving rise to an irreversible situation. This is already the case of many tropical forests in Africa.

(3) Sudden changes in ocean circulation due to increase inflows of freshwater into the North Atlantic. Eventually, after a critical point has been reached, northern areas will shift towards colder temperatures. Such a situation would be virtually irreversible and, where recovery is possible, centuries would have to pass before global circulation was restored.

The lessons to be learnt from our current understanding of both the climate and the biosphere (and their interaction) are clear. We cannot continue to disrupt ecosystems beyond their resilience point without suffering. The sustainable exploitation of ecological resources needs to be balanced and tied to an appropriate set of political decisions for the countries involved. The evolution of our society will take place in a new environmental context, in which some key resources have been depleted and climate fluctuations have increased. Humans are adapted to the warm, hospitable planet they inhabit. All our forecasts are based on the widespread hope that these basic conditions will not be modified too quickly, thus enabling us adapt to them. However, only an in-depth understanding of the tempo and mode of these issues over the decades ahead will allow mankind to safeguard our society.

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http://www.cdc.gov/mmwr/preview/mmwrhtml/rr5109a1.htm

Arena virus site
http://www.cvmvcd.org/information/diseases/arena.htm

West Nile virus site
http://www.cdc.gov/ncidod/dvbid/westnile/

Global warming site
*http://yosemite.epa.gov/oar/globalwar**m**ing.nsf/content/index.html*

Intergovernamental panel on climate change
http://www.ipcc.ch/