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Challenges posed by new and re-emerging infectious diseases in livestock production, wildlife and humans☆

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ABSTRACT

In today's world, emerging and re-emerging diseases have a significant impact on global economies and public health, and with bioterrorism a constant threat this has become a very topical subject in recent years. Bernard Vallat, director general of the OIE, made the statement, "As a result of globalisation and climate change we are currently facing an unprecedented worldwide impact of emerging and re-emerging animal diseases and zoonoses". He is not alone in this thinking, but are we facing an unprecedented impact of diseases and are globalisation and climate change the main driving forces? This paper examines some historical disease outbreaks and the factors that played a role in their emergence and compares these with recent emerging diseases. In doing so it highlights certain challenges that face livestock producers and decision makers today as they grapple with emerging diseases. One of the driving forces for the emergence of diseases is translocation of people and their livestock and this has often been coupled with invading armies or peoples, political unrest and a concurrent environment of socio-economic upheaval. Contact between wild animals, domestic animals and people is another driving force involving the interaction between naïve population groups that induces the emergence of new diseases. Pandemics are not new to human society and nor are many of the driving forces that caused them to occur in the past; what has changed is our increased knowledge and awareness of disease dynamics, allowing identification of challenges for the future and ways of addressing these. Modern farming practices often serve to amplify emerging infectious diseases and modern trade and transport mechanisms and routes have served to sometimes accelerate the spread of disease. How can we reduce the risks and should we only be worried about emerging infectious diseases or are emerging non-communicable diseases just as important in our modern society? This paper serves to explain some of the reasons for the emergence of diseases and to try and answer some of the pressing questions that confront livestock producers today.

1. Introduction

In today's world, emerging and re-emerging diseases are having a significant impact on global economies and public health, and with bioterrorism a constant threat, this has become a very topical subject in recent years. Bernard Vallat, Director General of the World Organisation for Animal Health (OIE) made the statement "As a result of globalisation and climate change we are currently facing an unprecedented worldwide impact of emerging and re-emerging animal diseases and zoonoses (animal diseases transmissible to humans)" (Vallat, 2007). He is not alone in this thinking, but are we facing an unprecedented impact and what is the role of globalisation and climate change?

2. The role of translocation

Diseases have been with man for millennia and an examination of history shows that pandemics are nothing

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new and have occurred many times before. Jewish literature for example cites Egyptian plagues more than 2000 years ago (Anonymous, 1988) and Greek literature contains reports of a devastating disease that struck Athens in 430 BC during the Spartan wars when people crowded into the city and died “like sheep”, in their homes, in the streets, public baths, temples and at the fountains (Beran, 2008). The Black Death, also called plague, raged in Asia for centuries before arriving by ship in Sicily in 1347 resulting in the extermination of entire villages as it ravaged across Europe (Beran, 2008). The Spanish conquistadors, introduced measles and smallpox, endemic in Europe, into the Americas with disastrous consequences for the native populations. However, it was not only people that were affected by invading armies. Genghis Khan, Attila the Hun and Napoleon all took contagious pleuropneumonia and rinderpest with them into conquered countries, which impacted greatly on local animal populations (Brown and Bolin, 2000).

That same rinderpest arrived in Africa with Indian cattle brought in by the Italians fighting in Somalia in the late 1800s and severely impacted on both wild-life and domestic animal populations. It covered the length of Africa within 10 years and killed more than 90% of Kenya's buffalo population resulting in a ripple effect that impacted on predators and even tsetse fly populations (Schwabe, 1969). A study of these outbreaks reveals that there are many commonalities between what has happened in the past and what is happening today and that what we are seeing today is not as new or revolutionary as we might think. The impact of rinderpest in the late 1800s in Africa was on a par with and probably exceeded the more modern outbreaks of Foot and Mouth Disease (FMD) and Bovine Spongiform Encephalopathy (BSE) in Europe today. Hence, the impact of emerging diseases today is certainly not unprecedented.

These pandemics of the past were often linked to human translocation across the globe. It is this movement of people and their animals that has commonly resulted in dissemination of exotic pathogens into naïve populations. The process of translocation, which involves the introduction of infected animals or people into new geographic areas, where they previously did not occur, is therefore an important driver for the emergence of diseases (Daszak et al., 2000).

Key factors that promote people-translocations include population expansion, social and political unrest and natural disasters and wars. With these people come their animals. The introduction of exotic fish species such as trout into many parts of the world by English settlers is a classic example of this, with disastrous consequences for many local fish species and ecosystems.

A result of translocation and introduction of non-native flora and fauna into new areas is something that has been referred to as “pathogen or biological pollution” (Daszak et al., 2000). The introduction of zebra into Spain, and with them horse sickness, serves as a modern example of biological pollution, caused by translocation, resulting in the emergence of horse sickness within Spain. The mechanics of translocation therefore involve international traffic in people and animals, but pathogens themselves, can also be spread by other means, such as agricultural materials, food crops and biological wastes such as landfill and ballast water, as some examples.

One of the knock-on effects of biological pollution is a loss in biodiversity due to the possibility of depopulation and local extinction. An example of the complex nature of these relationships is the local extinction of the endangered large blue butterfly (*Maculinea arion)* in the United Kingdom due to the change in habitat caused by the introduction of myxomatosis into rabbit populations (Daszak et al., 2000). The change in habitat because of the death of the rabbits resulted in the subsequent loss of red ant species (*Myrmica sabuleti*) required for the development of the butterfly, thus causing it to die out. In addition the rabbits were no longer available as the main food source for the Spanish lynx, causing their numbers to decline as well (Wikipedia, 2008). Sadly, there are many other examples of how biological pollution due to the efforts of humans has upset a stable ecosystem.

The first challenge that we need to consider then is how to monitor or prevent translocation of animals, people and their waste products?

Coupled to this is the realisation that problems in another part of the world can have knock-on consequences that can affect you, which highlights the importance of having a global strategy in dealing with emerging diseases.

3. The role of wildlife

If we think of emerging or re-emerging diseases as diseases caused by biological agents, such as bacteria, viruses, prions, protozoans, fungi and helminths, then about 60% of 335 disease events recorded over the last 60 years were caused by zoonotic disease agents, i.e. pathogens that can survive quite happily in animals and man and which can thus be transmitted between them, and 72% of these events originated from wildlife (Cunningham, 2005; Jones et al., 2008). Wildlife therefore, plays an important role in the frequency of emerging diseases. However, it must be kept in mind that the magnitude and impact of an emerging disease problem has very little to do with the fact that diseases come from wildlife. Other challenges determine the magnitude of the event, some of which are discussed below. So why do diseases come so frequently from wildlife and why are wild animals so important in our thinking?

To understand this we need to look at a few of the more recent emerging diseases (Fig. 1). One of the recent diseases to emerge is a paramyxovirus called Hendra virus that first occurred near Brisbane in Australia in 1994, affecting horses with respiratory and nervous symptoms and rapidly killing them and a few of the people that came into contact with them (Wild, 2009; Plowright et al., 2008). Another paramyxovirus is Nipah virus that emerged in Malaysia in 1998, and was first isolated from pigs, also showing respiratory and nervous signs, and this was also found to infect and kill people that had come into contact with infected pigs or their meat (Wild, 2009). Ebola disease was first discovered in 1976 in central Africa and Sudan and is caused by a Filovirus, which causes a haemorrhagic syndrome that rapidly kills people resulting in mortality rates of up to 90%. Marburg virus is also a Filovirus that first killed laboratory staff working with monkey kidney cells in Germany in 1967. The Filoviruses were initially associated with primates from which people can contract the disease (Pastoret, 2000). Of

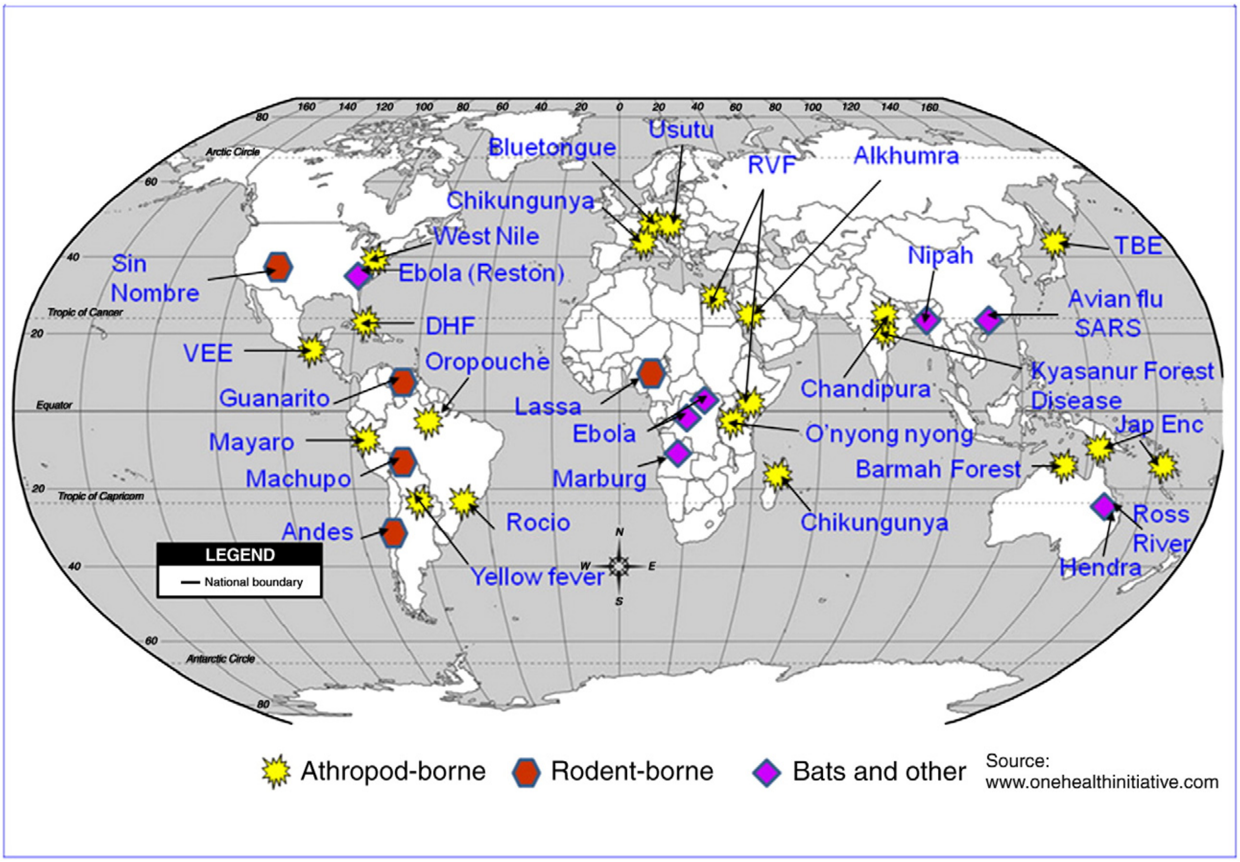

Fig. 1. Location of recent emerging and re-emerging infectious diseases and associated vectors or intermediate hosts.

more recent significance is Severe Acute Respiratory Syndrome or SARS, which killed 774 humans in 2003, rapidly travelling to nine countries by people-translocation during the Chinese New Year, primarily via the airlines. SARS was first associated with the Palm Masked Civet *(Paguma larvata*) (Kruse et al., 2004).

What struck epidemiologists about all these diseases was that the animals from which the people contracted the diseases themselves (i.e. the horses, pigs, primates, etc.) became sick and often died from the diseases. This meant that another reservoir for the viruses must be present or else the disease would be self-limiting. Where then did the intermediate (amplifier) hosts get the virus?

Further epidemiological investigation found Hendra virus in fruit bats (*Pteropus alecto*) nesting in a palm tree on the affected farm under which the horses had stood before getting sick. It was also found that Ebola virus could be isolated from at least three species of fruit bats and Nipah virus could be traced to another species of fruit bats (*Pteropus hypomelanus*) which had been congregating in orchids near affected pig farms. In addition to the above diseases, two species of Australian bats, the Black Flying Fox (*Pteropus alecto*) and the Little Red Flying Fox (*Pteropus scapulatus*) were found to carry lyssavirus, a newly identified virus related to rabies virus. In fact, since the 1990s, five new zoonotic viral diseases, Hendra, Nipah, Lyssa, Menangle and Melaka viruses have emerged from Pteropus species bats (Plowright et al., 2008). Even SARS can be linked to the horseshoe bats of the genus *Rhinolophus*. So what is it about bats and why the emergence of these diseases now when the viruses have probably been around in bats for many years?

A closer look at bats reveals that they encompass a great diversity of mammalian species, in fact roughly 20% of mammals are bats. In addition, they congregate in huge colonies close together and have a relatively long lifespan (Plowright et al., 2008). They are also old in evolutionary terms and therefore provide not only a huge melting pot within which viruses and other agents can be exchanged and mutated, but also maintained, even if they are fairly virulent strains. Their flying behaviour puts them into contact with many other species from the canopy of the forests to the ground, including rodents, monkeys, carnivores, birds, snakes and people thus creating an ideal environment for spill-over and spill-back of disease agents and also re-assortment of RNA. This combination of facts is probably why bats are so frequently associated with new diseases. The ingredients necessary for new diseases to emerge are thus close contact within a species (high population density), close contact between species and a rich biodiversity.

The second challenge then is to prevent or control that contact between domestic livestock, man and wildlife species.

From a sustainable livestock perspective this translates into on-farm biosecurity in commercial enterprises and minimising contact between domestic and wild animals, particularly exotic wild animals.

The question is why are so many of these diseases emerging now? The rich biodiversity needed for new diseases to emerge occurs mainly in the central rainforest areas of the world and it is only in the last 100 years or so that we have seen population expansion in these parts of the world not only causing people to encroach further into naïve wildlife habitats and come into contact with these viruses, but also causing wild animals to be increasingly compacted into smaller areas, affording greater contact between species and within species. However, even that would not cause pandemics. The other important factor playing a role in the emergence of these diseases is again translocation; with improved communication and movement of people (including ecotourism) and their animals, into and out of the rich biodiversity areas these diseases can now be spread more readily than ever before, particularly along trade routes, as has been the case with avian influenza (Gauthier-Clerc et al., 2007). Rodents are also an important component of emerging diseases and, like bats, live in large colonies and in close contact and come into contact with many species. So the driving forces are again population density, contact and translocation. The role of arthropods in emerging diseases will be discussed below.

Since we cannot always separate wild animals and food producing animals, the third challenge then becomes understanding the interface between people, domestic and wild animals.

By understanding how diseases are transmitted and move within this interface we can plan better control measures. However, there is another fundamental reason why we are identifying more emerging diseases today; and that is simply because we now have the tools to easily be able to find viruses. Historically, bacterial and protozoan diseases “emerged” in great numbers in the late 1800s and early 1900s when the light microscope was discovered and bacteria and protozoa could be seen easily and isolated. At present, it is interesting to note, the bulk of emerging diseases are viral (Coetzer and Tustin, 2004).

4. The role of intensification

Today, wild animals are being condensed into increasingly smaller areas resulting in an increase in population densities within wild animal populations and increased opportunity for spread and maintenance of disease. An example of the effect of this man-induced concentration of wild animals is the spread of *Salmonella typhimurium* and *E. coli* 086:K61 amongst birds at feeding stations in Great Britain. In the USA the same situation has resulted in the emergence of *Mycoplasma gallisepticum* in bird populations. By creating an artificial intensified environment for birds, the increased opportunity for disease transmission has resulted in the emergence of these pathogens, which have the potential to cause illness in the human population (Daszak et al., 2000). The role that intensified farming systems are playing in emerging diseases is to amplify the virus or disease. In many of the diseases described above, the intermediate domestic animal host played this role by providing opportunity for multiple passaging and a mechanism for species shift or re-assortment of virus. When this is coupled to livestock movement the ingredients are there for an epidemic or pandemic to occur. A good example of this has been avian influenza, where the highly pathogenic strains have largely been traced back to domestic birds, usually farmed intensively, while low pathogenic strains of the virus are wide spread in wild birds. The weight of evidence suggests that the dispersion of avian influenza is primarily due to trading and movement of domestic birds rather than wild-bird migration (Gauthier-Clerc et al., 2007). So, translocation remains the driving force for disease emergence, with intensification acting as the amplifier of the problem or the mechanism for a species shift.

The fourth challenge is therefore early detection and better control/biosecurity of intensified animal/farming systems and animal movement.

5. The role of global warming

Over the last twenty years the theory of global warming has become more and more widely accepted. Climatologists are predicting from their models that global mean temperatures are likely to rise by 1–3.5 °C during this century, with the main effects occurring in high latitudes during winter (Pastoret, 2000). This will result in changes in rainfall and wind patterns. So what does this mean in terms of emerging diseases? One of the main categories of diseases that are likely to be affected is vector-borne disease, because the effects of climate change are going to impact on the availability of habitat for the vectors and also as many of the vectors are cold blooded, they are much more susceptible to climate change than mammals. Climate change can thus be a two edged sword as there may be an increase in available habitat due to increased rainfall and higher humidity in some areas, but in other areas there may be a decrease in available habitat due to, for example, lower rainfalls and desertification. An increase may occur in vector-borne diseases in the higher latitudes and a decrease in them in the more central regions of the world. The effects are complex and warrant a separate paper. For example, most blood feeding groups of insects like blackflies (*Simulidae*), biting midges (*Culicoides*), horse flies (*Tabanidae*) and mosquitoes (*Culicidae*) have an aquatic or semi-aquatic stage in their lifecycle; hence changes in the availability of water to breed in will affect their survival. In addition, changes in wind patterns will affect dispersal of many flying insects, such as mosquitoes, sandflies (*Phlebotominae*) and midges (*Culicoides*). The effect of global warming then is therefore less likely to result in new emerging diseases, but more likely to result in changing distributions of diseases, with the high risk areas being the marginal areas where these vectors occur.

A look at some of the more recent re-emerging diseases reveals this pattern starting to develop. It seems for example that Blue Tongue was carried into Spain's Balearic Islands by winds during the 2000 outbreak (Saegerman et al., 2008). The Rift Valley Fever outbreaks that occurred in East Africa in 1997 and 1998, which claimed the lives of thousands of livestock and wildlife and a good number of people, is thought to be due to an El Nino-Southern Oscillation phenomenon that created precipitation in East Africa and amplified the mosquito vector population (Brown and Bolin, 2000). The West Nile virus outbreaks in the USA in recent years may be linked to climate changes, which affected the mosquito populations (Pastoret, 2000).

The fifth challenge is to identify areas of disease instability so that appropriate disease control can be implemented.

From a sustainable livestock point of view, we can alert farmers in unstable disease vector areas that they are at risk of re-emerging diseases occurring so that they can take the necessary precautions.

6. The role of socio-economics and governance

In the developing world today there is a tendency towards poor governance, which is resulting in a breakdown of efficient disease monitoring and control, causing the re-emergence of previously controlled diseases. At the same time there is often an increase in populations and a migration from rural areas, where people are in close contact with animals, to urban areas. This has resulted in an outstripping of community services such as potable water and sewerage disposal, thus creating an ideal environment for maintenance and propagation of enteric diseases such as Salmonellosis, *E. coli*'s, *Campylobacter* (Thorns, 2000) and water borne pathogens such as *Giardia* and *Cryptosporidium* (Macpherson et al., 2000). Compounding this further is the poor immune status of these populations due to HIV/AIDS, malnutrition and environmental pollution. This has resulted in previously benign diseases such as toxoplasmosis and ringworm becoming life-threatening conditions (Gummow, 2003). In addition, these populations are often poorly educated about hygiene and health matters resulting in ideal opportunities for the spread and maintenance of diseases and the emergence of resistant strains of pathogens, such as tuberculosis, due to non-compliance to treatment. The socio-economic fabric of the society is therefore probably one of the biggest drivers of high impact emerging diseases that are in many ways more devastating than the more high profile wildlife-associated diseases (Fig. 2). The risk to the livestock sector is that many of these diseases can be reverse transmitted back into animal populations from these communities.

The sixth and possibly the most important challenge, is therefore to improve the overall wellbeing and good governance of these societies in order to prevent disease emergence and outbreaks.

7. The role of emerging non-infectious diseases

Despite covering a lot of ground in this paper we are in essence still scratching the surface of the dynamics of emerging diseases. Although infectious diseases are usually what people associate emerging diseases with, another area that is usually not highlighted by the media is that of non-infectious or non-communicable (Murray and Lopez, 1996) emerging diseases.

Increasing industrialization and pollution impact increasingly on livestock. The resulting diseases are just as erosive and dramatic as many of the infectious diseases that are popular in the media. We are only now beginning to appreciate the erosive effects of long-term exposures to metal and other inorganic pollutants as well as organic pollutants. Just as livestock has encroached into areas where wildlife occurs, so industry is increasingly encroaching into what were previously traditional farming areas. To illustrate the emergence of non-infectious diseases as a result of increased contact between industry and livestock as they compete for available resources the following

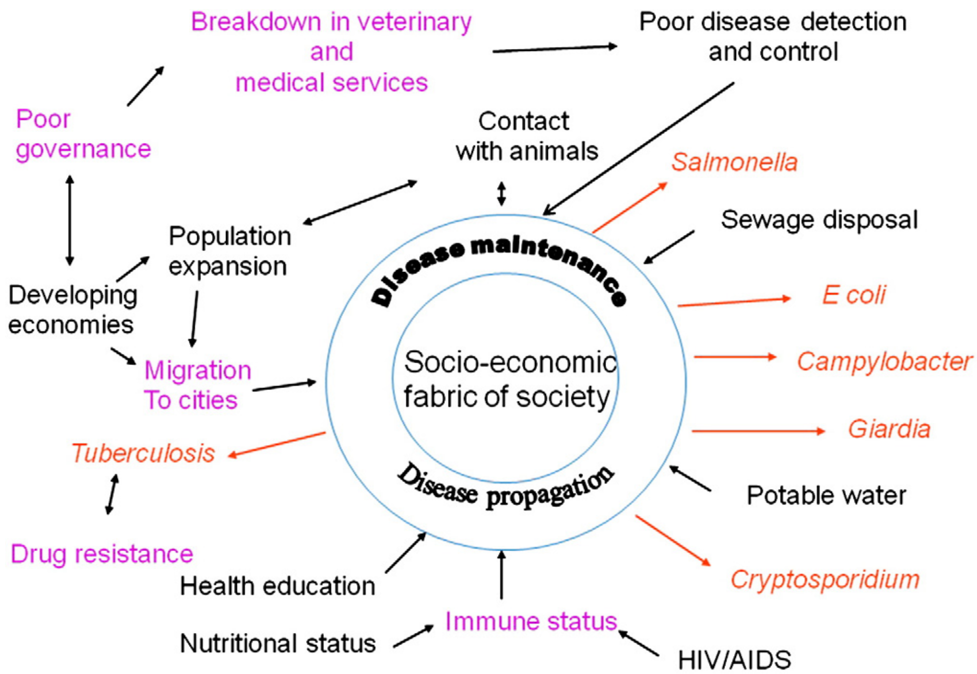

Fig. 2. Socio-economic factors (black text) playing a role in emerging diseases and related emerging diseases (red text) and knock-on effects (purple text).

examples are given: chronic copper poisoning in cattle in South Africa was an unknown entity prior to the 1990s (Gummow et al., 1991). Yet a significant outbreak of copper poisoning occurred amongst cattle near Palaborwa in 1989, which was also shown to be affecting the wildlife in Kruger National Park. The cause was traced back to aerial pollution from a mine in the area. Here a non-infectious emerging disease occurred in cattle for the first time in South Africa. In the 1990s calves in the Steelpoort area of Mpumalanga began wasting away and dying. The farmer was accused of poor management, but it turned out that his cattle were being exposed to vanadium coming from a nearby smelter that was contaminating the grazing. Vanadium poisoning in calves proved to be a new emerging disease in cattle (Gummow et al, 1994). In Russia the life expectancy of human males dropped from 65 to 57 between 1987 and 1994, probably as a result of exposure to decades of environmental contaminants (WRI/UNDP/WB, 1996). In the USA, air pollution is thought to be responsible for around 50000 deaths a year, which is 2% of their total deaths (Thurston, 1995). This is a sobering thought as we begin to become aware of the impact of pollutants on animal and human health. Many pollution-related emerging diseases are only now recognised, described and understood.

The seventh challenge, apart from the obvious need to reduce pollution, is also to recognise the interaction between non-infectious and infectious emerging diseases and to understand the effect and role that non-infectious diseases play. For example, many of these non-infectious diseases are now known to affect the immune system, thus predisposing animals and people to infectious diseases that may previously not have been a threat.

8. Conclusions

In conclusion then, we are not facing an unprecedented impact of emerging or re-emerging disease. There are many historical examples where diseases have played a much more dramatic role in the life of man than in modern times. The driving forces for infectious emerging diseases, namely translocation, overcrowding, socio-economic upheaval and contact with naïve populations, have remained the same since the recorded history of disease outbreaks. However, new diagnostic methodologies facilitate the identification of the diseases and the driving forces. We know more about how disease dynamics work today and are better equipped than ever before to deal with it. The main challenge is recognising the complexity of emerging diseases and identifying the key determinants. If we know the determinants we can implement the correct control strategies, provided we have the will to do so. Finally, it is apparent that non-infectious environmental contaminants are likely to play an increasingly important role as emerging diseases.

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