Introduction

Disease invasion: impacts on biodiversity and human health

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An introduction to the theme issue that includes papers that identify how, where and why infectious diseases in wildlife emerge, while also addressing their possible conservation impacts.

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The emergence of previously unknown infectious diseases has been high on the medical and political agendas in recent years, as evidenced by the global responses to severe acute respiratory syndrome, bird flu and swine flu, and the revision of the International Health Regulations [1,2]. A number of studies covering a wide range of taxa [3–5], including plants [6], have shown that such disease emergence is primarily due to host shifts of pre-existing disease agents, usually driven by anthropogenic factors, such as globalized trade and increased human–wildlife contact rates. Wild animals are the primary reservoir of new infections that spill over and infect human beings directly or via domestic or peri-domestic species, threatening the health of people or their livestock, but it should not be forgotten that wildlife are also the recipients of diseases from other species, including human beings. While infectious disease emergence has mainly been seen as a public health threat or as a direct threat to human resources and economies as a consequence of epidemics of crops and livestock, the transmission of infectious diseases from one species to another also threatens wildlife [7], including the survival of large and apparently robust wildlife populations [8]. This theme issue of the Philosophical Transactions of the Royal Society follows a conference held at the Zoological Society of London that focused on the extent to which wildlife pathogens threaten biodiversity and human health, the processes driving these disease threats, where future threats will arise, and how these might be mitigated.

Most emerging disease threats are caused by pathogens that capitalize upon the opportunities of exposure to transmit between species [3,4,6]. In most cases, one (or more) host species act as a reservoir for a pathogen that jumps species, with or without adaptation to the novel host [5], to infect a novel species that is at a twin disadvantage in being both susceptible and naive, and so there is an opportunity for spread throughout the population. These conditions set the stage for either a disease outbreak that dies out after causing a significant epidemic, or for the pathogen becoming endemic and establishing in the new host population, usually reducing it to a lower abundance [9]. Thus, even if the population of the new host falls below the level required for maintenance of infection, repeated spillover from the original host ensures continued pathogen exposure. Several papers in this issue explore our current understanding of the dynamics of such diseases, the processes of circulation in wild reservoirs, and the rare, enigmatic and critical process of spillover that leads to infection, and sometimes establishment, in new host species. This spillover process is both poorly understood and under-studied, partly because spillover events are rarely captured and partly because current analytical tools are inadequate to encapsulate the high degree of complexity involved in such systems [5].

There has been a recent increase in the studies of host–pathogen dynamics within reservoir hosts. This, along with the dynamics of pathogen spillover into new host species, is a key area for future studies. Ironically, the dynamics of the within-host interaction between the immune system and the apparently growing population of pathogens is more likely to readily match the underlying assumptions of many simple predator–prey systems, than are the actual dynamics of vertebrate predators and their prey, or even insect parasitoids and their hosts. There have been some recent highlights in this area [10], and it is an increasingly vibrant area of research that we expect to see...
expand, almost to the level of a sub-discipline, in the next decade. A key step here will be the development of a better understanding of the way that the immune system functions in different host classes. At present, we study the nuances of human immunity with fervour and detail, yet we have a very thin understanding of how, for example, bat immunity differs from mouse immunity; worse we tend to assume that migrating waterfowl that act as major reservoirs for influenza have analogous immune systems to chickens. Our knowledge of the immune systems of reptiles and amphibians is woefully vague, and this is particularly worrying given the global extinction of amphibians associated with the infectious fungal disease, chytridiomycosis [11]. Increases in the power of computers, coupled with increased availability of data, will make the development of within-host models a viable exercise, although the area is also ripe for insights derived from simple empirical studies and analytical models of the dynamics of a pathogen and the different major components of immunity. Some may complain that the devil is in the fine detail of immunological function, but, as with any complex emerging system, the detail of the immune system is likely to be organized in a way that is both hierarchical and containing subtly nested redundancies that interact to determine host susceptibility and infection outcomes, including pathogen transmission. There will certainly be more similarities between the network structure of food webs, nervous systems and immune systems than is currently perceived by most of those working in each of these fields, or by the funding agencies.

This theme issue not only includes papers that identify how, where and why infectious diseases in wildlife emerge, but also addresses their possible conservation impacts. Several papers present new ways of addressing disease emergence through modelling insights gained from empirical studies. These include new approaches to evaluating the biological and anthropogenic mechanisms that facilitate the spillover and spread of infection into new species (including humans) and geographical regions, and the selection pressures that can then lead to new endemic infections evolving [12,13]. Understanding the mechanisms involved in disease invasion is fundamental to understanding how emerging diseases can be best prevented and controlled [7,8]. This includes a need for natural scientists to work more closely with social scientists in order to improve our understanding of the drivers of disease emergence and spread [14]. Human activities are, after all, usually at the root of the problem, and their underlying causes need to be understood if behaviours are to be modified effectively to produce a sustainable solution. Aspects of emerging disease mitigation also are addressed in this issue, including the control of infections within their reservoir hosts and within the target species [2,15], as is a range of issues, from understanding molecular processes to the management of ecosystems, in order to identify and predict future threats [16,17]. Finally, policies for mitigating disease threats to conservation and human health are examined and science-based recommendations made.

It is always instructive to consider what is missed from a theme issue such as this, and to briefly scan likely future areas of development. We each felt it would have been deeply insightful to include more papers about plants and plant pathogens. The current epidemic of white pine blister rust in Canada and the northwestern United States illustrates that plant pathogens can have equally marked impacts on the structure of relatively pristine ecological communities, comparable to the rinderpest outbreak in nineteenth century sub-Saharan Africa, or the myxomatosis epidemic in rabbits in Australia and Europe [18]. Similarly, it would have been insightful to have included papers that examine the role of pathogen and host genetic diversity, although these will be covered in a forthcoming symposium that will be published as a theme issue of Philosophical Transactions of the Royal Society, B: Biological Sciences.

Overall, the meeting held at the Zoological Society of London and the papers that follow in this theme issue illustrate the energy and vibrancy of the field, laboratory and theoretical studies that are rapidly expanding our understanding of the dynamics of disease invasion and of infectious disease dynamics in their natural hosts. As McCallum remarked on the opening day of the symposium, the pioneering studies of Anderson & May [19] have themselves ignited an epidemic of studies that is far removed from the stuttering chains of intellectual infection that often characterize the emergence of new ideas and synthesis in other domains of scientific endeavour.

REFERENCES


