

Foresight

Infectious Diseases: preparing for the future

OFFICE OF SCIENCE AND INNOVATION

**T.11: Infectious Diseases:
Their Future Effects on Ecosystems**

**Summary of a workshop
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Introduction

A natural ecosystem largely comprises wild rather than domesticated species. Some natural ecosystems may be harvested, such as forests and oceans, and so may also be considered agricultural systems. Most natural ecosystems have a value to society in terms of recreation and tourism and, particularly, in terms of ecosystem services such as the provision of clean water and air. They will also have an 'existence value', which is hard to quantify.

Infectious diseases are natural components of ecosystems, and microbial pathogens are part of their biodiversity. Disease can contribute to the maintenance of biodiversity and to the dynamical stability of natural ecosystems. Outbreaks of disease, even dramatic epidemics, can be part of the normal functioning of ecosystems. It is when natural ecosystems are stressed that natural disease outbreaks may have longer-term, negative impacts on ecosystems and on society.

Disease in ecosystems may impact negatively on our society and economy via outbreaks that occur naturally or as a result of human activity. These two possibilities are at the opposite ends of a continuum of increasing human causation. The importance of the human dimension will continue to increase in the future.

Effects of disease on ecosystems

Diseases are often highly specific. The effect of diseases on ecosystems, by and large, will be to reduce the abundance or fitness of particular species within an interacting community of species. Outbreaks of disease may do this quite rapidly and extensively, leading to a rapid reduction in abundance or population fitness. It is rare, however, for disease epidemics to lead to the complete extinction of the affected species.

Therefore a new disease outbreak could have a direct effect on biodiversity by reducing the abundance of affected species, and an indirect effect by the loss of the role that that species plays in the functioning of the ecosystem. Such roles might include predation, primary production, the colonisation of new habitats, or competition for space, light or water.

Disease will affect an ecosystem most severely when it attacks a 'keystone' species that underpins an important ecosystem process, such as the mediation of competition between a community of herbivores or plants, or nitrogen fixation in soils. Few species will be keystone species, and natural ecosystems may also have enough redundancy for the loss of such a species to result in another species with similar properties filling its role.

The types of organisms most likely to be irreplaceable keystone species in ecosystem function include:

- pollinators, especially those that pollinate many plant species, such as the honey bee, *Apis mellifera*
- top predators

- certain herbivores that regulate vegetation growth and influence succession
- key organisms in the soil.

Simple ecosystems may have a more irreplaceable keystone species than complex ones. Freshwater and marine ecosystems may be examples of such systems by virtue of their simpler food chains.

Because diseases may affect only a few species, their broader impacts on ecosystems often result from a domino effect, which involves stepwise, compounding events. Examples include:

- the removal of a predator, leading to a population explosion among its prey species, competition between these species, or heightened herbivore activity
- the removal of a herbivore, leading, in a similar way, to plant competition and possibly a change in plant succession
- accelerated invasion by non-native species. Introduced animal and plant species often bring with them diseases that prove comparatively more virulent to native animals and plants, thereby driving the displacement of native species by the invasive species.

The timescale of these effects is important. Disease outbreaks may cause dramatic change in the short term, with rapid declines in species and bursts of effects on ecosystem function. However, natural ecosystems, when resilient, will eventually recover from a disease outbreak and its consequences, although in some cases their composition and functions will be altered permanently.

The kinds of ecosystem services which might be affected by disease effects include water conservation and purification, carbon sequestration, and the removal of atmospheric or aquatic pollutants. At the moment, it is unlikely that disease outbreaks will have major effects on these services over substantial areas. The limited number of keystone species and the specificity of diseases underpin this conclusion. For instance, viral diseases are common in phytoplankton. A devastating viral disease might in principle reduce oceanic plankton levels and lead to acidification of the oceans, with impacts on carbon cycling and climate. However, from what we now understand, the diversity of phytoplankton species and their particular viruses makes such a sequence of events unlikely to arise from a single new disease agent.

The recent history of species invasions, however, points to some dramatic ecosystem effects caused by taxa other than micro-organisms. In river systems, lakes and even seas, introduced plants, molluscs and predator invertebrates and fish have severely disrupted food chains, leading to eutrophication, crashes in fish stocks and changes in water quality and flow. In tropical and subtropical terrestrial systems, introduced trees and shrubs have overrun grasslands, aided by altered fire regimes, turning grassland into woodland, with effects on water conservation and provision to cities. The

opposite effect, where non-native grasses invade forests, converting them to grasslands, has also been suggested as having possible effects on carbon and water cycles. It is not out of the question that new diseases, arising through introduction, hybridisation or evolution, might have similar effects on ecosystem dynamics.

Another kind of ecosystem service likely to be affected by disease is the provision of attractive and useful biological diversity, with its value for recreation as well as agriculture. There is a strong precedent for species loss and decline associated with the introduction of non-native species, including animals, plants and micro-organisms. Even if it didn't cause severe ecosystem changes, the loss of particular species to disease could have important social and economic effects if it affected charismatic species with high tourism or existence values (for example, tigers) or species of potential commercial value, such as wild relatives of domesticated animals or crops.

Future risks

This suggests that the greatest impact on ecosystem functions and services would be caused by a disease that eliminates one or more keystone species and thereby generates a domino effect through an ecosystem. This could result in the disruption of major natural production systems such as fisheries, other valuable biodiversity, essential geochemical cycles, or all three.

The complexity and resilience of ecosystems buffer them against such specific disease impacts. This, in turn, identifies the greatest potential human hazard to such systems, which arises where human interference renders them so simplified and non-resilient that it becomes easier for a disease outbreak to have a disruptive domino effect on them.

Disease outbreaks are most likely to have an impact on natural ecosystems that are in some way degraded and simplified. Indeed, it is likely that even without the introduction of new diseases, outbreaks of local diseases will be a feature of degraded ecosystems.

A growing number of natural or semi-natural ecosystems might be classified as degraded and simplified. Over-fished marine ecosystems, eutrophied freshwater ecosystems, overgrazed grasslands, plantation forests and a wide range of ecosystems affected by invasive animal and plant species may have reduced biodiversity, fewer and more vulnerable keystone species and less capacity to return to their pre-disease structure and function. In future, these degradational processes – pollution, overproduction, habitat fragmentation and bio-invasions – are all likely to increase in developing countries. In developed countries, in particular in Europe, changes in natural resource and land use policy are likely to reduce pollution and overproduction in the next 20 years, and perhaps bio-invasions over a longer period.

Besides effects on ecosystem services, there are several more subtle risks associated with disease outbreaks in natural ecosystems and their effects on society. Disease outbreaks in natural ecosystems can affect human health, for instance, through zoonoses such as Lyme disease and West Nile virus.

Further, such outbreaks can cause governments to restrict access to natural ecosystems, as the UK Government limited access to the British countryside in response to outbreaks of foot-and-mouth disease. This might mean that natural ecosystems and wild species could come to be seen as a threat to society. Were this to devalue natural ecosystems, degradation might accelerate.

To conclude, the greatest potential impact on ecosystem services as a result of disease outbreaks would be to undermine water and geochemical cycles, ultimately contributing to climate change, but the probability of this is regarded as very low. Impacts on natural production systems and on other useful biodiversity, while of lower impact, have a greater probability. The probability, and therefore risk, of both events will increase as human activities simplify and degrade ecosystems.

Drivers of future risk

The introduction of new diseases to ecosystems is a major source of future risk, and a growth in trade will be a major driver. However, risks related to trade may be quite specific. The trade in horticultural plants and pets (including aquarium fish) stands out as a key pathway for the introduction of diseases into wild species and terrestrial natural ecosystems, while ballast water exchange and other aspects of shipping practice are the main pathway for marine systems. Increased movement of people and produce will also be important drivers as additional pathways for the introduction of disease. The hybridisation of species caused by the introduction of new plants or animals provides another pathway for the movement of diseases into wild species and ecosystems.

Factors that lead to the simplification and degradation of ecosystems will increase the probability of disease outbreaks and their impact.

Changing attitudes to the environment, particularly a growing interest in conservation, will drive concern about disease effects on biodiversity, and may make its protection a higher political and social priority. But a growing number of disease problems could reduce interest in enjoying natural ecosystems, as was mentioned above.

The urbanisation of wildlife, and the extension of human habitation into natural habitats, will drive an increase in awareness of diseases in natural ecosystems, but will also increase the risk of zoonotic disease. These factors will interact in a complex manner.

Actions to address risk and its drivers

Maintaining ecosystem health and resilience would reduce the frequency and impact of future disease outbreaks. In many cases, this will involve biodiversity conservation to minimise the degradation and fragmentation of natural ecosystems.

Natural ecosystems are extensive and complex, making the detection of new disease outbreaks and the monitoring of their spread difficult. Several kinds of disease may be particular future hazards. In plant diseases, for instance, the genus *Phytophthora* appears particularly active at present in evolving new virulent strains on a variety of hosts. Complex species interactions make it difficult to predict what cascade of events may follow the impact of disease on a particular species, and therefore what to monitor.

This lack of predictive ability points to the need to build and maintain broad expertise and capacity in the biology and taxonomy of pathogens and pathogen–host relations. This is particularly acute for the identification of new pathogens.

Scientists involved in the study of natural ecosystems are in the best position to discover and characterise new disease outbreaks. An informed public, including amateur naturalists, can be a valuable resource in detection and monitoring.

Improvements in communications technology and data mining and fusion will enhance the early detection of new problems through experts networking across disciplines, methodologies and countries. New detection, identification and monitoring technology may be valuable, but the priority is for organisational rather than technological change, and the better networking of experts involved in ecosystem research in order to enable communication and agility of response.

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