Infectious Diseases of Animals and Plants: An Interdisciplinary Approach

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Abstract

Animal and plant diseases pose a serious and continuing threat to food security, food safety, national economies, biodiversity and the rural environment. New challenges, including climate change, regulatory developments, changes in the geographical concentration and size of livestock holdings and increasing trade make this an appropriate time to assess the state of knowledge about the impact that diseases have and the ways in which they are managed and controlled. In this paper, the case is explored for an interdisciplinary approach to studying the management of infectious animal and plant diseases. Reframing the key issues through incorporating both social and natural science research can provide a holistic understanding of disease and increase the policy relevance and impact of

research. Finally, in setting out the papers in this Theme Issue a picture is presented of current and future animal and plant disease threats.

Introduction

Incidents of animal or plant disease are not solely natural occurrences. Human actions are extensively implicated in the spread and outbreak of disease. In turn, disease affects human interests widely, and much effort is spent in the control of disease. Consequently, it is difficult to prise apart the natural phenomena of disease and the social phenomena of the drivers, impacts and regulation of disease. Yet our understanding of animal and plant diseases is riven by a great divide between the natural and social sciences – a divide that is entrenched in differences of research methods, approaches and language. The resulting fragmentation of knowledge hinders progress in understanding and dealing with disease.

The aim of this theme issue is to bring together different academic disciplines to offer fresh insights into contemporary animal and plant disease threats. In this introductory paper we outline the complex interactions between the natural and the social in animal and plant diseases, and present the case for an interdisciplinary approach, combining natural and social sciences, to disease management. Firstly, we address the two most pressing drivers of disease spread - climate change and globalisation - to illustrate the interplay of human and natural factors. Secondly, we explore the interrelationship between disease and the political, social and economic context in which it occurs, demonstrating the significance of that context by comparing and contrasting the different regimes surrounding plant and animal health. The paper then introduces the concept of interdisciplinarity and the ways in which it can prompt new insights into the transmission, effects and management of disease. Finally, we set out the papers in this Theme Issue and the prospect they provide on present and future disease threats.

Drivers of future disease threats

Two contemporary processes stand out in their transformative and far-reaching impact on the spread of infectious animal and plant diseases. The first is climate change, which is profoundly altering the distribution of disease organisms, at the same time as it is increasing the vulnerability of agriculture in certain regions due to drought, salinity, flooding or extreme weather events. The second is globalization, the increasing movement of people, goods and information, that poses challenges for border controls, food supply chains and trade patterns, but is also a force behind the development of national and international systems of regulation.

Plant and animal disease experts in the UK were surveyed in 2006 regarding the most important drivers of future disease threats [1]. For plant diseases, the major drivers identified were pesticide-resistant disease strains and a lack of new pesticides, an increase in trade and transport of crops and plants, and an increase in ambient temperatures. For animal diseases, the major drivers were inadequate systems for disease control and weaknesses in their international implementation, the threat of bioterrorism, emergence of drug resistance and a lack of new drugs, increased trade in animals, the spread of illicit trading and other risky practices, and increased temperatures. Interestingly, lack of understanding of the biology of the pathogens did not figure, but aspects of climate change and globalisation appeared under both headings.

Climate change

Climate change in its contemporary form is not simply a 'natural' process, but is increasingly caused by human behaviour. In turn, climate change affects disease transmission at three levels: firstly, it acts directly on the biology and reproduction of pathogens, hosts or vectors; secondly, it affects the habitats present in a region, the community of hosts that can live in them and the lifecycles, or lifestyles, of those hosts; and thirdly, climate change induces social and economic responses, including adaptive and mitigating measures, which alter land use, transport patterns, human population movements and the use and availability of natural resources [2]. While the first is a matter of biology, the second and third levels include increasing social components.

The effects of climate change on disease will differ between pathogens. A Foresight analysis identified increasing disease risks as a result of warmer temperatures in Europe, including from powdery mildew and barley yellow dwarf virus and from vector-borne diseases such as Bluetongue, Lyme Disease and West Nile virus [2]. Depending on their biology and temperature and water requirements, plant diseases may increase or decrease. However, there is evidence that certain pathogens such as wheat rust that currently flourish in cool climates could adapt to warmer temperatures and cause severe disease in previously unfavourable environments [3]. For animal diseases, increases are likely for vector-borne diseases, because insect and tick reproduction and activity are particularly sensitive to increases in temperature. As well as affecting the incidence and severity of disease, climate change will also influence the spread and establishment of non-native plants and animals. If they prove invasive, they too may impact on crop management, livestock husbandry, silviculture and infrastructure maintenance, as well as the native fauna and flora. Such changes to host ecology and environment are additionally important as even relatively small changes in the basic reproduction rate can have large impacts on the incidence of infection in a population, as pathogens more successfully jump species [4].

While we can thus identify some likely trends in the status of particular diseases, a second and equally important feature of climate change is the increased uncertainty it ushers in. As the Foresight report notes, there is “considerable uncertainty arising from the many, often conflicting, forces that climate imposes on infectious diseases, the complex interaction between climate and other drivers of change, and uncertainty in climate change itself” [2]. Effects of climate change that act indirectly on infectious diseases, via effects on other drivers, are particularly hard to predict. These include the social and economic responses to climate change such as shifts in land use and transport and trade patterns.

Agricultural processes, for example, have an active interplay with climate change, altering the conditions for disease. While agriculture is affected by rising temperatures and changing precipitation patterns, and must adapt, the production of food is a significant generator of greenhouse gases and is under pressure to mitigate them. (Agriculture contributes about 7% of the UK’s greenhouse gas emissions [5].) Changes in agricultural systems are therefore likely to have complex consequences for disease threats. For example, agricultural adaptation will necessitate geographical shifts in cropping zones, potentially introducing disease into new areas and prompting novel disease challenges. Even agricultural mitigation measures may have unintended consequences. For example, one technology recently promoted to combat greenhouse gas emission is on-farm anaerobic digestion as a means of processing farm waste and generating green energy simultaneously [6]. However, pathogens can enter digestors in slurry and other feedstock and be re-introduced to the field when the digestate residue, if not properly treated, is applied to a crop [7].

Globalization

Globalization is the other major process increasing disease spread, through rising volumes of trade in plants and animals within and between countries, growing numbers of tourists and other travellers potentially transporting disease organisms, and an increasingly international food supply chain that extensively moves around plant and animal products for processing and sale. The effects are more strongly seen in the less regulated world of plants. In the UK, a rapid growth in horticultural trade has led to many new disease introductions including the fungus *Phytophthora ramorum* [8, 9], which poses a serious threat to a range of indigenous trees and shrubs. Forestry in general has seen a dramatic pattern of new disease and pest introductions, particularly through the recent opening up of trade between East Asia and other regions [10]. Over the 20^{th} Century, the number of new plant fungal, bacterial and viral diseases appearing in Europe has risen from less than five to over 20 per decade [11]. Much of this is attributable to increased trade, transport and travel, and there is no indication that the trend is abating.

Again, the agricultural sector is implicated in increasing disease threats, in this instance through changes to the scale of production and trade in response to globalising markets. For example, structural change in the international horticultural industry has been towards fewer and larger producers and an increasing involvement of multiple retailers, leading to a concentration in the number and size of companies together with a major expansion of trade pathways [12, 13, 14]. The geographical concentration and intensification of production that globalisation has fostered also favours certain diseases. For example, extremely high densities of European wheat crops have been linked to the increasing transmission potential of diseases such as yellow rust [15]. Similar restructuring processes are heightening disease vulnerability in livestock. The reduction in income per animal, coupled with mechanisation, has led to fewer farmers managing more animals per farm, and more animal movements between farms. For example, pig farms purchase breeding stock to maximise uptake of new genetics, and young pigs from many farms are moved and reared together in their thousands. These behaviours, and similar developments in other livestock sectors, help pathogens survive in metapopulations [16].

The threat posed by increasing trade and tourist movements is largely a threat to the biosecurity systems of individual farms and those put in place to prevent disease entering particular countries. These systems are increasingly sophisticated, underpinned by advances in rapid diagnostic technologies and, particularly in the horticultural sector, new approaches to risk assessment and management of emerging pathogens. However, the volume and diversity of threats is challenging these systems. Some pathways of disease introduction are difficult to measure and regulate efficiently, for instance illegal trafficking of bushmeat or booming horticultural imports. Globalisation also circumscribes the autonomy of traditional, nation-state based systems of authority, emphasising additionally: individual and collective arrangements and responsibilities amongst farms and businesses in sectors and supply chains; as well as transnational systems of regulation.

The open internal borders within the European Union and the variable exercise of external border controls reduce the capacity of any European nation to keep out diseases of animals and plants on its own [17]. European regulatory frameworks on animal and plant diseases are nested within international frameworks which determine what organisms and products can be denied trade access and under what circumstances, without contravening the rules of the World Trade Organisation. International plant health protocols, for example, compile lists of harmful organisms, principally pathogens that have spread beyond their centres of origin causing disease elsewhere. However, many of these ‘newly escaped’ organisms were previously unknown to science and were not therefore on any international list before they escaped and began to wreak havoc, including Dutch elm disease, sudden oak death, phytophthora and box blight in the UK [18].

As this brief overview has illustrated, the spread of animal and plant diseases is heavily influenced by human behaviour in direct and indirect ways. Human-induced globalisation and climate change are increasing the spread of disease, both separately and in conjuction. Disease organisms may be transported more easily as a result of extended trading systems, but they may also find more favourable conditions for reproduction and transmission as a consequence of global warming. Not just in relation to disease incidence, though, but in disease management also, one can see parallel interrelationships between the natural and social aspects. The regulation of animal and plant diseases is a fluid and multifaceted collection of impacts and management responses. We now review some of these impacts and responses, demonstrating how scientific understanding of disease spread must be understood in the context of human responses to disease threats.

Regulatory relations of infectious diseases

The management of disease takes place within regulatory frameworks set out by national governments and intergovernmental organizations. In the UK, there are different regulatory frameworks for animal and plant diseases, partly reflecting biological differences between the two. For example, there are many more species of plant farmed than livestock. Key crop species and threats vary depending upon geography and climate, making a global shortlist of crop threats less relevant, and favouring local risk analysis as a means of identifying national priorities [10].

However, there are also historical political factors affecting the ways that plant and animal diseases are dealt with. Animals are high-value investments relative to crops, which may account for the greater protection afforded against animal disease historically [10]. Over the past 150 years diseases have been controlled for a whole variety of different reasons, including protecting the nation’s reputation abroad, lobbying by livestock breeders, safeguarding public health and avoiding disruption of trade [19]. The political imperatives to control disease have important consequences for the governance structures that are put in place to regulate trade and monitor and combat diseases [20]. The ways in which different attitudes towards animal and plant diseases are manifested in different political and policy regimes are summarised in Table 1.

	Plant	**Livestock**
Government Intervention	Government does not compensate affected producers, but covers costs of testing, surveillance etc.	Government currently covers costs of disease control for exotic diseases plus compensation for some endemic diseases.
Industry Cohesion	Agricultural sector strong, with industry-led trade agreements, and market structures to discourage bad practice amongst producers. Less cohesion in horticultural sector.	Individualistic approach to endemic disease control; poor communication and "free-loading" by producers.
Disease Surveillance	Routine testing and surveillance of regulated plants and plant products (e.g. potatoes). No surveillance of unregulated endemic pests and pathogens.	Routine testing for government controlled (exotic) diseases; poor surveillance for endemic diseases.
Welfare	Apart from some aspects of biodiversity, plant welfare is not a public concern.	Zoonotic risks, animal welfare and biodiversity are important factors in disease control policy.
Professional Expertise	Plant pathologists and plant health inspectors have a low profile.	Veterinarians are a well organised profession and have a relatively high political profile; Chief Veterinary Officer holds considerable legal responsibilities.

Table 1: The different regimes for plant and animal disease in the UK

The regulation of animal and plant diseases should be informed by scientific evidence about the likely spread of diseases and the severity of the animal and plant health problems they pose. Government policy for regulating disease is also determined, however, by the wider impacts that disease outbreaks have upon society and the economy. The differences between the two regimes outlined in Table 1 stem largely from the fact that certain animal diseases are considered to have more detrimental social and economic effects than plant diseases. The following two sections examine more specifically how the social and economic relations of infectious diseases shape the way diseases are managed.

The social relations of infectious diseases

A range of social factors, including consumer concerns, human health risks, concerns for wildlife and risks to countryside users, influence the political and regulatory context for the management of infectious disease. Consumers expect wholesome and healthy food, and food-borne illnesses place vulnerable groups at risk of infection. Certain infectious diseases of animals are controlled because the human health impacts of animal diseases can be severe: approximately 75% of all recent emerging human diseases seem to originate from an animal source [21]. The Foresight report argues that this trend is “likely to continue and to be exacerbated by increasing human-animal contact and a growing demand for foods of animal origin” [21]. There are few direct risks to human health from plant diseases, notable exceptions being mycotoxins produced by some strains/species of *Fusarium*, which also cause head blight in cereal crops.

Consumers are also concerned with the provenance of food and in particular with animal welfare. Indeed, welfare standards in food production and the safety of meat produced by intensive farming methods are among the concerns most frequently expressed by consumers about food [22]. Likewise, with regard to crop production, many consumers express preferences for organically produced food or food grown with minimal chemical pesticides [23]. The use of chemical pesticides continues to rise, however, with Defra estimating that over 30 million ha of crops were treated in 2004, compared with 13.9 million ha in 1984. The rising incidence of plant diseases makes it a matter of urgency therefore that research and development work be done to improve the utility and take-up of biopesticides [24], although there are limits to the protection they can provide [25]. Alternative strategies such as the use of transgenic, disease-resistant crops appear to be a distant possibility due to public concern over genetically modified organisms [26].

An emerging concern, that is beginning to influence government policy-making, is the potential for disease outbreaks to interfere with public use or appreciation of the countryside. There are emerging human health risks, such as the threat of Lyme disease to countryside users which has reached almost 2000 cases per year in the UK. Such risks pose dilemmas particularly regarding sensitive risk communication to inform people of sensible precautions to take without unduly alarming them [27]. On the other hand, risk management responses such as the blanket closure of rural footpaths in a Foot and Mouth Disease outbreak (as happened in the UK in 2001) are now regarded as draconian, in preventing public use of the countryside: FMD poses no significant human health risk, and the rationale for the ban was to prevent the theoretical risk of recreational users spreading the virus [28]. This issue and others, such as serious incidences of E. coli 0157 at farm visitor attractions, highlight tensions between the recreational and productive use of the countryside which considerably complicates the objectives and tactics of disease management. The effects of plant diseases may be less immediate, but, in certain cases, they may have more profound impacts on the enjoyment of the landscape. The outbreak of Dutch Elm disease in the 1970s, for example, brought about the destruction of the majority of mature elms in the northern hemisphere, thus eliminating a prominent and ubiquitous feature of much of the open countryside [8]. The lessons to be learned from the Dutch Elm disease outbreak in the United Kingdom relate not only to the original scientific assessments made but the ways in which these were turned into official policies that downplayed the potential seriousness of the outbreak and failed to comprehend the cultural loss it would entail [29].

The final significant societal influence on government policy for disease control concerns the interplay between wildlife, livestock and society. There is substantial conflict surrounding wild mammals in agricultural ecosystems particularly in relation to the perceived impact of predation and disease on domestic stock. Wild mammals can infect livestock with a variety of diseases, including bovine tuberculosis [30], which has provoked significant conflict between badger conservation and farming groups [31, 32]. Likewise, the increase in deer populations in the countryside is causing discord with agriculture, in part because of the potential for deer to act as sources of infectious disease for livestock [33]. There is a tension between the management and regulation of wildlife for food chain security and that for biodiversity conservation. The former implies the need for a rigid protective boundary around any animal system connected with the human food chain. However, that could militate against the conservation of more ‘natural’ ecosystems, ‘co-produced’ with farming and landscape-level approaches to biodiversity conservation [34]. An analogous situation arises with the interplay between crop or trade plants and natural plant communities, where there is a shared pathogen, as seen for *P. ramorum* and *P.kernoviae* affecting a wide range of host plants in both the ornamental nursery trade and woodland and heathland habitats.

The regulatory context and the social impacts of diseases are inextricably linked. Understanding the importance of societal attitudes and preferences is essential to understanding why attempts to control disease succeed or fail, because seemingly 'irrational' behaviour may undermine the premises or application of policy. This is particularly apparent in the case of public judgements of risk where there is much evidence to suggest that risk assessment in practice draws upon a wide variety of knowledge and experience, of which scientific information may be only a small part [35]. Mills *et al* [9] demonstrate through their comparison of the ornamental and mushroom sectors (for diseases such as *P. ramorum* or Mushroom Virus X) and also the cereal and potato sectors that growers and their consultants make complex assessments of the risk of diseases. These risk assessments are based not only on technical analysis but on intuitive reactions and political judgements also [36].

The consequences of public concerns can be far-reaching in changing political and regulatory frameworks. An example is the recent decision to move from a risk-based to a hazard-based assessment system for chemical pesticides in the EU (the amendment of 91/414/EEC). Risk assessment is based on a combination of the intrinsic properties of a chemical and likely exposure; hazard assessment only takes account of the intrinsic properties. This will have a significant impact on the range of pesticides that can be used. The next section examines shifts occurring in the onus of responsibilities for disease management between the public and private sectors in response to the changing public and political perceptions of the scale and fairness of the distribution of costs involved.

The economic relations of infectious diseases

The second dimension that must be considered is the economic costs of managing disease and how these are distributed. Again, this is linked to, and has an influence on, the regulatory context. The economic impacts of disease are felt in terms of culled animals, damaged crops, lost productivity, loss of international trade, control and compensation costs, and rising food prices. As explained above, animal and plant diseases are treated differently by government and consequently their economic impacts are determined and distributed differently between state and industry.

For plant diseases, the costs of outbreaks are borne almost entirely by producers who receive no compensation from the government. Historically, given that many plant pests and pathogens require expert (often laboratory-based) identification, plant health controls have primarily relied on government plant health inspectors (supported by an extensive Government-funded diagnostic testing programme) intercepting regulated pest and pathogens in order to reduce the likelihood of serious outbreaks. As a consequence, although legislation allows Ministers to pay for the destruction of plants in certain circumstances, Government has not normally relied on compensation to incentivise notification of regulated pests by producers. Should it become necessary to destroy plants in large private gardens, however, plant disease control would become a much more contentious and politicised issue. Such a situation has already arisen in the USA where attempts to control citrus canker in Florida have involved the destruction of trees in residential areas [37].

The costs that growers have to bear from plant diseases are considerable. For example, the Mushroom Virus X disease complex has undermined the viability of the UK mushroom industry, causing losses of over £50 million per annum in recent years [9]. Economic losses to crops from invasive pests are estimated at £4 billion per annum in the UK alone [38]. Sectoral losses of up to £80 million per annum have been estimated if statutory controls were to fail and an exotic plant disease such as ring rot of potato were to become established [26]. Plant pests are a significant constraint on agricultural production, responsible for around 40 per cent loss of potential global crop yields, caused roughly equally by arthropods, plant pathogens and weeds. A further 20 per cent loss is estimated to occur after harvest [38].

Endemic diseases of livestock that do not affect humans, like plant diseases, are left largely to farmers to manage as they choose, within legal limitations focused on public health and animal welfare. There may be a wider industry interest in the epidemiology of these diseases expressed in technical norms; for example, management of mastitis in dairy cows focuses on minimising the levels of immune cells in milk whilst maximising milk yield. One consequence of the absence of external social and political interest in these endemic diseases, though, is a lack of funding for research. A major exception that reinforces government's reluctance to intervene in others is bovine tuberculosis, which government has been seeking to control and eradicate in the UK for more than a century. In 2007-8 Defra spent £77 million – a fifth of its animal health and welfare budget - on dealing with this disease alone [39]. With bovine tuberculosis, payment of compensation appears to have fostered a self-perpetuating reliance on government to manage the disease, with farmers not incentivised to take sufficient biosecurity and precautionary measures [40].

For exotic livestock diseases (FMD, avian influenza, Newcastle disease etc) government conventionally pays for the eradication of the disease and compensation to affected producers. In the case of large outbreaks, this can be a significant expense, as with the 2001 FMD outbreak, where costs of the epidemic were estimated at £5 billion to the private sector and £3 billion to the public sector [41]. A 2008 National Audit Office report cited animal disease outbreaks as one of the reasons why the responsible government department - the Department of Environment, Food and Rural Affairs (Defra) - repeatedly overspends on its budget, while a more recent report highlighted the fact that this leads to shortfalls in other important areas such as animal welfare [42, 39]. The costs involved run on between outbreaks, in the maintenance of surveillance and disease control systems and the capacity to fight future large scale outbreaks, including vaccine banks and levels of mobilisable veterinary staff. These public costs are generally justified in terms of the production, trade and welfare benefits of the disease-free status of UK livestock.

There are wider costs of disease beyond the impact on government and the agricultural sector. This is particularly true for livestock diseases. In the 2001 Foot and Mouth outbreak the economic impact on tourism and rural businesses – caused by footpath closures, disturbing images of ‘funeral pyres’ and appeals from the government and farming groups for people to ‘stay away’ from the countryside - was more severe than the losses to farming [43, 44]. For example in Cumbria, one of the worst affected counties, losses to the tourism sector were £260 million, compared with £136 million losses to agriculture [45]. Moreover, culled-out farmers received compensation for their losses from the government whereas the mainly small rural businesses that suffered losses received no compensation.

The economic impact of plant and animal diseases is inextricably linked to the regulatory context. As the cost to government of controlling animal diseases continues to rise to publicly unacceptable levels, the regulatory framework is beginning to change in order to curb and reallocate these costs. New developments such as the government's responsibility and cost sharing agenda could potentially transform the nature of disease control [46, 47, 48]. Through the sharing of responsibilities, government wants to achieve better management of animal disease risks so that the overall risks and costs are reduced and rebalanced between government and industry. Industry will assume a greater responsibility for developing policy and deciding what forms of intervention might be needed. Producers will have greater ownership of the risks, but will face less of a regulatory burden. This will entail greater attention to farm-level biosecurity, private measures such as insurance to compensate for disease losses, collective preventative schemes within farming sectors and government-industry partnerships to tackle disease. Overall, there will be greater emphasis on farmer and industry responsibilities. This may be problematic because farmers' ability to control animal disease is subject to a range of influences and constraints [49, 50]. Even so, the pace of change is likely to be forced by wider pressures on public expenditure which demand that government prioritise its commitments ever more ruthlessly.

Plant disease management with its history of private sector responsibility offers examples that the livestock sector might follow. Indeed, growers have devised imaginative programmes for biosecurity and crop insurance for major crops such as potatoes. However, the threats posed by horticultural plant imports to growers in general and to the wider environment may call for a more demonstrative response from government. Recently, some horticultural growers have experienced severe financial difficulties, particularly as a result of the ongoing *P. ramorum* outbreak, persuading government to explore the possibility of contributing to an industry-financed hardship fund for seriously affected producers. This may or may not set a precedent. The wider application of responsibility and cost sharing to plant disease, though, would face a number of technical obstacles, quite apart from the reluctance of government to enter into open-ended financial commitments [48]. There are a number of different sectors with different characteristics and disease vulnerabilities. It is also difficult if not impossible to assess the scale of the threat from as yet unrecognised pests and pathogens that could be introduced by unscrupulous or ill-informed traders. This leads to intractable issues about identifying who the risk takers and risk acceptors actually are in different situations and how the responsibilities and costs of risk assessment and management could be shared rationally and equitably between the taxpayer and different trade sectors.

An interdisciplinary approach

All of the emerging threats and challenges described above invite new framings of disease management as the relationship between agricultural production, the rural environment and society changes. It is imperative that debates around disease control take into account their intrinsic biological and physical factors. It is taken as given that we need to have a thorough understanding of the epidemiology of the diseases, the diagnostics available to recognize their presence and the available means of treating them. However our understanding of the biology of animal and plant diseases must also inform and be informed by social science research. As this review illustrates, animal and plant diseases impact upon society in many ways, including through changing landscapes and land use, issues of food security and safety, concerns over animal welfare and ethical food production, and the use of pesticides and GMOs. Societal drivers, in turn, impact upon the conditions for and transmission of disease, ranging from influencing the changing governance and nature of agriculture, food production and trade, to efforts to prevent or control disease outbreaks. The ability to predict future disease risks, taking into account drivers such as climate change, is a fundamental research priority [51].

The management of animal and plant diseases involves important political and economic choices that are more contestable the more the science is uncertain. For example, early in the BSE crisis there was considerable scientific uncertainty about whether the prion could transmit to humans, what the routes and probability of transmission were and the likely extent of mortality. Many persistent, food-borne, public health diseases such as E. coli 0157 are a function of complex, multi-causal relationships operating across food chains [52]. Such uncertainty and indeterminacy demand both interdisciplinary framings in research and holistic governance approaches that can incorporate a broader range of evidence [35]. In the past, policy-makers attempting to deal with disease and the contention it causes have taken a narrow scientific approach, sometimes with disastrous consequences. These experiences have led government to signal its desire to take a more holistic approach. In the 2004 Animal Health and Welfare Strategy, Defra stated its aim to “make a lasting and continuous improvement in the health and welfare of kept animals while protecting society, the economy, and the environment from the effect of animal diseases”. Likewise, Defra’s Plant Health Strategy (2005) broadened the objectives of plant health to include preserving the natural environment for recreation and protecting the country’s natural heritage and ecosystems.

At the same time, policy-makers are beginning to recognise the benefits of a broader range of expertise in decision-making [53]. There has been a drive to incorporate social science into policy to complement the more established sources of natural science advice. Defra has always been a heavy user of science, but the role for social science has been almost non-existent beyond narrowly defined economic and legal advice. Traditions of social science research in this field are much weaker than natural science traditions. With the exception of economic analyses of disease control and political science accounts of policy-making, social scientific research into the management and impact of infectious plant and animal diseases has been marginal [54, 55]. The lack of conceptual frameworks for analysing disease as an economic or politico-social phenomenon has been blamed on the tendency for veterinarians to claim animal health as their field of expertise [56]. There is also an increasing demand for stakeholder engagement with the policy process. For the international regulation of plant health, arguments have been made that the full knowledge base should be called on, involving a broader stakeholder community than regulatory scientists and policy makers [57]. A role here for social scientists may be to provide robust tools for stakeholder identification and analysis to enable effective participation in disease management.

A 2006 report by Defra’s Science Advisory Council identified the various potential contributions of social science evidence, including: setting strategic direction; identifying policy need (i.e. key needs and drivers); providing evidence on the likely impact of policy changes; policy implementation (assessing how to engage people); and policy evaluation (evaluating the impacts of policies once implemented) [58].

Moreover, the Science Advisory Council identified examples of 'big social science challenges' central to Defra's main policy objectives, including: combating and adapting to climate change; promoting customer focused sustainable farming; managing food/farming/environmental risk events while avoiding panic; and changing stakeholder behaviour in relation to biosecurity [58]. Although recognising that social issues are integral to current policy objectives and that social scientists can provide important evidence for policy formulation, the Science Advisory Council also acknowledged that a rigid separation of natural and social science was not conducive to effective policy-making. The report argued against an "end of pipe" role for social science, whereby it exists solely to make natural scientific developments more publicly acceptable. Instead the Science Advisory Council suggested that "Social science can be relevant and useful to Defra in clarifying and refining the processes through which natural scientific evidence is itself generated and interpreted. In particular, it can assist in making more robust the shaping, framing and prioritising of scientific research, as well as the analysis and policy interpretation of uncertainties, divergent views and gaps in knowledge" [58]. Defra's own ten year Forward Look recognised the interrelationship between scientific developments and societal reactions, and the role of interdisciplinarity in managing this interrelationship, stating that "Mixed and variable public attitudes to the roles and applications of science and technology will remain a major driver for our science policy for the foreseeable future. This will be shaped by broader social trends (e.g. in attitudes to risk, ethical and privacy issues) coupled with increasing aspirations towards public accountability and democratic control of the direction of development of science and technology" [59, 60].

True interdisciplinarity means not only that scientists and social scientists work together but that both parties have a role to play in problem formulation, strategy formation and problem solving. This requires a willingness on the part of each to familiarise themselves with the others' scientific literature and vocabulary so that a meaningful exchange can occur. Collaboration with the social sciences can bring different perspectives and methodologies to help reframe problems, or indeed reveal multiple or disputed understandings and thus expose diverse possibilities and alternative meanings [61]. In the context of infectious disease, this means challenging the artificial barriers that are created by governmental institutions and research cultures, including the divisions between plant and animal diseases, between diseases that affect agricultural production and those that do not, and between endemic and exotic diseases. Transcending the social/natural science divide thus throws open the field of inquiry and the range of possible solutions. Inevitably, therefore, there are diverse approaches to interdisciplinary collaboration [62]. The papers in this theme issue illustrate the range of possible ways for natural and social scientists to work together.

Contents of this issue

This theme issue sees the pairing of many different disciplines in a set of papers that address many of the most pressing issues in animal and plant disease management. The papers by Woods [20], Enticott *et al* [63], and Potter *et al* [8] demonstrate the value of introducing historical perspectives upon contemporary problems. In Woods' paper, the history of animal disease management is traced in order to improve our understanding of contemporary disease control policy, its determinants and its deficiencies. Importantly, it demonstrates the limitations of the sciences to provide solutions to problems that have an inherently political and economic character. Enticott *et al* [63] make a complementary argument about the changing use of disease expertise as the privatisation of the veterinary profession leads to a weakened capacity for state intervention in disease control. Potter *et al* [8] adopt a rather different approach to historical data, by using models of the Dutch Elm Disease epidemic of the 1970s to understand the current *P. ramorum* outbreak both in terms of its likely epidemiology and the social and economic effects that a large-scale tree disease outbreak will have. The paper highlights the relationship between scientific information and government's capacity to respond, a theme which also occurs in the analysis of endemic livestock diseases by Carslake *et al* [49]. The latter paper brings together a scientific analysis of the differing threats posed by a range of endemic cattle diseases with a political model of governance options, to show that policy responses are not always appropriate or proportional to disease risk. Together, these papers offer a critique of prevailing approaches to disease control that fail to take adequate account of the full range of scientific knowledge available.

The interrelationships between government regulation, industry and trade, and their effects on disease, are developed further by Chandler *et al* [24] who explore the role of biopesticides within an Integrated Pest Management approach, and consider the opportunities and limitations caused by public demand for alternative, non-chemical pest control, and burdensome regulations developed primarily to deal with chemical pesticides.

The communication of risk to the public is a crucial element of any disease control strategy and the effective communication of complex information is explored in three papers in this issue. Strachan *et al* [52] marry an epidemiological assessment of E. coli 0157 risk with a sociological approach that uncovers public perceptions of risk. By combining the two, the paper increases our understanding of the correspondence between disease risk and disease incidence. Quine *et al* [27] study the epidemiology of Lyme disease in order to integrate scientific knowledge of the disease with models of risk communication. Their paper looks for ways to prevent disease spread without disproportionate adverse effects on the use of the countryside for work and leisure. Fish *et al* [64] take the issue of risk assessment for a range of diseases and pathogens (Foot and Mouth Disease, Avian Influenza and cryptosporidiosis) and develop a unifying framework to explain how scientific uncertainty across the sciences about disease spread can be incorporated into decisions about control measures.

The last two papers of the issue consider the future of disease, using predictive models to extrapolate future trends. Mills *et al* [9] integrate natural and social science perspectives on risk to compare control strategies for *P. ramorum* and Mushroom Virus X, two plant diseases with the potential to impact seriously on the horticultural sector. Woolhouse [51] reviews methods of predicting the future of animal diseases such as BSE and Avian Influenza as well as the emergence of novel pathogens. The paper discusses the tendency for modellers to focus on particular drivers of change (such as global warming) to the detriment of other potentially important social factors such as civil disruption. Ultimately, then, each paper in this issue illuminates a part of the complex context in which disease outbreaks occur and are managed, and demonstrates the value of bringing multiple perspectives to bear on this inherently interdisciplinary problem.

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