RES-229-25-0016
Decision-making frameworks in management of livestock disease: interaction of epidemiology, economics and politics
"Governance of Livestock Disease (GoLD)"

End of Award Report

- ***Background***

Infectious disease of livestock remains an important problem, in the UK and globally. It is of welfare and financial concern that livestock health is sub-optimal. Some endemic diseases can also affect the health of humans and wildlife. Animal disease can seriously damage both the farm and non-farm rural economies, produce social disruption and impair public trust and confidence in government (Anderson, 2002).

There has been a tendency to perceive livestock disease as a scientific, public health or epidemiological problem. Indeed, the 2001 FMD epidemic prompted considerable interest in the epidemiology of disease in livestock (Royal Society, 2002), and the development and use of appropriate mathematical models (Ferguson et al, 2001; Keeling et al, 2001). However, with hindsight, this epidemic also threw the importance of the economic, political and legal aspects of disease control into sharp relief (Anderson, 2002) and is still the subject of much criticism and debate among many animal health professionals, rural sociologists and economists. These challenges are also true for endemic diseases, but are far more complex because the epidemiological, economic and political impacts are less easy to discern when nothing changes (i.e. the disease is always there), and because the whole system (including farming, meat industry, retailers, government etc.) has essentially developed to accommodate endemic disease.

A better understanding of the interaction of epidemiology, economics, law, regulation and politics in determining endemic livestock disease incidence is critical for the design of more effective policy and regulatory systems to control such disease in the UK. As far as we are aware, this research project was the first of its kind in attempting to bring together epidemiologists, lawyers, political scientists and economists to investigate simultaneously the drivers of endemic livestock disease using their respective frameworks and methodological tools.

- ***Objectives***

We posed four general questions relating to endemic diseases of livestock. Endemic diseases are those that are in the UK all the time, as opposed to exotic diseases, such as foot-and-mouth disease, which are kept out of the UK. Our progress on these questions is described below.

What are the best frameworks for understanding endemic disease control?

One of our key results is the importance of "problem framing" in the management of livestock disease. We find that "problem framing" provides the best conceptual framework for understanding the rationale for a decision maker's choice of endemic disease management. For example, whether a disease is defined as endemic or exotic is essentially driven by policy and political considerations. Once defined as exotic, a disease attracts central government resources to research certain aspects of the disease such as good diagnostics and traceability, and considerable resources are diverted to remove the disease when it comes into the UK. In contrast, endemic diseases generally receive far less funding for research, and attract little government involvement in control: they are regarded as problems for farmers and livestock industry. Consequently, farmers learn to live with them, and adopt management practices that might mitigate their impact, but which might also enhance their persistence. The degree of government involvement in a particular endemic disease management, is, however, determined by the interplay between epidemiological, political and economic considerations. We developed a framework that combined epidemiological modelling (i.e. mathematical descriptions of the processes of disease transmission), economic perspectives (e.g. whether freedom from disease is a public good) and political considerations (e.g. whether the disease affects human health or international trade) to classify diseases.

Bovine tuberculosis (bTB) is the exceptional endemic disease: commanding a high political profile and placing a considerable strain on government resources. A review of the National Archives showed that the involvement of a wildlife species, the badger, has made the disease unusual, in that there are many documents about bTB and very few about any other endemic disease. Essentially, the involvement of the badger has meant

that government has failed to reconcile the opposing, polarised views, resulting in "intractable policy failure". We held two workshops in which both the natural and social science perspectives of bTB were discussed, the aforementioned intractability problem highlighted, and ways forward suggested.

The issue of problem framing is especially relevant to bTB. There are multiple groups who have an interest in livestock disease (the "stakeholders"). However, they approach the problem, singularly, from different perspectives: livestock health, animal welfare, ecological conservation, productivity and profitability, and as a potential political issue. These different perspectives mean that the interpretation of scientific evidence is contested, and that it is difficult to find consensus approaches based on general principles. For example, the precautionary principle suggests that, in the face of uncertainty, decisions are taken to avoid the worst case outcome. In the case of bTB, the precautionary principle results in conflicting recommendations: if conservation is the main concern, it dictates not culling badgers, but from the viewpoint of animal health and productivity, culling badgers is the most pragmatic action.

Problem framing – in particular how different disease impacts are weighted - is also vital to understanding how animal disease will be managed. Diseases framed in different ways may engage the attentions and efforts of different stakeholder groups, be analysed and assessed using different data and indicators, managed using different types of policy and even related in different ways to 'objective' indicators such as stocking density. Exemplary framings include diseases viewed as primarily affecting animal welfare, diseases construed as economic diseases (threats to commercial productivity), those viewed primarily in terms of animal health, and diseases that are zoonotic (i.e. affect human health).

One group of stakeholders missing from the discussions on endemic diseases are the farmed animals themselves. It can be argued, depending on ones beliefs that farmed animals do not have rights when considering management of endemic diseases, however, there are many who would dispute this. We held a workshop on animal welfare to discuss its definition and role in livestock disease control. The legal situation was presented and framed in a presentation on theories underpinning ethical consideration, from utilitarianism to consensus approaches to evaluating animal welfare. A veterinary perspective proposed was that no-one is representing the animal itself and until the animal is given a voice it will probably be abused.

Can we improve the current frameworks?

During the period of the research, the government developed plans to change the way in which livestock disease is managed: the cost and responsibility sharing initiative. The idea is to pass the costs of disease management to the livestock industry, along with greater decision-making control. We contributed two reports to the consultations for this change.

The suggestion was to introduce a regulatory framework (i.e. where government proscribes the rules and conditions, but not the implementation). We suggested that it is prudent for animal keepers (i.e. farmers individually and collectively) to have a significant say in what and how disease is regulated. It is also sensible for the regulation to include all diseases, not only those deemed important by the current framing, so that any new regulatory framework allows diseases to be reframed, i.e. endemic disease is put on a more equal footing to exotic disease. This would require that a new regulatory body would have a budget for research to determine the impact of different diseases, and develop the necessary technologies (e.g. diagnostics and vaccines) for control. Finally, we argued that the structure of cost- and responsibility sharing should be aligned with the information, motives and powers to act of animal keepers; a wholesale transfer of cost and responsibility to individual animal keepers may not produce optimal results if they are not in possession of appropriate information, if significant disease risks are most efficiently monitored or managed collectively, or if government agencies and other significant stakeholders (e.g. other parts of the food industry) lose the incentive actively and appropriately to contribute their specific information and contributions.

What factors determine farmer decision making processes, and what are their impacts?

Patterns of disease (e.g. presence of a disease in a herd) are largely determined by farmer decisions (especially buying and selling of animals). These decisions are made on the basis of many considerations. There are two important aspects of these decisions.

First, movement of animals has different effects on different diseases. A novel aspect of our research was that we considered multiple diseases simultaneously (in contrast to most research and decision-making which treat different diseases assuming away the existence of any potential interaction among them). Selling cows from a herd might be good for one disease (e.g. if they are infected and infectious) and might be bad for another (e.g.

if they are immune). We undertook semi-structured interviews with about 40 farmers to understand, amongst other things, their motivations for decisions. Analysis of these interviews is on-going.

Second, our research reinforces the conclusions of others that farmers acting individually cannot completely eliminate disease from the UK. Some form of collective action is required so that the risks and benefits of disease control are shared in such a way that it is to the benefit of all. This is partly the basis for our conclusion that farmers have to be central to any regulatory or legal framework, in order to develop co-operation to achieve common goals.

How can this understanding be used to drive disease control?

It is too early in our continuing research to provide authoritative recommendations on the most desirable disease control policies. However, we can conclude that any decisions on disease control should not be based solely on the biology of the disease but also on the likely social ramifications. It is also clear that disease (and therefore its control) is determined by the interactions between the natural processes (e.g. biological and epidemiological), and social processes (e.g. economic, political and legal). These interactions are mutually reflexive, i.e. if policy changes, then epidemiology will change, which will in trun prompt policy to change. For example, the (political) decision to eliminate FMD from the UK in 2001 had a great (epidemiological) effect on the incidence of bTB, which has affected the (political) policy on bTB.

- ***Methods***

A description of the methods used by each subject is given here. The interaction is presented in the Interdisciplinary section.

Epidemiology

Epidemiological modelling: Carslake et al. (2011)

We developed large-scale individual-based (stochastic) simulations for the 115 farms, parameterised from British Cattle Movement Scheme data, so that we were able to recreate the exact demography and movement of animals into (including birth) and out (including death) with precise timing. Within this framework, we simulated transmission dynamics of three infections: bovine viral diarrhoea virus (BVDV), infectious bovine rhinotracheitis (IBR), and Johne's disease (*Mycobacterium avium* subspp. *paratuberculosis*). The transmission parameters were constant across all farms, providing a null hypothesis that farms are identical (with respect to these diseases), although farms were categorised as dairy or beef, as farmer decisions and drivers for behaviour are different. Note that these infections were chosen as exemplar pathogens covering a range of biological dimensions (e.g. viral & bacterial) and epidemiological dimensions (e.g. acute, short incubation period vs. long carrier state). They are also important endemic diseases in terms of welfare and productivity. We were able to compare the outcome of the simulations with the data that we had previously collected.

National-scale modelling: Vernon et al. (in preparation)

The type of modelling outlined above was extended to the entire cattle industry of Great Britain, tracking over 70 million movements of over 30 million bovine animals. The model was stochastic and fully individual-based such that the infectious status of each animal could be simulated.

Data Analysis: Carslake et al. (in preparation)

We embarked on an analysis of our data to determine if the five diseases for which we have data were linked. This was intended as a minor task, but turned out to be a major undertaking, which will be submitted for publication early 2011. The epidemiology of different pathogen species may be linked either through direct processes (e.g. infection of an individual with one pathogen influences the susceptibility to another), or through environmental and management processes that influence them commonly (e.g. transmission increases with increasing density). Such interactions have implications for management, because measures taken to control one pathogen would have unintended effects on others. Studies of multiple pathogens have often produced conflicting results, or not analysed rates of co-infection at all, perhaps because of statistical difficulties such as multilevel data, confounding factors, and the need to make an often arbitrary distinction between dependent and independent variables. We developed a multivariate multilevel method that solves many of these statistical

problems and apply it to serological data collected from 64 beef and 56 dairy herds in the south west of England.

Economics

We conducted semi-structured interviews with about 40 farmers in south-west and central England. We developed two econometric models using the Farm Business Survey for England and Wales. First, a model of moral hazard and adverse selection problems in livestock-disease related compensation Schemes (the case of bTB) (2002-2007). Second, we developed a model of the determinants of demand for preventive and therapeutic veterinary interventions among livestock farmers (1980-2007). We developed game- and network-theoretic models to understand the interaction between farmers' behaviour and the spread and persistence of endemic diseases.

Politics

We conducted semi-structured interviews with relevant actors inside and outside government. Substantial archival work using the National Archives on the development of animal disease policy and the role of vets within the civil service was carried out. Time was spent inside the DEFRA animal welfare team on a period of secondment.

Law

We held collaborative discussions and workshops on cost and responsibility sharing and European perspectives on animal health and welfare with Professor Marcou and colleagues (University of Paris 1 Sorbonne) and DEFRA representatives amongst others.

- ***Interdisciplinarity***

The project team met monthly to discuss specific research topics. These seminars were led by the post-doctoral researchers, and organised by Dr Justin Greaves (PDRA Political Science). Typically, a paper from a particular discipline was presented and then discussed emphasising disciplinary differences.

We held a training day for the team, facilitated by Dr Caron King (KingswoodPlus).

We wrote several articles on our experiences of interdisciplinary research (e.g. Greaves & Grant, 2010).

- ***Results***

Our research affirms the conjecture in the original proposal. Endemic and/or exotic livestock disease unfolds in a complex adaptive system in which the different spheres interact reciprocally. For example, disease epidemiology on a farm will affect farmers' disease management and biosecurity practices, which in turn affect the epidemiology of disease on many farms and resulting market impacts and which ultimately influence political response to disease via public sector and non-governmental organisations (such as National Farmers Union and Royal College of Veterinary Surgeons). Government responses to disease include the development of legal frameworks that eventually affect disease patterns and their market, welfare and epidemiological consequences. Consequently, the observed state of the system (epidemiology, politics, law and economics) is a consequence of multi-level complex, interactions.

One of our key results is the importance of "problem framing" in the management of livestock disease. For example, the definitions of which diseases are endemic and which exotic are essentially driven by policy and political considerations. The definition is as much political as it is to do with the pathogen; for example, if the public health implications of Johne's disease were perceived to be important, its political importance is raised, and if is perceived to be just a disease of cattle, its profile is lowered. Industry, scientists and policy makers might all have a different agenda for emphasising or dampening down the likelihood that Johne's disease is zoonotic. Scientific evidence is generally contested within such a debate, and the results used to (attempt to) reinforce the stakeholder's agenda.

We developed a model that includes the important drivers for determining the political profile of a disease, for example, is it zoonotic (i.e. can cause disease in humans) (see Carslake et al., 2011). We also developed a

framework that combines the epidemiological modelling (i.e. mathematical descriptions of the processes of disease transmission) and political considerations (e.g. whether the disease affects human health or international trade) to classify diseases. As far as we are aware this is the first attempt to understand the interaction between epidemiology and politics in terms of determining the pattern of disease and approach to control (Carslake et al., 2011).

Epidemiology

The results of the simulation modelling are presented in Carslake et al. (2011). They demonstrate that the epidemiology of the three pathogens (i.e. BVDV, IBR and MAP) is determined by different aspects of within and between farm processes, which has economic, legal and political implications for control.

The national scale model was used to assess how the epidemic potential has varied from 2000 to 2009 as the pattern of movements has changed in response to legislation and market forces. Our simulations show that the majority of policy changes lead to significant decreases in the epidemic potential (measured in multiple ways), but that this potential then increases through time as cattle farmers modify their behaviour in response. Our results suggest that the cattle industry is likely to experience "boom-bust" dynamics, with the actions that farmers take during epidemic-free periods to maximize their profitability likely to increase the potential for large-scale epidemics to occur.

The analysis of co-infection, after adjustment for confounding factors including age, breed and herd size, showed significant positive associations within samples in dairy herds between MAP and BHV, NC and LH and between BVDV and NC. There was a significant negative association between NC and LH Within a sample in beef herds, there were significant positive associations between BVDV and LH and MAP and NC and significant negative associations between BVDV and BHV within samples. The mechanisms behind these within sample associations remain unclear, but may include immunosuppression by one pathogen or unmeasured individual variability in general susceptibility to infection.

The significant associations between the endemic cattle pathogens studied suggests that there is indeed potential for pathogen-specific management interventions to have unintended consequences for other pathogens. We consider how the statistical analysis of co-infection can contribute to disease management, stressing the importance of distinguishing associative processes operating at different levels, and of considering patterns present both with and without confounding factors.

Interestingly, there appears to be no strong relationship between an animal's fate (i.e. whether an animal is kept, sold or slaughtered) and its endemic disease status. Whilst this is counter-intuitive, it does explain why these diseases persist. It also suggests that infectious endemic disease is a secondary consideration to other (esp. economic drivers) in cattle management – a hypothesis that we are exploring in analysis of the semi-structured interviews (see below).

Politics

Examination of the National Archives (including those in Scotland) for documents relating to animal health revealed that whilst there is considerable material relating to bovine tuberculosis (bTB), but very little on any other specific disease (Grant, 2009). The failure to eliminate bTB from the English and Welsh cattle herd represents a long-term intractable policy failure. Cattle-to-cattle transmission of the disease has been underemphasised in the debate compared with transmission from badgers despite a contested evidence base. Archival evidence shows that mythical constructions of the badger have shaped the policy debate. Relevant evidence was incomplete and contested; alternative framings of the policy problem were polarised and difficult to reconcile; and this rendered normal techniques of stakeholder management through co-option and mediation of little assistance.

We worked with stakeholders (particularly DEFRA) to better understand how policy is framed and developed. This led to development of a "political disease model" from which we hope to understand better why diseases are classified by governments as different sorts of problem.

Economics

Our research into the economics of endemic disease of livestock has developed in four directions. First, we have analysed the influence of government compensation attitude to risks and risk management, in particular focussing on the problem of "moral hazard" and adverse selection problems and how it might influence

endemic disease epidemiology. We find no conclusive empirical evidence of risk-related moral hazard and of adverse selection problems. These results suggest that the existing compensation scheme does not distort farmers' incentives in ways that helps spread bTb, and, consequently, compromises the government's disease control objectives.

Second, we have modelled the determinants of annual total and of per livestock unit preventive and therapeutic veterinary expenditures among livestock farmers in England and Wales. We find that farmers' expenditures on both total and per livestock unit preventive and therapeutic services are proportional to the size of their herds; that both total and per livestock unit preventive and therapeutic veterinary expenditures in the previous period persist into current period expenditures suggesting the existence of state and/or path dependence; that time-invariant unobservable farm-specific factors help explain differences in the amounts of these expenditures among farms; that there are economies of scale per livestock unit veterinary expenditure suggesting that farmers with larger herds experience lower average veterinary cost; that neither net farm income nor farm net worth appear to improve the fit of total and per capita per livestock unit veterinary expenditure models suggesting that livestock farmers consider these expenditures as necessities in their enterprise and thus ring-fence these expenditures from temporal fluctuations in income and net worth; and that there are random temporal variations in the amounts of these expenditures that are neither accounted for by farm characteristics nor by exogenous factors.

Third, we have continued to develop a game theoretic understanding of how farmers (and other stakeholders) interact, both in terms of disease control and also information. These models indicate the significance of farm and market contact structures (e.g. their clustering and other network topological aspects) in determining the risk and time-path of outbreaks; the models also address the reciprocal influence of disease on contact and movement patterns and find that disease- or market-induced changes in patterns of contact and movement can help to isolate disease outbreaks and moreover induce a second threshold in terms of infectivity (with fixed contact patterns, there is a distinct th4reshhold above which an outbreak of exotic disease will spread throughout the network; with endogenous variation in contact patterns there is a second threshold above which exotic disease will become endemic); the same analysis can explain cyclical fluctuations and the spontaneous emergence of a 'stratification' of the national herd into high-prevalence and low-prevalence clusters. A further extension of the model considered the adoption and spread of conventions of biosecurity and other disease management strategies and their interaction with disease outbreaks and transmission and with changing contact and movement patterns. As above, the combination of these effects produces results strikingly different from the 'isolated' analysis of the spread of conventions (in particular, patterns of disease management may be stabilised that are neither efficient nor 'risk dominant' – the criterion for stability in a fixed network – suggesting that polices that delay changes in contact patterns and reward or penalise departures from local norms can 'seed' more effective disease management even with cost and responsibility sharing targeted at individual farmers.

Fourth, we conducted semi-structured interviews with ~40 farmers to gather data on their motivations for disease control. These interviews will provide us with data to test our hypotheses and develop our frameworks, in which farmer behaviour turns out to be a critical process. The analysis of these interviews is still ongoing.

Law

The legal regulation of animal health and welfare was a primary focus of the legal aspects of our research and this developed in two ways. First, we considered the value of "independently regulated" bodies that were considered by DEFRA in their 2007 Consultation Paper as part of the Animal Health and Welfare Strategy (2007). We provided a response to the Consultation Paper and discussed the different forms of regulation that might be appropriate. Second, in collaboration with the social and natural sciences we adopted a problem focused approach to regulation found in our research methodology. We considered how really responsive regulation is relevant to engage regulatory problems within a framework that is both flexible and sufficiently robust to address the needs of enforcement and compliance. Placing emphasis on enforcement and compliance gives really responsive regulation the appropriate framework for evaluation in taking forward animal health and welfare strategies. The methodology adopted in our research provides an interdisciplinary study away from the traditional emphasis on state focused hierarchical command and control forms of regulation to a paradigmatic shift in favour of a reflexive precautionary approach to regulation to tackle disease through an innovative cost sharing principle. Cost sharing is likely to mean that livestock owners gain financial responsibilities that were hitherto largely held by government through subsidy and support. This will empower livestock awareness but also require a much more open debate and informed decision-making; a substantial departure from the lobbying

stance taken by stakeholders in the past. Co–regulation centred around problem focused on inter-disciplinary collaboration will enhance science led solutions. This is hoped to ensure effective compliance, the operation of competitive processes and networked frameworks for the engagement of various stakeholders. This interdisciplinary has, not only, combined political science, law, and economics, but also, uniquely brings together epidemiological and other factors. The disciplines have combined in our analysis of six animal diseases. This is in the overall context of animal health and welfare taking into account that the management of one disease may impact on another. It is also a means of engaging with the EU Animal Health Strategy 2007-13 The England Advisory Group has recommended a Partnership Board. Implementation of this proposal will have to take account of the findings of our research in terms of building a partnership between stakeholders and engaging in addressing the public interest in an accountable and transparent way.

Interdisciplinarity

The interaction between natural and social scientists led us to discuss the philosophy of science, in particular the similarities and differences between social and natural science, focusing on three issues: the problem of agency, the experimental research design and the individualistic fallacy. It is argued that interdisciplinary research can be fostered through shared understandings of what constitutes 'justified beliefs'. We also related our understanding of interdisciplinarity (and interdisciplinary problems) to complexity science.

The project's monthly research meetings have acted as research material for Dr Keith Richards (Centre for Applied Linguistics, University of Warwick; http://www2.warwick.ac.uk/fac/soc/al/staff/teaching/richards_k), who is researching interdisciplinary discourse.

- ***Capacity-Building and Training***

We held a day (6th July 2009) training session with Dr Caron King, a change consultant and business coach (see http://www.kingswoodplus.co.uk/index.asp), specialising in 'practical, measurable methods of improving individual, team and business performance'. This was designed to look at the vision of the project, how we work together, our interaction and understanding of stakeholders and the way we organise and operate our meetings. Team members completed and analysed Belbin team role questionnaires. Sam Mason (data technician) attended a RELU data management session.

Dr Habtu Weldegebriel attended ISSTI Masterclass on Interdisciplinarity, 22-23rd April 2009, Edinburgh. Dr Carslake presented research from the project at the British Ecological Society annual meeting (2009 and 2010). Dr Weldegebriel presented research from the project at the International Symposium on Veterinary Epidemiology and Economics (ISVEE XII) in Sept 2009. Dr Justin Greaves presented work on interdisciplinarity at the BBSRC CEDFAS conference May 2009. Drs Carslake and Weldegebriel presented at the Society for Veterinary Epidemiology and Preventive Medicine (SVEPM) annual meeting April 2009, during a pre-conference workshop that we ran.

- ***Outputs and Data***

The publication process from the project is continuing. We are in advanced discussion with publishers to finalise a contract to produce a book (tentatively titled *Governance of Livestock Disease*). As well as academic publications, we also contributed 4 responses to government consultations, and believe that these had some impact on development of policy (although cannot document this). We believe that the impact of this project will be only fully realised as the government structures and implements its cost and responsibility sharing framework.

The responses to our semi-structured interviews with farmers have been offered to for archiving. Additionally, we have offered the epidemiological data that were collected prior to the current project, as these were used within the current project. These data were collected and analysed with funding from DEFRA and BBSRC.

- ***Knowledge Transfer, User Engagement and Impacts***

Engagement with stakeholders, especially DEFRA, was a principal component of the project. Professor Wyn Grant work-shadowed in DEFRA were he spent spent May 2009 working in the animal welfare team. He was able to attend a wide range of meetings and was asked to write a paper on the topic of animal welfare labelling. He has provided a separate report on this activity to RELU. Dr Cave is in negotiation with DEFRA to work-shadow in their economics team.

Professors Laura Green and Wyn Grant visited Australia (Nov 2008 and Feb 2009 respectively). They met with major stakeholders in the livestock industry of these countries, and presented some of the project work in seminars and invited presentations.

We have run open access 3 workshop / seminars that attracted significant non-academic stakeholders: animal welfare policy (6th May 2009), Bovine Tuberculosis: People, Politics and Culture (12th May 2010), and Bovine Tuberculosis: Hosts, Pathogens and Environments (13th May 2010).

We have run 2 workshops by invitation only, and held under "Chatham House rules" to enable full participation, especially by DEFRA personnel: Anglo-French Seminar on Animal Health and Welfare (3-5 June 2010) and Cost and Responsibility Sharing (22 October 2010).

We took a full part and leading role in a RELU workshop on Animal and Plant Disease (DEFRA Innovation Centre, Reading, Sept 2009). We presented our project to about 12 DEFRA policy personnel in Nov 2009.

- ***Future Research Priorities***

Currently, the UK government is considering how to implement cost and responsibility sharing. It is highly likely that the legal framework introduced (whether it is regulatory or not) will operate differently in the devolved administrations, especially Scotland. The Scottish Government has already shown a distinct policy agenda, for example, by emphasising endemic disease and introducing central subsidies to persuade industry to eliminate bovine viral diarrhoea. A potent topic for future research would be how industry and farmers respond to the new arrangements and diversity between administrations.

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