BLUETONGUE - CONTRACT RESEARCH FUND FINAL REPORT

Project Title:

Assessing the Economic Impact of Different Bluetongue Virus (BTV) Incursion Scenarios in Scotland

Technical Report

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2. EXECUTIVE SUMMARY

Bluetongue virus (BTV) is a significant pathogen of ruminant livestock, carried by midge vectors, that was detected for the first time in England in the autumn of 2007. In recent years, the area affected by BTV has altered significantly with disease occurring in animals across wider parts of mainland Europe and the virus over-wintering in Northern Europe in 2006/2007.

There is a high likelihood that BTV will enter Scotland in the foreseeable future but there is significant uncertainty about many aspects of the disease including a full understanding of how both UK livestock and midge populations will respond to BTV and the effectiveness of existing disease control measures. The possible control measures include vector control, vaccination and movement restrictions combined with surveillance for early detection (*Defra, 2007).* However, despite the knowledge gaps there is a need to consider control strategies for Scotland and, prior to implementation, to evaluate their effectiveness in order to prepare for the possible incursion of BTV. Since the relevant biological information is not yet available, or at best is emerging, this report's economic analysis is based on expert knowledge, assumptions about how BTV will behave in Scotland and an integration of the work through epidemiological modelling.

A multidisciplinary expert panel, including BTV and midge experts, agreed a range of feasible BTV incursion scenarios, patterns of disease spread and specific control strategies. Our study was primarily desk based applying quantitative methodologies with existing models, where possible, and data already held by different members of the project team. We explored the most likely distribution of the disease given Scotland's agricultural systems, unique landscape and climate. We engaged with Scottish Government officials and with livestock industry representatives to help inform decision making and prioritisation of disease control options should BTV spread to Scotland.

The project had strict time and financial constraints and therefore had to be restricted to explore a limited number of possible incursion scenarios against a restricted range of control options agreed with Scottish Government (SG). The range of modelling tools adopted for this research allowed us to pull together the existing data and organise it in the best way to meet the project objectives. The expert panel helped with estimates where data were missing and generally advised upon procedures.

1. Development of feasible incursion scenarios (Objective 1)

The incursion scenarios agreed by the expert panel and the SG advisors were: a) northwards spread of infected midges, with BTV arriving in July 2008; b) northwards spread of infected midges, with BTV arriving in September 2008; c) northwards spread of infected midges, with BTV arriving in April 2009; d) import of infected animals in September 2008; and e) import of infected animals in April 2009. Subsequently, a limited range of control strategies was agreed with Scottish Government. Where possible the impact of the following control strategies was investigated: 1) implementing only the minimal requirements; 2) vaccinating 100% of holdings in a border protection zone (PZ); 3) vaccinating 80% of holdings in a PZ to the Highland Boundary Fault (B/F) line; 4) vaccinating 50% of holdings in a PZ comprising the whole of Scotland and 5) vaccinating 80% of holdings in a 100km PZ around the first identified holding (only applied if the incursion occurs above the Highland B/F line). (A supplementary technical report was produced in June 2008 to include an additional control strategy that involved vaccinating 80% of holdings in a PZ comprising the whole of Scotland.)

2. Development of epidemiological scenarios (Objective 2)

The epidemiological outputs indicated that for most scenarios infection seldom spreads after the initial incursion; only if an incursion occurred via northwards spread in July did outbreaks become more widespread in a substantial number of replicates. If it goes undetected, an import of infected animals is likely to result in large-scale outbreak, regardless of the time of the year when the import occurs. For all incursion scenarios vaccination is efficient at controlling the spread of BTV and widespread outbreaks will usually be prevented in areas using barrier vaccination with high levels (>80%) of vaccine uptake by farms. If random importation occurs then a higher level of spatial coverage at a lower level of vaccine uptake by farmers (assuming this was evenly distributed through the livestock population) is usually effective for disease control. Vaccination also has a marked impact on the longer-term dynamics of BTV. Infection typically dies out within two years if vaccination is used, whereas it persists if only minimal control measures are applied. (It is important to note that 100% efficacy of the vaccine was assumed in the absence of alternative data).

The analysis of Scottish vector data generated maps of suitable habitat for the bog-heathland Scottish biting midge *Culicoides impunctatus*. The northern uplands are at high risk of supporting large *C. impunctatus* populations. The Scottish biting midge is most likely to overlap with farmland, and with domestic ruminants and farm associated vectors in the North West Highlands, along the Great Glen at the foot of the Grampians, and in the Borders. Domestic ruminants overlap with large red deer populations on the Cairngorm plateau, along the Moray coast and sporadically through Highland areas. It is not yet possible to predict how the numbers of farm-associated midge vectors (*C. obsoletus* or *C. pulicaris* complexes) vary across Scotland on the basis of current vector surveillance data, but we outline a future framework for such predictions.

Our knowledge and information base for bluetongue infection is increasing all the time and new information is placed in ANNEX 5. The project call required a restricted focus to BTV serotype 8 however the UK should now be considered at risk from other strains of BTV and vaccination to BTV 8 will not necessarily protect against other strains such as BTV 1 that may reach UK soon. This is discussed in ANNEX 5 (a) with revised information about changes in the currently available tests and the GB capability to provide accurate test results in the face of widespread BTV8 disease provided in ANNEX 5 (b). During the last weeks of the project evidence for the risk of horizontal and vertical transmission of BTV came to light. The economic modelling does not incorporate all this information at this time but it is vital that this emerging information is taken into account when making decisions about how best to control bluetongue in Scotland ANNEX 5 (c).

3. Economics (Objectives 3 & 4)

The objectives of the economic aspects of the work were two fold:

- To develop an economic consequences model for identifying, measuring and valuing direct and indirect socio-economic consequences (costs due to disease control and other consequences) of the virus spreading to Scotland.

- To conduct, under each of the incursion scenarios, an economic evaluation of the strategies available for controlling the disease.

We have based our economic consequences model on the benefits of avoiding the direct and indirect costs of incursion of BTV into Scotland through current (baseline) costs of surveillance and other related activities aimed at reducing the risk of incursion and/or limiting the damage of any incursion. Baseline costs are estimated to be £141m in present value terms over the 5-year time horizon considered.

It is not possible to estimate the probability of each incursion scenario evaluated and these scenarios are in any case just a few of many possible incursions that are not mutually exclusive. This meant that BTV outbreak control options were compared within the specific incursion scenarios.

Benefits of avoiding disease incursion exceeded current baseline costs of prevention in all scenarios evaluated suggesting that the baseline costs are justified. However, without more information about the effectiveness of baseline costs in each scenario it was not possible to investigate this aspect in more detail.

Of the vaccination strategies evaluated, the one that delivered the lowest mean total outbreak losses under almost all scenarios was option 4: vaccinating 50% of holdings in a PZ comprising the whole of Scotland. The only exception to this was in incursion scenario e (importation of infected animals in September 2008) where the lowest mean total outbreak losses depend on vaccinating according to the location of the outbreak (control option 5). The highest mean total outbreak losses are always associated with option 2 (vaccinating 100% of holdings in a border PZ). Under some circumstances, the no vaccination option (1) delivered the lowest mean total outbreak losses. However, given the uncertainties surrounding the probabilities for each incursion scenario and the relatively small differences between the vaccination options, this did not give strong evidence against control by vaccination.

The vaccination strategy results are little affected by variations of up to 5% in the main assumptions, taking worst (95th percentile) or best (5th percentile) epidemiological predictions, whether or not a licence was available for movement to slaughter and whether the outbreak continued unabated or declined from year 3 to year 5. This robustness is reassuring. However, great uncertainty still surrounds the probability and nature of incursions of BTV into Scotland and the relative economic efficiency of alternative prevention and control options.

The separate potential impacts of BTV incursion on the sheep and cattle sectors were studied using an example (incursion a, control option 4). Although direct losses due to an outbreak of BTV (mortality, morbidity, vaccination etc.) were greater for sheep than cattle, these were dwarfed by other direct costs (baseline prevention costs, movement restrictions etc.), which were dominated by cattle associated losses. This result must be emphasised through communication with the Scottish cattle sector.

Direct costs were comparable with recently published estimates from the BTV epidemics in the Netherlands (about £30m per annum). However, direct costs were much smaller than indirect costs (loss of markets, price effects etc.). Although indirect costs are difficult to estimate, our results suggest that they may exceed £70m per annum, reinforcing the importance of investment in baseline costs that reduce the risk and extent of any incursion. (Indirect cost estimates were dominated by reduced demand for beef and hence lower beef prices. The extent of this effect will depend on consumer reaction to news of a BTV outbreak in Scotland. This is very difficult to predict but was assumed to be small at -£0.25/kg (no public health implications). However, a small reaction is magnified by the sensitivity of the beef price to demand change (elasticity) and the large quantity of beef produced in Scotland.) In our study the extreme epidemiological outputs made little difference to the economic assessment of alternative incursion control options based on average epidemiological outcomes. This combined with the results of the sensitivity analysis and the consistency between incursion scenarios is reassuring as it suggests that choice of best control option is robust to the nature and extent of the incursion.

3. INTRODUCTION TO THE PROJECT AND BACKGROUND INFORMATION

3.1 Given that bluetongue virus is circulating in England in autumn 2007, has over-wintered in mainland Northern Europe 2006/2007 and remains widespread, there is a high likelihood that the virus will enter Scotland in the near future. There is significant uncertainty about many aspects of the disease including a full understanding of how both UK livestock and midge populations will respond to BTV and the effectiveness of existing control measures for the disease. Such control measures include vector control, vaccination and movement restrictions combined with surveillance for early detection (*Defra, 2007).* Despite these gaps in knowledge appropriate control strategies must be drawn up as soon as possible and their effectiveness considered in order to prepare for the expected incursion of BTV into Scotland.

The Scottish Government recently commissioned research by Advanced Pest Solutions

(APS) Ltd., IAH and the University of Aberdeen to fill the gaps in knowledge about the biology of Scottish midge populations, their distribution, abundance, life histories and vector competence for BTV. This work will be completed in 2009 and will inform response to BTV in the medium to long term. However, events elsewhere indicate that Scotland must be prepared for a BTV outbreak sooner than 2009/10. Our project team therefore included collaboration between APS Ltd. and others with specialist knowledge of bluetongue to provide the best answers available in the immediate future. The decisions taken in the short term to halt, slow down or confine the spread of BTV in Scotland require economic evidence. Since the relevant biological information is not yet available, or at best is emerging, our economic analysis is based on expert knowledge, some assumptions about how BTV will behave in Scotland all integrated through epidemiological modelling.

A multidisciplinary expert panel, including BTV and midge experts, was set up to agree a range of feasible incursion scenarios, patterns of disease spread and control strategies. Our study was primarily desk based applying quantitative methodologies, existing models (where possible), and utilising existing data already held by different members of the project team. We explored the most likely distribution of the disease given Scotland's agricultural system and unique landscape and climate. We engaged with Scottish Government officials and livestock industry analysts to help inform decision making and prioritisation of disease control options should BTV spread to Scotland. Measures to reduce the risk of incursion or the extent of any subsequent spread imply a decision that should ideally balance additional control costs against the damages to be avoided. Social cost-benefit analysis provided a consistent framework for judging the economic efficiency of control options. Its application in this case required the consideration of relevant control options and the description of the economic damages likely to arise under credible outbreak scenarios that follow from disease modelling. The relevant perspective was that of government, which is interested in all relevant welfare effects related to control and outbreak scenarios.

Objective (i): Development of feasible incursion scenarios

To develop a set of bluetongue incursion scenarios for Scotland based on the available knowledge of the disease – including vector activity, geographical and climatic factors, livestock distribution and movements, and patterns of disease spread elsewhere.

Objective (ii): Development of epidemiological scenarios

To develop epidemiological scenarios for the incursion scenarios, taking into account different disease control strategies.

Combined Objectives (iii) & (iv) Development of an economic consequences model with evaluation of control strategies

To develop an economic consequences model for identifying, measuring and valuing direct (and if possible indirect) socio-economic consequences (costs due to disease control and other consequences) of the virus spreading to Scotland. To subsequently use this model to conduct an economic evaluation of strategies available for controlling the disease for the scenarios developed under Objective (i) above.

3.2 Staff employed on the project: See page 2 above

4. METHODS AND RESULTS

4.1 Description of methodological approaches

Our methodological approaches have been divided between economic methods, incursion scenario methods, epidemiological scenario methods and Scottish vector data methods to ease rapid assimilation. Clearly there had to be considerable overlap between the teams.

Incursion scenarios methods:

Three main routes for potential incursions were identified with agreement from SG and a number of approaches were used to determine which of these potential routes posed the greatest level of risk.

(i) *Wind-borne dispersal of vectors from south-east England, Northern Ireland or continental Europe*: The risk of incursion via wind-borne midges was assessed using ten years worth (1998-2007) of data on wind speed and direction and temperature. These were used to determine the frequency of winds suitable for carrying vectors from potentially infected areas to Scotland.

(ii) *Import of infected animals*: The risk of introduction via the import of infected animals was examined using movements data for 2006 to provide the number of movements to each Scottish county by month.

(iii) *Northwards spread of BTV from south-east England*: The risk of northwards spread was investigated using a model for the transmission of BTV between farms (see **ANNEX 2 (a))**. This was used to predict if and when BTV is likely to arrive in Scotland, following expansion from the current infected area in south-east England, assuming that only minimal control measures were applied. Analysis of climatological data (see (i) above) was also used to assess the risk of incursion if disease foci were to arise near the Scottish border.

More detail on the risk of incursion was added to the analyses by using the relationship between temperature and the extrinsic incubation period (EIP) to predict when and where vectors are likely to pose a transmission risk. This was done by linking an accumulated degree-hour model for the completion of the EIP with temperature data for Scotland.

Epidemiological scenarios methods:

For each of the incursion scenarios considered, the impact of a number of control strategies was investigated:

(1) Implementing only the minimal requirements;
(2) Vaccinating 100% of holdings in a border protection zone (PZ) (see **ANNEX 3 (a)).**
(3) Vaccinating 80% of holdings in a PZ to the Highland B/F line (see **ANNEX 3 (a));**
(4) Vaccinating 50% of holdings in a PZ comprising the whole of Scotland[1]; and
(5) Vaccinating 80% of holding in a 100km PZ around the first identified holding (only applied if the incursion occurs above the Highland B/F line).

For incursions which occur in 2008, vaccination strategies were reactive, whereas for incursion occurring in 2009, they were prophylactic with vaccination taking place in

[1] A supplementary technical report was produced in June 2008 to include an additional control strategy that involved vaccinating 80% of holdings in a PZ comprising the whole of Scotland.

January 2009. In control scenarios 2-5, additional reactive vaccination was applied (at 100% uptake) in a 20km control zone around any infected holding. A total of 21 incursion/control scenarios were considered (see Table in **ANNEX 3 (b))**.

The spread of BTV under each incursion/control scenario was assessed using a stochastic, spatial model for the transmission of BTV in Scotland (see **ANNEX 2 (a)** for a description of the model, including underlying assumptions and parameter estimation). For each scenario 100 replicates of the model were simulated with the initial conditions specified according to the incursion scenario. **Importantly, only a single incursion event was considered.** Each replicate was run for two years, starting in January of the year in which the incursion occurred.

Scottish vector data methods:

Candidate midge vectors for BTV in Scotland include farm-associated members of the *Culicoides pulicaris* and *Culicoides obsoletus* complexes. These have been incriminated by fine-scale overlap of their distributions with outbreaks, by isolation of virus from wild-caught adults in several sites across Europe and by vector competence experiments on UK populations (Carpenter *et al*. 2006). The potential role of the Scottish biting midge, *C. impunctatus* (also a member of the *C. pulicaris* complex) is more difficult to ascertain since this species generally prefers to bite humans and is autogenous – meaning that it does not require a blood meal to lay its first egg batch as an adult. For transmission to occur an infected vector must take a minimum of two blood meals, the first to acquire an infection and the second to pass the infection to a new host. In between these meals, virus must have replicated inside the midge and spread to the salivary glands and the time for this *extrinsic incubation period* depends on temperature. Since the interval between meals depends on the length of the reproductive cycle, the likelihood of transmission is very sensitive to the relative timing of the reproductive cycle and the *extrinsic incubation period*. Since *C. impunctatus* does not feed before the first egg batch, this species must survive to complete a minimum of three reproductive cycles (each taking between 5 to 8 days with around 60% of females surviving each cycle) before transmission can occur. Most midge vectors that feed before every egg batch must complete a minimum of two reproductive cycles to transmit virus.

Though UK *C. impunctatus* populations have been found to have relatively low levels of competence for BTV in the laboratory (~ 0.1-0.2%, Carpenter *et al*. 2006, Jennings & Mellor, 1988), vector species with low competence can still play a large role in transmission if they are highly abundant (e.g. *C. variipennis sonorensis* in North America). *C. impunctatus* is enormously abundant and widespread across Scotland particularly in bog/heathland areas and in the Highlands. Given the overlap of this species with both farm-associated vectors and wild ruminants, it cannot be discounted as a potential vector of BTV or other midge-borne pathogens. Wild ruminant species are considered as a potential reservoir for BTV, with both white-tailed deer (*Odocoileus virginianus*) and pronghorn (*Antilocapra americana*) being susceptible to disease in the US. During the recent BTV-8 outbreaks, fallow deer (*Dama dama*), roe deer (*Capreolus capreolus*), mouflon (*Ovis mouflon* – a wild sheep species) have all tested positive for BTV-8 in Germany (VLA, 2007) – albeit at low seroprevalence in an area with high prevalence in domestic ruminants.

In Scotland, the offspring of sheep bred in the Highlands, alongside wild ruminants (including roe, red, sika and fallow deer) and large *C. impunctatus* populations in summer, are brought to the lowlands areas in autumn, to live alongside cattle and farmland midge species until spring. These practices may provide potentially frequent opportunities for BTV to be transferred between farm-associated and bog/heathland vectors and between wildlife reservoirs and domestic ruminants. Potential interactions between hosts and vectors for bluetongue in the Scottish landscape can be summarised then according to the schematic below (**Table. 1**).

To describe, explain and predict geographic variation in the abundance of different vector species, one would ideally be armed with detailed knowledge of each species' competence levels and breeding site requirements as well as rich seasonal demographic data from many locations (with which to parameterise environmentally-driven statistical and biological models). Such data are largely lacking at present, but are being gathered for all potential vector groups across Scotland as of late 2007 by a parallel RERAD project (lead by APS Ltd).

Table 1 Schematic of the vector and host communities for BTV across Scotland

	Highlands	**Lowlands**
Habitats	Blanket bog and heathland habitat	Mosaic of farmland and semi-natural vegetation
Major hosts	Deer and highland sheep (summer)	Cattle and highland sheep (autumn)
Major candidate vectors	Dominated by *C.impuncatus* (*C.pularis* complex)	Dominated by farm-associated membrs of *C.obsoletus* and *C. pularis* complexes.

This project has provided us with a limited dataset on autumn vector abundance for this study. Given the 'data gaps' above our sub-project objectives were constrained to be the following:

(i) Relate autumn abundance of farm-associated midge vectors across Scotland to habitat and micro-climate variables (within statistical abundance models) with a view to producing predictive maps that indicate approximate levels of abundance of each of the important vector species. Such maps would enable us to estimate variation across Scotland in the ratio of vector to hosts - an important 'ingredient' of R_0 transmission models for vector-borne diseases.

(ii) Map habitat for the Scottish biting midge, *Culicoides impunctatus*. Since *C. impunctatus* is a major biting nuisance to humans, the habitat preferences and seasonality of this species have been relatively well-studied in Scotland. We aimed to extract characteristics of this species' preferred habitat from literature and expert knowledge and to map, qualitatively, the extent of this habitat in relation to ruminant densities and farmland across Scotland.

(iii) Map densities of susceptible hosts including wild ruminants and likely areas of interactions between hosts

Economic methods:

The basic model used for estimating the costs and benefits of BTV incursion and control freedom has been previously used for calculating the direct costs associated with endemic diseases of livestock in Great Britain (Bennett *et al.*, 1999). This spreadsheet model was based on the risk of livestock contracting a disease and associated costs of prevention, treatment and reduced performance. Menzies *et al*. (2002) applied this methodology to estimate the direct costs of cataracts in farmed Norwegian salmon. A spreadsheet model similar to that of Bennett *et al.* (1999) and Menzies *et al.* (2002) was adapted and extended by Moran and Fofana (2007) to account for the cost and benefits of fish disease incursion and control in the UK. The spreadsheet model methodology developed by Moran and Fofana (2007) was applied here to gather all data from the output of the BTV8 epidemiological model, trade, control, monitoring and surveillance costs of animal diseases in Scotland.

In economic terms, a cost avoided from an action is a benefit of that action. In the case of animal disease, the benefits of measures to prevent or reduce the deleterious effects of disease on animals include avoiding costs from the effects of disease, which would otherwise have occurred (Malcolm 2003). The benefits of avoiding BTV incursion in Scotland include both the output losses and control costs (e.g. vaccination costs and movement restrictions) of dealing with an incursion. These were termed the total cost of disease at farm level by McInerney (1996). **It is important to appreciate that these total costs are part of the 'benefits' and not the 'costs' in the following cost benefit analysis. Further explanation of this issue is therefore given in ANNEX 1h.** Our approach to the benefit-cost comparison was to consider the avoided costs of an outbreak as the benefits accruing to surveillance outlays i.e. those expenditures both public and private that are incurred in the hope of avoiding a BTV incursion or reducing its severity. These outlays are the unavoidable costs as they occur whether or not an incursion of BTV occurs in Scotland and are effectively constant across all incursion scenarios investigated. As such they form a benchmark against which to judge the impact of the different incursion scenarios and the alternative controls applied in each case. They also represent the current situation, i.e. emphasis on maintaining freedom from BTV incursion into Scotland.

An insight into the comparison of benefit-cost is to consider a scenario where there is no or limited disease surveillance. Any outbreak (ignoring for now risk and/or frequency of outbreak) incurs a total cost of C_1, consisting of a range of damage impacts across the industry. The implementation of an improved surveillance programme entails eventual outbreak cost of C_2; ($C_2 < C_1$). Any outbreak that occurs with this in place is necessarily identified and curtailed more rapidly. This alternative regime could be one of any number (say n) of configurations of surveillance that mix voluntary and mandatory measures. Surveillance benefits are then denoted as $B = (C_1 – C_2)$: the difference in costs in terms of the severity of the damage of the outbreak as a result of having surveillance in place. If the probability of incursion (and thus total costs $C_1$of BTV are incurred) in any year is R, then the expected benefit in any year as a result of having the surveillance is an expectation $R \times B$.

The costs of implementing surveillance programmes were C_3[2]. With this information a net-benefit estimate ($R \times B – C_3$) could be derived for the surveillance option, or a benefit-

[2] For the purposes of this analysis, surveillance costs are defined as the prevention and control costs incurred by the public and private sectors in advance of outbreak of BTV.

cost ratio for the programme (R x B/ C_3). If there is no estimate of probability of incursion, as is often the case for *ex-ante* evaluations, the benefit-cost ratio can be simply evaluated as B/C_3.

The appraisal of policy options using CBA require the identification of a baseline or status quo scenario against which the costs and benefits of alternative government interventions are evaluated. C_3 in the example provided above can be regarded as the baseline. It is the status quo of the investment which the public and private sectors make in the implementation of surveillance programmes to prevent BTV incursion or to limit the deleterious effects of an outbreak. In order to derive the cost related to investment, a percentage of public sector disease surveillance and control expenditure was assumed to be passively dedicated to BTV. In the private sector, good animal husbandry practices and expenditure on veterinary services are usually not disease specific but are meant to keep any form of disease at bay thus passively limiting the deleterious effects of BTV. The private sector cost estimated in this category was added to the estimated public sector cost assumed to be dedicated to surveillance and control of BTV to provide the total baseline or status-quo cost (see ANNEX 1a for specific assumptions). It was against this cost that all made-up or counterfactual scenarios (see ANNEX 1b for matrix of counterfactual scenarios) costs and benefits of alternative intervention are evaluated.

CBA requires the identification of the full range of costs and benefits associated with animal health surveillance policy actions and their measurement in physical terms. This entails the understanding, measurement, explanation and/or prediction of the impacts of BTV. This stage of the analysis is easier in *ex-post* evaluations and extremely complicated in *ex-ante* CBA due to the risks and uncertainties attached to making forecasts and predictions in this field. In this case, estimating the benefits of avoiding disease with (C_2) and without (C_1) investment in surveillance programmes (C_3) was particularly difficult due to lack of information about the effects of surveillance on the nature and extent of BTV incursions and on the probability of specific BTV incursions (R). We therefore adopted a ‘null hypothesis’ that surveillance would be successful i.e. that $C_2 = 0$ and thus the benefits of surveillance B= C_1 i.e. the total costs of the avoided incursion that would otherwise ensue without surveillance. This overstates the benefits but equally across all incursion scenarios and disease control options. It therefore does not affect the ranking of the alternative disease control (vaccination) strategies assessed.

All costs of a disease (whether baseline costs of prevention or their benefits due to disease losses avoided) are generally categorised into *direct* and *indirect* costs. Direct costs of diseases are the losses that may occur at farm input and output levels. At the input level, the costs are attributable to losses when disease destroys the basic resources of the livestock production process. The total direct cost of a disease is the sum of the production losses (direct and consequential) and the costs of disease control. Consequential on-farm losses include losses due to the fall in stock numbers, restrictions of movement when zoning restrictions are put in place and due to the loss in animal value.

Indirect costs are costs associated with revenue forgone through loss of markets, sub-optimal production methods and additional costs incurred to eradicate diseases. These costs were estimated by simulating the potential impacts on livestock and livestock product prices along the value chains. It was not possible to account for all that should be included in this category due to the methodological difficulties and constraints of this type of analysis and the extensive data requirements. The costs included are the business disruption costs suffered by farmers, cost incurred due to consumer responses and the loss of export revenue due to disease outbreak. There are potentially other losses that would occur along the value chain but to avoid the danger of double counting costs, only potential losses by the final consumer of UK meat and animal products were included.

That is the local final consumers and exports that represent external final consumers.

Monetisation of all impacts was then carried out using assumptions as detailed in ANNEX 1a. The final step consists of computing the net present value (NPV)[3] at the present time using an appropriate discount rate. The flows of costs and benefits associated with disease control measures take place over time. Discounting future costs and benefits is necessary so that all costs and benefits are expressed in a common metric: the present value.

Presentation of data supporting conclusions

Incursion scenarios results:

The results suggested that the epidemiological and economic analyses should focus on five incursion scenarios:

(a) northwards spread, with BTV arriving in April 2009
(b) northwards spread, with BTV arriving in July 2008
(c) northwards spread, with BTV arriving in September 2008
(d) import of infected animals in April 2009
(e) import of infected animals in September 2008

The months selected for northwards spread allow for the likely time of arrival in Scotland (autumn 2008 or spring 2009, following spread and over wintering in 2008). The incursion in July 2008 allows for the possibility that BTV could spread more rapidly than expected and, furthermore, coincides with the warmest temperatures and, hence, the greatest potential for spread. The months selected for incursion via imported animals reflect the peaks in the number of movements for both cattle and sheep. Although such an incursion could occur anywhere in Scotland, three counties (Aberdeenshire, Dumfries and Stirling) were particularly at risk because of the high number of movements to these counties.

One potential incursion scenario worth further consideration relates to Northern Ireland. This currently presents no risk, because BTV is absent. If, however, BTV were to spread to Northern Ireland, this would pose a distinct incursion risk to Scotland. All the remaining scenarios were discounted because they posed at most a low level of risk. These include direct introduction of BTV by wind-borne midges from southeast England or continental Europe (see **ANNEX 2 (b)),** or import of animals at other times of the year. However, this does not mean that these scenarios pose no risk and could not potentially occur.

The accumulated degree-hour EIP model suggested that the seasonal risk of vector-host transmission, a necessary requirement for onward transmission (and, hence, the declaration of a control zone under EU regulations) following introduction, is minimal between December and May-July in Scotland. The duration of the transmission-free period during 2006-2007 varied between 140 days to over 200 depending on region (see **ANNEX 2 (c)**).

Epidemiological scenarios results:

Several features are apparent from the results for each incursion/control scenario (see

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[3] $NPV = \sum_t \sum_i \frac{B_{it} - C_{it}}{(1+r)^t}$ where B is a measure of monetary benefits (element *i* at time *t*), C represents the monetary cost, and r is the discount rate. When all the market costs and benefits are measured in monetary terms, the aggregation is simple: the sum of the discounted value of the total costs over time is subtracted from the sum of total benefits also discounted over time.

ANNEX 3 (b)). For most scenarios infection seldom spreads after the initial incursion; only if an incursion occurred via northwards spread in July did outbreaks become more widespread in a substantial number of replicates. If it goes undetected, an import of infected animals is likely to result in large-scale outbreak, regardless of the time of the year when the import occurs. For all scenarios without vaccination, the pattern of spatial spread for those replicates which take-off reflects the density of livestock in Scotland.

For all the incursion scenarios, vaccination was efficient at controlling the spread of BTV. Prophylactic vaccination was more effective than reactive vaccination in preventing the initial spread of BTV following an incursion. If the incursion occurred in an area that had a high level (>80%) of vaccine uptake, infection seldom became widespread. Consequently, barrier vaccination with a high level of coverage (>80%) had the greatest impact in the case of incursion via to northwards spread. By contrast, a higher level of spatial coverage at a lower level of uptake was more effective in preventing spread in the case of incursion following an import of infected animals (i.e. where it is difficult to predict the location of the initial incursion). (**Vaccine was assumed to be 100% effective in this model given we had no information to contradict this.)**

Vaccination also had a marked impact on the longer-term dynamics of BTV. When only minimal control measures were applied, BTV was still present after two years in a number of replicates for which there was spread following the initial incursion. This was not the case if vaccination was used: infection died out in almost all replicates by the end of the two-year period over which the model was simulated.

Scottish vector data results: (i)Relationship between abundance of farm-associated midge vectors across Scotland and habitat and micro-climatic factors

To date, no relationships could be detected between the abundance of either the *C. obsoletus* or the *C. pulicaris* complex and environmental variation measured across Scotland – probably because the 'snapshot' of vector data currently available covers only the tail-end of the season's adult vector activity. However, the numbers of these two complexes were positively correlated with each other across farms – perhaps providing initial indications that these complexes are responding to similar climatic, host and landscape factors (Figure 3 below). The *C. obsoletus* complex tended to occur in higher abundance than the *C. pulicaris* complex by around 200 individuals.

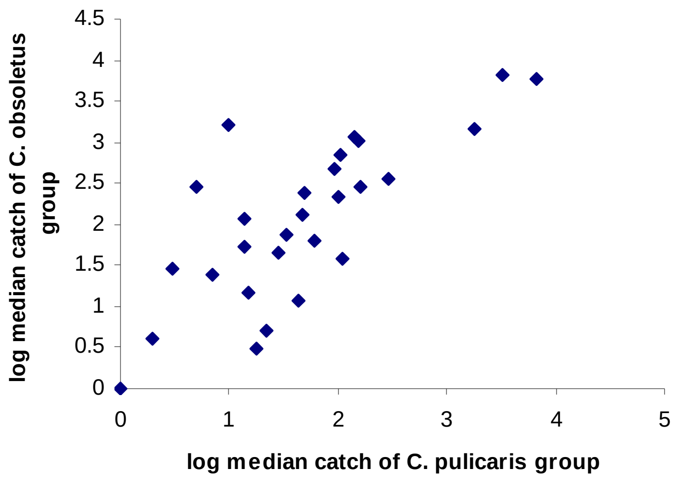

Fig. 3. Relationship between the abundance of the C. obsoletus and C. pulicaris groups across sites.

A future approach for predicting when and where in Scotland substantial populations of competent biting midge vectors may occur is outlined for application to the emerging seasonal datasets for farm-associated *Culicoides* vectors in Scotland (from the parallel RERAD project lead by APS Ltd).

(ii) Coincidence of favourable habitat conditions for the Scottish biting midge, *Culicoides impunctatus*.

Table 2, below, lists the habitat conditions, in terms of the soil characteristics, landcover and vegetation types preferred by *Culicoides impunctatus* according to existing literature. This species generally prefers bog or heathland habitat rather than pasture and acidic soils with high organic and water content. When environmental layers corresponding to these characteristics were overlaid, the north-west of Scotland (Cairngorms, northern Grampians and Wester Ross, southern Skye) and Perthshire could be delineated as being at the highest risk of supporting large *C. impunctatus* populations (having most favourable habitat characteristics) whilst lowland and eastern areas (in Aberdeenshire, the Moray Coast) were at low risk of doing so (**ANNEX 4 (a) i**). Farms were situated in medium to high risk areas *for C. impunctatus* in the north west Highlands, along the Great Glen and at the foot of the Grampians in Aberdeenshire, and in the Borders. These represent areas where 'hand-overs' of BTV may be particularly likely both between farm-associated vectors and *C. impunctatus* and between domestic ruminants and red deer**.** These habitat maps need ideally to be interpreted alongside data on the frequency with which *C. impunctatus* bites large ruminants, can replicate virus to transmissible levels and survive to complete sufficient reproductive cycles for transmission to occur.**(ANNEX 4 (a) ii)**.

Table 2. Habitat preferences of the Scottish biting midge *Culiciodes impunctatus*

Criteria	Preferred range	Literature source	Range of values of layer used as proxy
1. soil: high organic content	>40%	Blackwell et al. 1999 (figs 3 & 4)	>40% (maximum of layer 54.4%)
2. Soil;high water content	>60%	Blackwell et al. 1994, 1999	4:wet or 5: very wet
3. Soil: acidic	pH 4.3-5.4	Blackwell et al. 1994, 1999	PH 4.4-5.5
4. Landscape: high percentage cover of bog and heathland habitats	Bog-heathland land-cover found to be more favourable than drier pasture or marginal areas of bog-land	Kettle & Lawson 1960	Types 25, 26 and 27
5. Habitat: rush – pasture peat communities	National Vegetation Classification M25	Blackwell et al 1994	Not mapped: National vegetation classification data were only available for reserve areas in Scotland
6. Presence of indicator plants	Associated with *Juncus*	Blackwell et al 1994	Increasing richness of these species assumed to

articulatus, J. acutiflorus, Myrica gale, Sphagmun spp.	pose a higher risk of *C. impunctatus* population

(iii) <u>Overlap of wild and domestics hosts for BTV ruminants and likely areas of interactions between hosts</u>

When AgriCensus data were mapped, densities of sheep and cattle densitites are highest in lowland areas in Southern and central Scotland, in the north-east, in Angus and Aberdeenshire border areas and in most northern part of Scotland (**ANNEX 4 (b)**). Within the main range of red deer, domestic ruminants overlap with large red deer populations on the Cairngorm plateau, along the Moray coast and sporadically through Highland areas **ANNEX 4 (c).** Despite low average densities of sheep and cattle in the Highlands, the seasonal movement from the lowlands to the Highlands in spring and the reverse in autumn is of potential epidemiological significance – due to the potential for spread of virus to new areas and the difficulty of monitoring infection and disease in livestock that are ranging more widely alongside deer populations.

Economic results:

A worthwhile investment in BTV prevention (baseline surveillance costs C_3) in each scenario should generate sufficient benefits to at least cover the investment costs. This implies that the net present value (NPV), the expected net benefit (ENB)[4] should be positive and the benefit-cost ratio (BCR) greater than one. In economic terms, the higher the values of NPV, ENB and BCR, the more attractive the investment in the baseline surveillance/prevention costs of BTV. Figures 1a to 2b provide the average current discounted benefits (£m) of avoiding BTV incursion for each incursion scenario (a to e see **ANNEX 1b**) depending on whether the epidemic is constant through years 3 to 5 (**Figure 1a and 1b**) or declines (**Figure 2a and 2b**) and whether a licence is available to move to slaughter (**Figure 1b**) or not (**Figure 2b**). Full details including baseline costs, NPV and BCR are tabulated for each incursion scenario in ANNEX 1c. Within incursion scenario, CBA indicators are of the unweighted (without probabilities of BTV incursion R) options generated from the economic spreadsheet model for all scenarios using average epidemiological outcomes only (extreme cases- 5th and 95th percentiles are reported in **ANNEX 1d and ANNEX 1e** respectively). Since there are considerable uncertainties over assumed probabilities, unweighted benefit cost ratios were used to rank interventions in term of economic efficiency. Results of the weighted scenarios (with estimated probabilities of BTV incursion) are presented in **ANNEX 1f.**

In the following section, some interpretations of within incursion scenarios (a to e) and the control options C1 to C5 are provided in bullet points.

[4] Expected net benefit is equivalent to NPV multiplied by an appropriate probability of incursion.

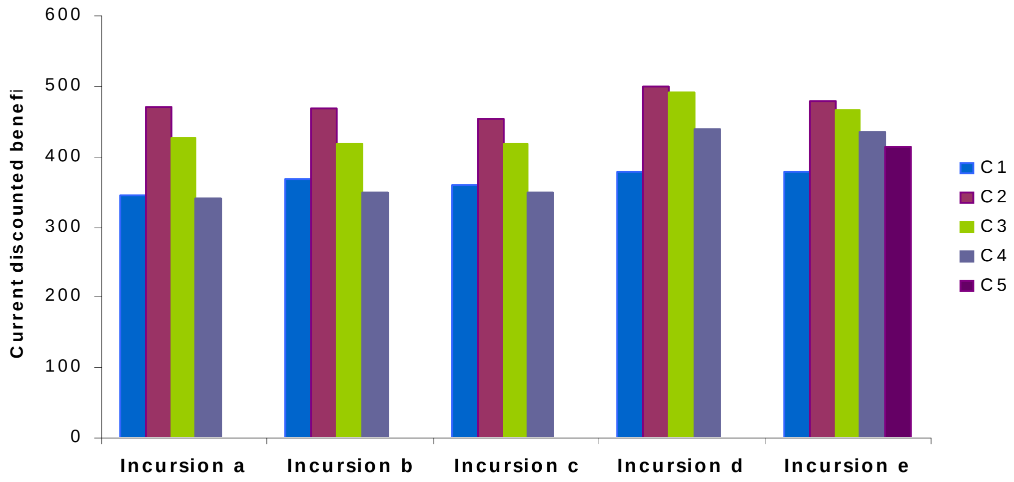

Figure 1a: Current 5-year Discounted Benefits (£m) of avoiding BTV incursions a - e (constant outbreak no slaughter licence)

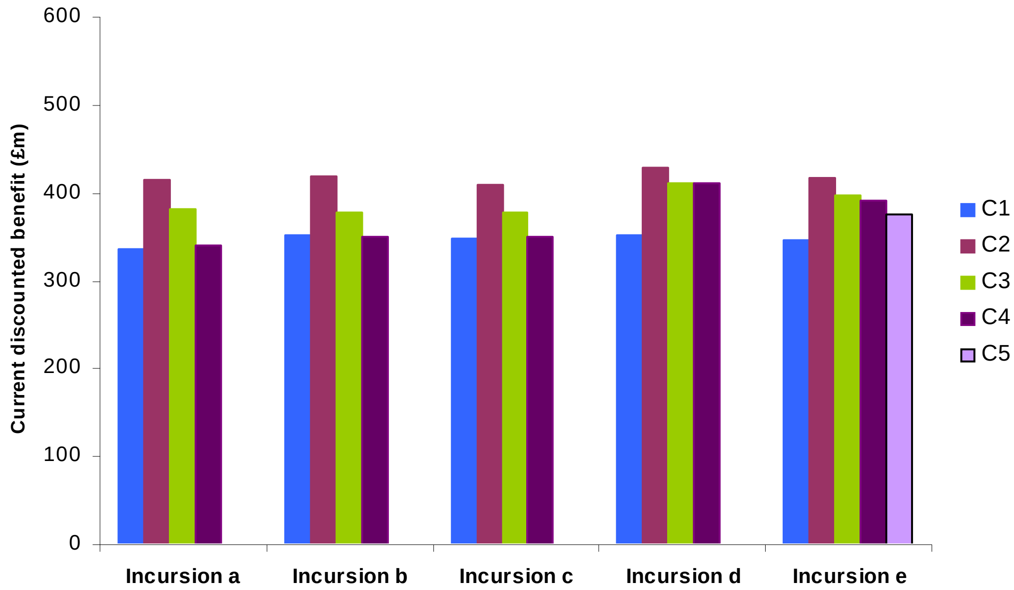

Figure 1b: Current 5-year Discounted Benefits (£m) of avoiding BTV incursions a - e (constant outbreak with slaughter licence)

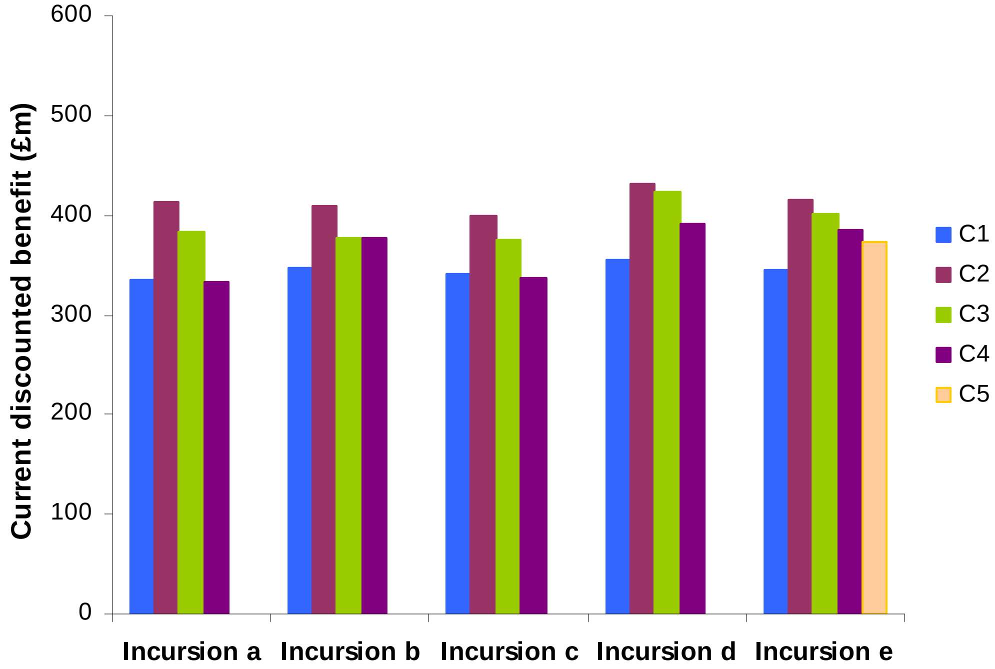

Figure 2a: Current 5-year Discounted Benefits (£m) of avoiding BTV incursions a - e (outbreak dies out no slaughter licence)

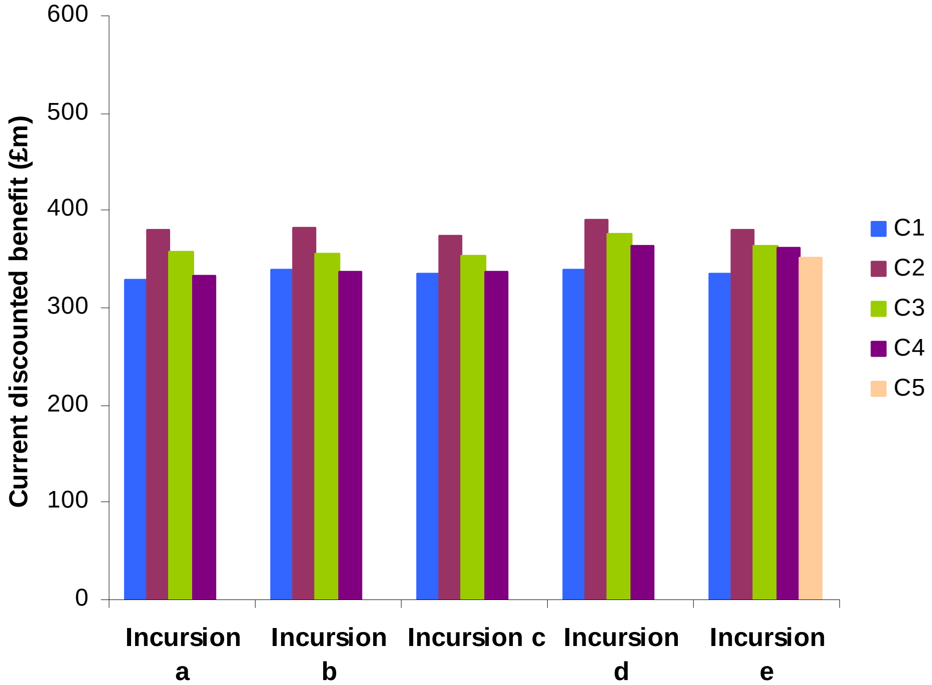

Figure 2b: Current 5-year Discounted Benefits (£m) of avoiding BTV incursions a - e (outbreak dies out with slaughter licence)

KEY for Figures 1 & 2: Control Option 1 (C1) = ‘Do nothing’; Control Option 2 (C2) = Border Protection Zone (PZ) with 100% vaccination; Control Option 3 (C3) = PZ to Highland B/F Line with 80% vaccination; Control Option 4 (C4) = PZ whole of Scotland with 50% vaccination; Control Option 5 (C5) = PZ of 100km around incursion with 80% vaccination within PZ

Within Incursion Scenario CBA Analysis

Incursion a (Midge transmission from south in April 2009)

- Total current discounted benefits for five years ranged between £330m - £471m for all incursion scenarios in a. (see **ANNEX** 1c)

- Scenario C2a yields the highest discounted benefit i.e. the greatest return to baseline surveillance costs C_3. However, as benefits are defined as total disease losses avoided, this control option is associated with the highest disease losses. This means that if this incursion does take place, control option C2 is associated with the highest outbreak costs. (see **ANNEX** 1h).

- The lowest return to baseline surveillance costs C_3. depends on obtaining a license for movement to slaughter. C4a delivers lowest return with no license to slaughter while C1a delivers lowest return with license to slaughter. These options have the lowest (avoided) disease losses (benefits) and their BCRs are therefore highlighted in bold in **ANNEX** 1c.

- **ANNEX** 1g gives a breakdown of BTV costs using this incursion scenario with control option C4 as an example. This is considered by the team to be the most likely incursion scenario (see **ANNEX** 1a) combined with the best control option (lowest benefits i.e. disease losses avoided). In this case the direct cost for sheep is more than £5M and for cattle more than £20M. Notice that although the direct outbreak costs are higher for sheep than cattle, these are dwarfed by the other direct costs, which are dominated by direct costs for cattle. These direct costs for cattle are mainly the unavoidable baseline veterinary and medicine costs (see **ANNEX** 1a). Notice too that indirect costs (lost markets etc.) far exceed direct costs.

Incursion b (Midge transmission from south in July 2008)

- Total current discounted benefit for five years ranged between £338m - £468m. (See **ANNEX** 1c**)**

- As in incursion scenario a, scenario C2b yields the greatest returns on investment in baseline surveillance costs C_3 (highest outbreak losses avoided).

- Unlike incursion scenario a, the lowest return to C_3 (lowest outbreak losses avoided) depends on the duration of the outbreak or the trajectory by which the disease persists after an outbreak as well as on the license position. Scenario C4b gives lowest disease losses avoided (best vaccination strategy) when BTV lingers and causes losses equivalent to year 2 levels up to year 5. C1b does the same when BTV gradually dies out after year 2 with no licence to slaughter. However, C4b remains the best vaccination strategy as C1b is the no vaccination option.

Incursion c (Midge transmission from south in September 2008)

- Total current discounted benefits for five years ranged between £336m - £454m. (See **ANNEX** 1c)

- As in incursion scenarios a and b, scenario C2c yields the most returns to C_3 (highest outbreak losses avoided).

- As in scenario a, the lowest return to C_3 (lowest disease losses, best disease control) depends on obtaining a license for movement to slaughter. C4c gives lowest return to C_3 with no license to slaughter while C1c gives lowest return with license to slaughter.

Incursion d (Animal import April 2009)

- Total current discounted benefits for five years ranged between £339m - £500m.(See **ANNEX** 1c)

- As in scenarios a, b and c, scenario C2d yields the most returns to C_3 (highest outbreak losses avoided).

- The lowest return to C_3 (lowest outbreak losses avoided) in scenario d appeared not to be influenced by either license for move to slaughter or the time trajectory of the disease when an incursion occurs. The lowest returns on baseline costs C_3 remained scenario C1d for all treatment options. However, as this was the 'no vaccination' strategy, C4d remained the vaccination strategy with the lowest disease losses avoided.

Incursion e (Animal import September 2008)

- Total current discounted benefits for five years ranged between £334m - £478m. (See **ANNEX** 1c)

- As in scenario a, b, c and d, scenario C2e yields the most returns on investment in baseline surveillance and control costs C_3.

- As in scenario d, the lowest return to C_3 and therefore the lowest avoided disease losses appeared not to be influenced by license for move-to-slaughter or the time trajectory of the disease when an incursion occurs. The lowest returns on investment costs C_3 remained scenario C1e for incursion scenarios. The vaccination strategy with the lowest returns on investment costs C_3 and therefore the lowest disease losses was C5e.

Summary of 'within' incursion Scenario Analysis

As the relative risk of alternative incursion scenarios is uncertain, it was useful to assess alternative control options within scenarios. The higher a CBA ratio within a scenario, the more favourable is that investment in economic efficiency terms. In all scenarios, the ranking of CB ratios and sum of current discounted benefits indicates that control option C2 (see Figures in the **ANNEX** 1c) yields the most returns on investment. In other words, if the £141m discounted costs of disease prevention are successful and BTV is avoided then C2 would give the greatest discounted current benefits (costs avoided). This means that C2 is associated with the greatest total disease losses. Maintaining the same assumptions but looking at the extreme cases- 5^{th} and 95^{th} percentiles of the CBA (see **ANNEX** 1d and 1e for results) shows that control option C2 again is associated with the highest disease outbreak losses (greatest benefit if avoided and therefore greatest return to C_3) while C1 is associated with the lowest disease outbreak losses (lowest benefit if avoided and therefore lowest return to C_3l). As C1 is the 'do nothing' option the 'cure' is often more expensive than the disease i.e. output losses under C1 must often be less than the total disease losses (lowered output losses plus control costs) under other control options. However, as C4 (PZ all Scotland, 50% vaccination) often provides the lowest avoided costs (benefits) or runs a close second to C1, this is the best vaccination strategy examined. The only exception to this rule seems to be incursion e (animal import Sept 08) where the localised vaccination strategy (C5e) gives the lowest avoided total disease losses.

Sensitivity Analysis

The sensitivity analysis addresses the presence of uncertainty in the CBA based on the key assumed parameters adopted. In essence, sensitivity analysis proposes "what if" scenarios by manipulating certain variables to determine minimum and maximum values of the analytic measures. In this way, the CBA becomes more robust concerning any challenges to its original assumptions. Sensitivity analysis was conducted for the most uncertain parameters used in the CBA analysis. Sensitivity analysis was conducted for changes of ±2% and ±5% for the following parameters: weight loss; milk loss; fertility loss; wool loss; export multipliers for cattle and sheep; own-price elasticities for sheepmeat, beef and milk.

The 'means' & 'q95' & 'q5' CBA:

The sensitivity analysis indicated no change in the CBA ratios for all the three cases (means, q95, q5) when changes of ±2% and ±5% were applied for weight loss, milk loss, fertility loss and wool loss. Again, no change in the CBA ratios when changes of ±2% were applied for export multipliers for cattle and sheep and own-price elasticities for sheepmeat, beef and milk. However, the sensitivity analysis showed a change of ±1% in the CBA ratios when export multipliers for cattle and sheep and own-price elasticities for sheepmeat, beef and milk were varied by ±5%.

4.2 Links/Institutional co-ordination (for projects at several centres).

The project was led by Prof. George Gunn from SAC who is one of the EPIC PIs for EPIC Module 1. This Module includes the subject area covered by the objectives of this current study. George co-ordinated the work of four overlapping teams within the project. These teams were:

Epidemiology Modelling led by Dr Simon Gubbins, IAH Pirbright

Animal Health Economics led by Dr Alistair Stott, SAC

Vector Information led by Dr Beth Purse, CEH

Expert Panel led by Dr Kathy Johnston, SG

The Epidemiology team was primarily IAH based but included staff from the Met. Office.

The Economics team were SAC staff but they liaised closely with IAH staff and both teams worked with BioSS to agree the epidemiology output interface with economics. The Vector team included close collaboration with Advanced Pest Solutions and Macaulay Institute. The vector team liaised closely with the Epidemiology team. The full project was managed through a series of three expert panel meetings and these were organised by Kathy Johnston in liaison with George Gunn. The project staff listed above attended each meeting but was joined by colleagues from Edinburgh University, Moredun Research Institute and Glasgow University in addition to advisors from Scottish Government and ultimately representatives of NFU Scotland and the Scottish Livestock Markets.

4.3 Summary of results

Incursion scenarios outputs

- The most likely incursion scenarios are northwards spread from south-east England or import of infected animals.
- The risk of direct incursion of infected vectors from affected areas in south-east England or mainland Europe is very low, but not negligible.
- If a focus of infection were to become established in the north of England or Northern Ireland, this would pose a distinct incursion risk for Scotland.

Epidemiological outputs

- Under most scenarios infection seldom spread after the initial incursion; only if the incursion occurred in July did outbreaks become more widespread in a substantial number of replicates.
- Barrier vaccination at a high level of uptake had the greatest impact on the incursions via northwards spread.
- However, a higher level of spatial coverage with a lower level of uptake was most effective at controlling an incursion via imported animals.

Scottish vector data outputs

- Maps of suitable habitat for the bog-heathland Scottish biting midge -*Culicoides impunctatus* have been produced. The northern uplands are at high risk of supporting large *C. impunctatus* populations.
- The Scottish biting midge is most likely to overlap with farmland, and with domestic ruminants and farm associated vectors north west Highlands, along the Great Glen and at the foot of the Grampians, and in the Borders
- Domestic ruminants overlap with large red deer populations on the Cairngorm plateau, along the Moray coast and sporadically through Highland areas.
- We could not predict how the numbers of farm-associated midge vectors (*C. obsoletus* or the *C. pulicaris* complexes) – is likely to vary across Scotland on the basis of current vector surveillance data. We outline a future framework for such predictions.

Economics Outputs

- Economic analysis is based primarily on the average discounted benefits of avoiding BTV8 in Scotland due to baseline surveillance costs.
- It was not possible to estimate the probability of incursion under each scenario modelled because the epidemiologists did not believe sufficient information was available to make such estimates.
- Higher economic indicators show best return to baseline surveillance costs. This was always control option C2 (border PZ, 100% vaccinated) i.e. C2 was

associated with highest disease incursion losses avoided. It follows that this vaccination strategy is associated with high total disease losses.

- Assuming the incursion investigated does take place, either vaccination of all Scotland at 50% uptake (C4) or 'no vaccination' (C1) offer the lowest total disease losses (average discounted benefits of disease losses avoided).

- At the extremes of the epidemiological output (95^{th} and 5^{th} percentiles) the lowest average discounted benefits (disease losses avoided) were with control option C1 regardless of incursion scenario, with option C4 usually giving the next lowest disease losses avoided.

- Sensitivity analysis showed no major impacts on the cost benefit analysis results after ±5% change in key assumptions.

5. CONCLUSIONS

5.1 Discussion of main findings and their biological significance

The most likely incursion scenarios are northwards spread of infected midges from south-east England or importation of infected animals. The risk of direct incursion of infected vectors from affected areas in south-east England or mainland Europe is very low, but not negligible and if a focus of infection were to become established in the north of England or Northern Ireland, this would pose a distinct vector associated incursion risk for Scotland. We could not predict how the numbers of farm-associated midge vectors (*C. obsoletus* or *C. pulicaris* complexes) is likely to vary across Scotland on the basis of current vector surveillance data but we outline a future framework for such predictions.

Under most scenarios BTV infection seldom spreads after the initial incursion; only if the incursion occurred in July do outbreaks become more widespread in a substantial number of replicates. From an epidemiological perspective barrier vaccination at a high level of uptake has the greatest impact on the incursions via northwards spread. However, a higher level of spatial coverage with a lower level of uptake was most effective at controlling an incursion from importation of infected animals.

The economic analysis assumes a common baseline unavoidable cost of public and private measures that together contribute to prevention of incursion of BTV8 into Scotland. These costs continue over the 5 year horizon of this analysis regardless of whether or not a BTV8 epidemic occurs in Scotland. The total present value was found to be approximately £141m over the 5 year period. The benefit of this investment is from the avoided costs of a BTV8 outbreak. This will depend on the time, location and nature of the incursion, on the control strategies adopted to counter each incursion, on the persistence of the incursion and on the opportunities to mitigate the damage. Specific variations in all these aspects have been explored. In all cases, control option C2 (Border PZ with 100% vaccination) was associated with the highest outbreak losses. (If avoided this would deliver the greatest benefit from investment in baseline prevention costs. However, in terms of outbreak losses, this vaccination strategy was always most costly.)

To see if the benefits of avoided disease justify the costs of the baseline investment in prevention it is necessary to know the probability of BTV8 incursion into Scotland. However, it is not possible to establish this probability. Control options are therefore ranked within each incursion scenario. Within all incursion scenarios the outbreak losses (average discounted benefits) were minimised with either no vaccination (C1) or a PZ across all Scotland with 50% vaccine uptake (C4). This ranking depends on the incursion scenario, the persistence assumption (declines in years 3 to 5 or persists) and/or mitigation opportunity (license to move to slaughter or not). The vaccination strategy that consistently minimised outbreak losses is therefore C4. The only exception to this is incursion scenario e (Imported animal, September 2008) where the vaccination strategy associated with the lowest outbreak losses was control option C5 (localised vaccination according to where the outbreak takes place).

The direct costs of disease were shown by example to be about £30m per annum, with the major proportion attributed to cattle rather than sheep. This compares with recent analysis in the Netherlands that estimates BTV epidemic damage costs in 2006 at 28m Euro, 25m of this to cattle and 3.5m to sheep rising to 44m and 5.5m respectively in 2007. The greater direct costs in the Netherlands can be attributed to the greater extent of the epidemic.

Although a between incursion scenario analysis was not possible because of the difficulty of estimating the relative probability of each outcome, it is important to appreciate a distinction between incursion scenarios of particular significance for the interpretation of the economic results. Two incursion scenarios (a and d) take place in 2009 rather than 2008. This represents a different decision environment i.e. we have greater knowledge of the probabilities and likely outcomes of the alternative control outcomes in 2009 compared to 2008. These distinctions cannot be factored in at the time of this analysis, adding to the difficulties of making between scenario comparisons.

Importantly the indirect costs of a BTV incursion are far greater than the direct costs. This is because most modelled epidemics are limited in size (see ANNEX 3(b)) and direct costs are small. Indirect effects of the disease i.e. its effects on trade and on market prices were largely dependent upon knowledge of disease presence in the country rather than upon the extent of its impact. It is very difficult to predict the size of indirect effects in advance of an incursion. However, **because indirect effects were assumed to be independent of the nature and extent of the incursion and control scenarios they do not alter the relative rankings of control options.** Their purpose in this CBA is to reflect the full potential economic damage of any BTV incursion into Scotland by capturing effects beyond the farm gate, which are likely to be considerable.

Surprisingly, using the extreme epidemiological outputs made little difference to the economic assessment of alternative incursion control options based on average epidemiological outcomes. This combined with the results of the sensitivity analysis and the consistency between incursion scenarios is reassuring as it suggests that choice of best control option are more robust to the nature and extent of the incursion than might have been expected.

5.2 Consequences of findings from the programme as a whole

The findings provide an objective basis for decision makers dealing with the putative bluetongue outbreak facing GB this summer.

5.3 Recommendations for future strategy:

- We have carried out an extensive interdisciplinary piece of work in a very short period. Much effort has been invested in checking the models, assumptions and output over the latter weeks. However, so little is known about BTV-8 and the probable epidemiology in GB that these results must be viewed as the basis for decision support rather than providing definitive answers at this stage.
- We would recommend that the decision makers convene with the full expert panel to discuss these results in some detail before reaching conclusions.
- The project has been structured in such a way as to allow new scenarios and control options to be tested rapidly as each new question emerges and we suggest that full advantage is taken of these options as the putative outbreak develops and/or more information becomes available.
- We recommend that our finding that the economic impact of a potential BTV8 output in Scotland is particularly severe for the cattle sector be widely communicated within the farming industry. Given that previous studies have suggested that BTV8 is more damaging to sheep, cattle farmers may place insufficient emphasis on control thus exposing sheep farmers to greater risk from virus circulating in the cattle population. This hypothesis ignores the relatively small proportion of diseases losses that stem directly from an outbreak and the large indirect costs of BTV8 that affect predominantly cattle farmers whether their farm is infected or not.
- We suggest that, if possible, a relative risk assessment is carried out on the most likely incursion scenarios facing Scotland. The aim should be to quantify the probability of alternative incursion scenarios so that economic evaluations can be made across incursion scenarios rather then just within incursion scenarios as for this current study. This would allow the expected (probability weighted) benefits of each incursion to be assessed. With such information it would be possible to identify the outbreak control option that minimises the expected cost of the disease prior to any incursion rather than the one that minimises the cost of disease given a particular incursion scenario.

- If resources are available for further analyses then we would recommend a more in-depth study of control options than was possible here. For example, the timing, coverage and efficacy of a control option should be explored further.

6. COMMUNICATED OUTPUTS

6.1 Refereed Publications : To follow

6.2 Popular and trade articles : To follow

6.3 Presentations to expert panel:

7th January 2008
Economics research approach,
Epidemiological models,
Climate research approach
Scottish vector data research approach

5th February 2008
Economics research approaches,
Epidemiological modelling preliminary results,
Climate research results
Scottish vector data initial results & discussion of constraints

17th March 2008
Economics research preliminary results,
Epidemiological modelling results,
Scottish vector data results

17th January 2008
Presentation to Chief Veterinary Officer (Scotland)

23rd June 2008
Presentation to Bluetongue Stakeholder Group

6.4 Other reports/publications/communications : To follow

6.5 Technology Transfer: To follow

6.6 Patents applied for : Not relevant

7. ACKNOWLEDGEMENTS

Other staff contributing to this project:

University of Glasgow, University of Edinburgh and MRI staff contributed to this project without making direct charge. Dr Ben McCormick (an SAC Co-PI) and Dr Bouda Vosough Ahmadi contributed using resources from SG RERAD Programme 2.

The project team acknowledges the support of the Scottish Government RERAD and the contributions of the unpaid members of the expert panel.

8. ANNEXES

ANNEX 1 (a)

Assumptions

The evaluation of BTV control measures in different outbreak scenarios requires a combination of assumptions on economic parameters. The economic parameters are needed to provide cost estimates of the trade effects in each outbreak scenario and the control and surveillance programmes for both the public and private sectors. Using this information, the parameters are used in a spreadsheet modelling framework to evaluate the benefits and costs of different outbreak scenarios of BTV. (Whether the assumption relates to disease losses avoided (benefits) or unavoidable surveillance costs is denoted in the assumptions column by either [B] or [C] respectively.)

Assumptions	Definitions/Notes	Parameter values
Forecast of business as usual production of sheep, cattle, sheepmeat, beef, milk, wool and prices of the above in Scotland. [B,C]	Ex ante evaluation there is the need to make forecasts	Autoregressive integrated moving average (ARIMA) time series forecasting technique was used to make all forecasts of trade data up to 2013.
Veterinary and medicine costs [C]	It is assumed that veterinary treatment of animals is good husbandry practice, which is helping to keep diseases out and reduce deleterious effect of disease when it occurs. Veterinary and medicine cost extracted from SAC farm management hand book 2007	General veterinary and medicine for sheep and cattle £3/head and £12/head for sheep and cattle respectively
Veterinary services [C]: PCR, ELISA for pre-testing of imports from BTV-affected countries and from the RUK [B]: PCR, ELISA for pre-testing of domestic livestock due to movement restrictions	Pre-movement testing and BTV vaccine cost for sheep and cattle. Information supplied by Scottish Government (SG).	PCR (£15/head), Pre-movement testing ELISA (domestic) (£3/head), BTV Vaccine per sheep (£0.5/head), BTV vaccine per Cattle (£1/head);
Voluntary and compulsory vaccination [B]	Government strategy to the uptake of vaccination can be either compulsory or voluntary depending on BTV control option. Where 100% uptake was evaluated, vaccination was assumed compulsory.	Cost of uptake of voluntary and compulsory vaccination was obtained from Scottish government as follows: Mail shot to all livestock holders Specialist media (advertising) £25,000- Cost of advert placed in the Scottish Farmer- this applies to voluntary programmes (i.e. 80% and 50% vaccination) Mail shot to all vets £500-This applies to all 170 large animal practices in Scotland.

		Animals for export are vet administered and certified - 1st cattle (£50), next 9 (£10 each), the rest (£5 each). 1st sheep (£50), next 9 (£10 each), the rest (£1.50 each). If voluntary, all other animals are farmer administered – Vet expenses are estimated as £80 per holding as cost of vet time for prescription and supplying of vaccination. Costs of legislation and random monitoring in the case of compulsory vaccination were not included.
Carcase disposal cost **[B]**	The burial or burning of animal carcasses within EU Member States is banned. The only legal methods of disposal of diseased animal carcasses are by rendering or incineration.[5] On farm incinerators are allowed providing they conform to certain standards and are approved. Incineration of animal carcasses attracts costs. Data from Defra (2007)	Carcase disposal cost was assumed to be £75/head and £20/head for sheep. (BTV casualties)
Fertility **[B]**	Dairy based on Santarossa et al. (2004), beef on Gunn et al. (2004) and sheep on Conington et al. (2004). Note these figures exclude impacts of fertility on production to avoid double counting. This explains why beef > dairy.	Loss of fertility for beef cows (£2.7/head), Loss of fertility for dairy cows (£2.5/head), Loss of fertility for sheep (£0.60/head). Mean for ALL head on infected farms.
Wool loss **[B]**	In some flocks, no clinical sign is apparent, whereas in other flocks infected by the same virus up to 30 % may develop signs of disease. Sheep that recover from BTV infections may render wool fragile and in some cases this can lead to partial or complete shedding of wool. [6]	An average of 2.5 kg of wool is produced per sheep.[7] Wool not sheared from 30% of BTV infected sheep.
Weight loss (morbid animals)	There is no guidance in the literature on the degree of weight loss in	9% of infected cattle and 11% of infected sheep would show weight

[5] The only exemptions to the ban in the UK are for remote areas of the Highlands and Islands of Scotland (http://www.allgoats.org.uk/carcase.htm).

[6] http://www.vet.uga.edu/vpp/gray_book02/fad/blt.php

[7] Production of wool per sheep varies considerably from 1.7 kg – 9kg per animal (see Roche, J. (1995). *The international wool trade*. Woodhead Publishing)

[B]	morbid animals. A lower and an upper band of weight loss is assumed for sheep and cattle. Our assumptions are drawn from personal communications with experts in various countries.	loss. Cattle: a lower bound of 10% and upper bound 15% of sheep biomass is lost due to BTV infection. a lower bound of 5% and upper bound 10% of cattle biomass is lost due to BTV infection
Milk loss (morbid animals) **[B]**	Personal communication with J.Winkelmann suggests 15% milk loss with a range of 10% to 30% but up to 50% for acute cases over a 100 day period (say 1/3rd of lactation). With a lactation yield of 8800 kg this works out at about 400kg milk lost per morbid animal i.e. about 5% of whole lactation yield.	5% of milk is lost due to BTV infection
Surveillance cost **[C]**	Animal disease surveillance and control costs were obtained from SG recorded in financial year format. To make these data compatible with the rest of the data it was taken to represent calendar years.	There is no specific public sector cost dedicated to the surveillance of BTV. Therefore it was assumed that 2% and 0.5% of total public sector surveillance constitute passive surveillance costs for sheep and cattle respectively.
Palliative care cost **[B]**	Palliative care is any form of medical care or treatment that concentrates on reducing the severity of BTV disease symptoms. The goal is to prevent and relieve suffering and welfare in that condition. It was assumed that 600 kg cow would require a dose of (60 ml per 600 kg bodyweight) of alamycin la[8] and fluxin.[9]. Since sheep are the most susceptible to BTV, it is assumed that a 80 kg sheep would require doses of alamycin la and fluxin for 5 and 3 days respectively.[8,9]	**Cow** Alamycin la] £12.60; Flunixin £8.48 Sheep Alamycin la £1.68 (x5 days), Flunixin £2.55 (x3 days)
Compensation to farmers **[B]**	Slaughter of animals due to BTV related health reasons with compensation deemed to be unlikely (Scottish Government)	Compensation unlikely
Labour costs **[B]**	It is assumed that family labour will be used to supplement farm labour in the event of an incursion of BTV.	As family labour has a low opportunity cost, labour cost was assumed to be £1/hour as in Gunn et al. (2004). Extra labour 2mins/morbid sheep and 7mins/morbid cattle per day.
Movement restriction	Zoning regulations apply in the event of an outbreak.	Assumed that movement restriction will cost 5% of the

8 http://www.norbrook.co.uk/products/ProductPrintable.cfm/product_Key/441/CatKey/1/Section/Veterinary_Products/

9 http://www.banamine.com/disclosure/index.html

[B]		value of the animal. (Defra, 2007)
Prices and quantity relationship **[B]**	The apparent reduction in demand by beef and sheep meat consumers was modelled using relevant estimates of price elasticity of demand. Price elasticity of demand is the degree of responsiveness of price due to a change in demand. Thus the magnitude of the fall in consumption of beef and sheep meat due to BTV outbreak would depend on the responsiveness of beef and sheep meat demand to changes in their prices. These relationships are usually measured over relatively small price and quantity changes; it is likely that a similar price and quantity relationship will hold for a much larger increase in price (Fofana et al. 2004)[10].	Own price elasticities used to simulate the effects of change in domestic consumers' perception of Scottish animal production as a result of BTV incursion. Own price elasticities were extracted from Defra[11] as follows: beef -0.92, Sheepmeat -1.29 and Milk -0.17. Corresponding price changes were assumed to be £0.25 and £0.10 for beef and sheepmeat. Milk price was assumed to decline by 4% in year 1 but this effect was reduced to 3%, 2% 1% and 0% in years 2 to 5 respectively.
Duration of trade impact **[B]**	Cost component of all items depend on the duration of outbreak and time taken to eradicate the disease	Modelled on the duration and re-occurrence of BTV from epidemiological model output
Input-Output multipliers **[B]**	Multipliers are commonly used in economic studies which attempt to show how important one business or industry is to a given geographic region or community. Multipliers are numbers which measure the magnitude of the direct and indirect effects that a given amount of production (in this case trade restrictions or export ban) has on a region (Scotland). Mahul and Durand (2000) used multipliers to simulate the effects of international trade ban in FMD outbreak in France. Multipliers were extracted from Scottish, Economy Statistics - Input-Output Tables 2004	Input-Output multipliers used to simulate the effects of export ban on live animals.
International trade in live animals **[B,C]**	International trade in live animals are the most affected during an outbreak of BTV.	Assumed 75% of international imports of live animals are from BTV affected countries which need pre testing and 100% of imports of live animal from the rest of UK need pre testing.
Discount rate	A discount rate is the percentage by	Official UK guidance on the

[10] Fofana, A, Moran , D, and Stott, A. (2004). An Economic Evaluation of Notifiable fish diseases. A report prepared for SEERAD and DEFRA

[11] http://statistics.defra.gov.uk/esg/publications/nfs/2000/Section6.pdf

[B,C]	which the value of a cash flow is reduced for each time period by which it is removed from the present. It is used to bring all future values to the current time or period.	choice of a discount rate is given in HM Treasury Green Book. The HM Treasury's 'core' social time preference discount rate is currently 3.5%.
Probabilities **[B]**		See special note below.

Special note on probabilities assumed for each incursion scenario

After consideration of experts in the various meetings during this project and further deliberation at IAH the following statement was made:

"Given the level of uncertainty involved it is very difficult to derive any quantitative estimates for the probability of each incursion scenario (Rn, where n denotes the scenario: a, b, c, d or e) (see incursion x control matrix table in **ANNEX** 1b). It is possible, however, to rank the incursion scenarios in terms of risk, as follows:

- the lowest risk is Rb, because it is unlikely that BTV will have spread to Scotland by July 2008;

- the highest risk is Ra, because it is possible that BTV could spread to Scotland by April 2009 (though this will clearly depend on the success of any vaccination strategy in England);

- the northward spread scenarios can be ranked Rb<Rc<Ra, given the timing of each incursion;

- the import scenarios can be ranked Re<Rd, given that the BTV-affected area is likely to be larger in April 2009 compared with September 2008;

- the import scenarios are most likely to be the result of an illegal movement, because they would occur outside the vector-free period; hence, they are less likely than BTV spreading to Scotland by September 2008 or April 2009;

This suggests that a plausible ranking for the five incursion scenarios is Rb<Re<Rd<Rc<Ra"

Given this assessment, the following quantitative assumptions were used for the purposes of this interim report:

Ra = 0.20 Rc=0.15 Rd = 0.10 Re=0.05 Rb = 0.01

These are purely weighting factors to reflect the above hierarchy and NOT assessments of risk of incursion. It should be remembered that the scenarios chosen are not mutually exclusive or collectively exhaustive.

ANNEX 1 (b) Economics outputs

BTV8 Incursion x Control Matrix as discussed at the expert meeting on 5th February 2008, SAC, Edinburgh, last modified 27/2/08

Incursion Control Scenario	Incursion a South–April 09 (Midge) Prob=Ra	Incursion b South-July 08 (Midge) Prob=Rb	Incursion c South-Sept. 08 (Midge) Prob=Rc	Incursion d Animal import April 09 Prob=Rd	Incursion e Animal import September 08 Prob=Re
1. Do nothing (control cost = c1=0) outcome = C1 or **counterfactual** (minimum required response)	Expected loss=RaC1a	Expected loss=RbC1b	Expected loss=RcC1c	Expected loss=RdC1d	Expected loss=ReC1e
Control zone options:					
2. Border PZ - 100% vaccinated at cost=c2	Expected loss=RaC2a	Expected loss=RbC2b	Expected loss=RcC2c	Expected loss=RdC2d	Expected loss=ReC2e*
3.PZ to Highland B/F line - 80% vaccinated at cost=c3	Expected loss=RaC3a	Expected loss=RbC3b	Expected loss=RcC3c	Expected loss=RdC3d	Expected loss=ReC3e*
4.PZ all Scotland - 50% vaccinated at cost = c4	Expected loss=RaC4a	Expected loss=RbC4b	Expected loss=RcC4c	Expected loss=RdC4d	Expected Loss=ReC4e
5. 100km PZ around incursion above the Highland B/F line - 80% vaccinated at cost = c5	NA*	NA*	NA*	NA*	Expected Loss=ReC5e
Benefit (b/c ratio)					
B2 = R(C1 – C2)/c2					
B3 = R(C1 – C3)/c3					
Bn = R(C1 – Cn)/cn					

*See note 4.

Notes:

1. Five incursion scenarios a, b, c, d and e with probability of occurrence of Ra, Rb, Rc, Rd and Re respectively. Incursions a, b and c assume that BTV8 arrives in Scotland via wind blown midges originating in the south. Note that the April incursions are assumed to take place in April 2009.

2. Four main control strategies 1, 2, 3 and 4 with costs c1, c2, c3 and c4. Strategy 1 is the counterfactual i.e. no control scenario i.e. c1=0. This scenario DOES include the minimum required control, i.e. movement restrictions but no vaccination. Where incursion takes place in April 2009 (incursions a and d) vaccination is assumed to take place BEFORE incursion i.e. in January 2009 (when animals are likely to be more accessible). For the other incursions vaccination takes place AFTER initial detection of the incursion. An extra treatment (5) is included to cover the special case of incursion (e) where vaccine location depends on place on incursion (see note 4).

3. Expected output losses are C1, C2, C3 and C4 for control strategies 1 to 4 respectively. These will depend on the incursion scenario under test, e.g. C1a, C1b, C2c etc.

4. Our control strategies are based on an RZ with a CZ, PZ (either Border, Highland B/F line, whole of Scotland or 100km round Northern import) and SZ, and we do compulsory (100%) vaccination within a temporary CZ (put in place for vaccination purposes only around any new IP) and assume 100%, 80% or 50% uptake in the rest of the PZ for strategies 2, 3 and 4 respectively. In the case of incursion e (import in September 2008) the PZ would be established depending on where the incursion takes place. If the incursion takes place within the Border PZ, then option 2 is to be used. If the incursion takes place South of the Highland B/F line, control strategy 3 is put in place, and if the incursion takes place North of the Highland B/F line, then a 100km PZ is established around the holding where the incursion occurred, and 80% uptake is assumed within this PZ. In line with the other vaccination options, a 20km CZ will also be established around the incursion with 100% vaccination. Therefore a fifth control strategy 5e will complement options 2e and 3e, in the case of a Northern import. This gives 21 incursion x control scenarios.

5. We assume that the probability of a particular incursion e.g. Ra is independent of the control strategy in place i.e. control strategies limit the damage (Cn) from a possible incursion not the probability of incursion.

6. It may be difficult to separate output losses Cn from control expenditure cn. For example, declaration of a PZ in order to use vaccine (cn) will trigger movement restrictions and extra surveillance costs (cn) even in the absence of BTV. However, subsequent incursion will require additional movement and trade restrictions and extra surveillance costs (Cn) as well as farm-level output losses due to the disease (Cn).

7. The BTV epidemic model will generate output for year 1 and 2 only. Expert input on 5th Feb indicated that by year 5 the disease will have naturally declined. We will therefore extrapolate year 2 costs into years 3 to 5, assuming a decline to 0 by end of year 5. This assumption will be highlighted as a caveat in the report. All model runs start in January of the year of incursion, i.e. 2008 for incursions b, c and e or 2009 for incursions a and d.

8. The analysis is confined to BTV8. (Again to be reported as a caveat in the report).

9. The levels of vaccination uptake in the above control scenarios 2, 3 and 4 assume a compulsory vaccination scheme, voluntary vaccination scheme with extensive industry uptake and voluntary vaccination scheme with less industry uptake respectively. We will assume that promotion costs (supplied by SG) will be the same for each voluntary vaccination control scenario.

ANNEX 1 (c) Within incursion scenario CBA for average values from the epidemiological model

Table 1a: Incursion a (Midge transmission from south in April 2009)

	BTV constant at yr 2 values in years 3-5				BTV dies out gradually after year 2			
Scenario	**C1a**	**C2a**	**C3a**	**C4a**	**C1a**	**C2a**	**C3a**	**C4a**
No license for move-to-slaughter								
Sum of discounted cost (£m)	140.76	140.76	140.76	140.76	140.76	140.76	140.76	140.7
Sum of discounted benefits (£m)	344.52	470.51	426.22	340.74	334.68	412.57	384.20	333.5
NPV	203.76	329.75	285.46	199.98	193.92	271.81	243.44	192.8
BCR	2.45	3.34	3.03	**2.42**	2.38	2.93	2.73	**2.37**
With license for move-to-slaughter								
Sum of discounted cost (£m)	140.76	140.76	140.76	140.76	140.76	140.76	140.76	140.7
Sum of discounted benefits (£m)	335.91	414.85	380.85	340.74	329.60	379.25	356.87	333.5
NPV	195.15	274.09	240.09	199.98	188.84	238.49	216.11	192.8
BCR	2.39	2.95	2.71	**2.42**	**2.34**	2.69	2.54	2.37

Table 1b: Incursion b (Midge transmission from south in July 2008)

	BTV constant at yr 2 values in years 3-5				BTV dies out gradually after year 2			
Scenario	**C1a**	**C2a**	**C3a**	**C4a**	**C1a**	**C2a**	**C3a**	**C4a**
No license for move-to-slaughter								
Sum of discounted cost (£m)	140.76	140.76	140.76	140.76	140.76	140.76	140.76	140.7
Sum of discounted benefits (£m)	344.52	470.51	426.22	340.74	334.68	412.57	384.20	333.5
NPV	203.76	329.75	285.46	199.98	193.92	271.81	243.44	192.8
BCR	2.45	3.34	3.03	**2.42**	2.38	2.93	2.73	**2.37**
With license for move-to-slaughter								
Sum of discounted cost (£m)	140.76	140.76	140.76	140.76	140.76	140.76	140.76	140.7
Sum of discounted benefits (£m)	335.91	414.85	380.85	340.74	329.60	379.25	356.87	333.5
NPV	195.15	274.09	240.09	199.98	188.84	238.49	216.11	192.8
BCR	2.39	2.95	2.71	**2.42**	**2.34**	2.69	2.54	2.37

Table 1c: Incursion c (Midge transmission from south in September 2008)

	BTV constant at year 2 values in years 3-5				**BTV dies out gradually after year 2**			
Scenario	**C1c**	**C2c**	**C3c**	**C4c**	**C1c**	**C2c**	**C3c**	**C4c**
No license for move-to-slaughter								
Sum of discounted cost	140.58	140.58	140.58	140.58	140.58	140.58	140.58	140.5
Sum of discounted benefits	359.10	453.60	417.17	349.80	341.69	398.90	375.30	337.8
NPV	218.52	313.03	276.59	209.22	201.11	258.32	234.72	197.2
BCR	2.55	3.23	2.97	**2.49**	2.43	2.84	2.67	**2.40**
With license for move-to-slaughter								
Sum of discounted cost	140.58	140.58	140.58	140.58	140.58	140.58	140.58	140.5
Sum of discounted benefits	348.42	408.74	376.92	349.80	335.77	374.14	352.92	337.8
NPV	207.84	268.16	236.34	209.22	195.19	233.57	212.34	197.2
BCR	**2.48**	2.91	2.68	2.49	**2.39**	2.66	2.51	2.40

Table 1d: Incursion d (Animal import April 2009)

	BTV constant at year 2 values in years 3-5				**BTV dies out gradually after year 2**			
Scenario	**C1d**	**C2d**	**C3d**	**C4d**	**C1d**	**C2d**	**C3d**	**C4d**
No license for move-to-slaughter								
Sum of discounted cost (£m)	140.76	140.76	140.76	140.76	140.76	140.76	140.76	140.7
Sum of discounted benefits(£m)	378.94	499.63	491.17	438.87	354.99	432.31	423.45	391.7
NPV	238.18	358.86	350.41	298.11	214.23	291.55	282.69	250.9
BCR	**2.69**	3.55	3.49	3.12	**2.52**	3.07	3.01	2.78
With license for move-to-slaughter								
Sum of discounted cost (£m)	140.76	140.76	140.76	140.76	140.76	140.76	140.76	140.7
Sum of discounted benefits	352.66	428.78	411.88	411.88	339.41	389.77	375.66	363.5
NPV	211.90	288.02	271.12	271.12	198.65	249.01	234.90	222.7
BCR	**2.51**	3.05	2.93	2.93	**2.41**	2.77	2.67	2.58

Table 1e: Incursion e (Animal import September 2008)

	BTV constant at year 2 values in years 3-5					BTV dies out gradually after year 2				
Scenario	**C1e**	**C2e**	**C3e**	**C4e**	**C5e**	**C1e**	**C2e**	**C3e**	**C4e**	**C5e**
No license for move-to-slaughter										
Sum of discounted cost (£m)	140.76	140.76	140.76	140.76	140.58	140.76	140.76	140.76	140.76	140.58
Sum of discounted benefits (£m)	378.94	478.24	466.49	434.01	414.79	345.48	414.43	401.81	384.91	373.94
NPV	238.18	337.48	325.73	293.25	274.22	204.72	273.67	261.05	244.15	233.37
BCR	**2.69**	3.40	3.31	3.08	2.95	**2.45**	2.94	2.85	2.73	2.66
With license for move-to-slaughter										
Sum of discounted cost (£m)	140.76	140.76	140.76	140.76	140.58	140.76	140.76	140.76	140.76	140.58
Sum of discounted benefits (£m)	345.48	417.03	397.48	391.96	375.18	334.28	380.63	363.32	361.32	351.79
NPV	204.72	276.27	256.72	251.20	234.60	193.52	239.87	222.56	220.55	211.21
BCR	**2.45**	2.96	2.82	2.78	2.67	**2.37**	2.70	2.58	2.57	2.50

ANNEX 1 (d) 5^{th} percentile

Within Incursion Scenario CBA Analysis -

Table 1a: Incursion a

Scenario	**C1a**	**C2a**	**C3a**	**C4a**	**C1a**	**C2a**	**C3a**	**C4a**
No license for move-to-slaughter								
Sum of discounted cost (£m)	140.76	140.76	140.76	140.7	140.76	140.76	140.76	140.
Sum of discounted benefits	353.37	457.80	437.45	371.9	353.37	417.62	404.39	365.
NPV	212.61	317.04	296.68	231.1	212.61	276.86	263.63	224.
BCR	**2.51**	3.25	3.11	2.64	**2.51**	2.97	2.87	2.59
With license for move-to-slaughter								
Sum of discounted cost (£m)	140.76	140.76	140.76	140.7	140.76	140.76	140.76	140.
Sum of discounted benefits	353.37	421.25	402.58	371.9	353.37	395.63	383.05	365.
NPV	212.61	280.49	261.82	231.1	212.61	254.87	242.29	224.
BCR	**2.51**	2.99	2.86	2.64	**2.51**	2.81	2.72	2.59

Table 1b: Incursion b

	BTV constant at year 2 values in years 3-5				**BTV dies out gradually after year 2**			
Scenario	**C1b**	**C2b**	**C3b**	**C4b**	**C1b**	**C2b**	**C3b**	**C4b**
No license for move-to-slaughter								
Sum of discounted	140.58	140.58	140.58	140.58	140.58	140.58	140.58	140.
Sum of discounted	353.73	408.55	387.38	376.22	353.57	384.83	375.35	375.
NPV	213.15	267.97	246.80	235.64	212.99	244.25	234.78	234.
BCR	**2.52**	2.91	2.76	2.68	**2.52**	2.74	2.67	2.67
With license for move-to-slaughter								
Sum of discounted	140.58	140.58	140.58	140.58	140.58	140.58	140.58	140.
Sum of discounted	353.73	398.47	379.36	376.22	353.57	378.84	370.26	364.
NPV	213.15	257.89	238.78	235.64	212.99	238.26	229.69	223.
BCR	**2.52**	2.83	2.70	2.68	**2.52**	2.69	2.63	2.59

Table 1c: Incursion c

	BTV constant at year 2 values in years 3-5				BTV dies out gradually after year 2			
Scenario	**C1c**	**C2c**	**C3c**	**C4c**	**C1c**	**C2c**	**C3c**	**C4c**
No license for move-to-slaughter								
Sum of discounted	140.58	140.58	140.58	140.58	140.58	140.58	140.58	140.
Sum of discounted	353.51	388.84	371.96	379.12	353.44	371.44	362.35	367.
NPV	212.93	248.27	231.38	238.54	212.86	230.87	221.77	226.
BCR	**2.51**	2.77	2.65	2.70	**2.51**	2.64	2.58	2.61
With license for move-to-slaughter								
Sum of discounted	140.58	140.58	140.58	140.58	140.58	140.58	140.58	140.
Sum of discounted	353.51	384.50	368.16	379.12	353.44	369.28	360.44	367.
NPV	212.93	243.92	227.58	238.54	212.86	228.70	219.87	226.
BCR	**2.51**	2.74	2.62	2.70	**2.51**	2.63	2.56	2.61

Table 1d: Incursion d

	BTV constant at year 2 values in years 3-5				BTV dies out gradually after year 2			
Scenario	**C1d**	**C2d**	**C3d**	**C4d**	**C1d**	**C2d**	**C3d**	**C4d**
No license for move-to-slaughter								
Sum of discounted cost	140.76	140.76	140.76	140.76	140.76	140.76	140.76	140.
Sum of discounted	353.92	501.86	497.41	470.46	353.68	446.10	440.38	423.
NPV	213.16	361.10	356.65	329.70	212.92	305.34	299.62	282.
BCR	**2.51**	3.57	3.53	3.34	**2.51**	3.17	3.13	3.01
With license for move-to-slaughter								
Sum of discounted cost	140.76	140.76	140.76	140.76	140.76	140.76	140.76	140.
Sum of discounted	353.92	447.02	433.56	433.56	353.68	412.96	401.69	395.
NPV	213.16	306.26	292.80	292.80	212.92	272.20	260.93	254.
BCR	**2.51**	3.18	3.08	3.08	**2.51**	2.93	2.85	2.81

Table 1e: Incursion e

	BTV constant at year 2 values in years 3-5					BTV dies out gradually after year 2				
Scenario	**C1e**	**C2e**	**C3e**	**C4e**	**C5e**	**C1e**	**C2e**	**C3e**	**C4e**	**C5e**
No license for move-to-slaughter										
Sum of discounted cost (£m)	140.76	140.76	140.76	140.76	140.58	140.76	140.76	140.76	140.76	140.58
Sum of discounted benefits (£m)	353.92	500.21	481.33	466.10	401.60	353.52	440.23	425.96	416.99	380.66
NPV	213.16	359.45	340.57	325.34	261.03	212.76	299.47	285.20	276.23	240.08
BCR	2.51	3.55	3.42	3.31	2.86	2.51	3.13	3.03	2.96	2.71
With license for move-to-slaughter										
Sum of discounted cost (£m)	140.76	140.76	140.76	140.76	140.58	140.76	140.76	140.76	140.76	140.58
Sum of discounted benefits (£m)	353.63	444.08	425.71	424.05	385.70	353.52	408.97	394.60	393.40	371.71
NPV	212.87	303.32	284.95	283.29	245.12	212.76	268.21	253.84	252.64	231.14
BCR	2.51	3.15	3.02	3.01	2.74	2.51	2.91	2.80	2.79	2.64

ANNEX 1 (e) 95th percentile

Within Incursion Scenario CBA Analysis

Table 1a: Incursion a

	BTV constant at yr 2 values in years 3-5				BTV dies out gradually after year 2			
Scenario	**C1a**	**C2a**	**C3a**	**C4a**	**C1a**	**C2a**	**C3a**	**C4a**
No license for move-to-slaughter								
Sum of discounted cost (£m)	140.76	140.76	140.76	140.7	140.76	140.76	140.76	140.
Sum of discounted benefits	332.81	528.84	455.15	343.6	327.03	448.94	401.82	335.
NPV	192.05	388.08	314.39	202.8	186.27	308.18	261.06	194.
BCR	2.36	3.76	3.23	2.44	2.32	3.19	2.85	2.38
With license for move-to-slaughter								
Sum of discounted cost (£m)	140.76	140.76	140.76	140.7	140.76	140.76	140.76	140.
Sum of discounted benefits	332.81	456.02	398.90	343.6	327.03	405.44	367.98	335.
NPV	192.05	315.26	258.14	202.8	186.27	264.68	227.22	194.
BCR	2.36	3.24	2.83	2.44	2.32	2.88	2.61	2.38

Table 1b: Incursion b

	BTV constant at year 2 values in years 3-5				BTV dies out gradually after year 2			
Scenario	**C1b**	**C2b**	**C3b**	**C4b**	**C1b**	**C2b**	**C3b**	**C4b**
No license for move-to-slaughter								
Sum of discounted	140.58	140.58	140.58	140.58	140.58	140.58	140.58	140.
Sum of discounted	340.87	550.38	457.17	352.40	331.68	462.56	400.86	400.
NPV	200.30	409.80	316.59	211.83	191.10	321.98	260.28	260.
BCR	2.42	3.92	3.25	2.51	2.36	3.29	2.85	2.85
With license for move-to-slaughter								
Sum of discounted	140.58	140.58	140.58	140.58	140.58	140.58	140.58	140.
Sum of discounted	340.87	483.19	401.80	352.40	331.68	424.10	368.84	340.
NPV	200.30	342.62	261.22	211.83	191.10	283.52	228.26	199.
BCR	2.42	3.44	2.86	2.51	2.36	3.02	2.62	2.42

Table 1c: Incursion c

	BTV constant at year 2 values in years 3-5				BTV dies out gradually after year 2			
Scenario	**C1c**	**C2c**	**C3c**	**C4c**	**C1c**	**C2c**	**C3c**	**C4c**
No license for move-to-slaughter								
Sum of discounted	140.58	140.58	140.58	140.58	140.58	140.58	140.58	140.
Sum of discounted	329.91	504.94	446.40	350.97	325.92	430.28	392.11	338.
NPV	189.33	364.36	305.82	210.39	185.34	289.70	251.54	198.
BCR	2.35	3.59	3.18	2.50	2.32	3.06	2.79	2.41
With license for move-to-slaughter								
Sum of discounted	140.58	140.58	140.58	140.58	140.58	140.58	140.58	140.
Sum of discounted	329.91	445.13	394.62	350.97	325.92	397.21	363.41	338.
NPV	189.33	304.55	254.05	210.39	185.34	256.63	222.84	198.
BCR	2.35	3.17	2.81	2.50	2.32	2.83	2.59	2.41

Table 1d: Incursion d

	BTV constant at year 2 values in years 3-5				BTV dies out gradually after year 2			
Scenario	**C1d**	**C2d**	**C3d**	**C4d**	**C1d**	**C2d**	**C3d**	**C4d**
No license for move-to-slaughter								
Sum of discounted cost	140.76	140.76	140.76	140.76	140.76	140.76	140.76	140.
Sum of discounted	345.78	571.50	532.89	439.95	334.46	480.57	448.58	392.
NPV	205.02	430.74	392.13	299.19	193.70	339.81	307.82	252.
BCR	2.46	4.06	3.79	3.13	2.38	3.41	3.19	2.79
With license for move-to-slaughter								
Sum of discounted cost	140.76	140.76	140.76	140.76	140.76	140.76	140.76	140.
Sum of discounted	345.78	483.31	436.48	436.48	334.46	427.59	390.73	364.
NPV	205.02	342.55	295.72	295.72	193.70	286.83	249.97	223.
BCR	2.46	3.43	3.10	3.10	2.38	3.04	2.78	2.59

Table 1e: Incursion e

	BTV constant at year 2 values in years 3-5					BTV dies out gradually after year 2				
Scenario	**C1e**	**C2e**	**C3e**	**C4e**	**C5e**	**C1e**	**C2e**	**C3e**	**C4e**	**C5e**
No license for move-to-slaughter										
Sum of discounted cost (£m)	140.76	140.76	140.76	140.76	140.58	140.76	140.76	140.76	140.76	140.58
Sum of discounted benefits (£m)	345.78	509.51	473.03	435.63	458.92	329.49	436.05	407.27	386.71	399.84
NPV	205.02	368.75	332.27	294.87	318.34	188.73	295.29	266.51	245.95	259.26
BCR	2.46	3.62	3.36	3.09	3.26	2.34	3.10	2.89	2.75	2.84
With license for move-to-slaughter										
Sum of discounted cost (£m)	140.76	140.76	140.76	140.76	140.58	140.76	140.76	140.76	140.76	140.58
Sum of discounted benefits (£m)	337.44	441.29	403.42	393.58	401.10	329.49	398.53	368.46	363.12	367.51
NPV	196.68	300.53	262.66	252.82	260.52	188.73	257.77	227.70	222.36	226.93
BCR	2.40	3.14	2.87	2.80	2.85	2.34	2.83	2.62	2.58	2.61

ANNEX 1 (f) Weighted benefit cost analysis

Table 1: Cost and Benefit Analysis BTV stays constant at year 2 values in years 3-5.

Scenario	**C1a**	**C1b**	**C1c**	**C1d**	**C1e**
No license for move-to-slaughter					
Probability of incursion	0.20	0.01	0.15	0.10	0.05
Sum of discounted cost (£ million)	140.76	140.58	140.58	140.76	140.76
Sum of discounted benefits (£ million)	344.52	367.11	359.10	378.94	365.99
Net present value (£ million)	203.76	226.53	218.52	238.18	225.23
Expected benefit (£ million)	-71.86	-136.91	-86.71	-02.87	-122.46
Benefit-cost ratio	0.49	0.03	0.38	0.27	0.13
With license for move-to-slaughter					
Sum of discounted cost (£ million)	140.76	140.58	140.58	140.76	140.76
Sum of discounted benefits (£ million)	335.91	351.77	348.42	352.66	345.48
Net present value (£ million)	195.15	211.19	207.84	211.90	204.72
Expected benefit (£ million)	-73.58	-137.06	-88.32	-05.49	-123.49
Benefit-cost ratio	0.48	0.03	0.37	0.25	0.12

Table2: Cost and Benefit Analysis BTV dies out gradually after year 2

Scenario	**C1a**	**C1b**	**C1c**	**C1d**	**C1e**
No license for move-to-slaughter					
Probability of BTV incursion	0.20	0.01	0.15	0.10	0.05
Sum of discounted cost (£ million)	140.76	140.58	140.58	140.76	140.76
Sum of discounted benefits (£ million)	334.68	346.97	341.69	354.99	345.48
Net present value (£ million)	193.92	206.39	201.11	214.23	204.72
Expected benefit (£ million)	-73.82	-137.11	-89.33	-105.26	-123.49
Benefit-cost ratio	0.48	0.02	0.36	0.25	0.12
With license for move-to-slaughter					
Sum of discounted cost (£ million)	140.76	140.58	140.58	140.76	140.76
Sum of discounted benefits (£ million)	329.60	338.22	335.77	339.41	334.28
Net present value (£ million)	188.84	197.64	195.19	198.65	193.52
Expected benefit (£ million)	-74.84	-137.20	-90.21	-106.82	-124.05
Benefit-cost ratio	0.47	0.02	0.36	0.24	0.12

Table3: Cost and Benefit Analysis BTV stays constant at year 2 values in years 3-5.

Scenario	**C2a**	**C2b**	**C2c**	**C2d**	**C2e**
No license for move-to-slaughter					
Probability of incursion	0.20	0.01	0.15	0.10	0.05
Sum of discounted cost (£ million)	140.76	140.58	140.58	140.76	140.76
Sum of discounted benefits (£ million)	470.51	468.71	453.60	499.63	478.24
Net present value (£ million)	329.75	328.13	313.03	358.86	337.48
Expected benefit (£ million)	-46.66	-135.89	-72.54	-90.80	-116.85
Benefit-cost ratio	0.67	0.03	0.48	0.35	0.17
With license for move-to-slaughter					
Sum of discounted cost (£ million)	140.76	140.58	140.58	140.76	140.76
Sum of discounted benefits (£ million)	414.85	419.52	408.74	428.78	417.03
Net present value (£ million)	274.09	278.94	268.16	288.02	276.27
Expected benefit (£ million)	-57.79	-136.38	-79.27	-97.88	-119.91
Benefit-cost ratio	0.59	0.03	0.44	0.30	0.15

Table4: Cost and Benefit Analysis BTV dies out gradually after year 2

Scenario	**C2a**	**C2b**	**C2c**	**C2d**	**C2e**
No license for move-to-slaughter					
Probability of BTV incursion	0.20	0.01	0.15	0.10	0.05
Sum of discounted cost (£ million)	140.76	140.58	140.58	140.76	140.76
Sum of discounted benefits (£ million)	412.57	409.83	398.90	432.31	414.43
Net present value (£ million)	271.81	269.25	258.32	291.55	273.67
Expected benefit (£ million)	-58.25	-136.48	-80.74	-97.53	-120.04
Benefit-cost ratio	0.59	0.03	0.43	0.31	0.15
With license for move-to-slaughter					
Sum of discounted cost (£ million)	140.76	140.58	140.58	140.76	140.76
Sum of discounted benefits (£ million)	379.25	381.56	374.14	389.77	380.63
Net present value (£ million)	238.49	240.98	233.57	249.01	239.87
Expected benefit (£ million)	-64.91	-136.76	-84.46	-101.78	-121.73
Benefit-cost ratio	0.54	0.03	0.40	0.28	0.14

Table5: Cost and Benefit Analysis BTV stays constant at year 2 values in years 3-5.

Scenario	**C3a**	**C3b**	**C3c**	**C3d**	**C3e**
No license for move-to-slaughter					
Probability of incursion	0.20	0.01	0.15	0.10	0.05
Sum of discounted cost (£ million)	140.76	140.58	140.58	140.76	140.76
Sum of discounted benefits (£ million)	426.22	418.04	417.17	491.17	466.49
Net present value (£ million)	285.46	277.46	276.59	350.41	325.73
Expected benefit (£ million)	-55.52	-136.40	-78.00	-91.64	-117.44
Benefit-cost ratio	0.61	0.03	0.45	0.35	0.17
With license for move-to-slaughter					
Sum of discounted cost (£ million)	140.76	140.58	140.58	140.76	140.76
Sum of discounted benefits (£ million)	380.85	378.00	376.92	411.88	397.48
Net present value (£ million)	240.09	237.42	236.34	271.12	256.72
Expected benefit (£ million)	-64.59	-136.80	-84.04	-99.57	-120.89
Benefit-cost ratio	0.54	0.03	0.40	0.29	0.14

Table6: Cost and Benefit Analysis BTV dies out gradually after year 2

Scenario	**C3a**	**C3b**	**C3c**	**C3d**	**C3e**
No license for move-to-slaughter					
Probability of BTV incursion	0.20	0.01	0.15	0.10	0.05
Sum of discounted cost (£ million)	140.76	140.58	140.58	140.76	140.76
Sum of discounted benefits (£ million)	384.20	378.01	375.30	423.45	401.81
Net present value (£ million)	243.44	237.43	234.72	282.69	261.05
Expected benefit (£ million)	-63.92	-136.80	-84.28	-98.42	-120.67
Benefit-cost ratio	0.55	0.03	0.40	0.30	0.14
With license for move-to-slaughter					
Sum of discounted cost (£ million)	140.76	140.58	140.58	140.76	140.76
Sum of discounted benefits (£ million)	356.87	354.70	352.92	375.66	363.32
Net present value (£ million)	216.11	214.12	212.34	234.90	222.56
Expected benefit (£ million)	-69.39	-137.03	-87.64	-103.19	-122.59
Benefit-cost ratio	0.51	0.03	0.38	0.27	0.13

Table7: Cost and Benefit Analysis BTV stays constant at year 2 values in years 3-5.

Scenario	**C4a**	**C4b**	**C4c**	**C4d**	**C4e**	**C5e**
No license for move-to-slaughter						
Probability of incursion	0.20	0.01	0.15	0.10	0.05	0.05
Sum of discounted cost (£ million)	140.76	140.58	140.58	140.76	140.76	140.58
Sum of discounted benefits (£ million)	340.74	349.90	349.80	438.87	434.01	414.79
Net present value (£ million)	199.98	209.32	209.22	298.11	293.25	274.22
Expected benefit (£ million)	-72.61	-137.08	-88.11	-96.87	-119.06	-19.84
Benefit-cost ratio	0.48	0.02	0.37	0.31	0.15	0.15
With license for move-to-slaughter						
Sum of discounted cost (£ million)	140.76	140.58	140.58	140.76	140.76	140.58
Sum of discounted benefits (£ million)	340.74	349.90	349.80	411.88	391.96	375.18
Net present value (£ million)	199.98	209.32	209.22	271.12	251.20	234.60
Expected benefit (£ million)	-72.61	-137.08	-88.11	-99.57	-121.16	-21.82
Benefit-cost ratio	0.48	0.02	0.37	0.29	0.14	0.13

Table8: Cost and Benefit Analysis BTV dies out gradually after year 2

Scenario	**C4a**	**C4b**	**C4c**	**C4d**	**C4e**	**C5e**
No license for move-to-slaughter						
Probability of incursion	0.20	0.01	0.15	0.10	0.05	0.05
Sum of discounted cost (£ million)	140.76	140.58	140.58	140.76	140.76	140.58
Sum of discounted benefits (£ million)	333.56	378.01	337.81	391.71	384.91	373.94
Net present value (£ million)	192.80	237.43	197.23	250.95	244.15	233.37
Expected benefit (£ million)	-74.05	-136.80	-89.91	-01.59	-121.52	-121.88
Benefit-cost ratio	0.47	0.03	0.36	0.28	0.14	0.13
With license for move-to-slaughter						
Sum of discounted cost (£ million)	140.76	140.58	140.58	140.76	140.76	140.58
Sum of discounted benefits (£ million)	333.56	337.91	337.81	363.54	361.32	351.79
Net present value (£ million)	192.80	197.34	197.23	222.78	220.55	211.21
Expected benefit (£ million)	-74.05	-137.20	-89.91	-04.41	-122.69	-122.99
Benefit-cost ratio	0.47	0.02	0.36	0.26	0.13	0.13

ANNEX 1 (g) Example breakdown of BTV costs (£m)

For scenario C4a for average epidemiological outcomes. (Incursion a (midge transmission from the south in April 2009) was considered the most likely incursion scenario, and C4 (vaccination all Scotland at 50% uptake) gave the lowest outbreak losses (minimum average sum of discounted benefits, costs avoided) i.e. C4 would be the least outbreak cost control option given this incursion scenario).

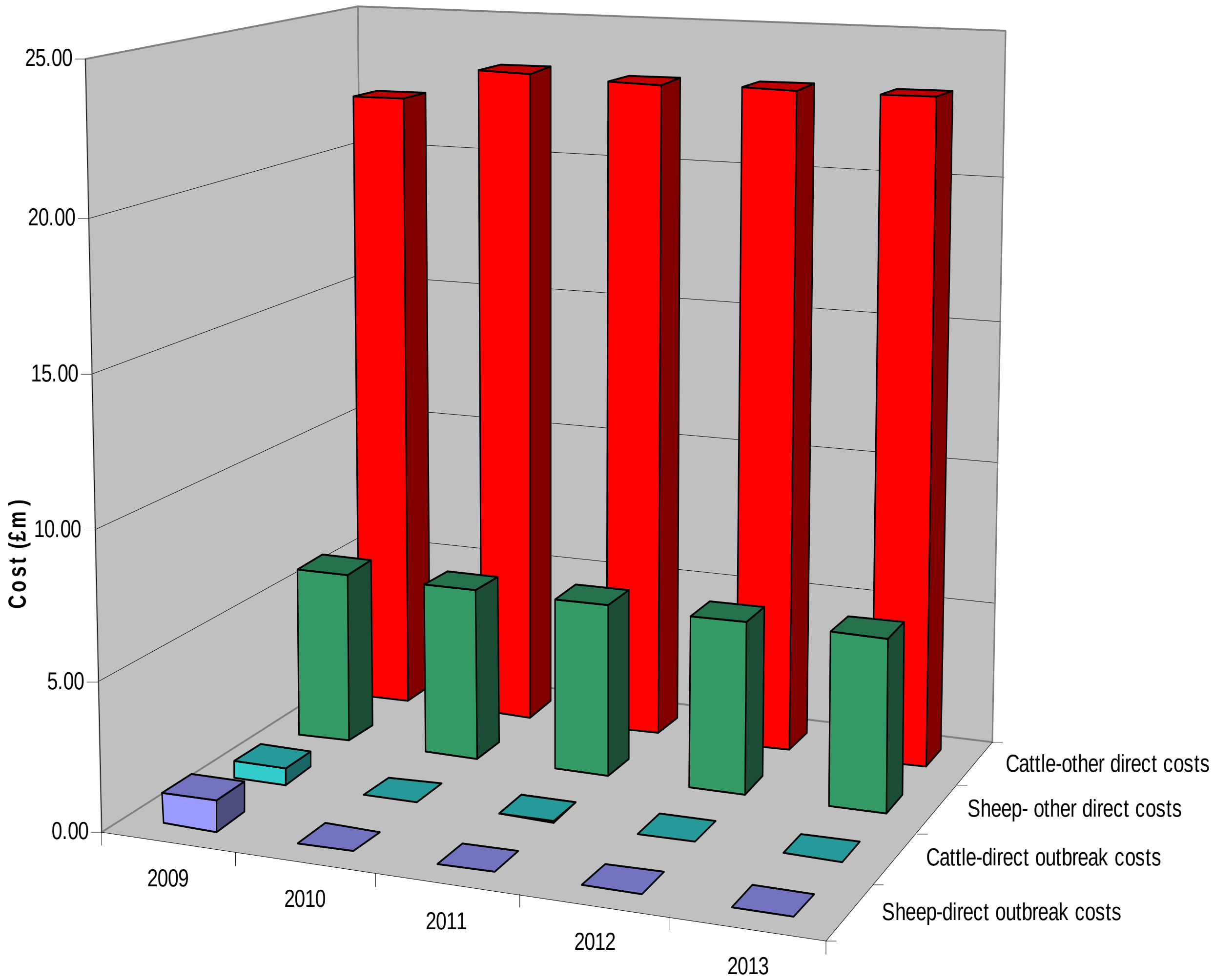

Figure 1g1: Direct costs* of BTV for Cattle and sheep

*Direct outbreak costs are those costs incurred by BTV infected farms and associated directly with an outbreak such as loss of farm outputs of milk and meat through mortality and morbidity, farm labour to deal with an outbreak, palliative care costs etc. Other direct costs are incurred by all farms whether infected with BTV or not such as vaccination costs and movement restriction costs. Other direct costs also includes baseline costs such as private and public veterinary surveillance costs that contribute to prevention of a BTV incursion and/or reduce its severity by ensuring rapid detection and response.

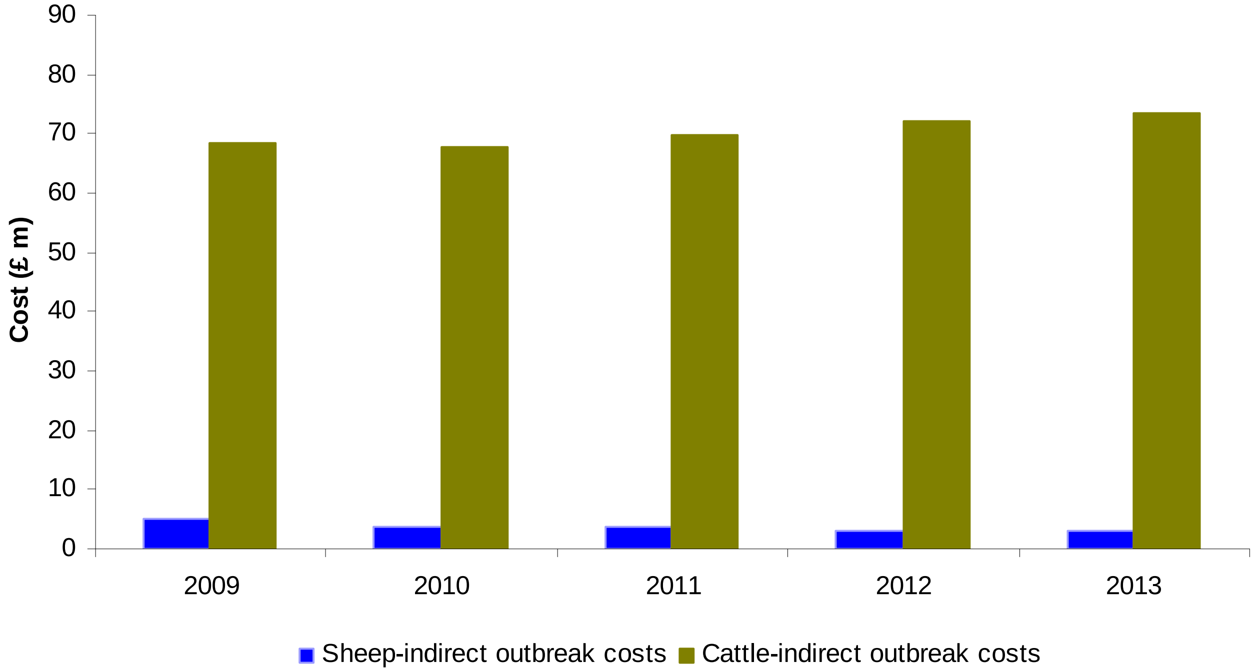

Figure 1g2: Indirect outbreak costs of BTV for Cattle and sheep

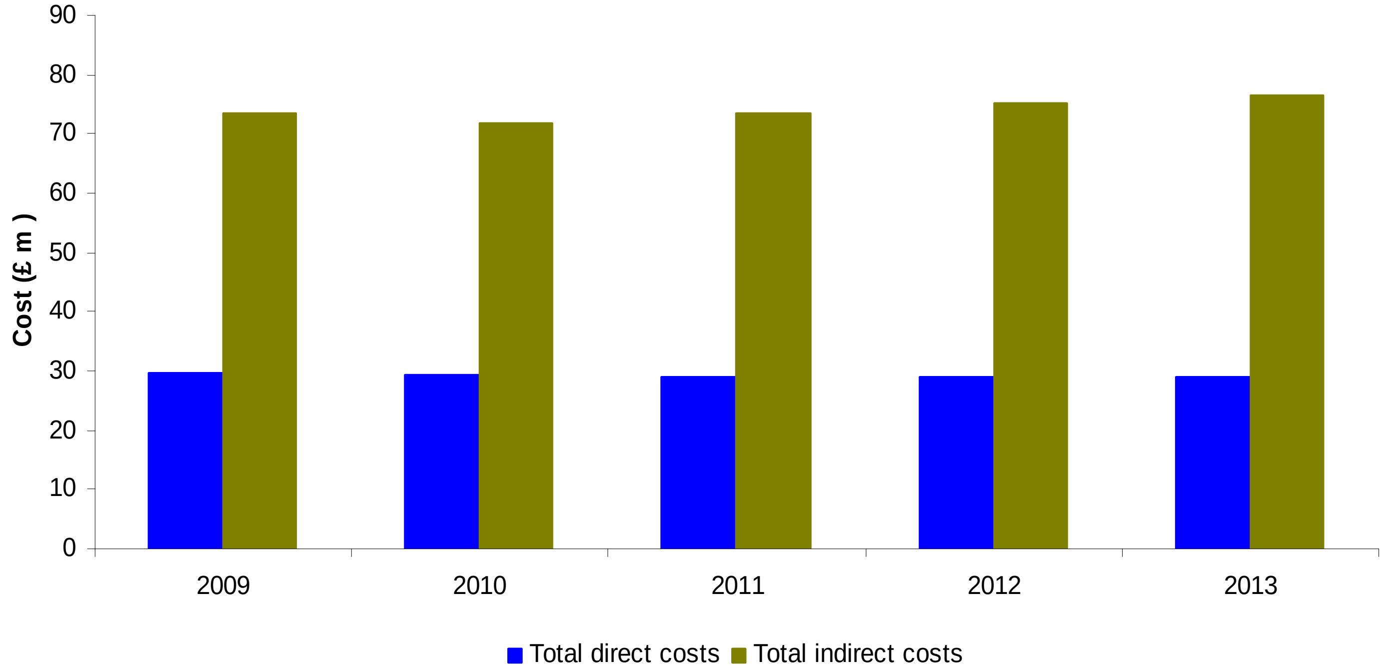

Figure 1g3: Total direct and indirect costs of BTV for Cattle and sheep

ANNEX 1 (h) Interpretation of cost benefit analysis results

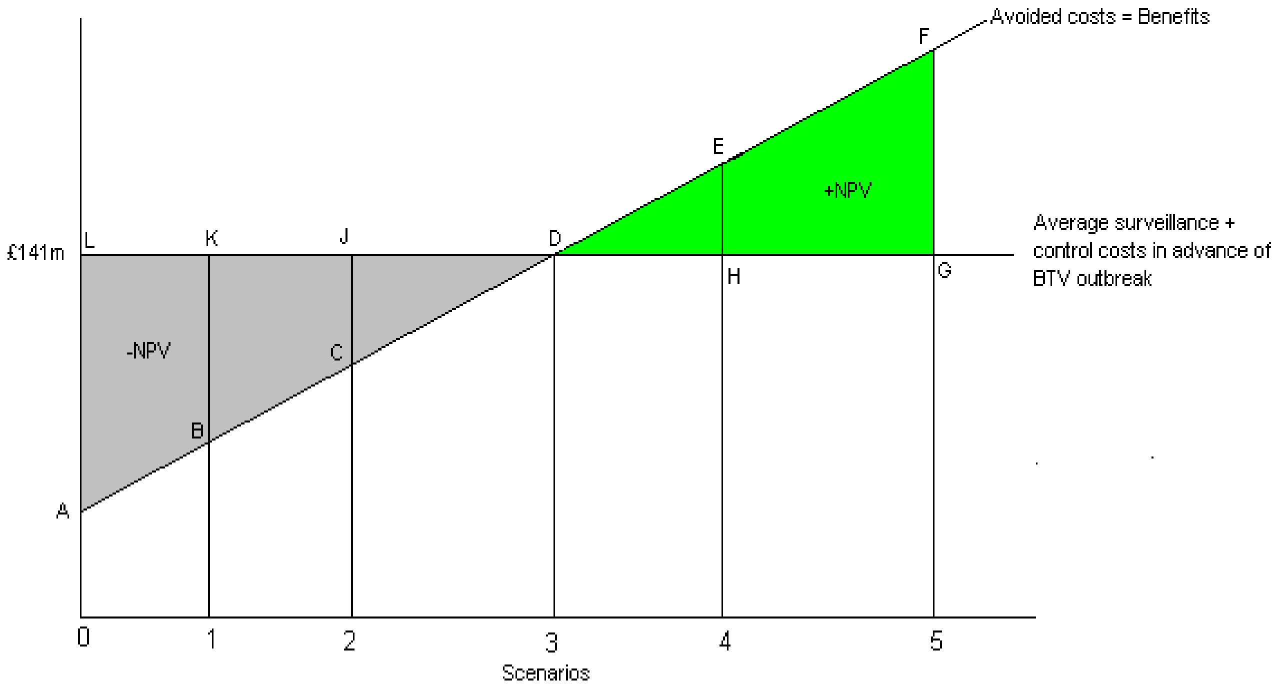

Figure 1h1- Cost benefit analysis

In order to interpret the results of the CBA presented in this report, it is essential to understand the methodology. To facilitate this process we present the above diagrammatic representation and the following bullet points.

- The factual or baseline scenario is represented in Figure 1h1 by LG which in our analysis was equivalent to £141 million in today's money equivalent. These are the baseline surveillance 'costs' in the cost benefit analysis against which the benefits will be judged. They represent the sum of all *ex-ante* investments that will reduce the risk of BTV outbreaks and/or reduce their severity in Scotland.

- A series of hypothetical or counterfactual BTV incursion scenarios 0 to 5 are introduced. For illustrative purposes these are placed in order of linearly increasing total BTV losses A to F expressed in today's money terms. These are the 'benefits' in the cost benefit analysis as they are the total of all losses due to BTV avoided because of the investment in the baseline surveillance 'costs'. These benefits will include any expenditure on vaccination (control options C2 to C5 in our analysis).

- In scenario 3 the benefits of BTV losses avoided exactly balance the baseline costs. In this case we have breakeven i.e. the cost benefit ratio (CBR) = 1.0.

- For scenarios 0 to 2 benefits A, B and C are less than the baseline surveillance costs, CBR< 1.0. The net present value (NPV) (e.g. J-C) for the investment in the disease control is negative (grey area). If this situation is known to prevail, then the costs of preventing BTV incursion exceed the benefits of keeping it out i.e. in financial terms, the precautions taken are excessive.

- For scenarios 4 and 5, benefits E and F are more than the baseline surveillance costs, CBR> 1.0. The net present value (NPV) (e.g. E-H) for the investment in baseline surveillance costs is positive (green area). If this situation is known to prevail, then the baseline surveillance costs of preventing/reducing BTV incursion are justified in financial terms.

- A limitation arises in this *ex-ante* study as the incursions we appraised are only 5 of an infinite number of possible scenarios that are not mutually exclusive. Furthermore, it was not possible to assess the risk of each incursion scenario taking place. We therefore could not weight the benefits by their probability of occurrence (R). Our benefits were therefore ranked within incursion scenarios. Our benefits were therefore much greater than the expected benefits if one assumes only one incursion scenario is possible but not inevitable. However, more than one incursion is possible and the losses from each are partially additive, leading to higher expected benefits. In the absence of prior knowledge of the exact nature of the BTV incursions, we felt it reasonable to take R=1 for the incursion of interest and R=0 for all other incursions. This precluded comparisons between incursion scenarios.

- A potential difficulty of interpretation occurs because vaccination strategy is part of the disease losses avoided (benefits) not part of the baseline costs. Higher benefits stem from greater disease losses avoided. As the risk of incursion is unknown, and the only other variable in the incursion scenarios is vaccination strategy, the scenarios with the highest benefits are associated with the most costly vaccination strategies. For example, vaccination strategy C2 (Border PZ, 100% vaccinated) always delivered the highest benefits but was therefore the vaccination strategy with the highest avoided disease losses (output losses due to BTV plus control costs including costs of vaccine). The reverse was true for vaccination strategy C4 (all Scotland PZ, 50% vaccinated).

ANNEX 1 (i) A detailed example of the cost benefit analysis (C4a)

Table 1.i shows a description of components and formulae used in an example of the economic costing spreadsheet model in Table 2.i that brings all economic data and epidemiological model output together. The first column in Table 1.i gives the row reference, the second column gives a description of variable/ parameter / constant and the third column defines the formula and provides a brief explanation with respect to the reference cells in the spreadsheet model in Table 2.i.

Table 1.i: Description of components and formulae used in the worksheet

Row Ref	Variable/ Parameter	Formula/Explanation
12	Weight loss (% of biomass)	
14		Lower bound weight loss as a percentage of biomass of sheep due to BTV infection
15		Upper bound weight loss as a percentage of biomass of sheep due to BTV infection
17		Lower bound weight loss as a percentage of biomass of cattle due to BTV infection
18		Upper bound weight loss as a percentage of biomass of cattle due to BTV infection
27	Cattle milk loss	B27= 0.05*(epidscen!Q3*DATA!J38/DATA!J32)*(DATA!J61/DATA!J38) * B78. It was assume d that 5% of milk is lost due to BTV infection. This is represented by the 0.05 parameter in the formula. where epidscen!Q3 = number of infected cows; DATA!J38 = Total Scottish population of Dairy cows; DATA!J32 = total Cattle population and B78 = price of milk per litre
28	Weight loss (% of biomass)	
29	**Sheep/Lamb**	
30	Low	B30 = epidscen!Q4*$B$14*B68*0.111. It was assumed that 11% of infected sheep would show weight loss. This is represented by the 0.11 parameter in the formula. where episedscen!Q4=number of infected sheep;

		$B$14= Lower bound weight loss as a percentage of biomass of sheep due to BTV infection ; B68 = sheep price per/head
31	High	B31 = epidscen!Q4*$B$15*B68*0.111. It was assumed that 11% of infected sheep would show weight loss. This is represented by the 0.11 parameter in the formula. Where episedscen!Q4 = number of infected sheep; $B$14= Upper bound weight loss as a percentage of biomass of sheep due to BTV infection; B68 = sheep price per/head
32	**Cattle**	
33	Low	B33 = epidscen!Q3*$B$17*B67*0.9. It was assumed that 9% of infected cows would show weight loss. This is represented by the 0.9 parameter in the formula. Where episedscen!Q3 = number of infected cows; $B$14= Lower bound weight loss as a percentage of biomass of cows due to BTV infection; B67 = price of cow per/head
34	High	B34 = epidscen!Q3*$B$18*B67*0.9. It was assumed that 9% of infected cows would show weight loss. This is represented by the 0.9 parameter in the formula. Where episedscen!Q3 = number of infected Cows; $B$14= Upper bound weight loss as a percentage of biomass of cows due to BTV infection; B67 = cow price per/head
35	**Abortion/Infertility**	
36	Sheep	B36 = ((epidscen!Q4*Pfs))*0.5. It was assumed that 5% of infected sheep will become infertile and this was represented in formula as 0.5. where Pfs =Loss of fertility for sheep (£/head); episedscen!Q4 = number of infected sheep
37	**Cattle**	
38	Dairy cattle	B38 = (epidscen!Q3*Pfdc)*(DATA!J38/DATA!J32)*0.019 It was assumed that 1.9% of infected cows will become infertile and this was represented in formula as 0.019. Where episedscen!Q3 = number of infected cows; Pfdc= value of loss of fertility for dairy cattle(£/head)
39	Beef cattle	B39 = (epidscen!Q3*Pfbc)*DATA!J44/DATA!J32*0.019 It was assumed that 1.9% of infected cows will become infertile and this was represented in formula as 0.019. Where episedscen!Q3 = number of infected cows; Pfdc= value of loss of fertility for beef cattle(£/head)
40	Sheep mortality	B40 = epidscen!Q8*Ps Where Ps is price of sheep/head; epidscen!Q8= number of dead sheep due to BTV
41	Cattle mortality	B41 = epidscen!Q7*Pc where Pc is the price cattle/head; epidscen!Q8= number of dead cows due to BTV
42	Wool loss	B42 = 2.5*epidscen!Q4*B79*0.3 It was assumed that normal yield of wool per sheep is 2.5 kg and 30% of sheep may develop signs of disease. where episedscen!Q4 = number of infected sheep; B79 = price of wool per kg;
43	Veterinary cost of morbid sheep	B43 = epidscen!Q4*B80, Where episedscen!Q4 = number of infected sheep,

		B80 = Veterinary and medicine cost per sheep (£/head)
44	Veterinary cost of morbid cattle	B44 = epidscen!Q3*B81, Where episedscen!Q3 = number of infected cows; B80 = Veterinary and medicine cost per cow (£/head)
45	Sheep carcass disposal cost	B45 = epidscen!Q8*B66; where epidscen!Q8= number of dead sheep due to BTV B66= carcass disposal cost (£/sheep)
46	Cattle carcass disposal cost	B46 = epidscen!Q7*B67; where epidscen!Q7= number of dead cows due to BTV B67= carcass disposal cost (£/cow)
47	**Palliative Care**	
48	Sheep	B48=epidscen!Q4*(DATA!$D$204*5+DATA!$D$205*3)+epidscen!Q8*(DATA!$D$204*5+DATA!$D$205*3); Where epidscen!Q4= number of infected sheep, epidscen!Q8= number of dead sheep due to BTV; DATA!$D$204 = cost of alamycin la by 5 doses, DATA!$D$205 = cost of flunixin by 3 doses
49	Cattle	B49=epidscen!Q3*(DATA!$D$201+DATA!$D$202)+epidscen!Q7*(DATA!$D$201+DATA!$D$20)where epidscen!Q3 = number of infected cows, epidscen!Q7= number of dead cows due to BTV; DATA!$D$201= cost of administration of alamycin la ; DATA!$D$202= cost of administration of flunixin
50	**Movement restrictions (includes PCR and ELISA pre-testing cost)**	
51	Sheep	B51= 0.05*B68*(epidscen!Q26+epidscen!Q32)+epidscen!Q27*B90+epidscen!Q28*B89 Where The parameter of value 0.05 represents the assumption that movement restriction will cost 5% of the value of the animal B68= price of sheep (£ /head) epidscen!Q26 = Number of sheep movement (live-live) lost in the counties where control will be undertaken epidscen!Q32 = Number of sheep movement (live- slaughter) lost in the counties where control will be undertaken epidscen!Q27 = Number of sheep vaccinated with PCR before movement (live-live) in the counties where control will be undertaken B90 = Pre-movement testing PCR cost (£/head) epidscen!Q28 = Number of sheep vaccinated with ELISA before movement (live-live) in the counties where control will be undertaken B89= Pre-movement testing ELISA cost (£/head)
52	Cattle	B52 = 0.05*B70*(epidscen!Q23+epidscen!Q31)+epidscen!Q24*B90+epidscen!Q25*B89 Where The parameter of value 0.05 represents the assumption that movement restriction will cost 5% of the value of the animal epidscen!Q23= Number of cattle movement (live-live) lost in the counties where control will be undertaken epidscen!Q24= Number of cattle vaccinated with PCR before movement (live-live) in the counties where control will be undertaken epidscen!Q25= Number of cattle vaccinated with ELISA before movement (live-live) in the counties where control will be undertaken epidscen!Q31= Number of cattle movement (live-slaughter) lost in the counties where control will be undertaken B70= price of cattle (£ /head) B90 = Pre-movement testing PCR cost (£/head) B89= Pre-movement testing ELISA cost (£/head)

53	Cattle movement to slaughter costs - add to 'no license' CBA	B53 = epidscen!Q31*B70*0.15 Where epidscen!Q31= Number of cattle movement (live-slaughter) lost in the counties where control will be undertaken B70= price of cattle (£ /head) The parameter of value 0.05 represents the assumed 15% reduction in live animal cost due to move to slaughter delay (Loss in revenue due to decrease in price of cattle because of a reduction in price due to 'movement to slaughter' delays or increased costs.).
54	Sheep movement to slaughter costs	B54 = epidscen!Q32*B68*0.15 Where epidscen!Q32= Number of sheep movement (live- slaughter) lost in the counties where control will be undertaken B68= price of sheep (£ /head) The parameter of value 0.05 represents the assumed 15% reduction in live animal cost due to move to slaughter delay (Loss in revenue due to decrease in price of cattle because of a reduction in price due to 'movement to slaughter' delays or increased costs.).
59	**Increase in labour cost due to BTV infection**	
60	Cattle	B60 = ((7*epidscen!Q3)/480)*60*1 It was assumed that family labour will be used to supplement farm labour in the event of an incursion of BTV. As family labour has a low opportunity cost, labour cost was assumed to be £1/hour as in Gunn et al. (2004). Extra labour was assumed to be 7mins/morbid cattle per day. Where epidscen!Q3 = Number of Infected cattle The parameter of value 7 (measure unit minutes) represents the number of minutes spent to nurse an infected animal The constant 480 (measure unit minutes) represents the duration of a labour day, namely sum of 1 hour/day (60 minutes) to organise treatment regardless of flock size and 8hrs/day =420 minutes The constant 60 represents the number of animals nursed by one family labourer. The constant 1 represents the labour cost, which was assumed to be £1/hour.
61	Sheep	B61 = ((2*epidscen!Q4)/480)*60*1 It was assumed that family labour will be used to supplement farm labour in the event of an incursion of BTV. As family labour has a low opportunity cost, labour cost was assumed to be £1/hour as in Gunn et al. (2004). Extra labour was assumed to be 2 mins/morbid cattle per day. Where epidscen!Q4 = Number of Infected Sheep The parameter of value 2 (measure unit minutes) represents the number of minutes spent to nurse an infected animal The constant 480 (measure unit minutes) represents the duration of a labour day, namely sum of 1 hour/day (60 minutes) to organise treatment regardless of flock size and 8hrs/day =420 minutes The constant 60 represents the number of animals nursed by one family labourer. The constant 1 represents the labour cost, which was assumed to be £1/hour.
62	**Direct cost**	B62=0.5*(B22+B23)+0.5*(B25+B26)+B27+B29+0.5*(B30+B31)+0.5*(B33+B34)+B36+0.5*(B38+B39)+B40+B41+B42+B43+B44+0.5*(B5+B6)+0.5*(B8+B9)+B45+B46+B48+B49+B51+B52+B53+B54+B60
63	**Avoided cost**	B63=B62
95	Sheep BTV Vaccination	B95=B82*epidscen!Q6, where B82= BTV Vaccine per sheep (£/head), epidscen!Q6 =number of vaccinated sheep
96	Cattle BTV Vaccination	B96=B83*epidscen!Q5 where B83= BTV Vaccine per cow (£/head), epidscen!Q5 =number of vaccinated cows,

97	Sheep - Veterinary supervision, certification and animal identification - farm level	B97=epidscen!Q10*Cc where epidscen!Q10= Number of infected Sheep farms, Cc = certification cost per sheep farm
98	Sheep Veterinary supervision, certification and animal identification - for exports	B98=(50+9*10+(0*(DATA!J4*epidscen!Q38/DATA!J2)-10)*1.5) As per RERAD communication it was assumed that all animals are vet administered and certified. Veterinary supervision, certification and animal identification ion cost as follows-: initial estimates of costs are 1st cattle (£50), next 9 (£10 each), the rest (£1.5 each). Where DATA!J4 = total sheep export (heads) DATA!J2= Total live domestic production of sheep (heads) epidscen!Q38 =Total number of sheep in the PZ The parameter of value 0 represents the assumption that all sheep exports from the PZ area are banned - as peak export time is outside the free-vector period (which is the only time when exports are allowed).
99	Cattle Veterinary supervision, certification and animal identification - farm level	B99=epidscen!Q9*Cc where epidscen!Q9= Number of infected cattle farms, Cc = certification cost per cattle farm. Cc was given as £80 per holding
100	Cattle Veterinary supervision, certification and animal identification - for exports	B100=(50+9*10+(0.33*(DATA!J34*epidscen!Q37/DATA!J32)-10)*5) As per RERAD communication it was assumed that all animals are vet administered and certified. Veterinary supervision, certification and animal identification cost as follows-: initial estimates of costs are 1st cattle (£50), next 9 (£10 each), the rest (£5 each). Where DATA!J34 = total cattle exports (heads) ; epidscen!Q37= Total number of cattle in the PZ DATA!J32= Total live domestic production of cattle (heads) The parameter of value 0.33 represents the assumption that cattle exports from the PZ area are allowed for 33% of the duration of the year.
101	Veterinary, medicine and other costs (cattle)	B101=B81*DATA!I32 where DATA!I32= Cattle total live production (heads), B81= Veterinary and medicine cost per cattle (£/head)
102	Veterinary, medicine and other costs (sheep)	B102=B80*DATA!J32 where DATA!I32= sheep total live production (heads), B80= Veterinary and medicine cost per cattle (£/head)
103	Sheep BTV pre-testing PCR (imports)	B103=B90*DATA!J3*0.75
104	Cattle BTV pre-testing PCR (imports)	B104=B90*DATA!J33*0.75; where B90=Pre-movement testing PCR (£/head), B90 = Total cattle imports (heads)
106	Slaughtering cost for imported BTV infected sheep	B106=SUM(B101:B104)
107	Total treatment costs	
108	Avoided cost	B108=B95+B96+B97+B98+B99+B100+B105+B106
		Indirect costs - Public surveillance costs
110	Sheep BTV Vaccination	B110=0*B82*epidscen!Q6 This element of the cost was included as public sector cost or part of the surveillance cost in scenarios
111	Cattle BTV Vaccination	B111=0*B83*epidscen!Q6
112	Sheep Veterinary supervision,	B112=0*(50+9*10+(epidscen!L38-10)*1.5) Where

	certification and animal identification	The parameter of value 0 is used to multiply the rest of the formula **only** in the spreadsheets for the 'Voluntary vaccination' scenarios to indicate no public costs regarding sheep veterinary supervision, certification and animal identification.
113	Cattle Veterinary supervision, certification and animal identification	B113=0*(50+9*10+(epidscen!L37-10)*5) Where The parameter of value 0 is used to multiply the rest of the formula **only** in the spreadsheets for the 'voluntary vaccination' scenarios to indicate no public costs regarding cattle veterinary supervision, certification and animal identification.
	Sheep	
115	Probable BTV surveillance costs	B115=Survecost!J26*0.02+700 It was assumed that 2% of total public sector surveillance constitute passive surveillance costs for sheep. where Survecost!J26= surveillance cost as supplied by RERAD The constant '700' represents the assumed routine cost for inspection of farms with suspicion of outbreak.
	Cattle	
117	Probable BTV surveillance and control costs	B117=Survecost!J26*0.005+300. It was assumed that 0.5% of total public sector surveillance constitutes passive surveillance costs for cattle and 300 represent…
118	Sheep BTV pre-testing ELISA for animal imported from the RUK	B118=DATA!J5*B89. where DATA!J5= Sheep total 'Imports' from the rest of UK (heads), - B89=ELISA pre- movement testing cost (domestic) (£/head)
119	Sheep BTV pre-testing PCR for animal imported from the RUK	B119=DATA!J5*B90. where DATA!J5= Sheep total 'Imports' from the rest of UK (heads), B90= PCR movement pre- testing cost (domestic) (£/head)
120	Cattle BTV pre-testing ELISA for animal imported from the RUK	B120=DATA!J35*B89 where DATA!J35= cattle total 'Imports' from the rest of UK (heads), B89=ELISA movement pre- testing cost (domestic) (£/head)
121	Cattle BTV pre-testing PCR for animal imported from the RUK	B121=DATA!J35*B90 where DATA!J35= cattle total 'Imports' from the rest of UK (heads), B90= PCR movement pre- testing cost (domestic) (£/head)
122	Total public surveillance cost and disease control costs ((incl. mail shots, ads, etc)	B122=B115+B117+B118+B119+B120+DATA!$B$132+DATA!$B$133
123	**Avoided costs**	B123=B110+B111+B112+B113
		Apparent domestic consumption and export loss during disease outbreak (quantity)
125	Sheep live animals export loss (heads) (banned)	B125=DATA!J4*epidscen!Q38/DATA!J2 where DATA!J4= Sheep total export (heads); epidscen!Q38= Total number of sheep in the PZ; DATA!J2= Sheep total domestic production (heads)
126	Cattle live animals export loss (heads) (banned)	B126=DATA!J34*epidscen!Q37/DATA!J32-0.33*(DATA!J34*epidscen!Q37/DATA!J32) where DATA!J34=Cattle total exports (heads), epidscen!Q37= Total number of cattle in the PZ; DATA!J32= Cattle total live production (heads); DATA!J34= Cattle total exports (heads)
131	Sheep meat domestic consumption loss (kg) (change in domestic consumers perception)	B131=(DATA!J99*DATA!J20* 0.1)/B75 Price elasticity of demand was used to predict the likely price effects that BTV outbreak-related shortages may cause. It was assumed that when BTV breaks out it would have an almost instant impact on the amount meat products that will be consumed due to negative

		media coverage. Thus the formula used in the estimation of meat product do not include lags where DATA!J99= own price elasticity of lamb (meat); DATA!J20= Apparent domestic consumption of sheep meat (kg); B75= Sheep meat price (£ /kg)
132	Beef domestic consumption loss (kg) (change in domestic consumers perception)	B132=(DATA!J102*DATA!J55*0.25)/B77 Price elasticity of demand was used to predict the likely price effects that BTV outbreak-related shortages may cause. It was assumed that when BTV breaks out it would have an almost instant impact on the amount meat products that will be consumed due to negative media coverage. Thus the formula used in the estimation of meat product do not include lags where DATA!J102= own price elasticity of beef; DATA!J55= Apparent domestic consumption of beef (kg); B77= beef price (£ /kg)
134	Milk domestic consumption loss (litre) (change in domestic consumers perception)	B134=(1+((B78*0.96)/DATA!K169-1)*DATA!J103)*DATA!J67*0.999 Where B78=milk price per litre DATA!K169= milk price per litre DATA!J103 = Milk own price elasticity DATA!J67= Apparent domestic population milk consumption (litres) It was assumed that when BTV disease occurs milk would not be immediately affected media coverage of the disease. Therefore the estimation of BTV outbreak include lags to simulate slow response of milk consumers.
		Indirect Cost Apparent domestic consumption and export losses
136	Sheep live animals export loss (banned)	B136=B125*B68*DATA!J88 where B125= Sheep live animals export loss (heads) ; B68= Sheep price (£ /head); DATA!J88 = input output multiplier for sheep
137	Cattle live animals export loss (banned)	B137=B126*B70*DATA!J89 where B126= cattle live animals export loss (heads) ; B70= cattle price (£ /head); DATA!J88 = input output multiplier for cattle
142	Sheep meat domestic consumption loss (change in domestic consumers perception)	B142=B131*B75 where B131=Sheep meat domestic consumption loss (kg) (change in domestic consumers perception); B75= price of Sheep meat (£ /kg)
143	Beef domestic consumption loss (change in domestic consumers perception)	B143=B132*B77 where B132=beef meat domestic consumption loss (kg) (change in domestic consumers perception); B77= price of beef meat (£ /kg)
145	Milk domestic consumption loss (change in domestic consumers perception)	B145=(DATA!J67-B134)*B78 where DATA!J67= Apparent domestic milk consumption (litres); B134= milk domestic consumption loss (litres) (change in domestic consumers perception); B78= price of milk (£ /litre)
146	**Total indirect cost**	B146=SUM(B136:B145)
147	**Avoided cost**	B147=SUM(B136:B145)
		Estimated indirect cost of disease (assume no license for move-to-slaughter - than add lines 53, 54)
149	Estimated indirect cost of disease	B149=B146+B123+B122
150	Estimated direct cost of disease	B150=B62+B107
		Estimated direct and indirect cost of disease (£million)

152	Estimated direct and indirect cost of disease	B152=B149+B150
		Cost and Benefit Analysis
155	Undiscounted Benefit (avoided cost)	B155=B63+B108+B123+B147
156	Discounted Benefit	B156=B155/(1+0.035)^r where 0.035 represent the discount rate, r=0 in year 1, 1 in year 2 etc
157	Undiscounted Cost	B157=B107+B122
158	Discounted cost	B158=B157/(1+0.035)^r where 0.035 represent the discount rate, r=0 in year 1, 1 in year 2 etc
		Estimated indirect cost of disease (assume license for move-to-slaughter)
161	Estimated indirect cost of disease	B161=B146+B123+B122
162	Estimated direct cost of disease	B162=B62+B107
		Estimated direct and indirect cost of disease (£million) (assume license for move-to-slaughter)
164	Estimated direct and indirect cost of disease	B164=B161+B162
		Cost and Benefit Analysis (assume license for move-to-slaughter)
167	Undiscounted Benefit (avoided cost)	B167=B63+B108+B123+B147-B53-B54
168	Discounted Benefit	B168=B167/(1+0.035)^r . where 0.035 represent the discount rate, r=0 in year 1, 1 in year 2 etc
169	Undiscounted Cost	B169=B107+B122
170	Discounted cost	B170=B169/(1+0.035)^r . where 0.035 represent the discount rate, r=0 in year 1, 1 in year 2 etc
171	CBA ratio (**assume no license for move-to-slaughter)**	B171=SUM(C156:G156)/ SUM(C158:G158)
172	CBA ratio (**assume with license for move-to-slaughter)**	B172=SUM(C168:G168)/ SUM(C170:G170)

Table 2.i: Sample of economic costing spreadsheet model

	A	B	C	D	E	F
	Disease:	**Blue Tongue Virus**				
	System affected:	**Sheep and Cattle**				
	Year	**2009**	**2010**	**2011**	**2012**	**2013**
12	**Weight loss (% of biomass)**					
13		**Sheep**				
14	low	0.10				
15	high	0.15				
16		**Beef cow**				
17	low	0.05				
18	high	0.10				
		Valuation of effects (£)				
		Direct Cost-Cost due to BTV disease effects (direct Cost)				
27	**Cattle milk loss**	0.00	4.47	2.64	1.42	0.00
28	**Weight loss (% of biomass)**					
29	**Sheep/Lamb**					
30	low	0.505	0.060	0.039	0.020	0.000
31	high	0.758	0.090	0.059	0.030	0.000
32	**Cattle**					
33	low	8.336	2.498	1.673	0.849	0.000
34	high	7.628	0.878	0.588	0.298	0.000
35	**Abortion/Infertility**					
36	**Sheep**	0.34	0.04	0.03	0.01	0.00
37	**Cattle**					
38	Dairy cattle	0.01	0.00	0.00	0.00	0.00
39	Beef cattle	0.03	0.01	0.01	0.00	0.00
40	**Sheep mortality**	2.42	0.41	0.27	0.14	0.00
41	**Cattle mortality**	6.92	0.00	0.00	0.00	0.00
42	**Wool loss**	1.64	0.19	0.13	0.07	0.00
43	**Veterinary cost of morbid sheep**	1.02	0.12	0.08	0.04	0.00
44	**Veterinary cost of morbid cattle**	29.64	8.88	5.95	3.02	0.00
45	**Sheep carcass disposal cost**	1.20	0.20	0.13	0.07	0.00
46	**Cattle carcass disposal cost**	0.75	0.00	0.00	0.00	0.00
47	**Palliative Care**					
48	Sheep	115.72	1,211.78	1,211.78	1,211.78	1,211.78
49	Cattle	71.67	4,326.04	4,326.04	4,326.04	4,326.04
50	**Movement restrictions (includes PCR and ELISA pre-testing cost)**	0.00	0.00	0.00	0.00	0.00
51	Sheep	0.00	0.00	0.00	0.00	0.00
52	Cattle	0.00	0.00	0.00	0.00	0.00
53	**Cattle movement to slaugher costs - add to 'no license' CBA**	0.00	0.00	0.00	0.00	0.00
54	**Sheep movement to slaugher costs**	0.00	0.00	0.00	0.00	0.00
55	**Movement to slaughter license cost**	0.00	0.00	0.00	0.00	0.00
59	**Increase in labour cost due to BTV infection**					
60	Cattle	2.16	0.65	0.43	0.22	0.00
61	Sheep	0.28	0.03	0.02	0.01	0.00
62	**Direct cost**	242.11	5,554.54	5,548.66	5,543.40	5,537.81

63	**Avoided cost**	242.11	5,554.54	5,548.66	5,543.40	5,537.81
	Direct cost-Private treatment costs					
95	Sheep BTV Vaccination - include this as private cost for 'voluntary vacc.' scen. (c3a-e, c4a-e,c5e)	1,048,641.61	0.00	0.00	0.00	0.00
96	Cattle BTV Vaccination	553,265.74	0.00	0.00	0.00	0.00
97	Sheep - Veterinary supervision, certification and animal identification - farm level	59.20	4.80	3.22	1.63	0.00
98	Sheep Veterinary supervision, certification and animal identification - for exports	125.00	125.00	125.00	125.00	125.00
99	Cattle Veterinary supervision, certification and animal identification - farm level	80.80	8.80	5.90	2.99	0.00
100	Cattle Veterinary supervision, certification and animal identification - for exports	5,827.92	6,884.72	5,250.21	2,967.52	90.00
101	Veterinary/medicine and other costs (cattle)	22,002,000	23,128,697	22,948,596	22,951,566	22,908,917
102	Veterinary/medicine and other costs (sheep)	5,548,551.00	5,505,345.00	5,506,057.50	5,495,826.00	5,480,692.50
103	Sheep BTV pre-testing PCR (imports)	459,189.68	447,093.00	432,590.51	418,826.14	405,501.41
104	Cattle BTV pre-testing PCR (imports)	121,015.80	112,176.21	108,084.49	124,510.05	153,570.94
105	Slaughtering cost for imported BTV infected cattle	0.00	0.00	0.00	0.00	0.00
106	Slaughtering cost for imported BTV infected sheep	0.00	0.00	0.00	0.00	0.00
107	Total treatment costs	28,130,757	29,193,311	28,995,329	28,990,728	28,948,682
108	Avoided cost	1,608,000.27	7,023.32	5,384.32	3,097.15	215.00
	Indirect costs - Public surveillance costs					
110	Sheep BTV Vaccination - include this as public cost for 'compulsory vacc.' scen. (c2a,c2b,c2c,c2d,c2e)	0.00	0.00	0.00	0.00	0.00
111	Cattle BTV Vaccination - include this as public cost for 'compulsory vacc.' scen. (c2a,c2b,c2c,c2d,c2e)	0.00	0.00	0.00	0.00	0.00
112	Sheep Veterinary supervision, certification and animal identification	0.00	0.00	0.00	0.00	0.00
113	Cattle Veterinary supervision, certification and animal identification	0.00	0.00	0.00	0.00	0.00
110	**Sheep**					
151	Probable BTV surveillance costs	480,977.58	512,246.69	543,515.80	574,784.90	606,054.01
116	**Cattle**					
117	Probable BTV surveillance and control costs	120,369.39	128,186.67	136,003.95	143,821.23	151,638.50
118	Sheep BTV pre-testing ELISA for animal imported from the RUK	101,633.98	98,956.58	95,746.70	92,700.19	89,750.98
119	Sheep BTV pre-testing PCR for animal imported from the RUK	508,169.91	494,782.92	478,733.50	463,500.93	448,754.90
120	Cattle BTV pre-testing ELISA for animal imported from the RUK	26,784.83	24,828.34	23,922.70	27,558.22	33,990.37
121	Cattle BTV pre-testing PCR for animal imported from the RUK	133,924.15	124,141.68	119,613.50	137,791.12	169,951.84
122	Total public surveillance cost and disease control costs ((incl. mail shots, ads, etc)	1,237,935.69	1,259,001.20	1,277,922.64	1,302,365.47	1,330,188.76
123	**Avoided costs**	0.00	0.00	0.00	0.00	0.00
	Apparent domestic consumption and export loss during disease outbreak (quantity)					
125	Sheep live animals export loss (heads) (banned)	25,047.26	13,666.88	8,697.84	4,200.95	0.00
126	Cattle live animals export loss (heads) (banned)	2,329.94	1,675.92	1,272.77	709.74	0.00
131	interim calc Sheep meat domestic consum86ption loss (kg) (change in domestic consumers perception)	271,063.50	216,188.93	189,691.65	132,844.24	118,522.15
132	interim calc Beef domestic consumpti89on loss (kg) (change in domestic consumers perception)	9,605,627.98	9,457,944.98	9,339,126.49	9,407,765.81	9,358,001.02
134	Milk domestic consumption loss (litre) (change in domestic consumers perception)	175,333,234	177,013,912	172,267,526	172,905,487	173,321,697
	Indirect Cost Apparent domestic consumption and export losses					
136	Sheep live animals export loss (banned)	1,815,575.68	1,020,424.02	634,072.85	309,802.97	0.00
137	Cattle live animals export loss (banned)	2,901,758.92	2,155,910.50	1,737,294.31	1,000,155.15	0.00
142	Sheep meat domestic consumption loss (change in domestic	2,114,295.32	1,707,892.58	1,517,533.24	1,076,038.37	971,881.62

	consumers perception)					
143	Beef domestic consumption loss (change in domestic consumers perception)	64,517,801.24	64,944,555.54	65,529,538	67,422,322	68,469,374
145	Milk domestic consumption loss (change in domestic consumers perception)	712,460	496,402.48	1,368,447	1,328,923	1,326,940
146	**Total indirect cost**	72,061,891	70,325,185	70,786,885	71,137,241	70,768,196
147	**Avoided cost**	72,061,891	70,325,185	70,786,885	71,137,241	70,768,196
	Estimated indirect cost of disease (assume no license for move-to-slaughter)					
149	Estimated indirect cost of disease	73,299,826.36	71,584,186.31	72,064,808	72,439,606	72,098,385
150	Estimated direct cost of disease	28,130,998.59	29,198,866	29,000,877	28,996,272	28,954,219
	Estimated direct and indirect cost of disease (£million) (assume no license for move-to-slaughter)					
152	Estimated direct and indirect cost of disease	101,430,825	100,783,052	101,065,685	101,435,878	101,052,604
	Cost and Benefit Analysis (assume no license for move-to-slaughter)					
		2009	2010	2011		2013
155	Undiscounted Benefit (avoided cost)	73,670,133	70,337,762.97	70,797,818	71,145,881	70,773,949
156	Discounted Benefit	73,670,133.06	67,959,191.28	66,090,521	64,169,509	61,675,407
157	Undiscounted Cost	29,368,692.17	30,452,312.21	30,273,251	30,293,094	30,278,870
158	Discounted cost	29,368,692.17	29,422,523.88	28,260,404	27,322,635	26,386,286
	Estimated indirect cost of disease (assume license for move-to-slaughter)					
161	Estimated indirect cost of disease	73,299,826	71,584,186	72,064,808	72,439,606	72,098,385
162	Estimated direct cost of disease	28,130,999	29,198,866	29,000,877	28,996,272	28,954,219
	Estimated direct and indirect cost of disease (£million) (assume license for move-to-slaughter)					
164	Estimated direct and indirect cost of disease	101,430,825	100,783,052	101,065,685	101,435,877	101,052,604
167	Undiscounted Benefit (avoided cost)	73,670,133	70,337,763	70,797,818	71,145,881	70,773,948
168	Discounted Benefit	73,670,133.06	67,959,191.28	66,090,521	64,169,509	61,675,407
169	Undiscounted Cost	29,368,692	30,452,312	30,273,251	30,293,094	30,278,870
170	Discounted cost	29,368,692	29,422,524	28,260,404	27,322,635	26,386,286
171	**CBA ratio (assume no license for move-to-slaughter)**	2.42				
172	**CBA ratio (assume with license for move-to-slaughter)**	2.42				

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(2008) Kostenbaten analyse Bluetongue Schade epidemieën 2006 en 2007 en evaluatie vaccinatiestrategieën [1] Bedrijfseconomie, Wageningen Universiteit [2] Divisie virologie, Centraal Veterinair INSTITUUT, WUR

ANNEX 2 (a) Transmission of bluetongue virus within and between farms

This appendix provides a summary of the models used to describe the transmission of bluetongue virus (BTV) within and between farms in Great Britain (GB), including the assumptions made and the data used.

Within-farm model

- The structure of the model has been described elsewhere (Gubbins *et al*. 2008). However, in the GB spread model a stochastic, rather than a deterministic formulation is used.
- The model includes two host species (cattle and sheep) and one vector. For simplicity, the population sizes (i.e. number of cattle, sheep and vectors on a holding) are assumed to be constant.
- Parameter estimates were obtained from the published literature, using those applicable to the GB situation wherever possible (Gubbins *et al*. 2008)[12].
- Explicit temperature dependence was included for the reciprocal of the time interval between blood meals (related to the biting rate), the vector mortality rate and the extrinsic incubation period.
- Other critical parameters (probability of transmission from vector to host, vector to host ratios) were set by sampling from appropriate ranges for the parameters.
- For the remaining parameters point estimates were used where robust; otherwise, values were sampled from appropriate ranges.

Between-farm model

- A stochastic, spatially explicit farm-level model with a daily time step was developed to describe spread between farms. A farm is considered infectious once the first newly infectious vectors appear on the farm.
- Transmission between farms is modelled by a generic dispersal kernel, which includes both animal and vector movements. The probability of transmission depends on the distance between farms (i.e. the kernel) and the species composition of the farms.
- If a farm acquires infection, the within-farm model (see above) was simulated based on the number of cattle and sheep kept on the farm. An affected farm was assumed to be detected if an animal died due to BTV infection or if overt clinical signs appeared. For each affected farm the following are recorded:
    - time of challenge;
    - time at which farm becomes infectious;
    - time of appearance of clinical signs in cattle and sheep;
    - time at end of outbreak;

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[12] One change from the published article is the inclusion of BTV-associated mortality in cattle. The disease-associated mortality rate was set to match the observed mortality in the BT outbreak in northern Europe during 2006 and 2007 of 0.2% (Albers *et al*. 2006; Szmaragd *et al*. 2007)

  - o number of cattle ever infected and number of cattle dead; and
  - o number of sheep ever infected and number of sheep dead.

- Parameters for the transmission probability were estimated using data on clinically affected holdings in northern Europe in 2006 (Albers *et al*. 2007; EFSA 2007). Estimation was done principally using data for the initial Maastricht focus, but similar estimates were obtained for the Ghent and Cologne foci. The estimates implicitly take into account the impact on transmission of movement restrictions in place at this time.

- Species-specific probabilities for an animal showing overt clinical signs were estimated from OIE reports for 2007.

Overwintering

- Overwintering of BTV occurs in the model via two mechanisms:

  - o Hosts infected at the end of one season and which have a very long duration of viraemia could act as a source of infection for newly emerged vectors in the following season.

  - o Vectors infected at the end of one season and which survive to the beginning of the following season will act as a source of infection (Wilson *et al*. 2007). The likelihood of this happening will depend on the vector mortality rate at low temperatures, which for the temperature-dependent function used in the within-farm model is very low. However, this is based on extrapolation from data which considered vector mortality over a restricted temperature range (10-30°C; Gerry & Mullens 2000).

- Three further overwintering mechanisms have been posited: vertical transmission in the vertebrate host (Anonymous 2008); covert persistence of BTV in immune cells in the vertebrate host (Takamatsu *et al*. 2003); and vertical transmission in the vector (White *et al*. 2005). However, none of these mechanisms has been quantified in the field, and so they cannot be easily incorporated in the model.

- In summary, it is likely that model overestimates the importance and frequency of overwintering in the vector and underestimates that in the ruminant host. Consequently, the overall frequency of overwintering is probably captured by the model, if not the precise mechanisms.

Vaccination

- It is assumed that vaccination acts by reducing the probability of vector to host transmission (i.e. acquisition of infection) and host to vector transmission (to reflect lower virus titres in infected, vaccinated animals).

- The effect of vaccination is assumed to start at zero at the time of vaccination and increases linearly until full protection is reached. Data on the time to full protection in sheep and cattle were obtained from information supplied by the vaccine manufacturers. In sheep this is reached at 14 days post vaccination (dpv); for cattle it is reached at 60 dpv.

- Vaccination is assumed to be 100% effective in all animals.

- Farms belonging to a protection zone (PZ) are vaccinated so that a specified percentage of holdings are covered.

Initial conditions

- The initial conditions were set depending on how the model was being used.

- For the incursion scenarios (i.e. spread in GB) the model was initialised with a single infected farm (Baylham Farm, near Ipswich) on 04 August 2007. Six long range transmission events in Cambridgeshire, Kent and Sussex (i.e. affected farms identified at a long distance from the main East Anglia cluster) were seeded in the model to allow for spread which cannot be easily replicated in the simulations.

- For the epidemiological scenarios where BTV was introduced to Scotland via northwards spread the initial status of farms in Scotland (and the four northernmost counties in England) were extracted from the results of the GB model run until the end of December 2008. For each replicate of the Scotland model the initial status was selected at random from one (out of ten) replicate of the GB model.

- For the epidemiological scenarios where BTV was introduced to Scotland via imported infected animals a single farm was selected as the initial affected location. The initial farm was selected in a two-step process. First, a county was selected at random with probability given by the proportion of movements from England to that county. Second, a farm within the county was selected at random with each farm having an equal probability of being selected. The number of animals imported was drawn from a negative binomial distribution parameterised for each species according to the distribution of batch sizes from the movement data.

Input data

- Farm locations and number of sheep and cattle on the holding were obtained from June agricultural survey data for 2006.

- Hourly temperature records were obtained for 19 meteorological stations throughout GB. Data from 2006 were used for most (14) stations, while data from used for 2005 for the remaining 5 stations; these represent the most complete data-sets. Each farm used temperature records for the nearest station.

Movement data

- Movement data for 2006 for cattle and sheep were obtained from CTS, AMLS and SAMS.

- These data have been aggregated by county and by month to provide:

    - number of cattle movements to live and to slaughter from one county to another; and

    - number of sheep movements to live and to slaughter from one county to another.

- By linking these with the time at which each county becomes part of a PZ, it is possible to estimate the number of movements of each type lost as a result of movement restrictions.

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ANNEX 2 (b) Incursion scenarios: meteorological assessment

Summary of the highest risks to Scotland (medium risk) †

Scenario	Sub scenario	Risk period (Scotland)
Northward expansion from 2007 foci	Series of foci in England	Late summer/early autumn
Inadvertent creation of new disease foci near Scottish border	Spread across Scottish Uplands	June to August
	Long distance windborne spread from Northumberland coast to Fife	May to September
	Long distance windborne spread from Cumbria to Galloway across Solway Firth	May to October
Disease centre in north eastern Northern Ireland	Over the sea	May to November (only if disease centre is established)

Summary of other risks to Scotland

Scenario	Sub scenario	Level of risk†	Risk period (Scotland)
Long distance transport over the sea from mainland Europe	Denmark (no outbreaks in 2008)	Negligible	None
	Denmark (outbreaks in 2008 on west coast)	Very low	May to October
	Germany (based on outbreak locations in 2007)	Very low	May to October
	Germany (expansion of outbreaks to north west Germany in 2008)	Very low	May to October
	Netherlands (outbreaks as in 2007)	Low	May to October
	France/Belgium	Very low	May to October
Northward expansion from areas infected in East Anglia in 2007	Single jump overland	Very low	May to October
	Single jump over the sea	Very low	June to October
Inadvertent creation of disease foci near to Scottish border	Near Southern Uplands then northward over border	Low	September to October
	Series of foci along the Northumberland coast then to Dundee area	Low	May to September
	Local spread in the Carlisle area then on the wind along the Galloway coast	Low	May to October
Northern Ireland	Based on 2007	Negligible	None

† see OIE (2004) *Handbook on import risk analysis for animals and animal products. Volume I: Introduction and qualitative risk analysis*. Paris, France: OIE.

ANNEX 2(c) Temperature, the EIP and transmission-free period

(*a*)

(*b*)

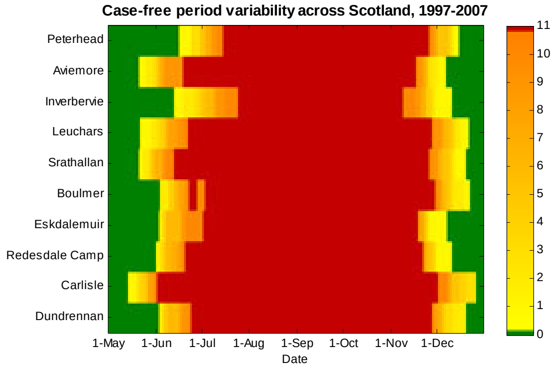


Figure 2.1. (*a*) Location of meteorological stations used in the EIP analysis. (*b*) Seasonal transmission-free period for each site, based on temperature data from 1997 to 2007. Green indicates that vector-host transmission could not occur in any of the sample years, red indicates risk in all years, and yellow-orange indicates intermediate levels of risk. The colour bar indicates the number of years for which vector to host transmission could have occurred for a given date.

ANNEX 3 (a) Protection zones used in control scenarios

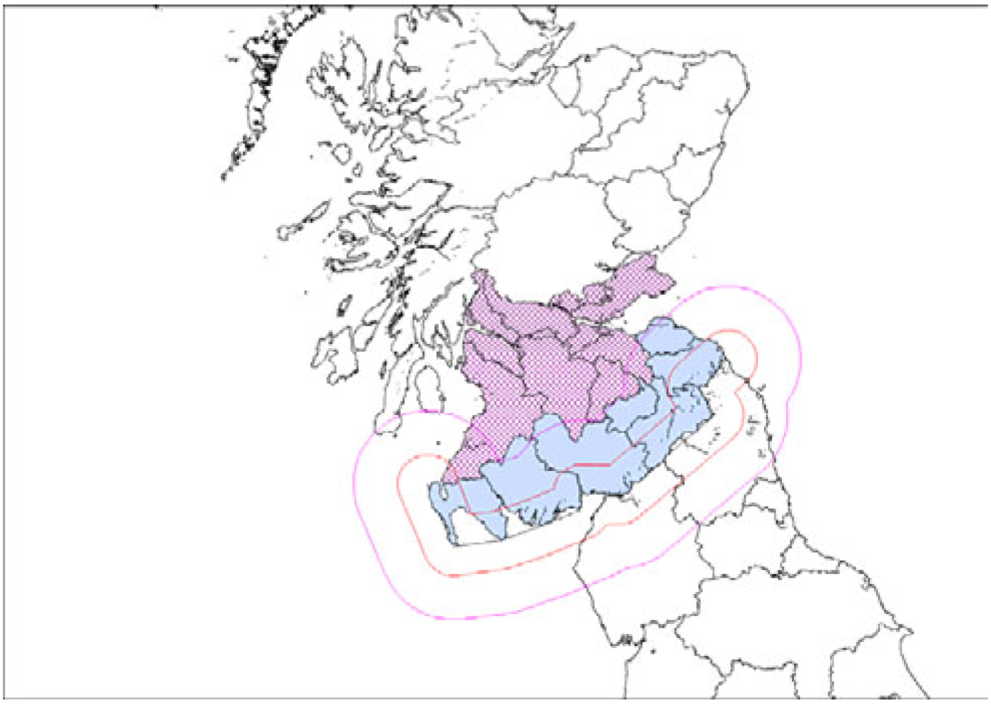


Figure 3.1. Protection zones (PZ) used in control scenarios 2 and 3. The red line indicates the contour of a 20km buffer zone around the England/Scotland border, and the pink/magenta line the contour of a 50km buffer zone. Counties indicated in blue were be used to define the border PZ for vaccination (scenario 2), while the purple-checked counties and the blue-shaded counties were those included in PZ to the Highland B/F line (scenario 3).

ANNEX 3 (b) Epidemiological scenarios results

Table 3.1. *Proportion (%) of replicates for which there was an increase in the number of infected holdings.*

- Results are based on one hundred replicates of the model for each incursion/control scenario.
- The results show the proportion (%) of replicates for which there was ***any*** increase in the number of infected holdings, not just major outbreaks.
- Within each incursion scenario there were no significant (*P*>0.05) differences between control scenarios in the proportion of replicates for which there was an increase in the number of infected holdings.

Incursion Scenario Control Scenario	a. Northwards spread - July 08	b. Northwards spread - Sept. 08	c. Northwards spread - April 09	d. Animal import - Sept. 08	e. Animal import - April 09
1. do nothing beyond the minimum requirements	50	3	8	28	17
2. vaccinate 100% of holdings in a border PZ	40	4	14	30	12
3. vaccinate 80% of holdings in a PZ to the Highland B/F line	52	5	9	24	14
4. vaccinate 50% of holdings in a PZ comprising the whole of Scotland	54	5	11	18	9
5. vaccinate 80% of holdings in a 100km PZ around the first affected holding (only if the incursion occurs above the Highland B/F line)	NA	NA	NA	22	NA

Table 3.2. *Mean, 2.5th and 97.5th percentiles for the cumulative number of infected holdings at the end of year two of the simulations.*

- Results are based on one hundred replicates of the model for each incursion/control scenario.
- The first number gives the mean and the numbers in brackets give the 2.5th and 97.5th percentiles for the cumulative number of infected holdings at the end of year two of the simulations.

Incursion Scenario / Control Scenario	a. Northwards spread - July 08	b. Northwards spread - Sept. 08	c. Northwards spread - April 09	d. Animal import - Sept. 08	e. Animal import - April 09
1. do nothing beyond the minimum requirements	874.3 (1-8816)	45.9† (1-39.5)	303.8 (1-3728.5)	1117.0 (1-10522)	1447.3 (1-14353)
2. vaccinate 100% of holdings in a border PZ	19.8 (1-46)	3.9 (1-21)	3.5 (1-16)	35.6 (1-357.5)	3.1 (1-25.5)
3. vaccinate 80% of holdings in a PZ to the Highland B/F line	25.5 (1-89)	12.0 (1-25.5)	3.2 (1-11)	33.3 (1-467.5)	3.2 (1-23)
4. vaccinate 50% of holdings in a PZ comprising the whole of Scotland	21.5 (1-103)	7.9 (1-19.5)	3.2 (1-14.5)	17.7 (1-186)	2.5 (1-22.5)
5. vaccinate 80% of holdings in a 100km PZ around the first affected holding (only if the incursion occurs above the Highland B/F line)	NA	NA	NA	2.1 (1-168.5)	NA

† the high mean (relative to the 97.5th percentile) for this scenario is a consequence of one large outbreak (4064 infected farms)

Table 3.3. *Proportion (%) of replicates for which infection had died out within the two-year time period of the simulations*.

- Results are based on one hundred replicates of the model for each incursion/control scenario.
- This table includes only those replicates for which there was an increase in the number of infected holdings (see Table 3.1).
- Within each control scenario there were no significant (*P*>0.05) differences amongst incursion scenarios in the proportion of replicates dying out. However, the proportion of replicates dying out was significantly (*P*<0.05) higher for all vaccination strategies (control scenarios 2-5) compared with that in which only the minimal requirements were implemented (control scenario 1).

Incursion Scenario / Control Scenario	a. Northwards spread - July 08	b. Northwards spread - Sept. 08	c. Northwards spread - April 09	d. Animal import - Sept. 08	e. Animal import - April 09
1. do nothing beyond the minimum requirements	46.0%	33.3%	25.0%	42.9%	17.6%
2. vaccinate 100% of holdings in a border PZ	100.0%	100.0%	100.0%	96.7%	100.0%
3. vaccinate 80% of holdings in a PZ to the Highland B/F line	98.1%	100.0%	100.0%	100.0%	100.0%
4. vaccinate 50% of holdings in a PZ comprising the whole of Scotland	100.0%	100.0%	100.0%	100.0%	100.0%
5. vaccinate 80% of holdings in a 100km PZ around the first affected holding (only if the incursion occurs above the Highland B/F line)	NA	NA	NA	95.5%	NA

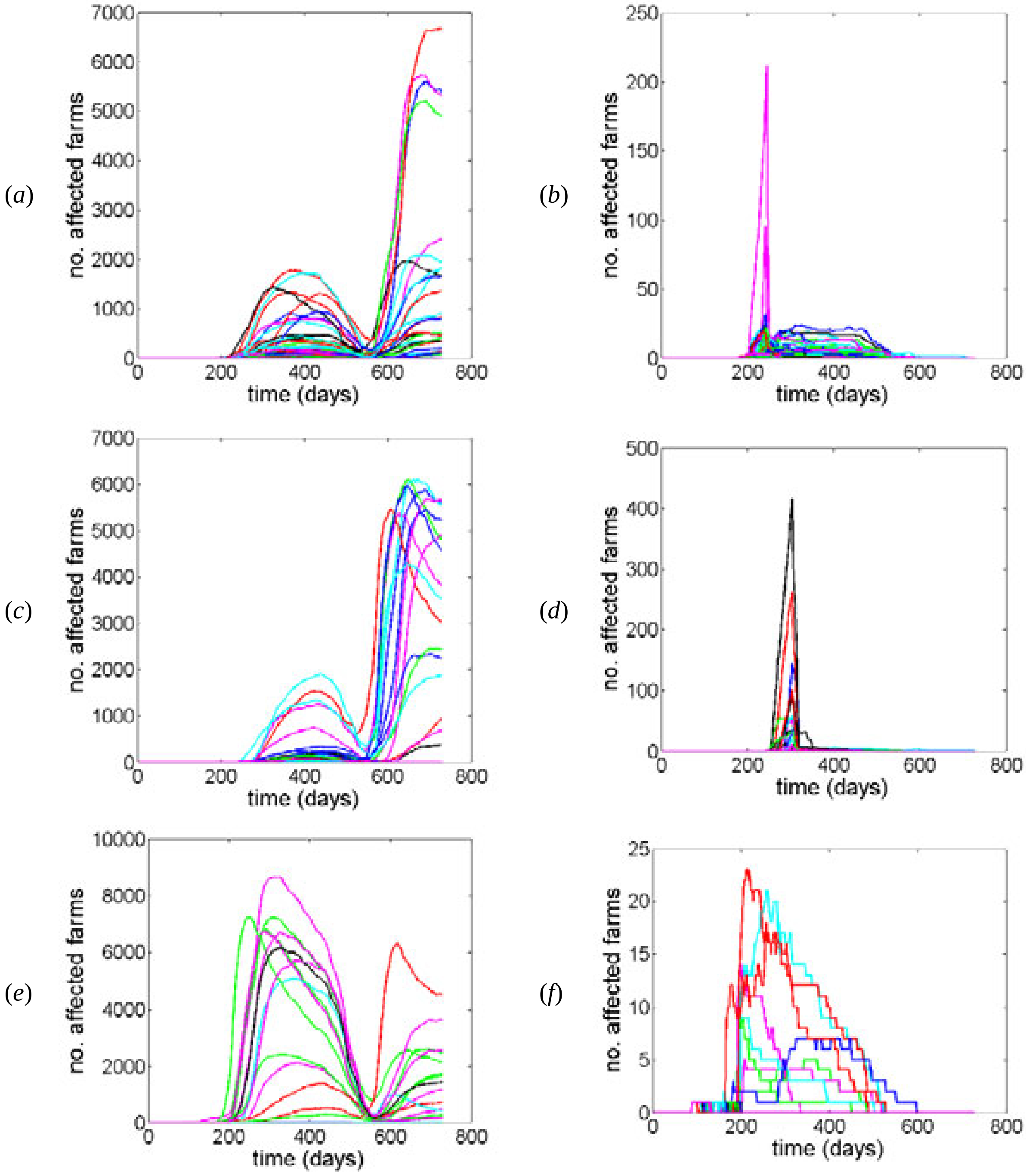


Figure 3.2. Changes in the number of affected holdings over time for different incursion/control scenarios. (*a*,*b*) Incursion via northwards spread in July 2008 with: (*a*) minimal control; and (*b*) reactive vaccination of all farms in a border protection zone (PZ). (*c*,*d*) Incursion via animal import in September 2008 with: (*c*) minimal control; and (*d*) reactive vaccination of 80% of farms in a 100km radius PZ. (*e*,*f*) Incursion via animal import in April 2009 with: (*e*) minimal control; and (*f*) prophylactic vaccination of 50% of farms in a PZ comprising all of Scotland. Lines in each figure represent the results of individual replicates.

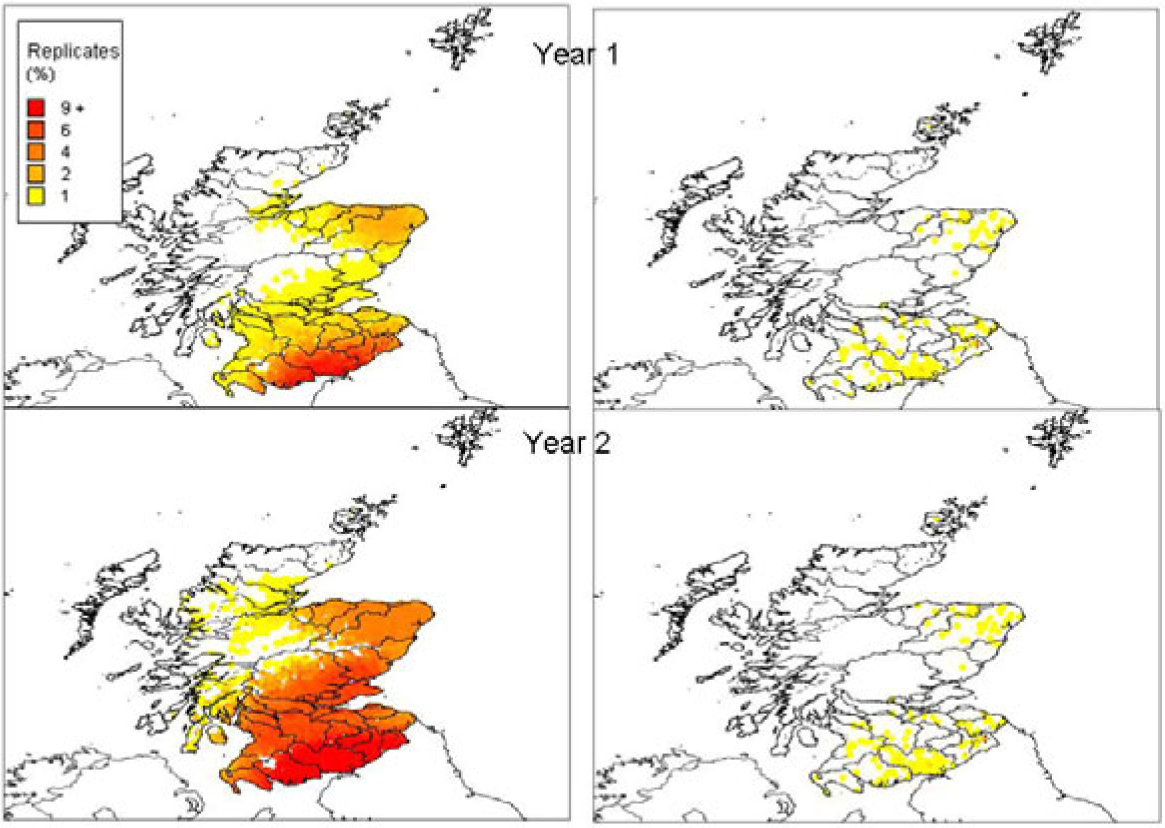
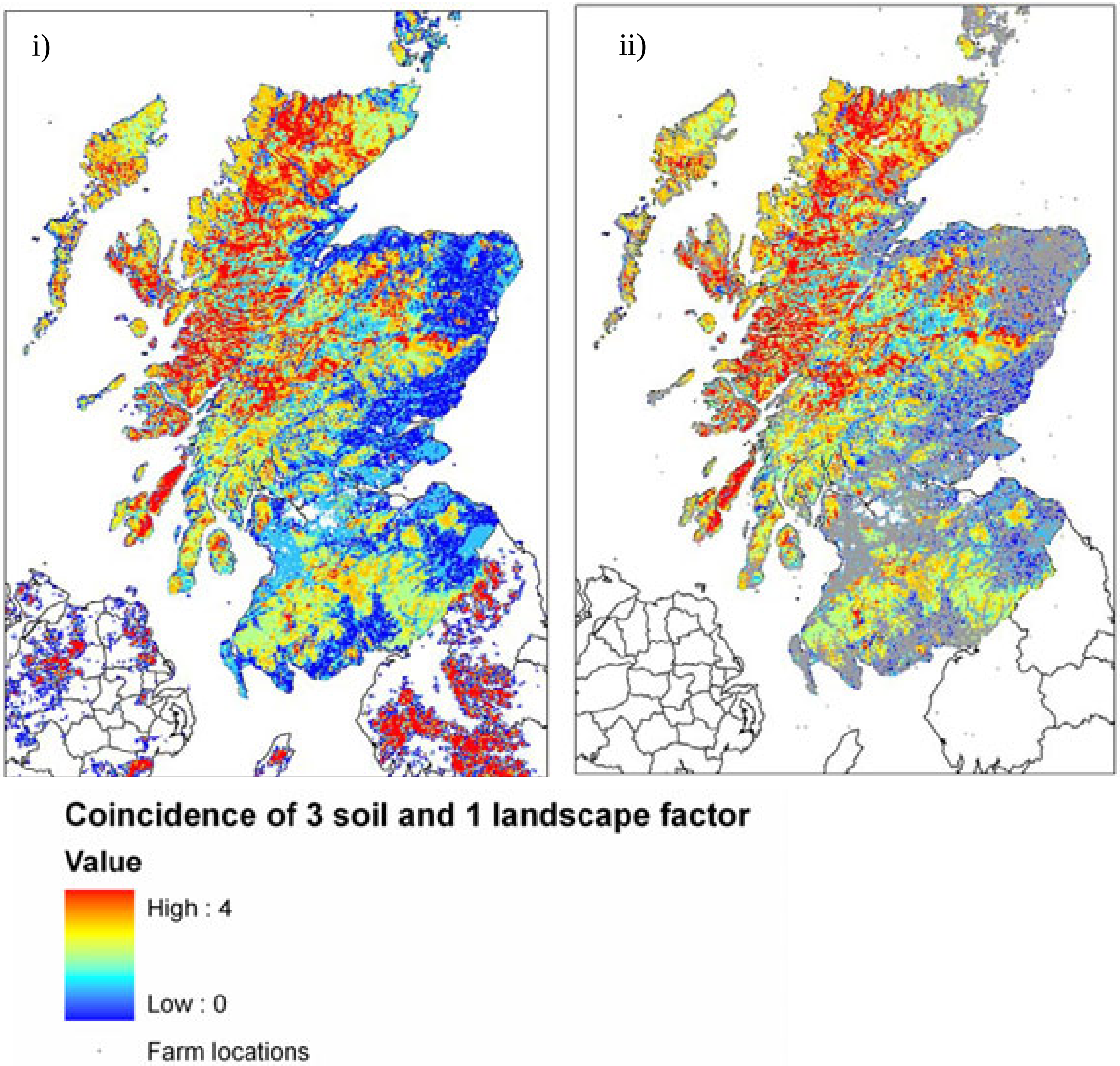


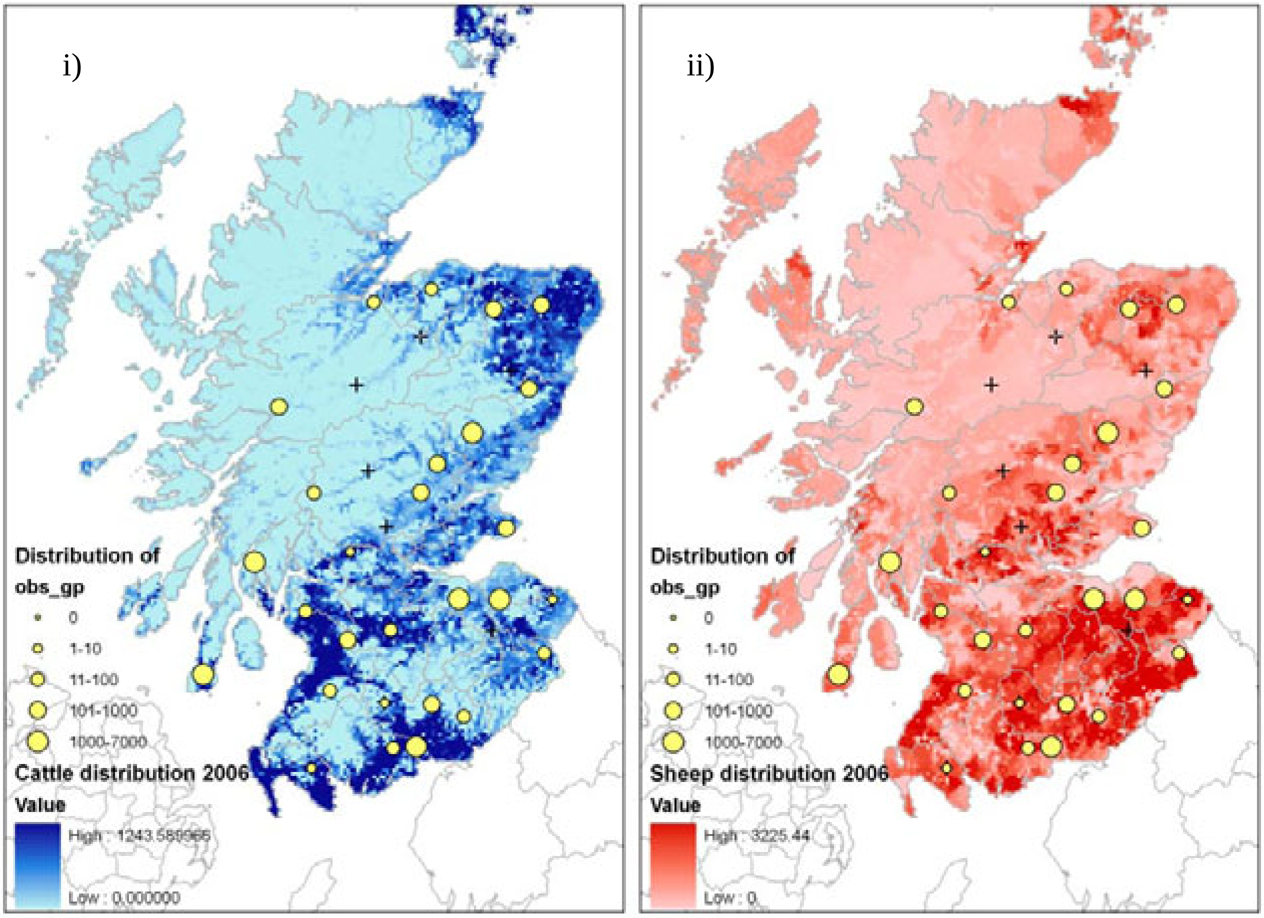
Figure 3.3. Incursion via animal import in April 2009 with either minimal control (left-hand maps) or prophylactic vaccination of 50% of farms in a protection zone comprising all of Scotland (right-hand graphs). The legend indicates the proportion (%) of replicates for which each 5km grid square contained at least one affected farm.

ANNEX 4 (a) Scottish vector data outputs

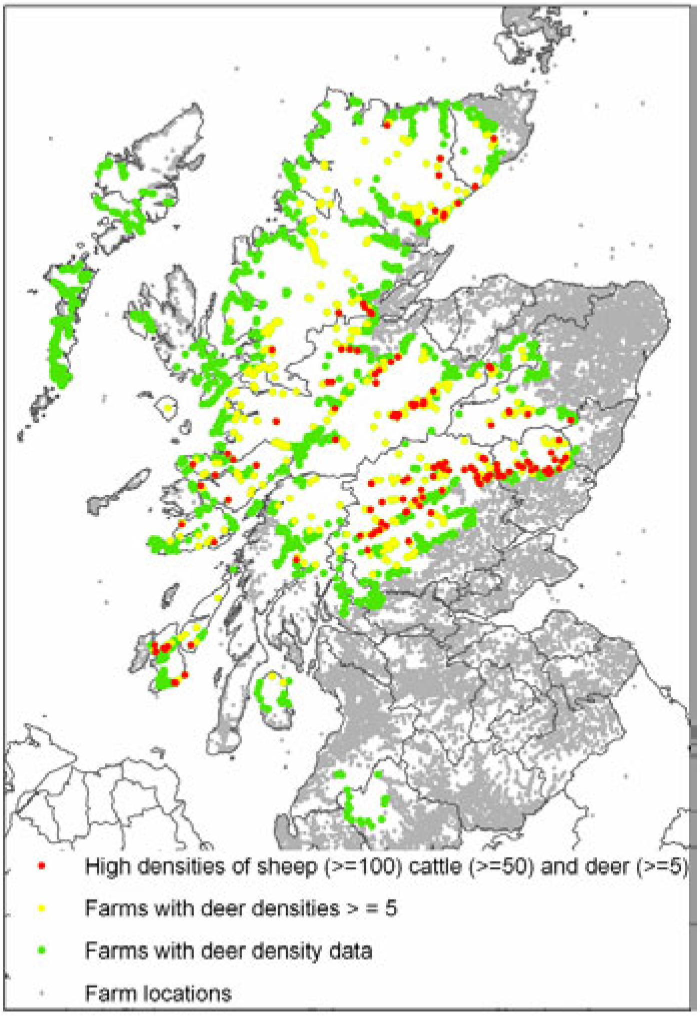


Annex 4a (i) This panel maps where favourable habitat characteristics for the bog-heathland Scottish biting midge -*Culicoides impunctatus*- coincide. High values delineate areas of Scotland that are most likely to support high populations of *C. impunctatus* (ii) This panel maps where farms overlap with favourable habitat for *C. impunctatus* and indicates where this species is most likely to interact with farm-associated vectors and domestic livestock.

It should be noted that favourable habitat characteristics were compiled for *C. impunctatus* from field studies reported in the literature. These were carried out in only a handful of UK sites and may not represent a complete range of preferences for this species.



ANNEX 4 (b) (i) Cattle and **ANNEX 4 (b)** (ii) sheep distribution across Scotland (from AgricCensus data) overlaid with the autumn abundance levels of the *C. obsoletus* complex – one of the major, farm-associated, candidate midge vector groups in Scotland.



ANNEX 4 (c)

Where in Scotland will wild and domestic ruminant host for BTV overlap?: Locations of all farms (grey), farms overlapping with high red deer densities (in yellow), farms having high densities of sheep and cattle as well as red deer (in red). Deer density data were available across the main range of red deer though large populations are known to exist outside of this area in Dumfries and Galloway.

ANNEX 5

Contents

ANNEX 5 A BTV-8 and the threat posed by other BTV serotypes.

Peter Mertens - IAH Pirbright,

The 'BTV – Scotland' project is specifically designed to assess risks and model the spread of the northern European strain of BTV-8 to Scotland. This 'spread' could occur either as a gradual movement of the virus northwards from infected regions in the south of England, Wales or Ireland, or could result from a more sudden and long distance 'jump', as has been seen on several occasions in mainland Europe (possibly as a result of infected animal and/or insect movements).

However, there are 24 distinct serotypes of the bluetongue virus (BTV) and multiple strains exist within each 'type' (Maan et al, 2007), many of which can cause severe disease in ruminants (particularly sheep). The events of 2006 onwards show that local *Culicoides* populations can support the replication, transmission and spread of the bluetongue virus in northern Europe, including the UK. Therefore the whole of Europe must now be considered at 'high risk' of disease outbreaks caused by BTV, and potentially by certain other arboviruses.

The current series of European bluetongue outbreaks started in the Mediterranean region, with the introduction of BTV-9 into the Greek island of Lesbos in 1998. In subsequent years there have been multiple introductions of 8 new strains belonging to 6 of the 24 BTV 'serotypes', with new introductions every year except 2002 (see www.reoviridae.org/dsRNA_virus_proteins/ReoID/BTV-mol-epidem.htm).

BTV is transmitted by biting midges of the genus *Culicoides.* In the Mediterranean region and North Africa, the major vector species is thought to be *Culicoides imicola.* This may explain why some of the outbreaks of the disease in southern Europe have remained restricted to regions where this insect species is present. However, since the 1980s the distribution of *C.imicola* has increased in the Mediterranean region, coinciding with climate change. This has allowed an overlap with other more northerly (Palaearctic) *Culicoides* species (including members of the *C.obsoletus* and *C. pulicaris* complexes), that are abundant and widespread across northern Europe, including the UK. These changes have also provided an opportunity for the virus to colonise (and potentially adapt to) these northerly insect species as novel vectors, leading to transmission of certain BTV strains in regions where *C. imicola* is absent.

The most dramatic of the European outbreaks has been caused by the arrival of an African strain of BTV-8 in the Netherlands during August –July 2007, the first time this serotype had ever been recorded in Europe. It is still unclear exactly how this African virus arrived in the region, far from any known cases of BTV-8 infection. Indeed, without clear information concerning the route and mechanism of entry it is very difficult to close this particular ‘door’ to prevent other ‘sudden’ arrivals of novel bluetongue viruses anywhere in Europe, including the UK or Scotland. Indeed such introductions may have happened periodically in the past, and it is only now with climate change that these viruses can survive, replicate in the insect vectors and be transmitted, causing devastating disease outbreaks in the naïve and highly susceptible host populations in Europe.

During 2007, an African strain of BTV-1 spread across the Iberian Peninsula, from Morocco, through to southern France. This virus is now in a region of France containing the northern European vectors, suggesting that it is likely to continue its movement towards the UK during the summer of 2008. It is also possible that other viruses (like the European strain of BTV-8) may ‘parachute’ in from further afield.

Although this project is limited to a single bluetongue serotype (BTV-8), it does provide a paradigm for the introduction, spread, persistence and costs of a BT outbreak that could potentially be caused by any serotype. The different BTV serotypes do not cross protect, and could in practice be considered as the causes of different diseases. However, in reality different BTV strains can interact, exchanging genome segments, and after multiple serial infections causing some cross-protection, although this would only be evident in infections of an individual animal by a third or subsequent serotype.

ANNEX 5 B Costs of testing

Based on a Paper from the CRL, IAH Pirbright describing cost of BTV testing and lab testing capacity in a 'non-outbreak' scenario, prepared *by Chris Oura – 26th November 2007; updated for molecular typing by Peter Mertens 18th March 2008*

Background: At IAH Pirbright there are 7 full-time staff working on diagnostics within the Non-Vesicular Reference labs. These laboratories include the FOA World, OIE and national reference labs for Morbilliviruses, the OIE and national reference lab for African Swine fever virus, the OIE and national reference labs for capripox viruses (sheep pox, goat pox and lumpy skin disease), the OIE, EC and national reference laboratory for bluetongue and the OIE and national reference lab for African Horse sickness. We receive many samples into these labs from around the world but also receive samples from the UK.

Molecular typing of BTV, AHSV and EHDV, also involves the Arbovirology Research Group, which includes a further four staff members involved in virus strain identification and molecular epidemiology.

Note – If bluetongue testing is to be shared between IAH Pirbright and VLA Weybridge, it may be important to reach a joint decision on testing costs. This document only explains the current testing costs at IAH Pirbright.

1. Antibody ELISA testing:

Ongoing Commercial charges for BTV antibody testing by competition ELISA (using the Pourquier assay kit): First sample - £51; Samples 2-50 - £16; Samples 51-100 - £13; Samples 101+ - £8

Note: Antibody ELISA testing on samples from imported animals since the start of the BTV-8 incursion into northern Europe in 2006, has been at the expense of IAH Pirbright. No extra money for this testing has been supplied by DEFRA. Around 5000 samples have been tested from imported animals and this testing has cost IAH Pirbright around £25,000 in reagents and staff time. The CRL has also carried out all the testing for Scotland, Northern Ireland and Wales without charge.

The cost of testing depends entirely on how many samples are tested at one time. If fewer samples are tested the individual tests become significantly more expensive, simply because as it takes a similar amount of staff time to process 20 as well as 40 samples. For maximum efficiency and the lowest cost we need to test 'full plates'. The costs (including staff time and reagent cost) are given below for antibody ELISA using a 'full plate' of samples. We presently carry out all testing in duplicate. However, to reduce the cost of the test, samples could be tested individually, although this slightly decreases the reliability of the test.

Actual costs per sample (with no profit margin) for BTV antibody ELISA detection (full plate of samples)

Staff costs per hour at FEC = ~ £75 per hour

Duplicate testing by ELISA = £6.00 per sample

Single testing by ELISA= £4.00 per sample

Testing capacity for BTV antibody ELISA testing at IAH Pirbright:

The capacity for ELISA testing depends on many factors. The limiting factor is the processing of the samples prior to testing as the ELISA test is relatively quick and easy to perform. If samples come in large batches it is much easier and quicker to process the samples than when samples are submitted in small batches. Our capacity for ELISA testing also depends how many PCR tests are being performed at the same time. Taking into consideration the staff that we have in the reference lab at the present time we could test the following amount of samples:

For testing in duplicate: 300 samples a day (1500 samples a week)

For testing singly: 400 samples a day (2,000 samples a week)

Note: If the samples are submitted in small batches capacity would reduce.

2. Real-time PCR testing to detect BTV RNA ('group' specific assay).

Ongoing Commercial charges for BTV RNA detection by real-time RT-PCR: Samples 1-5: £60 per sample; Samples 6-20 - £40 per sample; Samples 20+ - £20 per sample.

Note: All testing of samples from imported animals since the 2006 incursion of BTV-8 into northern Europe has been at the expense of IAH Pirbright. No extra money for this testing has been supplied by DEFRA. The primary test is based on that described by Shaw et al (2007) Around 5000 samples have been tested by RT-PCR from imported animals and this testing has cost IAH Pirbright around £60,000 in reagents and staff time. The cost of testing depends on how many samples are tested at one time. The fewer samples tested the more expensive the test. For maximum efficiency we need to test full plates. The costs (including staff time and reagent cost) are given below for RT-PCR with a full plate of samples. We presently carry out all RT-PCR testing on samples from imported animals processed singly, and all UK report case samples are processed in duplicate.

Note: It is important to note that because vaccinated animals will give a positive test result by the Pourquier ELISA, the real time RT-PCR may become the only, current major test system, that can be used to identify infected animals.

Cost per sample (with no profit margin) for BTV real-time RT-PCR (full plate of samples).

Staff costs per hour at FEC = ~ £75 per hour

Duplicate testing: = £20 per sample

Single testing = £12 per sample

Testing capacity for real-time RT-PCR testing at IAH Pirbright:

The capacity for PCR testing depends on how many ELISA tests are being performed at the same time. Taking into consideration the staff that we have in the reference lab at the present time we could test the following amount of samples:

For testing in duplicate: 80 samples a day (400 samples a week);

For testing singly: 160 samples a day (800 samples a week)

Note: If the samples are submitted in small batches capacity would reduce. Samples submitted for movement regulations are tested singly.

3. Virus Isolation of Bluetongue virus and serotyping by SNT or VNT

Virus isolation is a lengthy and relatively slow procedure and should not therefore be carried out as a routine test for the diagnosis of BTV. The real time RT-PCR test that was developed at IAH Pirbright

(Shaw et al 2007) is more sensitive and more reliable, although it detects viral RNA rather than whole infectious virus.

The virus isolation testing procedure is complex and expensive, involving isolation on KC cells (a cell line derived from *Culicoides varipennis,* or injection of material into embryonated hen eggs, then passage the virus in tissue culture (e.g. BHK or Vero cells) prior to confirming the presence and identity of the virus by RT-PCR or ELISA. Although this method is too expensive to carry out routinely, it was previously been used for ‘typing’virus isolates and still has value as a ‘gold standard’ for virus serotype identification.

Serological typing of BTV isolates in virus neutralisation assays (VNT) requires access to standardised antisera for all 24 BTV types, reagents that are difficult to prepare and in short supply. These assays take ~ one week to complete and may need repetition. They also involve a great deal of staff time and are therefore costed at £1500 per virus sample tested (after virus isolation has already been completed).

Similar serum neutralisation assays (SNT) can be used to determine the specificity of test antisera by reacting them with reference strains of the 24 BTV types. These are also time consuming (~one week), laborious, may need repetition and would also cost £1500 per serum tested. The SNT require access to pre-titrated preparation of all 24 BTV reference strains, and can give high levels of cross-reactions with sera from areas where more than one type is circulating.

If further details of methods (and costs) used for virus isolation of BTV and VNT or SNT are required, these could be obtained from the CRL but these assays are very expensive.

4. Identification of Bluetongue virus serotype by conventional RT-PCR

Serotype is controlled by outer capsid protein VP2, which is encoded by segment 2 of the Bluetongue virus genome (Maan et al 2007). It is therefore possible to identify the virus type by sequence analyses of Seg-2 (Maan et al 2007), or by conventional RT-PCR assays using primers directed against Seg-2 (Mertens et al 2007).

These are currently conventional and gel based assays and the initial RT-PCR assay uses at least two primer sets for each BTV ‘type’. The costs of reagents and staff time are estimated at £1500 (including RNA extraction, RT-PCR assays, gel electrophoresis, photography and report preparation) for each sample. Initial sequence analysis of a positive band, followed by phylogenetic analysis to determine the identity of the virus strain within a specific serotype, will cost a further £1500.   These costs are based on FEC but non-profit making.

Serotyping viruses by these methods is expensive and would not be carried out routinely for multiple samples. Molecular typing can be conducted on a real time RT-PCR positive blood sample, or virus isolate. It has the major advantage that it will give positive identification of each type and can be used to detect multiple serotypes in a single sample.   It would currently be possible to type up to 3 samples per person per day.

ANNEX 5 C Vertical transmission

(extract from document prepared by Philip Mellor, Chris Oura, Karin Darpel and Peter Mertens - IAH Pirbright, circulated to Brussels and CVOs - March 2008)

Until recently most scientific authorities agreed that transplacental infection of the ruminant foetus by BTV, from a dam infected during pregnancy, only occurred when tissue culture passaged (TC) virus was used. In such cases resorption, abortion, birth of weak or deformed offspring, or birth of viraemic offspring could result. Work at IAH-Pirbright (Gibbs *et al* 1979) using TC virus has demonstrated the birth of lambs that were viraemic for up to 60 days post-parturition. As the dams were infected at around 60-70 days of gestation, this means that there was a period of approximately 145 days between infection of the dam and the end of viraemia in the lamb. Such a time would easily cover the period from the end of one BTV-transmission season (December) to the start of the next (April) in northern Europe. However, recent observations in northern Europe (in Holland, Belgium and the UK) indicate that ruminant offspring that are weak, still born and PCR positive for BTV, are now being born to dams infected in 2007 with BTV. This is a new finding since such events are the result of **field infections with a wild type virus strain,** not infections with TC virus. This phenomenon requires further investigation to confirm its occurrence and frequency as, it could account for the widespread over wintering that was detected in northern Europe in 2006 to 2007.

During January 2008 (in the vector-free season) eight pregnant BTV-seropositive but RT-PCR negative animals were imported from the Netherlands into Northern Ireland (which was BTV free). Although these animals were also PCR-negative for BTV at 12 and 42 days post-importation, three of the calves born to these animals in Northern Ireland were shown to be infected with BTV by real-time RT-PCR and one calf was positive by virus isolation (virus isolation results pending on the other 2 calves) soon after it was born, demonstrating vertical transmission. The infection was also likely to have been passed to two previously sero-negative and RT-PCR negative animals that had been housed in the same building, indicating the possibility of horizontal transmission in the absence of any detectable numbers of adult vector insects.

The data from Northern Ireland not only demonstrate trans-placental transmission of BTV from dam to calf, but also provide strong evidence for horizontal (possibly mechanical or oral transmission) of the virus. Once BTV has been passed trans-placentally, it may persist in calves at significant levels, possibly indicating that the calf is immuno-compromised, or that the virus is cell-associated and protected from circulating antibodies. Cell-association is a widely recognised aspect of BTV infection. The length of time from initial infection of the dam to the end of viraemia in the calf is significant and is considered likely to be long enough to span the winter. Transmission of the virus to other animals, in the absence of adult insect vectors, may also extend the overall infection period - thus collectively providing an efficient over-wintering mechanism.

Indeed, it was in late 2007 that staff of the CRL and the Arbovirology programme at IAH Pirbright became convinced, contrary to previous scientific opinion, that there was evidence from the UK and other parts of northern Europe for overwintering of BTV in the field via trans-placental transmission through ruminant hosts. BBSRC was approached during early 2008 to request emergency funding to carry out an intensive investigation into the BTV overwintering phenomenon, the work being designed specifically to identify the mechanism or mechanisms involved. This proposal was accepted by the BBSRC in Feb 2008 and work has now commenced, providing early indications that the observations from Northern Ireland are not unusual.

ANNEX 5 References

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