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Influences of farmer and veterinarian behaviour on emerging disease surveillance in England and Wales

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SUMMARY

Surveillance for new and re-emerging animal diseases in England and Wales is based on post-mortem and syndromic analysis of laboratory data collated in a central database by the Animal Health and Veterinary Laboratories Agency (AHVLA), with the aim of providing early warning of disease events prior to clinical diagnosis. Understanding the drivers for participation in such systems is critical to the success of attempts to improve surveillance sensitivity. The aim of this study was to investigate the decision-making process governing the submission of biological samples on which this surveillance system is based by use of questionnaires. Data extracted were used to structure and parameterize scenario trees modelling the probability of generating an entry in the surveillance database. The mean probability for database entry per case ranged from 0·085 for neurological disorders to 0·25 for enteric disease. These findings illustrate the importance of on-farm decision making to the generation of surveillance data.

Key words: Emerging infections, modelling, surveillance.

INTRODUCTION

The eradication of the main transboundary diseases in the UK implies that it has a large naive population of livestock, which is based in intensive production systems and complex food value-chains. This has required the strengthening of surveillance systems that can quickly detect the re-emergence and emergence of transboundary disease in order to limit the potential economic cost in terms of lost production and trade and to allow the quick implementation of disease control programmes [1]. In addition, the public health implications of emerging zoonotic animal diseases, such as bovine spongiform encephalopathy and avian influenza, have further heightened awareness of the need to reduce time-to-detection of disease outbreaks by enhancements in veterinary surveillance. In England and Wales, one attempted solution has been the implementation of early-warning surveillance, a syndromic surveillance system [2], by the Animal Health and Veterinary Laboratories Agency (AHVLA). This system is described in detail by Gibbens *et al.* [3], summarized as follows: A network of 16 regional laboratories (RLs) staffed by AHVLA Veterinary Investigations Officers (VIOs) receive carcases and biological samples submitted from farms via the private veterinarian. Each sample is classified by disease syndrome according to case history using specific definitions. Further, each sample is then classified into 'reasonable' or 'limited' testing; that is, do the tests performed have a realistic expectation of producing a diagnosis? Cases for which diagnosis is not reached (DNR) and testing is believed to be reasonable are entered into the database

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FarmFile. FarmFile data is then subject to automated statistical analysis looking at trends in DNR numbers by syndrome classification relative to total submissions and seasonal patterns [4]. This analysis takes place on a quarterly basis, and is reviewed by a species-specific group of experts. In this manner key indicators of the health status of a population can be monitored to provide early warning of a change in status of that population prior to clinical diagnosis. This system acts as a complement to the potential detection of new or re-emerging disease by the network of VIOs performing the investigations.

Early-warning surveillance is an enhanced passive surveillance system; the basis being the voluntary participation of the private sector followed by active investigation of any data determined to be of interest by the statistical or species-group analysis described above. Since the foundation of the system is a passive system with voluntary participation, the decisions surrounding participation are of interest as they have the potential to influence system sensitivity. Numerous key decision steps exist at farm level before any contact is made with AHVLA. Farmer's must first detect the symptoms of disease within their herd at which point they must make the decision to contact the private veterinarian. Given differentials that would require laboratory testing of samples to reach diagnosis, the private veterinarian may then decide to send these samples to either a private laboratory or to AHVLA, or in the case of a dead animal, recommend a post-mortem be performed. In cases where notifiable disease is not suspected, the farmer is responsible for the cost of this testing. Furthermore, the extent of testing must be 'reasonable' in order to generate useful surveillance data, meaning the farmer may be required to pay for multiple tests to be performed, and in the case of post-mortem, for the delivery of the carcase to the laboratory. To summarize, numerous decision points are reached prior to any information reaching the AHVLA.

Social sciences research methods are of increasing use in the veterinary sphere as human behaviour is increasingly recognized as a decisive component in the successful implementation of a disease control programme or surveillance system. Questionnaire- and interview-based studies to define factors driving disease reporting behaviour [5], implementation of improvements in biosecurity [6] and implementation of disease control programmes [7] have served to describe the behaviour of stakeholders in such systems. To the authors' knowledge, no prior attempt has been made to assess probabilities of participation in a passive or enhanced-passive surveillance system by use of a questionnaire-based survey.

The purpose of this study is to pilot a method by which the effect of decision-making on the sensitivity of a surveillance system can be explored quantitatively. It was hypothesized that significant differences in response to disease would be indicated in subsets of the population determined by farm, farmer and disease characteristics. These were explored through the use of scenario-tree models illustrating the probability of a single disease case being entered into the FarmFile database. Explanation for detected differences was sought through the exploration of factors with potential to motivate farmers' decision-making.

METHODS

General overview

A generic scenario tree representing the AHVLA early-warning surveillance system was developed to identify parameters required for scenario-tree models. Probabilities associated with the actions of the farmer and private veterinarian following identification of a sick animal (steps 2–4), were identified for investigation by questionnaire of farmers and veterinarians. Secondary data were provided by AHVLA regarding the likelihood of a given sample reaching a diagnosis or DNR with reasonable or limited testing (Fig. 1).

A convenience sample of cattle farms and veterinary practices drawn from the contact database of the Welsh Regional Veterinary Centre (WRVC) was used. A total of 227 cattle farms (of 2384 in the study area [8]) and 27 veterinary practices (of 27 known to work with cattle in the study area) were invited to participate in the survey. Respondents' postcodes were used to calculate distances by road to AHVLA Carmarthen using Google Maps (http://maps.google.co.uk). Respondents otherwise remained anonymous.

Questionnaire design

Two questionnaires were constructed, one for farmers and one for veterinarians. Both questionnaires were trialled, on a pilot group of three beef farmers and a group of three veterinarians and feedback incorporated into revised questionnaire designs. Each questionnaire consisted of closed questions. Questionnaires were approved by the Welfare and Ethics Committee of the Royal Veterinary College (reference 2011

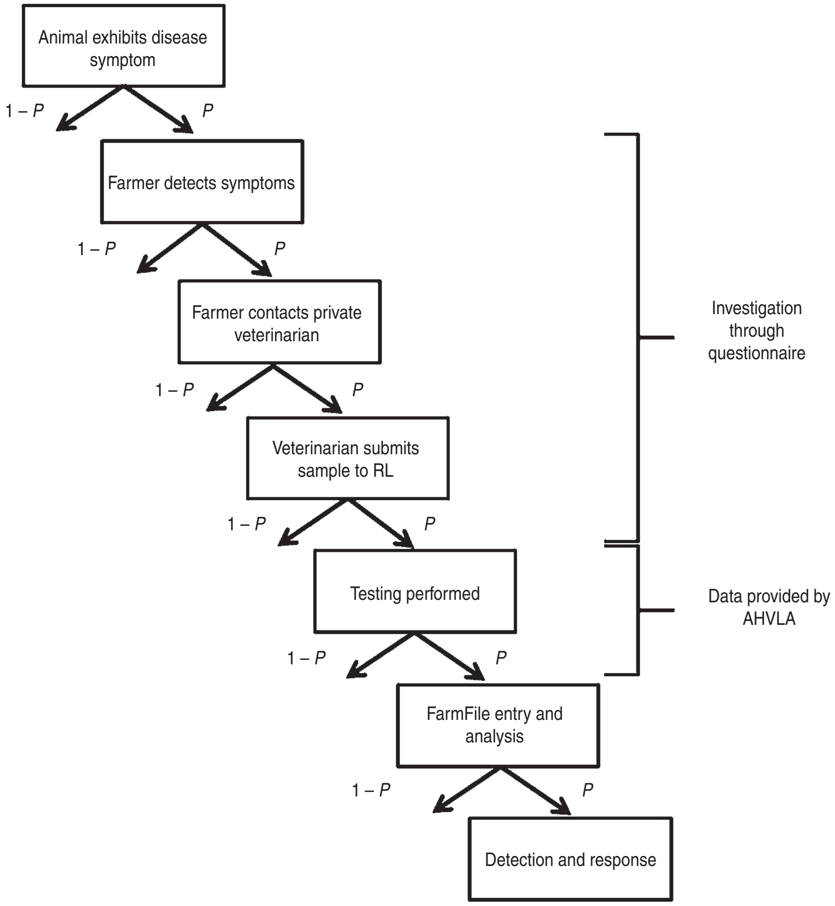

Fig. 1. Basic scenario tree illustrating the principle by which early-warning surveillance in England and Wales operates and how data were collected in this study. FarmFile = Central database recording surveillance data; RL = Regional laboratory.

0032H). A detailed list of variables for which data were collected is provided in Tables 1 and 2. These variables included the probabilities required to structure scenario trees, investigation of motivating factors or attitudes which were thought to have potential to influence the decision-making resulting in these probabilities, and attributes of respondents which could be used to stratify the respondents' probability estimates for the development of scenario trees, as well as potential confounding factors.

In the farmers' questionnaire, two methods for probability assessment were employed. The first, referred to as 'prospective' assessment, was of the form 'How often would you perform the following action?' The second method was to ask for recollection of events over the preceding 6 months. This is referred to herein as 'retrospective' assessment. Quantitative frequency estimates for events surrounding the death of animals on-farm were collected both prospectively (D_{PRO}) and retrospectively (D_{REC}). Collection of two alternative measures of the same variable (retrospective and prospective), allowed comparison to be made between the two measures, as each was thought to have inherent biases. Deaths were used for this comparison as they are thought to be more memorable events and therefore produce more reliable estimates for retrospective data collection. Prospective frequency estimates for veterinary contact by farmers were collected for four disease syndromes with a short clinical description, those being: enteric disease (ED), neurological disease (ND), wasting disease (WD) and reproductive disease (RD). These disease syndromes were selected as follows. Enteric disease, described as an animal presenting with diarrhoea and inappetence represented a case that was likely to be seen relatively frequently and with a wide range of aetiologies, a moderate impact on animal welfare and production, and may present as a case where treatment would be performed on-farm without veterinary supervision. Neurological disease described as staggering and loss

Table 1. *Variables identified for investigation in the farmers' questionnaire*

Variables of interest	Predictors	Motivators/attitudes
Prospective veterinary contact by disease syndrome	Distance to AHVLA	Within-herd disease prevalence
Retrospective veterinary contact on death of an animal (6-month period)	Production type: dairy, beef, mixed	Relationship with veterinarian
Retrospective submission numbers for post-mortem (6-month period)	Membership of herd health monitoring scheme	Cost of veterinary intervention/investigation
	Frequency of veterinary contact • Routine visits • Non-routine visits	Value of affected animals
	Demographic profile: • Age • Gender • Role on farm	Responsibility of care
	Herd size	Attitude toward state veterinary service
	Duration of written animal record keeping	Production losses
		Potential for indemnity payments

AHVLA, Animal Health and Veterinary Laboratories Agency.

Table 2. *Variables to be investigated in the veterinarians' questionnaire*

Variables of interest	Predictors	Motivators/attitudes
Retrospective frequency of recommendation for post-mortem examination (6-month period)	Demographic profile: • Age • Gender • UK qualified	Cost of AHVLA testing services
Retrospective level of compliance by following recommendation for post-mortem (6-month period)	Large animal or mixed practice	Use of consultation with AHVLA veterinarians
Retrospective frequency of call-outs relating to dead cattle on-farm (6-month period)	Years experience of farm-animal practice	Client considerations, e.g. cost
Categories of testing for which AHVLA are used (nine maximum)	Experience in state veterinary service	Range of tests available
	Farm visits per week	Quality of service provided by AHVLA
	Call out charges applied	Necessity of reaching diagnosis
	Proportion of work with beef and dairy	

AHVLA, Animal Health and Veterinary Laboratories Agency.

of control of movements, represented a case with more serious welfare considerations as well as a notifiable disease (bovine spongiform encephalopathy) and a nutritional imbalance (hypomagnesaemia) among the differential diagnoses. Wasting disease, described as steady weight loss over a period of 3 months, was included as it was of relevance to another ongoing study at the time, and was thought to represent a case with moderate welfare and production implications. Reproductive disorder, described as repeated return to service, was included as a syndrome which has few welfare implications for the animal but is of significance to production, particularly in dairy and beef suckler systems.

For farmers, Likert-scale questions were used to categorize farmers' attitudes regarding surveillance and contact with veterinary services. Respondents were asked to place themselves in ordinal groupings with verbal and numerical frequency estimates to allow self-assessment of frequency of veterinary contact given an animal presenting with each syndrome or upon death. These questions were of the form 'How often would you contact the veterinarian given a single animal presenting with the following symptoms?'; possible answers were: never (0%), rarely (25%), sometimes (50%), often (75%), always (100%). These estimates were collected for the four syndromes listed and for the death of an animal. Retrospective data on mortality, veterinary investigations of deceased cattle on farm and submissions to AHVLA for post-mortem over a 6-month period were also collected. This information was used to calculate the probability of veterinary contact upon the death of an animal (D_{REC}). It was assumed that the figures given were from the farmer's recollection, rather than farm records.

Data were collected on farmer demographics and the management and production type of the farm. Farmers were offered a financial incentive for participation in the form of a prize draw. The questionnaire was administered by post during summer 2010 and 1 month was allowed for collection of responses. Respondents were offered the opportunity to receive a report outlining the findings.

The veterinarians' questionnaire was structured as follows: the first section attempted to estimate the frequency of use of AHVLA services for ante-mortem diagnostic testing. Categories of testing offered by the AHVLA, as defined in the AHVLA scientific tests price list offered in June 2010, were listed and respondents asked for which of the categories they would use AHVLA services. The categories were: biochemistry, haematology, bacteriology, virology, bacteriology – milk, virology – milk, parasitology, serology, and dermatology. The second section concerned submission of samples for post-mortem: quantifications of how frequently veterinarians recommended submission of carcases and how frequently this advice resulted in submission. Subjects were asked to recall events in the preceding 6 months. Both sections also included Likert-scale questions to gauge the respondent's attitudes and motivations which could influence their use of AHVLA as a diagnostic service provider. The third section collected demographic data and information on the type of practice in which the respondent worked. The questionnaire was hosted online for 1 month during the summer of 2010; responses were canvassed for by email, telephone and post. Respondents were anonymous. IP addresses were recorded as a precaution against duplicate submissions. Both questionnaires are available from the corresponding author upon request.

Data handling and analysis

Data collected were entered in Microsoft Excel® (version 2007) and statistical analysis was performed using PASW Statistics v. 18 (SPSS Inc., USA).

Many of the variables had a high variation in response within the relatively small sample taken. As a result categories were introduced to allow univariate analysis to be performed for association between the variables of interest and predictor variables. Additionally, univariate analysis was performed to identify covariance between predictor variables.

Cross-tabulations were performed to detect significant differences at the 10% level ($P \leqslant 0{\cdot}1$) using Somers' D when one or more variables were ordinal and Fisher's exact test, two-tailed for two categorical variables. Scale variables were tested for difference in means using the Mann–Whitney U test for non-parametric data. Significant factors identified through univariate analysis were then entered into a multivariate ordinal logistic regression model to account for the effect of interactions between predictor variables and either retained or rejected from the final model.

Once significant associations between the variables of interest and predictor variables had been identified, six scenario trees were developed, one for each syndrome and one each for death (prospective) and death (retrospective) from the generic scenario tree illustrated in Figure 1. Each of these was structured according to the results of the statistical analysis (Figs 2, 3). The format of the scenario trees follows that used by Martin *et al.* [9].

Scenario trees were modelled stochastically. Probabilities attached to each branch of scenario trees were generated as follows: where data were of a binary character (e.g. proportion of farmers being a member of a herd health scheme, proportion of farmers having routine vet visits), the 95% confidence interval around the maximum-likelihood estimate proportion of positive responses was calculated and used to define the maximum and minimum points of a uniform distribution. Where data were in ordinal categories (e.g. farmers' probability estimates for veterinary contact), distributions were fitted to the data using the

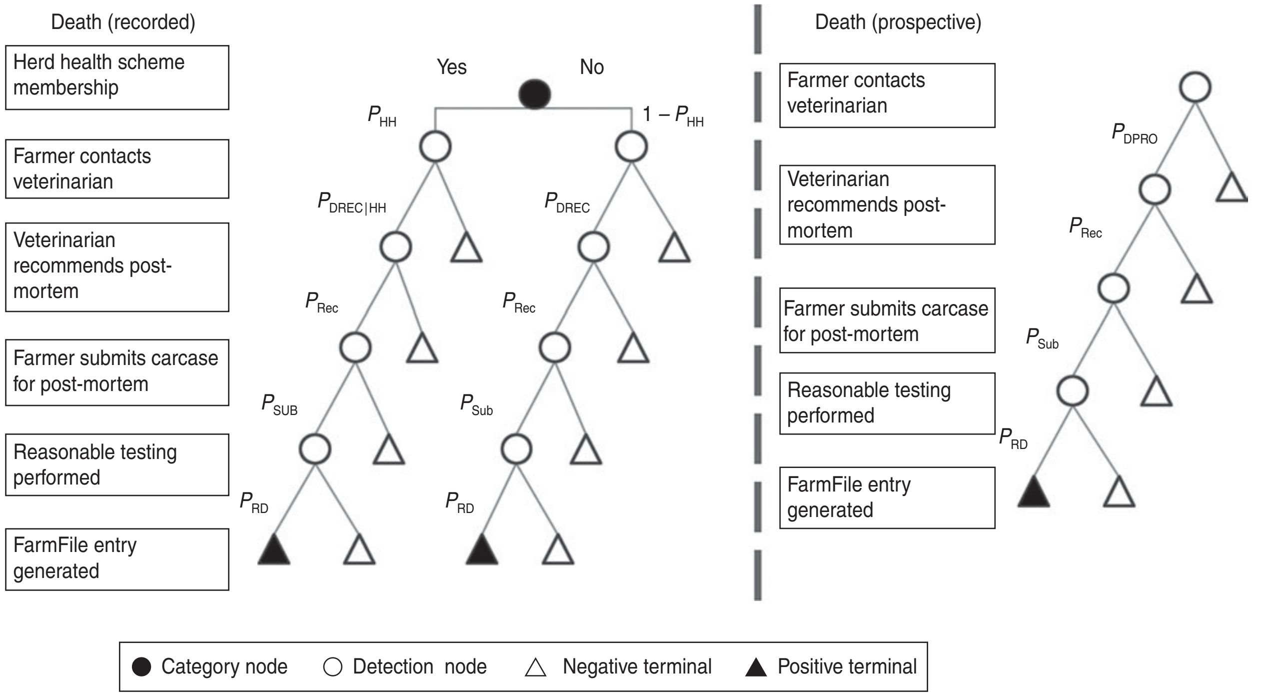

Fig. 2. Scenario trees for the probability of generating a FarmFile entry upon death of an animal. Notation for probabilities can be found in Table 4. The two trees represent the two methods of data collection, retrospective and prospective.

Palisade @Risk 6 distribution-fitting tool (Palisade Corporation, USA). Goodness-of-fit was assessed by the P value of a χ^2 goodness-of-fit test. Where no distribution was found to be a good fit through χ^2 testing, the top ranking distribution determined by use of Akaike's Information Criterion was chosen. The probability distributions used and their goodness-of-fit statistics are listed in Table 4.

Where sample data were known to be unrepresentative of the population (on the ratio of dairy to beef holdings in the region), Welsh Government statistics [8] were used to weight probabilities to reflect reality. Where fitted distributions could give probabilities >1, distributions were truncated at $x=1$. Multiplication down each scenario tree to the positive terminus, or where more than one terminus was present, the sum of positive termini, provided the output for each tree: the probability of a single disease case leading to the generation of a useful piece of surveillance data.

A Monte-Carlo simulation was run for 10 000 iterations and output recorded. Sensitivity analysis was conducted as follows: individual probability distributions were assessed for their level of influence over the outcome at fixed points ranging in value from 0·1 to 1·0 while all other variables were fixed at mean values. This process was repeated with all the variables in each scenario tree and results recorded.

The same statistical process of univariate and bivariate analysis outlined above was then performed to look for differences in the attitudes and motivational factors assessed in the questionnaire between the subsets used to structure the scenario trees.

RESULTS

Survey results

A total of 69 responses were received from the farmers' questionnaire, giving a response rate of 30·4%. Of the responses received, 46 came from dairy and 23 from non-dairy farmers. There were 20 farms that were members of herd health schemes, of which 15 were dairy farms, and 37 respondents had routine veterinary visits to their farm; this was found to be strongly associated with production type ($P<0{\cdot}001$), 76% of dairy farms having routine veterinary visits compared to 9% of non-dairy farms. Within dairy production, increased herd size was associated with the presence of routine veterinary visits ($P=0{\cdot}025$).

The mean distance between farm and AHVLA laboratory was 22·26 miles [standard deviation

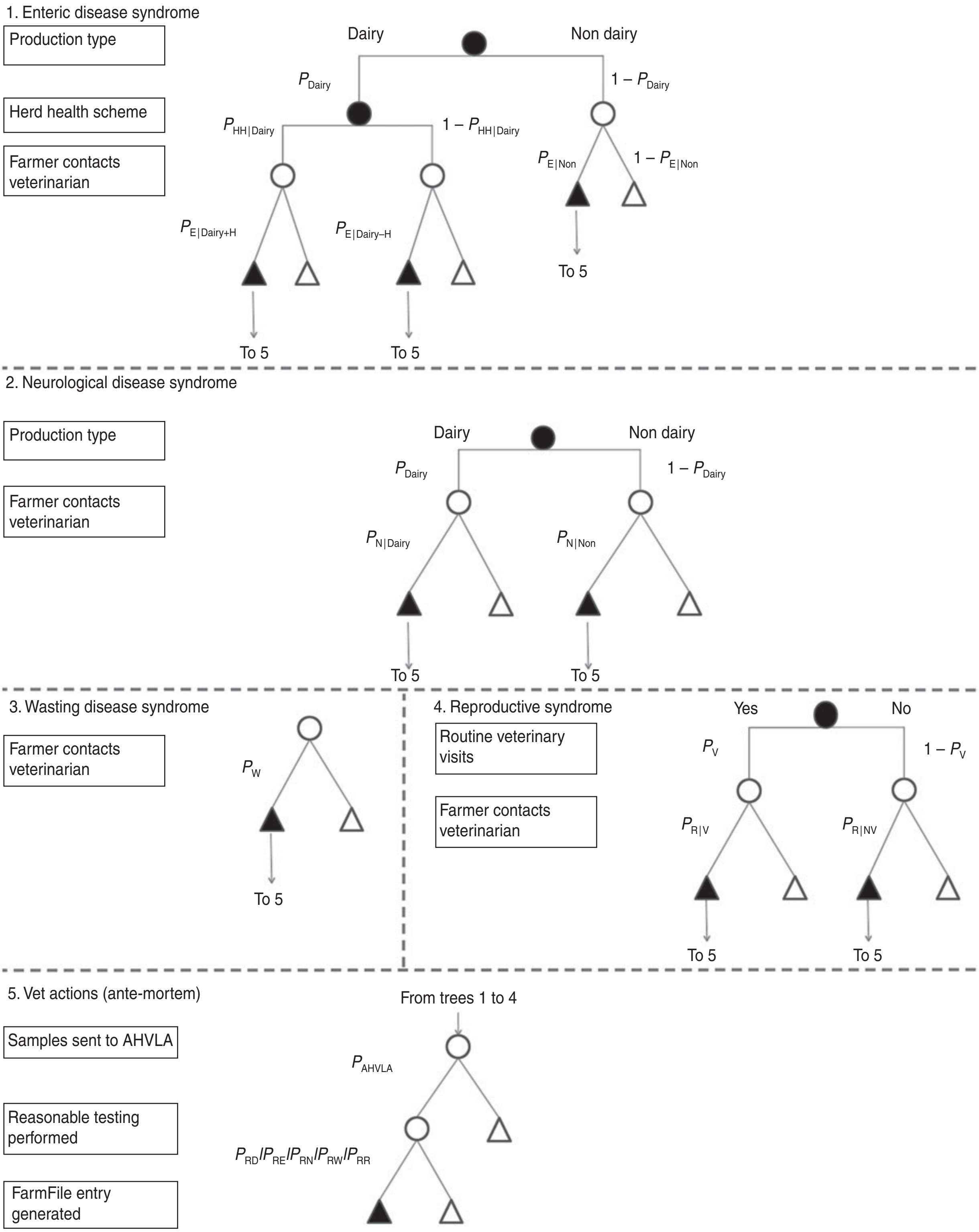

Fig. 3. Scenario trees generated for analysis of actions ante-mortem. Stages 1–4 differ by disease syndrome. All syndromes then share a common termination in stage 5. Notation for abbreviations can be found in Table 4.

(s.d.) = 9·33 miles]. The distribution of herd sizes among both production types was found to be positively skewed. Mean herd size for dairy production was 337 adult animals (s.d. = 263) with a median of 230 animals. Beef herds had a mean size of 86 animals (s.d. = 89) with a median of 72 animals. Eleven farms

Table 3. *Statistically significant associations between probabilities and attributes used to structure scenario trees. Attributes tested: production type, age, gender, herd size, herd-health scheme membership, role on farm*

Probability of veterinary contact given variation in listed attribute	*P* value	Description	Accepted/ rejected	Reason for acceptance/rejection
On death (recorded) of an animal with or without herd-health scheme	0·08	Members of a herd-health scheme showed an increased probability.	Accepted	—
On ED syndrome ± dairy production	0·029	Dairy farms showed a lower probability.	Accepted	—
On ED syndrome ± herd health scheme within dairy farms	0·051	Dairy farms showed a greater probability when members of a herd-health scheme.	Accepted	Significant in multivariate analysis when controlling for production type
On ED syndrome with age of farmer	0·059	Younger farmers less probability to report	Rejected	Insignificant when controlling for production type in multivariate analysis
On ND syndrome ± dairy production	<0·001	Dairy farms showed a lower probability than non-dairy	Accepted	—
On ND syndrome with large herd size	0·036	Lower probability with large herd size	Rejected	Large herd size associated with dairy production ($P<0{\cdot}001$). Insignificant when controlling for production type
On ND ± routine veterinary visits	0·041	Lower probability with routine veterinary visits	Rejected	Routine visits associated with production type ($P<0{\cdot}001$). Insignificant when controlling for production type
On RD ± routine veterinary visits	0·021	Those units with routine veterinary visits showed a greater probability	Accepted	—

ED, enteric disease; ND, neurological disease; RD, reproductive disease.

had experienced no mortality within the 6 months prior to completing the questionnaire. Half of the remaining 58 farms had no veterinary investigation of deaths in the preceding 6 months, and seven farms had 100% of mortality events investigated by a veterinarian. This resulted in a positively skewed distribution with a mean investigation percentage of 24·22 (s.d. = 34·1%) and a median result of 0·02%. In the total sample group, 11 instances of dead animals being sent for post-mortem from six different farms from a total of 325 mortality events (0·034% post-mortem rate) were captured. Submission for post-mortem was found to be associated with routine veterinary visits ($P=0{\cdot}005$).

A total of 10 veterinarians from nine of the 27 veterinary practices invited to participate responded to the veterinary questionnaire (33% response rate). The small sample size precluded any statistical analysis. Instead, descriptive statistics of responses received are presented. Respondents were all aged <40 years, with the modal age group being 20–29 years (six respondents). All respondents had used AHVLA laboratory services in the preceding 6 months, with 50% also having used private laboratory services for diagnostics in the same time period. Levels of experience of working with cattle ranged from 1 to 10 years with a mean of 4·85 years (s.d. = 3·1).

All the veterinarians sampled had recommended a client to submit an animal for post-mortem in the last 6 months with a maximum of eight recommendations and a minimum of one. The mean number of recommendations was 3·33 (s.d. = 2·51) in a 6-month period. Post-mortems were recommended at a mean rate of 0·86 per dead animal investigated (s.d. = 0·24) Veterinarians were asked how many of post-mortem recommendations actually led to submission of a carcase to AHVLA. This information was used to calculate the rate of submission per recommendation made (mean = 0·41, s.d. = 0·45).

Statistical analysis and scenario trees

Table 3 lists the statistically significant differences detected in respondents' likelihood of veterinary contact when tested against various predictors used to structure the scenario trees. Table 4 describes the probability distributions used for the probability of each branch on each scenario tree.

The output of the scenario trees is presented in Table 5. The mean probability of a FarmFile entry ranged from 0·079 for reproductive disorders to 0·26 for enteric disease. Comparison of D_{REC} with D_{PRO} indicated the prospective estimate was approximately double that generated from recall of past events (0·085 *vs.* 0·15). Sensitivity analysis performed on the scenario trees identified the probability of reasonable testing as being the most influential variable in three out of four ante-mortem testing scenarios; probability of selection of AHVLA for testing services ranked second in three out of four scenarios. In post-mortem scenarios, the probability of initial contact between farmer and veterinarian was found to have the greatest potential to influence the outcome, followed by the probability of the farmer complying with the recommendation of post-mortem by the attending veterinarian.

The statistical analysis of motivational factors yielded a number of associations of interest. The value of animals appeared to be of greater concern to dairy farmers when considering contacting a veterinarian, with 82% of respondents ranking this factor as important or very important, compared to 48% in non-dairy farmers ($P = 0{\cdot}008$). The effect of disease on production was ranked as very important by 75% of farmers having routine veterinary visits and important by the remaining 25%. This was significantly greater than the level of importance attached by farmers who did not have routine veterinary visits ($P = 0{\cdot}045$). Increasing within-herd prevalence of disease showed a similar pattern with respect to presence or absence of routine veterinary visits ($P = 0{\cdot}039$), with those having routine visits attaching greater importance to it. Since routine veterinary visits were associated with dairy production within the sample, stratifying by production type showed routine visits remained a significant or marginally significant factor when examining these two motivators within dairy farms ($P = 0{\cdot}009$ and 0·13, respectively). Fees for post-mortem examination were considered reasonable by 65% of herd health scheme members compared to 30% of non-members ($P = 0{\cdot}01$). Welfare of the animal was universally considered important or very important. Only two respondents believed they had a poor working relationship with their private veterinarian. Three questions indicate scepticism of value in contacting the state veterinary services were included, the results of which showed significant covariance (all $P < 0{\cdot}01$), suggesting approximately 20% of respondents held negative attitudes toward state veterinary services. No characteristic of respondents was identified as a predictor for such negative attitudes.

DISCUSSION

This study provides an insight into the route by which surveillance data are generated from the cattle population in England and Wales. The results indicate that the probability of generating useful surveillance data per case is highly variable (Table 5) even within a small sample. An expansion and refinement of the method used would allow for a more detailed investigation of the motivational factors influencing participation in passive surveillance to be performed.

Maintenance of submission numbers is critical to the sensitivity of the system. The statistical component of surveillance data analysis depends on detecting changes in a baseline level of submission for each syndrome by comparing rates of DNR with historical levels. It would be necessary for multiple database entries to be generated before a threshold (determined by the method of analysis) is reached at which detection can take place. Likewise, a pathologist is likely to require seeing more than one case of a new disease before triggering a full investigation. The relative sensitivity of these two detection mechanisms working in parallel is difficult to define; however, both are contingent on seeing multiple cases in a given time period. With these factors in mind, the prospective probability estimates generated by this model are expected to be over-estimates of the true likelihood of data generation. Comparison of the probabilities of submission of dead animals using farmers' recall against prospective estimates indicates a tendency for over-estimation when respondents were considering the theoretical rather than the actual. This potential bias was assumed to be constant in all prospective estimates in order to allow comparison between results. The prospective probabilities of surveillance data being generated per case, ranging between 0·085 and 0·25, if used to extrapolate and combined with thresholds for detection for the two detection mechanisms, could provide an indicator of the minimum number of cases required in a population to detect an emerging or re-emerging disease threat. Due to the complexity of defining detection thresholds once samples have been submitted to the laboratory, it is beyond the scope of this paper to provide an example of such a calculation; however, it would be beneficial to perform

Table 4. *Input parameters used to estimate probabilities of a FarmFile entry*

Description of input parameter (probability of)	Notation	Distribution	χ^2 goodness-of-fit P value	AIC ranking	Data source
Dairy production	P_{Dairy}	Point estimate 0·234	—	—	Point estimate 558 of 2384 commercial holdings in area of study of dairy or grazing production types, from census data [8]
Herd health scheme membership.	P_{HH}	Uniform (0·196,0·406)	—	—	95% confidence interval of proportion in questionnaire response
Routine veterinarian visits	P_{V}	Uniform (0·165, 0·408)	—	—	95% confidence interval of questionnaire response weighted for the true proportion of dairy farms within the population
Herd health scheme membership within dairy	$P_{\text{HH} \mid \text{Dairy}}$	Uniform (0·209, 0·471)	—	—	95% Confidence interval of proportion of HH scheme members within dairy respondents to questionnaire.
Farmer contacting veterinarian on death of an animal given herd health membership	$P_{DREC \mid \text{HH}}$	Exponential (0·353) Truncated at $x = 1$	0·15	1	Best-fit distribution to proportion of deaths on farm investigated by veterinarian amongst questionnaire respondents
Farmer contacting veterinarian on death of an animal without herd health membership	P_{DREC}	Exponential (0·196) Truncated at $x = 1$	0·003	1	Best-fit distribution to proportion of deaths on farm investigated by veterinarian amongst questionnaire respondents
Farmer contacting veterinarian on death of an animal (prospective)	P_{DPRO}	Triangular (0, 0, 1·280) Truncated at $x = 1$	0·13	2	Best-fit distribution to estimated frequency of veterinary contact on death of an animal among questionnaire respondents
Farmer contacting veterinarian for ED given dairy production and herd health membership	$P_{\text{E} \mid \text{Dairy+HH}}$	Triangular (0, 1, 1)	0·18	4	Best-fit distribution to frequency of veterinary contact on animal presenting with enteric disease among questionnaire respondents.
Farmer contacting veterinarian for ED given dairy production without herd health membership	$P_{\text{E} \mid \text{Dairy - HH}}$	Triangula r(0, 0·5, 1)	0·15	1	Best-fit distribution to frequency of veterinary contact on animal presenting with enteric disease among questionnaire respondents.
Farmer contacting veterinarian for ED given non-dairy production type.	$P_{\text{E} \mid \text{Non}}$	Uniform (0·216, 1·0)	0·77	1	Best-fit distribution to frequency of veterinary contact on animal presenting with enteric disease among questionnaire respondents
Farmer contacting veterinarian for ND given dairy production.	$P_{\text{N} \mid \text{Dairy}}$	Triangular (0, 1, 1)	0·99	1	Best-fit distribution to frequency of veterinary contact on animal presenting with neurological disease among questionnaire respondents
Farmer contacting veterinarian for ND given non-dairy production	$P_{\text{N} \mid \text{Non}}$	Triangular (0·414, 1, 1)	<0·001	1	Best-fit distribution to frequency of veterinary contact on animal presenting with neurological disease among questionnaire respondents
Farmer contacting veterinarian for WD	P_{W}	Triangular (0, 1, 1)	0·007	1	Best-fit to frequency of veterinary contact on animal presenting with wasting disease among questionnaire respondents

Table 4 (*cont*.)

Description of input parameter (probability of)	Notation	Distribution	χ^2 goodness-of-fit *P* value	AIC ranking	Data source
Farmer contacting veterinarian for RD given routine veterinary visits	$P_{\mathrm{R}\vert\mathrm{V}}$	Triangular (0, 1, 1)	0·13	1	Best-fit to frequency of veterinary contact on animal presenting with reproductive disease among questionnaire respondents
Farmer contacting veterinarian for RD without routine veterinary visits	$P_{\mathrm{R}\vert\mathrm{NV}}$	Uniform (0, 1)	0·02	1	Best-fit to frequency of veterinary contact on animal presenting with reproductive disease among questionnaire respondents
Veterinarian recommending submission of carcase for post-mortem	P_{REC}	Triangular (0·233, 1, 1)	0·025	1	Best-fit distribution for rate of recommendation among questionnaire respondents
Farmer submitting carcase following recommendation by veterinarian	P_{SUB}	Triangular (0, 0·1, 1·319) Truncated at $x=1$	0·34	1	Best-fit distribution to for rate of submission among questionnaire respondents.
Submission of samples to AHVLA for ante-mortem diagnosis	P_{AHVLA}	Uniform (0·22, 1)	—	1	Distribution of relative frequency of use among questionnaire respondents for AHVLA diagnostic testing for 9 categories of testing. Tests given equal weighting. Maximum and minimum values used to define distribution.
Reasonable testing on post-mortem	P_{RD}	Uniform (0·9625, 0·9759)	—	1	AHVLA data, 95% confidence interval of the proportion of carcase submissions for which either diagnosis was reached, or DNR with reasonable testing.
Reasonable testing for ED	P_{RE}	Uniform (0·6571,0·6586)	—	—	AHVLA data, 95% confidence interval of the proportion of ED submissions in 2010 for which diagnosis was reached or DNR with reasonable testing.
Reasonable testing for ND	P_{RN}	Uniform (0·1393,0·2396)	—	—	AHVLA data, 95% confidence interval of the proportion of ND submissions in 2010 for which diagnosis was reached or DNR with reasonable testing
Reasonable testing for WD	P_{RW}	Uniform (0·3461, 0·3721)	—	—	AHVLA data, 95% confidence interval of the proportion of systemic and miscellaneous submissions in 2010 for which diagnosis was reached or DNR with reasonable testing.
Reasonable testing for RD	P_{RR}	Uniform (0·2069, 0·2289)	—	—	AHVLA data, 95% confidence interval of the proportion of RD submissions in 2010 for which diagnosis was reached or DNR with reasonable testing.

AIC, Akaike's Information Criterion; ED, enteric disease; RD, reproductive disease; ND, neurological disease; WD, wasting disease; AHVLA, Animal Health and Veterinary Laboratories Agency; DNR, diagnosis not reached.
Parameter estimation integrated data from a variety of sources. Distributions were defined to allow for uncertainty over source data's representativeness.

Table 5. *Estimated probabilities of FarmFile entry for a single case of a given disease syndrome or death at a single point in time*

Component	Mean	Median	5th percentile	95th percentile
Probability of FarmFile entry being generated for a single case of:				
Death (recorded) (D_{REC})	0·069	0·045	0·0051	0·21
Death (prospective) (D_{PRO})	0·16	0·106	0·0072	0·47
Enteric syndrome (ED)	0·25	0·22	0·087	0·47
Neurological syndrome (ND)	0·085	0·08	0·033	0·15
Wasting syndrome (WD)	0·15	0·13	0·038	0·29
Reproductive syndrome (RD)	0·088	0·079	0·025	0·18

such work in future to aid interpretation. Assuming the further stages in the detection process do not have perfect sensitivity, this would result in a further decrease in the probability estimates generated by the model reported herein. By taking the inverse of the probability estimates produced, an expected 4–15 cases are required on farm to produce a single FarmFile entry depending on syndrome presentation. If the sensitivity of the subsequent steps in the detection process was incorporated, it would be interesting to calculate the likely prevalence a disease would reach to have a reasonable chance of detection.

The majority of respondents that believed the prices for post-mortem were at an appropriate level were members of herd health schemes, whereas the majority of those who thought prices were too high were not part of such schemes. Proportionally, non-herd health scheme members represented the majority of the population sampled. This tendency was supported in the data collected relating to the 6 months prior to the study; herd health scheme members had a mean probability of contacting a vet on the death of an animal of 0·35 compared to 0·2 for non-members prior to weighting for their relative frequency within the sample (mean of distributions $P_{D\mathrm{REC}}$ and $P_{D\mathrm{REC|HH}}$ given in Table 5). Logically it would be expected that farmers who are herd-health scheme members would have a greater incentive to closely monitor the health of their animals, and that they would also have a greater willingness to pay for post-mortems to be performed. In economic terms, this result is an indicator that demand for post-mortems may be elastic (i.e. demand responds to changes in price), or that reducing prices might encourage submission from sections of the population with a lower motivation to pay. Changing of prices in relation to diagnostic testing may therefore have a significant influence on sample numbers and as a result, the sensitivity of surveillance. This assertion is supported by other data: in October 2010, the fee charged by AHVLA for post-mortem on adult cattle rose from £140 to £240 (inclusive of carcase disposal). Submission numbers for post-mortem for the period October 2010 to April 2011 showed a decrease of approximately 59% (data provided by AHVLA, not presented here) when compared to the same time period in the previous year, again indicating that demand for post-mortems was relatively elastic.

Since the generation of surveillance data has a strong public good component, and the maintenance of submission numbers is critical to the sensitivity of the system, it would be recommended that a study of the demand function and willingness to pay for diagnostic services be conducted to assess pricing structures for AHVLA services set against the goal of collecting sufficient useful surveillance data. Further, raising the price at which a service is provided may open the market to competition from private laboratories resulting in a loss of a public good since data generated in private laboratories is not currently integrated into the surveillance system.

The detection of numerous strata within the sample, when considering different disease syndromes, is thought to be indicative of variations in management practices and priorities. For example, the detected difference in reporting of enteric disease by farmers who were herd-health scheme members was expected. Such schemes include control programmes for bovine viral diarrhoea, Johne's disease and calf diarrhoea (reviewed in [10] and [11]) and producer association schemes which enhance the value of produce. Similarly, a greater desire to identify the causative agent for any disease would explain the increased willingness to contact a veterinarian on the death of an animal seen among herd-health scheme members. It is concluded therefore that demand for veterinary diagnostic testing, and thus the sensitivity of early-warning surveillance, cannot be assumed to be constant across production types or for all disease syndromes. Identification of risk groups within a population for specific disease types may allow future allocation of resources to enhance surveillance, for example by targeted subsidies.

The analysis of motivating factors detected an interesting contradiction that may be of interest for further investigation. The presence of routine veterinary visits was observed to be an indicator that a farmer was more likely to consider the number of sick animals within the herd before contacting the veterinarian for an additional visit. In the case of infectious disease, requiring a certain threshold within-herd prevalence to be reached could provide a delay in diagnosis which would allow further transmission, potentially between herds to take place. Intuitively it would appear that routine veterinary visits would improve the detection of disease events on farm. The data collected here indicate that the timeliness of detection could be reduced in these circumstances.

The output of the model developed highlighted that on-farm decision-making process has a major influence on the probability of surveillance data being generated in a passive surveillance system. Intuitively this would be expected as people on-farm are the first point of contact for observing disease symptoms and for calling for support and advice. This study also brought to light several improvements that could be made to the method employed. The low response rate (33%) resulted in a small sample (69 respondents). This led to numerous categorizations being made within the data to allow statistical analysis to be performed. For example, all farms with dairy production were grouped together, and all without dairy being classified as non-dairy. No distinction was made in the analysis between, for example, beef suckler and fattener herds, which could conceivably have different priorities when combating disease. The sample of respondents was known to be unrepresentative of the population in the region: 66% of responses came from farms with dairy production, compared to 23% of farms having dairy as their primary production type within the region [8]. In future, an analysis of the characteristics of respondent and non-respondent farms could be performed through use of alternative data sources to determine to what degree a response bias is likely to have been introduced. In addition, it is noted that the high number of comparisons made in the statistical analysis increases the risk of introduction of type I errors. Attempts made to control this risk by subsequent multivariate ordinal logistic regression modelling were limited by the small sample size; however, a significant effect of herd-health scheme membership among dairy farms when considering enteric disease was noted. Some categories of variables (large herd sizes, routine veterinary visits) occurred too infrequently in the non-dairy sample to allow resolution using this method. As a result these were investigated by stratifying the sample and exploring within dairy farms alone for any effect. This method, however, served to further reduce the sample size and had a resulting decrease in power, so it cannot be said with certainty that the lack of significant effect observed was not in fact a type II error. Further, the limited sample size meant that applying a *post-hoc* correction when the power was already limited could have resulted in the introduction of type II errors. Ultimately, the validity of the results would be more certain had the sample size been increased to allow more detailed analysis.

The WRVC database used as a sample frame consists of farmers involved in previous studies in the region including intervention studies. It is therefore likely that a bias was introduced to the sample as the subjects were more likely to have an established interest in disease control. Second, of this sample frame, the 33% who responded may be those with the highest motivation to take action on disease issues, and thus would produce higher estimates for probability of veterinary contact than the population as a whole. Further to this, bias in response to questions regarding behaviours to which the respondent may perceive there to be a social stigma (e.g. non-reporting of a disease) is well documented [12]. This phenomenon, termed social desirability bias, is driven by the subconscious desire to present oneself in a positive light or consciously to do so to further one's own interests. Social desirability bias in response data was sought to be controlled by anonymity [13] but this is thought only to limit the conscious component of bias. Use of a random sampling methodology would have been beneficial, but was impractical within the framework of this project. It would have been beneficial if the sample size of veterinarians responding to the questionnaire had been larger, as this would have reduced uncertainty in modelling parameters and allowed the population to be stratified for veterinarians as it was for farmers. For example, it was hypothesized at the outset that differences in post-mortem submission rates from veterinarians working exclusively with farm animals compared to veterinarians working in mixed practice would be observed. The limitation of sample size also introduced uncertainty around the goodness of fit of several distributions fitted for the scenario-tree analysis. The following distributions were found to be poor fits to the data by χ^2 analysis: P_{DREC}, $P_{\mathrm{N|Non}}$, P_{W}, $P_{\mathrm{R|NV}}$,

P_{REC}. However, the distributions in question were all relatively wide so it was felt that the uncertainty in the data was adequately reflected. Further, four of the five distributions were drawn from a relatively small sample of data points ($n < 20$) which could have affected the ability of χ^2 testing to truly reflect the goodness of fit.

The results of the sensitivity analysis showed an interesting dichotomy between post-mortem and ante-mortem testing. In cases of ante-mortem testing, the choice of AHVLA as a diagnostic service provider and the extent of testing performed were shown to be the factors with the most potential to alter the outcome of data generation in FarmFile, reflecting the 'bottleneck' these two steps create in the scenario trees. For ante-mortem testing therefore, the decision-making at these two critical points is shared: the farmer, as financier, determines the extent to which testing is performed and the private veterinarian determines to which laboratory samples will be sent. In the case of post-mortem testing the initial decision to contact the veterinarian and to comply with the recommendation for post-mortem were shown to have the greatest potential to change the outcome; these decisions rest with the farmer alone. It is recognized that the relationship between farmer and veterinarian may influence this decision making. The data collected and made available through AHVLA regarding these stages did not permit any investigation of factors influencing these decisions. In the case of the veterinary survey, the sample size was too small to elucidate any influential factors predicting laboratory selection, and in the case of the extent of testing, the data provided by AHVLA were aggregated over a time period and did not provide case-by-case information. As a result, all farms were treated as homogenous with respect of their likelihood for reasonable testing. In reality it may be that this probability would not be uniformly distributed and may actually reflect the availability of resources or prioritization of disease relevant to a particular production or management type. Further, the extent of testing performed may be governed by the available diagnostic procedures ante-mortem; for example, cattle presenting with a nervous disorder consistent with a diagnosis of bovine spongiform encephalopathy could not be tested before death. This finding illustrates the importance of post-mortem submissions in such instances.

In summary, this project provided an initial investigation of the social and economic drivers for participation in a passive surveillance system and highlighted the potential for decisions made at farm level to influence the generation of surveillance data. Within a small sample of individuals likely to possess high motivation to act on disease issues, a wide variance in reporting frequency was observed. It is indicated that further investigation of behavioural parameters regarding surveillance and disease control would improve our understanding of the operation of these systems and thus improve our ability to optimize these systems towards their specified goals. The results provide evidence that demand for diagnostic testing services is not uniform, varying with production type, management practices and disease symptoms. Further, the generation of surveillance data is likely to occur at a relatively low rate per case on-farm. An interdisciplinary investigative approach, combining analysis of behavioural and economic factors is recommended to determine how participation in surveillance can be optimized to achieve the maximum efficiency in public spending for the generation information which forms a public good.

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DECLARATION OF INTEREST

None.

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