SOCIETY FOR VETERINARY EPIDEMIOLOGY AND PREVENTIVE MEDICINE

Proceedings of a meeting held at the University of Exeter on the 31st of March and the 1st and 2nd of April 1993

Edited by M.V. Thrusfield

ISBN 0 948073 13 6

ACKNOWLEDGEMENTS

Secretarial assistance in collating the proceedings was provided by Mrs R. Hunter and Mrs R. Muirhead.

The following company provided financial support for the conference and for publication of these proceedings:

Solvay-Duphar Veterinary

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MODELLING ANIMAL HEALTH ECONOMICS[†]

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INTRODUCTION

There is still a tendency among non-economists to qualify economics as the discipline that simply measures things in monetary units, while everyone else uses physical units. This view, however, is far too simple and is inappropriate. Economics - as a science - primarily deals with decision-making, in which money is only one of the elements of the system (Boehlje and Eidman, 1984). Animal Health Economics, therefore, can be described as the discipline that aims to provide a framework of concepts, procedures, and data to support the decision-making process in optimizing animal health management.

The scientific foundation for the discipline of Animal Health Economics was laid 20 to 25 years ago in Australia (Morris, 1969) and England (Ellis, 1972). These two authors successfully introduced a simple but essential economic principle in making veterinary decisions. Disease control input should be increased to the level where the cost of an additional input equals the return from the additional output. This so-called equimarginal principle can be considered a fundamentally different approach from the previously more common opinion of disease control being an all-or-nothing affair. Since then, increasing effort has been made to apply this principle in the various areas of Animal Health Economics (Howe and McInerney, 1987).

The Netherlands is among the countries that first adopted the new approach, initiated by the work of Renkema and Stelwagen (1979). Systematic research that includes three interrelated phases was started (Dijkhuizen, 1983): (1) quantifying the financial losses caused by animal disease, (2) optimizing decisions when individual animals, herds, or populations are being affected, and (3) determining the costs and benefits of preventive disease control. Experience with this approach will be used to present and discuss the promising field of Animal Health Economics in the remaining part of this public lecture.

THE ECONOMIC FRAMEWORK OF LIVESTOCK DISEASE

The basic conceptual model underlying economic analyses includes three major components: people, products, and resources (McInerney, 1987). It is people who want things and make decisions, therefore providing the driving force for economic activity. Products are goods and services that satisfy people's wants, and may be regarded as the outcome of economic activity. Resources are the physical factors and services that are the basis for generating the products, and, as such, are the starting point of economic activity.

Animal disease in this context can be considered as an influence that affects the resource transformation process and causes extra resource use and/or less production to result than before. These effects may be immediately visible (death, abortion), or obscured (reduced weight gain). To express the physical effects in economic terms, the 'value' of products and 'cost' of resources are

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[†]*Inaugural speech delivered upon entering the post of Professor in Animal Health Economics in the Department of Farm Management at Wageningen Agricultural University on February 27, 1992.*

required. The idea of value is not intrinsic in any product or service, but is determined by the people's request for the products, and is relative to its availability ('supply and demand'). Economics attempt to deal with the real value of any product, which may or may not be accurately captured by its recorded price. Similarly, the idea of cost comes from the resources that are used in making a product available. This underlies the definition of the real cost (or 'opportunity cost'), which again may not be adequately reflected by financial expenditures incurred in its production. Both 'real value' and 'real cost', and hence the losses of one and the same disease, may differ considerably across the various economic levels to be considered, that is, the individual farmer, the joint livestock owners, the consumers, and the national economy (Dijkhuizen *et al.*, 1991).

In the case of common diseases that the individual farmer can control (the so-called enzootic diseases, such as mastitis), supply and demand force animal-product market prices to move over time with the average disease level. Thus the resulting losses are transferred to the consumers, and conversely it is the consumer who benefits from improved animal health. In a sufficiently large market (such as the EC) there is hardly any relation between the extent and seriousness of these diseases, on the one hand, and the average income of the joint livestock owners, on the other. However, for the individual farmer, this linkage exists. The farm in question may suffer more (or less) from disease than is compensated by the average 'disease margin' included in the market price. To a lesser extent, this also applies to a group of livestock owners.

In the case of an incidental outbreak of contagious diseases (the so-called epizootic diseases, such as swine fever), market prices of output will primarily depend on whether or not foreign trade restrictions occur. When an outbreak does not lead to export bans, the market prices may temporarily rise a little, depending on the spread and duration of the outbreak. If exports are restricted, however, prices in countries that are major exporters will drop substantially due to an oversupply of the domestic market. This fall in price causes losses which may greatly exceed the direct losses of the disease due, for instance, to mortality. Unaffected farms also suffer from this drop in market prices. Consumers will benefit, however, making the losses for the national economy considerably less than those for the joint livestock owners. Income transfers, namely between consumers and producers, are not relevant to the assessment of national economic losses (Renkema, 1980).

The calculation of the losses is, in itself, not very important but can help to provide a better overall view of the impact of disease and can contribute to estimation of the extent of the losses to be avoided. The latter is particularly the case if the spread in losses between farms (or countries) is indicated in addition to the losses in the average situation. The accuracy of the outcome depends largely on the availability and usefulness of the underlying data. But, even with enough data available, it is not a simple task to quantify the losses of disease because their effects (Ngategize and Kaneene, 1985) (1) are not always obvious and pronounced, (2) are influenced by other factors such as nutrition and housing, (3) have a temporal dimension which adds to the complexity of determining their impacts at different stages in time, and (4) often manifest themselves in a complex with other diseases. This may help to explain why the outcome of calculations often differs so much, even for similar farm and price conditions (Schepers and Dijkhuizen, 1991).

MATHEMATICAL MODELLING IN ANIMAL HEALTH ECONOMICS

Models are an essential tool in the understanding of Animal Health Economics. Mathematical models are especially useful in this context and are commonly defined as a set of equations to describe or simulate an interrelated part (system) of the real world (Hillier and Lieberman, 1989). More specifically, a system in this context can be described as a set of related components (e.g., animal, farm, national economy) that exist within some defined boundary and react as a whole to internal and external stimuli (e.g., diseases, prices). Placing of the boundary is considered the key issue in defining and structuring any system, and should depend primarily on the function that the model has to fulfil (Dent and Blackie, 1979).

Basically, two different modelling approaches can be considered: a positive approach and a normative approach. The positive approach can best be indicated as a description of relevant processes and characteristics by statistical/epidemiological data analysis (so-called empirical modelling). In Animal Health Economics, greater attention is being paid to the normative approach which uses computer simulation techniques (so-called mechanistic modelling). Computer simulation is a method for analyzing a problem by creating a simplified mathematical model of the system under consideration which can then be manipulated by input modification. It is especially attractive where real-life experimentation would be either impossible, costly, or disruptive (e.g., with highly contagious diseases), and to explore strategies that are not yet applied. Special attention has to be paid to the correspondence between model and reality to obtain meaningful results for real-world situations.

During computer simulation, six interrelated steps are usually considered: (1) definition of the system and objectives for modelling, (2) gathering the data and specifying relations relevant to the model, (3) constructing the model, (4) validation of the model, (5) carrying out a sensitivity analysis, and (6) using the model to provide results.

A clear description of the system, and a statement of the reasons why the system simulation is being carried out, are essential first steps. The system under consideration, the nature of the problems to be solved, the relevant data and relations available (step 2), and in what degree of detail answers are required, determine the type of model to be used. Different types of model are available (France and Thornley, 1984), and are applied in the field of Animal Health Economics (Dijkhuizen, 1988). The first choice is that between static and dynamic models. A static model does not contain time as a variable, and therefore cannot simulate the behaviour of a system over time, as opposed to a dynamic model. A model that makes definite predictions for quantities (such as milk production and liveweight) is called deterministic. A stochastic model, on the other hand, contains probability distributions which deal with uncertainty in the behaviour of a system (i.e., disease occurrence, price level). Probability distributions offer the possibility to include random elements. With random elements, repeated runs of the model ('replicates') are necessary to provide insight into the spread in outcome. A final difference to consider concerns optimization versus simulation. An optimization model determines the optimum solution given the objective function and restrictions, whereas a simulation model calculates the effects of pre-defined sets of input variables (scenarios, strategies).

Constructing the model itself (third step) is usually a multistage procedure. Three different approaches can be considered: (1) the 'bottom-up' approach, beginning with the components of the model at the lowest level of organization and melding them together without any aggregation, (2) the 'top-down' approach, which begins with a simple representation of the entire system, and is complete when the resolution of the model is sufficient to satisfy the objectives, and (3) the prototyping approach, representing an iterative compromise between the first two alternatives. Development under the prototype approach begins with simple modelling of single subsytems. The process of development proceeds by formulating more sophisticated representations of the most important subsystems, and aggregating, deleting or ignoring subsystems of lesser importance. Because of its flexibility, the prototyping approach is especially favourable for models of large and complex systems, such as livestock farming.

Validation is considered a very important but difficult (fourth) step in the entire modelling procedure. The key issue here is to judge whether or not the model mimics the real system well enough to fulfil the purposes for which it has been developed. A distinction must be made between internal and external validation. Internal validation is a continuous process throughout the development stage of the model, ensuring that each equation or part of the model has a logical and correct basis. External validation refers to the comparison of the model's performance against the performance of the real system. This may include sensitivity analysis (fifth step) in which the values of relevant parameters are systematically varied over some range of interest to determine their impact on the results. Knowledge of sensitive parameters should be available and entered into the model. If such knowledge is not available, sensitivity analysis can help to set priorities for further research. In this way a valuable interaction between system modelling and field data analysis is possible. System modelling may be used to quantify the significant gaps in veterinary knowledge, while knowledge obtained from field data research increases the reality of economic models. This interaction is considered fundamental to the study of disease and disease control. If completed and accepted, the model can be used (sixth step) to provide the final answers to the questions for which it has been built.

In the following paragraphs this type of modelling is applied at three levels of decision making in Animal Health Economics: the animal, herd, and national level.

MODELLING THE ECONOMICS OF REPLACEMENT DECISIONS AT THE ANIMAL LEVEL

Animal health and production decisions at the animal level include replacement as one of the alternatives. Usually, these decisions are based on economic considerations: animals are culled not because they are no longer able to produce in a biological sense, but because replacement animals are expected to yield more profit. The income potential of the replacement animal cannot be realized as long as the available animal is kept in the herd, and, therefore, can be interpreted as the opportunity cost of postponed replacement (Renkema and Stelwagen, 1979; Dijkhuizen *et al.*, 1986). So, not only the net revenue of the animals present in the herd, but also the net revenues of the current and all subsequent replacement animals, are to be maximized.

Dynamic programming is considered the most appropriate technique for determining the optimum replacement decisions in livestock. It allows nonlinear relationships, genetic improvement, seasonal variation and variation in expected performance of both the present and all subsequent replacement animals to be included. In the Netherlands, extensive research has been carried out to apply this technique to cows (Van Arendonk, 1985) and sows (Huirne, 1990). Decisions were optimized for animals that differ in age, productive capacity, and reproductive status. A major outcome of the research is an economic index called Retention Pay-Off (RPO) which enables ranking of individuals within the herd on their expected future profitability: the higher the RPO, the more valuable the animal. A value below zero means that replacement is the most profitable choice. Results show that selection on insufficient productive capacity, apart from any disease, should be significantly stronger in cows than in sows. The key factor here is the repeatability of performance across parities, which is much higher for milk production than for litter size. Reproductive performance, on the other hand, is economically far more important in sows than in cows. Costs of a one-day delay in conception, for instance, reduce annual sow income by about 1% against 0.1 to 0.3% in cows. So, culling on reproductive failure should be significantly stronger in sows than in cows. This means that fewer number of breedings are allowed before the RPO index falls below zero and replacement becomes the more profitable option.

Having the RPO index available in this way, about half of the decisions for replacement in dairy cattle and sows can be directly supported. Moreover, the outcome can provide some indirect help with decisions on treatment or culling in the case of health problems. This is because its value represents the maximum amount that should be spent in trying to keep the animal in the herd. Decisions on whether or not to treat abomasal displacement in cows, for instance, has been worked out in this way, using decision-tree modelling techniques (Breukink and Dijkhuizen, 1982). Surgical treatment involving laparotomy turned out not to be profitable, unless the cow's productive capacity exceeds the average of the herd. Research is underway to include other health problems in the dynamic programming approach. Mastitis in dairy cattle, commonly recognized as the cause of considerable losses in many countries, is the first to be considered (Houben *et al.*, 1991).

When considering health problems, however, not all relevant aspects should be expressed quantitatively. Qualitative aspects also play a role in the farmer's decision-making process, e.g. with respect to leg weakness, udder quality and body constitution. These qualitative aspects, however, cannot be included directly in the dynamic programming approach. Therefore, research was started to develop a hybrid decision-support system combining the dynamic programming approach with expert system features (Huirne *et al.*, 1991). Expert systems are a modelling representation of the human reasoning process, using expert knowledge to attain high levels of performance in a narrow problem area (Turban, 1988). They typically represent knowledge symbolically, and examine and explain their reasoning process. Huirne *et al.* (1991) entered rules of thumb derived from veterinary experts into the system, making it possible to recalculate the initial RPO value for the specific more qualitative health status of the animals under consideration. For that, it is also possible to include the farmer's subjective weights on specific deviations and problems. Results are promising so far, which justifies increased research input in this particular area.

MODELLING THE ECONOMICS OF VETERINARY SERVICES AT THE FARM LEVEL

Controlling the cost of production is becoming increasingly important in modern livestock farming. Improving animal health and fertility can play a major role in this context. Total losses caused by health and fertility problems in Dutch dairy cattle, for instance, are currently estimated to average about Dfl. 500 per cow per year (Dijkhuizen, 1990). This is almost 10% of the gross production value, and 40 to 50% of income for a typical farmer. Differences between farms are estimated to be of the same magnitude.

Veterinarians try to anticipate herd health control by changing their services to individual farms from the so-called 'first-aid' practice or 'fire brigade' approach to planned prevention and control programmes in which farm advisory visits play a central role (Noordhuizen, 1984). Throughout the world, several field trials have been carried out to investigate the economic attractiveness of such programmes. Very few of these trials, however, were properly designed for sound economic analysis. Such an analysis requires data from situations in which programmes have, and have not, been implemented. These data may be obtained before (*b*) and after (*a*) application of the programme, collected on farms participating in the programme (*P*) as well as from comparable control farms (*C*). When available, these data make it possible to estimate the causal effects of the programme more precisely, that is, $(P_a - P_b) - (C_a - C_b)$, especially when particular herds with obvious health problems take part in the programme.

In the Netherlands, the field trial the most appropriate for economic analysis was carried out on dairy farms from 1974 to 1977 (Sol *et al.*, 1984). A total of 30 programme farms and 31 control farms were included, none of them showing specific herd health problems. In the preparatory year (1974/75), the two groups showed no large differences in economic results. After two years of programme application, statistically significant improvements were found, both regarding fertility (calving interval) and replacement due to reproductive failure and ill health. Regarding udder health (i.e., milk cell count) no significant effect was found. The average increase in gross returns minus feed cost per cow was Dfl. 460 in the programme group, which was Dfl. 176 more than in the control group. Additional veterinary costs per cow were estimated to average Dfl. 35 at most, indicating that this herd health programme was a sound investment. The latter conclusion was further confirmed by the finding that the programme effect had soon disappeared after the experiment was finished (Hogeveen *et al.*, 1992). It therefore appears to be profitable to apply such programmes more than temporarily.

To optimize this type of input on farms according to the equimarginal principle mentioned before, much more detailed information is required. The current single-point estimates of results need to be extended to include a wide range of possible contents and frequencies for the various programmes and/or measures. Provision of this kind of information only by field trials will not be feasible because it is too costly and time-consuming. Computer simulation is an appropriate alternative.

Experience in this respect was gained with a stochastic simulation model, using random numbers, primarily designed to explore and evaluate management strategies on reproduction and replacement in dairy cattle (Dijkhuizen *et al.*, 1987). In the model, cows are individually generated according to a set of predetermined herd characteristics. After an initial herd has been generated (year 0), changes in the herd can be followed at 20-day intervals over 15 years. For each strategy under consideration, 20 runs of calculations are carried out to obtain precise results. Each run is conceived as a separate herd or farm. The possibilities for studies are then extensive. For typical Dutch farms with Black and White cows it was found that a 20% increase in both the calving rate after first insemination, and the oestrus detection rate has a relatively small effect on income: 2 to 3% of net return on labour and management. Where herd health and management programmes in the field are still restricted to fertility, a broadening of the content is economically desirable and necessary. Improving the herd's production level (e.g., by reducing health problems) has the biggest effect on income. But the farmer's insemination and culling strategy should also be taken into account. Fertility performance indicators can be improved considerably while income is decreased, as shown with a strategy in which the maximum allowable number of inseminations per cow is reduced. The advantage of a shorter calving interval is outweighed then by the negative effects of increased herd turnover and replacement. A shorter calving interval, therefore, should be achieved by improved herd fertility management rather than by increased culling of cows that fail to conceive.

With these kinds of structured experiments, computer simulation can help to set priorities in herd health and management programmes (Marsh *et al.*, 1987). By entering farm-specific data into the model, it is possible to explore strategies tailored to individual farm conditions (King and Dijkhuizen, 1988). Research to make such models available for use in the field, suitable for running on the personal computer, is underway (Jalvingh *et al.*, 1992a and b) and should be further extended.

Increasing efforts are also being made to model farms within a production chain as a whole. The various participants in such chains can all have their own specific goals and interests, which do not have to be optimal for the chain as a whole. This possible conflict becomes more important where consumers put an increasing demand on product quality, food safety, and animal welfare. More than ever, therefore, insight is desired into the possibilities for, and economic consequences of, optimising the animal production chain as a whole. Within this context, animal disease control is also considered a major aspect of common interest.

MODELLING THE ECONOMICS OF NATIONAL DISEASE CONTROL PROGRAMMES

Outbreaks of contagious animal diseases are understandably feared, especially in major exporting countries such as the Netherlands. Control of this type of disease goes beyond the range of influence of the individual farmer, and needs to be carried out at the national or even international level. Current control strategies differ between countries as well as between diseases on (1) whether or not routine vaccination is applied to prevent this type of disease, and (2) what eradication measures are taken if a certain disease does occur, for example, vaccination policies versus 'stamping out' of infected animals and/or herds. Decisions on what strategy is best to apply are very sensitive to uncertain conditions, especially with respect to the risk of outbreaks and foreign trade restrictions. To make economically sound decisions, therefore, an integrated modelling approach is required that simulates the effects of different conditions and scenarios considering (1) the spread of the disease, (2) the direct cost of prevention and eradication, and (3) the indirect effects due to export bans. Published work in this field is scarce and hardly goes beyond the first two stages (Houben and Dijkhuizen, 1990; Van der Kamp *et al.*, 1990). Therefore, research was started to develop a method for quantifying and including the indirect losses of export bans (Berentsen *et al.*, 1992a).

The basic principle for determining the indirect effects due to export bans is illustrated in Figure 1. This figure shows the supply curve (S) and the demand curve (D) for a country exporting a certain product. At the basic price level, P, producers supply amount Q_s while consumers demand amount Q_d, with the difference (Q_s-Q_d) being exported. When export bans occur, a new equilibrium will arise at a lower price level, influencing the welfare of both producers and consumers.

Assuming producers strive for maximum profits in competitive markets, the supply curve (*S*) is the same as the rising part of the so-called marginal cost curve, indicating the costs of an additional unit of output. The return to fixed inputs, therefore, is formed by the gross returns (quantity x price) minus the variable costs (the area under the supply curve), and is commonly called producer surplus. Consequently, the losses for the producers due to a drop in price from *P* to *P'* is the reduction in producer surplus (area *PFCP'*). In the short term, a large part of the costs are fixed and the supply curve will be steep. With short-lived disease outbreaks, therefore, the vertical supply curve (*S'*) can be used to quantify the losses in producers' income. Actual losses for the producers are reduced by any compensation paid by the government.

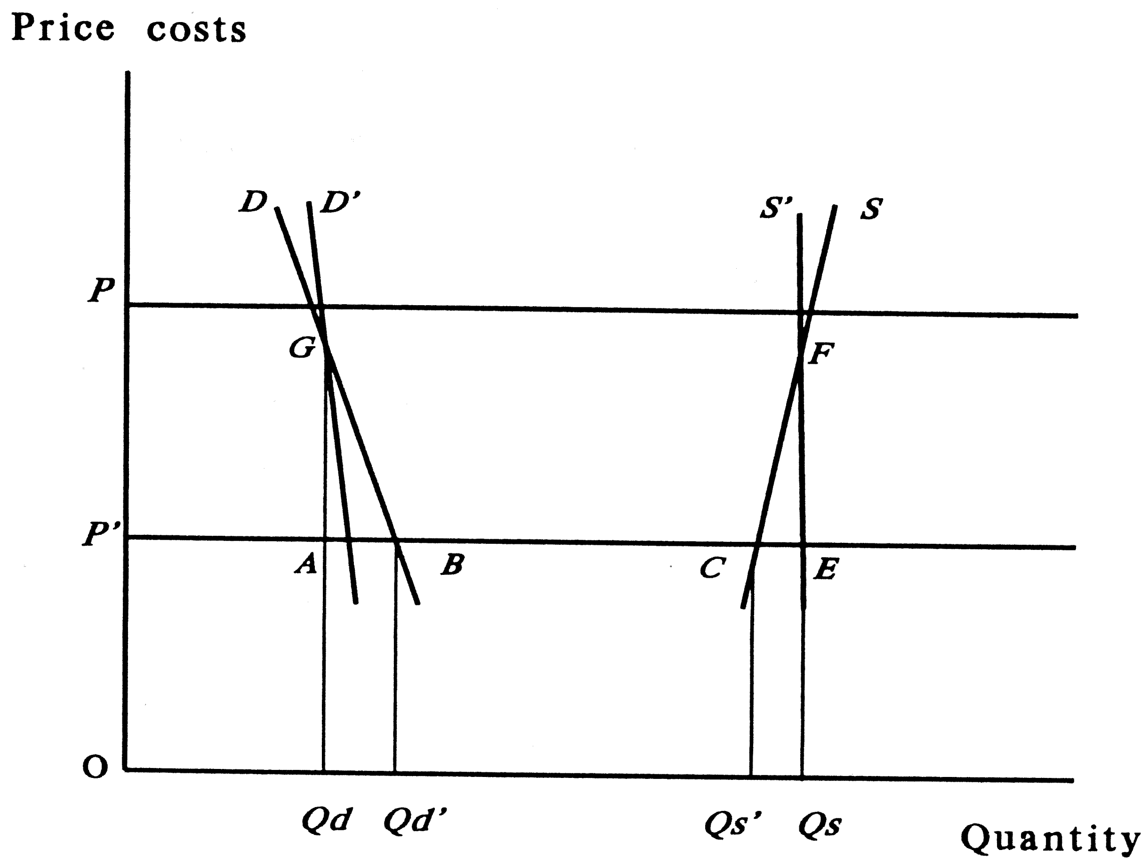

Figure 1. The market situation for a country exporting a product

Consumers gain from a drop in price, indicated by the increase in consumer surplus (area *PGBP'*). The consumer surplus is defined as the difference between the willingness to pay for a certain quantity and the amount actually paid, illustrated in Figure 1 by the area under the demand curve and above the price line. From the alternative demand curve (*D'*) it can be concluded that the slope of the curve (i.e., the price elasticity of demand) is not very important for the calculation of an increase in consumer surplus.

There is discussion within the theory of welfare economics about the aggregation of benefits and costs at the national level (Just *et al.*, 1982). Simple aggregation of these effects presumes an equal weight of benefits and costs for each group and individual, which is usually not the case. From an investigation of EC dairy policy in the years 1980 to 1987, for instance, it emerged that one guilder of producer income was considered about twice the weight of one guilder of consumer income (Oskam, 1988). It is therefore recommendable to report both the separate effects and their equally weighted total, giving policy makers the opportunity to include their own weights.

The basic principle for determining the indirect losses of export bans has recently been elucidated out for, and applied to, foot-and-mouth disease (FMD), focusing on the decision whether or not to stop annual vaccination of cattle (Berentsen *et al.*, 1992b). The various export markets for meat and breeding cattle were described by the volume of export, the level of consumption, the price elasticity of demand, and the transport costs per unit of product. For the domestic market, the import and the price of the products were specified. Some countries (such as the USA, Japan and South Korea) do not accept meat from countries with an annual FMD-vaccination scheme. As a result, the price paid for meat on these FMD-free markets was assumed to be about 10% higher than on other markets. In calculating the indirect effects, it was also necessary to specify what reactions to expect in importing countries in case of an FMD outbreak in the Netherlands. Moreover, possibilities for temporarily increasing export to other markets, as well as the storage behaviour of traders, had to be specified. Results showed that the indirect losses, indeed, are many times greater than the direct costs, although they did not influence the economic ranking of the various strategies in this case. Strategies without annual vaccination were found to be preferable for the Netherlands; these findings support the decision of the European Community to cease vaccination against FMD from January 1, 1992.

A further integration of the EC towards a common market makes a coordinated policy against contagious animal diseases increasingly important. From Brussels, therefore, more strict demands are to be expected considering control and eradication of a wide range of diseases, starting with Aujeszky's disease in swine, infectious bovine rhinotracheitis in cattle and Newcastle disease in poultry (De Ruijter, 1991). To anticipate these demands, a modelling environment is desired in which 'what if' scenarios can be performed to explore the epidemiological and economic effects of the various diseases and control strategies. This requires input flexibility regarding (1) the type and density of farming in the region or country under consideration, (2) the type of disease, (3) the prevention and control strategy to apply, (4) the extent and segmentation of export markets, including intervention possibilities, (5) the country-specific probabilities of trade restrictions, and (6) the various prices and demand/supply elasticities. A combined approach across countries would make it possible to examine the impact of a coordinated strategy within the EC as a whole. Increased effort is desired to develop and include possibilities for electronic identification and registration of individual animals. The system derived will be a flexible tool to support real-life policy making in an increasingly important area and, therefore, will have high priority within this new Chair of Animal Health Economics.

TEACHING ACTIVITIES IN ANIMAL HEALTH ECONOMICS

A close relationship between research and teaching, as is the intention within academic studies, is considered extremely important for the quality of both. Related to the afore-mentioned research activities, therefore, increasing efforts are being made to develop and provide courses in Animal Health Economics.

A first and very short introduction to the field is included in a more general course in Agricultural Economics of 20 theoretical lectures, offered in the 4th year of the curriculum within the Veterinary Faculty in Utrecht. In this introduction, the basic economic framework of animal disease is presented and illustrated with some quantitative examples. In their 6th (last) year, veterinary students receive further training in this field in small groups of 9 to 12 students. A 6-day economics course has been incorporated into an extensive training programme in preventive medicine and herd health control. Theoretical principles are combined with practically oriented case studies, using interactive computer models that focus on production, reproduction, and replacement economics in livestock.

A more theoretically oriented and advanced course in Animal Health Economics has recently been made available at the Wageningen Agricultural University, including 24 theoretical lectures and six computer laboratory sessions. The contents of this course are centered on the three interrelated research issues mentioned before: (1) quantifying the financial losses of disease, (2) optimizing treatment and/or control decsions, and (3) determining the profitability of preventive measures. Different economic modelling concepts and their applications are discussed and illustrated, including partial budgeting, cost-benefit analysis, Markov chains, dynamic programming, Monte Carlo simulation, and expert systems. Lecture notes and computer laboratory sessions are available in English. The course is also open to qualified people from outside the University.

From these courses in the regular curricula, specific aspects are frequently made available for post-graduate training. Usually, this occurs within zootechnically and/or epidemiologically oriented courses. A specialized (international) post-graduate course in Animal Health Economics is also being prepared for May 1993. Finally, there is an increasing number of people from other (EC) countries interested in visiting the Netherlands for individual training in this area. A proposal to establish (and fund) a European Training Centre, closely related to the above-mentioned research and teaching activities, has recently been submitted to Brussels. Such a Centre could also help to develop and share a more uniform approach in Animal Health Economics within the EC as a whole.

EXCHANGE AND COOPERATION

By establishing this new (part-time) chair in Animal Health Economics, and with it a 4-year PhD project, the Dutch Veterinary Service and the National Animal Health Committee emphasize their striving for an economically sound disease control policy. It is a real challenge for all of us involved to find a good working balance between the not always predictable and often time-stressed questions that emerge from active policy making on the one hand, and the need for more long-term scheduled approaches in scientific studies on the other.

Scientific research is primarily an individualistic activity, but is difficult to perform without a stimulating environment of fellow researchers. It is a great privilege, therefore, that this new Chair is made available within an active research group, covering various modelling activities in closely related areas. These activities centre around the development and use of computerized management support. Our close cooperation and mutual exchange of methods and ideas have been both pleasant and beneficial - all the more reason to continue.

Working in the field of Animal Health Economics requires a multidisciplinary approach, including agricultural economics, animal science, informatics, operations research and veterinary epidemiology. The fact that such a multidisciplinary network of contacts and cooperation really exists (and works), makes the 'Dutch approach' unique in the world. The approach would be doomed to fail, however, if not embedded in a wider network of international contacts and cooperation. The provision of this public lecture in English is meant to stress the importance of such an international exchange.

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MODELLING AND ECONOMICS

THE CONSEQUENCES OF PRRS IN FATTENING PIGS

Th. Blaha*

A new pig disease occurred in the USA in 1987, the main symptoms of which were an increase of late abortions, stillbirths and mummies. The spread of the disease and its epidemiological pattern pointed to an infectious and communicable disease, the aetiology, however, remained unknown for years. Therefore, the Americans named the disease mystery disease. In November, 1990, an epidemic of reproductive failures in sows with symptoms comparable to the American mystery disease started in the region Nordrhein-Westfalen of Germany, with its spread being much faster than in the USA. This rapid spread, both centrifugally and towards the Northwest of Germany (the pig-densest area), led to the fact that as soon as in May 1991 as much herds were affected in Germany as in the USA from 1987 to 1991.

In February, 1991, the Netherlands got affected, undoutedly from Germany, since the spread of the disease started at the Dutch East-border. The remarkable difference in the type of spreading in Germany (all directions) and in the Netherlands is obviously due to the differences in animal movement. Whereas in Germany piglets are transported through the whole country, mainly following regional changes in prices, the movement of Dutch piglets is more restricted than that of German ones. Therefore, the spread of the agent via infected animals predominated in Germany; in the Netherlands, however, due to the very short distances between pig herds, the flat country and a steady wind from Southwest, the aerogenic spread of the agent came to the fore.

In the course of 1991, more and more European countries turned out to be affected, with mainly animal movement being responsible for the spread.

During the first months of the epidemic, the awareness of farmers and veterinarians exclusively was focussed on the abortions, the stillbirths and mummies, as well as on the respiratory distress of the surviving piglets from affected litters. Only from the summer of 1991 onwards, it became apparent that the health and development of fattening pigs originating from clinically affected breeding herds were heavily impared.

Meanwile, the causative agent was discovert, first in Lelystad, later on at Boehringer Ingelheim in the USA and in Tübingen. Thus, a new phase of research on the epidemiology of the disease commenced. First results of comparative investigations of porcine sera from the Netherlands, the UK, the USA and Germany showed that the European isolates of the virus (an RNA virus

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belonging to the arteri-like viruses like the agent of Equine Arteritis) are closely related to each other, but antigenetically slightly different from the American strains. The next step was the application of the serological test for the purpose of epidemiological follow-up studies from the affected breeding herds to the corresponding fattening units.

By that time, the severity of the reproductive part of the disease (the European countries came gradually to an agreement on the name of the disease: PRRS = Porcine Reproductive and Respiratory Syndrome) was fading away step by step. However, there was no increase of the number of serologically positive breeding herds, i.e. there were more and more sow herds with PRRS-titres without a history of clinical PRRS prior to the serological investigation. During the end of 1991 and 1992, "only" the obviously PRRS-induced problems remained in the fattening herds as the clinical pattern of the epidemic. These problems were single underdeveloped pigs with a white or yellow skin in many pens and an increase of the respiratory diseases varying in kind and severity from herd to herd, i.e. no really typical clinical pattern could be described for PRRS in fattening pigs. However, most farmers and veterinarians state that there had been a deterioration of the health status of fattening herds, since the fatteners have obtained PRRS-positive weaners from the breeders. The purpose of the investigation presented was to objectify to which extend and in which way PRRS influences the health status of fattening pigs.

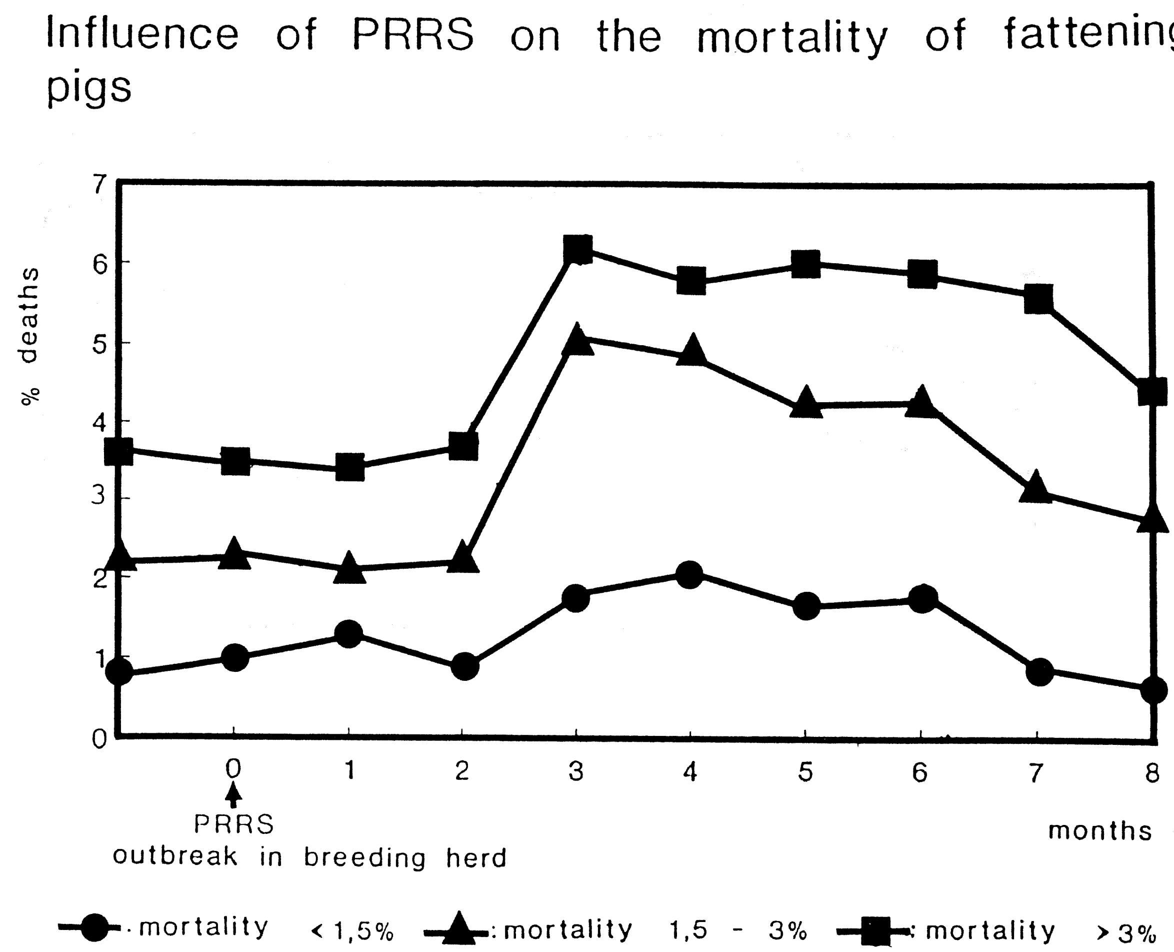
MATERIAL AND METHODS

Data of the mortality and morbidity (measured by the frequency of lung lesions at slaughter) from the fattening pigs of 4 farrow-to-finish herds, 6 fattening herds with only one source of weaners, and 2 fattening herds with commingled weaners were recorded. In all cases, the data of the pre-epidemic phase, i.e. the data of fattening pigs originating from litters born before the PRRS occurred in the corresponding breeding herd, were compared to the data of the same farm of the post-epidemic phase, i.e. the data of the fattening pigs originating from litters born after the corresponding breeding herd had been affected with PRRS. In order to verify the hypothesis: the worse the hygiene and management in a fattening herd, the more severe the PRRS-consequences, the data were stratified into herds with high, medium and low hygiene and management levels measured by the pre-epidemic mortality ($< 1.5\%$, 1.5% to 3% and $>3\%$).

RESULTS

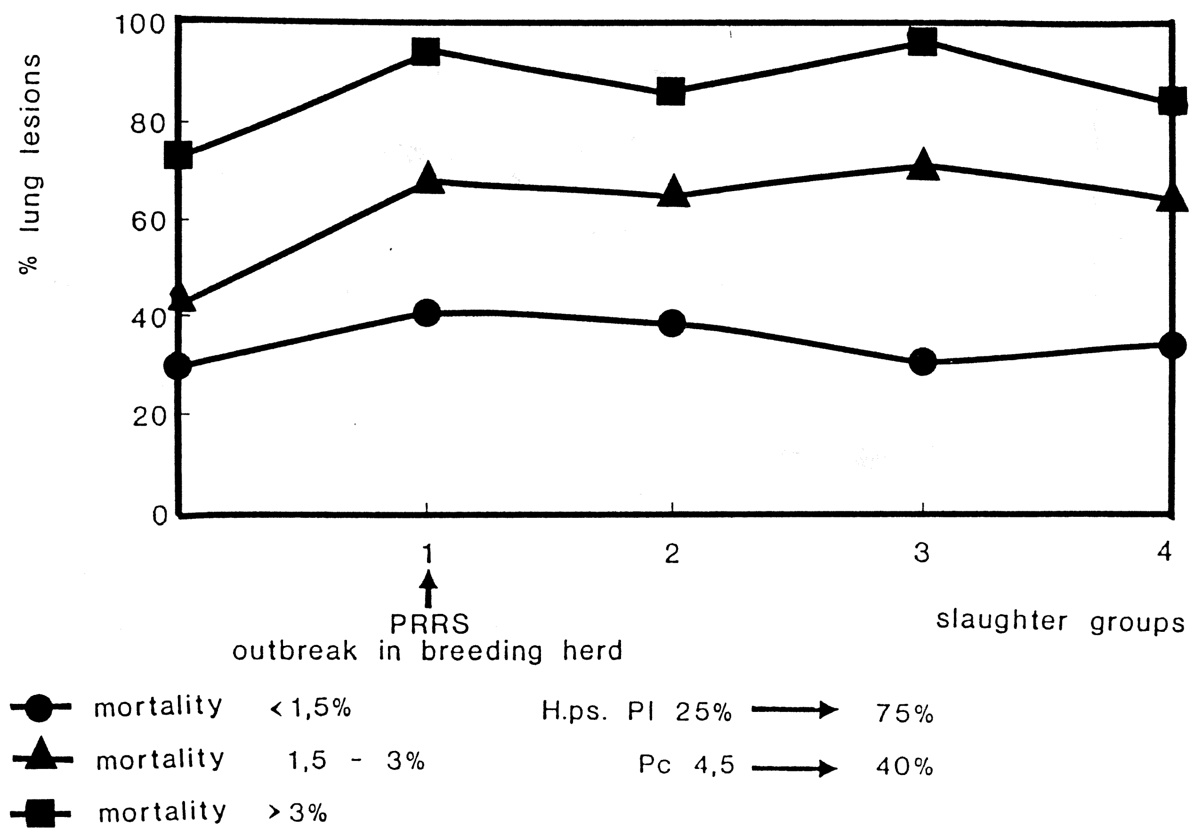
The average mortality rates of all 12 herds changed from pre-epidemic 2.2% to post-epidemic 4.3% three months and 2.8% eight months after the PRRS-outbreaks in the corresponding breeding herds. Fig. 1 shows the detailed mortality rates of the three groups of fattening farms.

Fig. 1:



The average frequency of lung lesions at slaughter of all 12 herds changed from about 45% in the slaughter groups before the PRRS epidemic to about 70% in the slaughter groups consisting of pigs born during and after the PRRS-outbreak in the breeding herds delivering the weaners. Fig. 2 shows the detailed lung lesion scores of the three groups of herds. The table only indicates the quantity of lung lesions. The quality, i.e. the kind and severity of the lesions varied largely from low to high grade lesions and from catarrhalic to necrotizing or purulent or heamorrhagic pneumonias with or without serositis. In one herd for instance, only the number of pleuritis and pericarditis increased as indicated in figure 2.

Fig. 2: Influence of PRRS on the proportion of lungs affected with lesions at slaughter



DISCUSSION

The results show quite clearly that the assumption on the correlation between hygiene and management on the one hand and the severity of the PRRS-consequences in fattening pigs on the other is correct: it is true that the virus of PRRS induces an aggravation of respiratory diseases in growing pigs, but this aggravation is the more the worse the hygiene and the management concerning animal health is on the farm in question. The explanation for this lies in the pathogenesis of the PRRS-induced respiratory diseases in pigs, i.e. in the drastic reduction of lung macrophages resulting from the infection with the PRRS virus. Due to this lack of lung macrophages, porcine pneumotrophic pathogens do much more harm to the infected lungs than in times with the normal nummber of macrophages on the surface of the alveoles. There is even the phenomenon that in pigs died from severe bacterial pneumonias aggravated by the PRRS virus the normally locally acting bacteria like pasteurellae and actinobacilli can be found in other organs, which can be explaned by the fact that these bacteria were not confronted to the normal barrier in the lung, and were, therefore, able to invade the pigs' bodies causing septicaemias. If the hygiene and the health-oriented management is poor, the infection pressure due to pneumotropic pathogens is high so that the reduction of the lung macrophages, i.e. the PRRS infection, leads to much more severe pneumonias than in well-run farms.

There is no typical "PRRS-pneumonia", since in every PRRS-affected fattening herd, the clinical pattern of the respiratory diseases is determined by the predominating bacterias in the herd, i.e. in one herd the respiratory picture is that of mycoplasmas plus pasteurellas, in another herd it is that of Actinobacillus pleuropneumoniae or of Haemophilus parasuis and so on. This observation is not only based on the clinical picture in the herds, but also on the largely varying patholgical pictures at slaughter as mentioned in table 2: the pleuritides = Pl and pericarditides = Pc due to Haemophilus parasuis = H.ps. increased in one herd from 25% to 75% and from 4.5% to 40%, resp., wereas in other herds only the pneumonic lesions showed an increase.

These described consequences of PRRS in fattening herds and the fact that contrary to the respiratory diseases no enteric diseases are increasing in PRRS-infected fattening herds support the opinion that PRRS does not lead to an immunosuppression, but "only" to a deterioration of the local defence in the lung.

MODELLING TO SUPPORT DECISIONS ON LEPTOSPIROSIS CONTROL IN DAIRY HERDS

RICHARD BENNETT*

Quantitative 'economic' modelling of disease problems is a potentially useful approach to aid decision making concerning the choice of livestock disease-control strategies both by producers and policy makers. Much has been written about the application of various 'economic' quantitative modelling techniques to animal health (Bennett, 1992) and many examples exist of models designed to provide useful information on the relative merits or otherwise of particular health strategies or programmes.

For decision problems concerning the control of disease, decision makers are likely to ask the following questions:

1. What is the current disease status of the livestock population (e.g. herd)?
2. How is this likely to change over time?
3. What are the production and other losses associated with the current and likely future disease profile of the livestock population?
4. What is the 'value' (i.e. significance) of these losses?
5. What are the options to reduce these losses?
6. What are the relative benefits and disbenefits of each option?

A survey of nearly 1000 dairy farmers in England and Wales found that 61% of respondents felt that they needed more/better information about leptospirosis and the strategies for control together with the associated costs and benefits (Bennett, 1991). In response to this need for information, the author decided to try to construct a simple computer model which would help to address the above questions with regard to leptospirosis (due to <u>Leptospira interrogans</u> serovar <u>hardjo</u> infection) in dairy herds.

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APPROACH AND METHODS

Two characteristics of livestock production, disease and decision making are particularly important and need to be incorporated into any model designed to support decision makers - risk and dynamics. Decision making is always made under conditions of uncertainty and involves risk. This is necessarily true since information is never perfect, and future events cannot be known for sure before they occur. Decisions are made at different points in time on the basis of information from the past about events that will happen some time in the future. Livestock production and disease are very much dynamic in nature. Inputs are transformed into outputs over time, disease-causing entities change over time and affect this process in a way which cannot be known for sure beforehand. Thus livestock disease-control decision making is characterised by dynamics and risk.

In addressing the questions above, it is apparent that the current disease status of a livestock population may be uncertain and even if known with some degree of certainty, future disease status is likely to be less certain. Many of the answers to the questions above will depend on the 'states of nature' pertaining at the time and these will vary over time, often in a very uncertain way. Thus the prevalence or incidence of a particular disease in a livestock population and its effects may depend on a host of inter-acting and ever-changing factors ranging from the weather to the movements of animals.

Given such uncertainties, it seemed important to assess the possible risks from leptospirosis facing a dairy producer and the financial implications of the disease over time. To this end three main aspects were considered:

1. the likelihood of the disease being (or having been) introduced into a herd:
2. the likely effects of the disease on the dairy enterprise, both physically and financially, following initial infection:
3. the likely longer-term (i.e. endemic) effects of the disease in the herd for a producer over time.

The concept of a risk chain (Merkhofer, 1987) can be used to consider the risks associated with a hazard such as disease. The risk chain contains four main elements - a hazard, exposure processes, effects and their valuation. The risk chain concept is similar to the decision analysis framework of actions, states and consequences and so is well suited to a decision-oriented approach to disease-control problems.

A number of exposure processes (risk factors) has been identified by which *L. hardjo* may be introduced into dairy herds (Pritchard *et al*., 1989 with supporting evidence from Bennett, 1991). These include purchase of cattle, co-grazing or common grazing of cattle and sheep, the use of a hired bull, and access by cows to streams and other, possibly contaminated, water. Other important exposure processes include weather conditions and husbandry factors such as yard drainage, slurry removal etc. In addition, other factors will influence the possibility and extent of herd infection, in particular, the state of immunity or degree of resistance of the herd to the disease.

The main physical effects of L. hardjo infection are abortion and milk loss in the dairy herd and the risk of illness in humans (Pritchard, 1986a), although the disease may also be a cause of infertility in cattle (Ellis, 1986). Calf rearing enterprises associated with the dairy herd may also be affected. The disease will generally be more severe in calves (Gunn, 1986) with an increased likelihood of secondary infection by other diseases and increased risk of mortality as well as losses in liveweight gain as a result of infection.

Valuation follows estimation of the likely magnitude of these disease effects within the herd and involves placing a money value on litres of milk lost, number of calves aborted or born weak, human illness etc. Producer market prices for milk, calves etc. are probably most appropriate for the individual producer, but valuation of the effects of the disease on human health is difficult, not least because of the difficulties of placing a value on human suffering. One tangible financial cost associated with the disease in a worker is the wage cost of hiring a replacement worker during the period of illness, but this is only a partial valuation.

The risk chain approach was used to construct a simple model to help assess the risks from L. hardjo facing a dairy producer. Figure 1 is a flow diagram which summarises the structure of the model and the main parameters included in it. Following the diagram from left to right, the probability of cows in the dairy herd being infected by L. hardjo depends on the prevalence of the disease (e.g. in the area), the presence of risk factors (used as weightings on prevalence), susceptibility of the herd to the disease and the likelihood that susceptible animals will contract the disease. The effects of disease will also depend on a number of factors, including the stage of lactation of dairy cows. The likelihood of possible disease effects (abortion, milk drop etc.) following infection are represented by a probability of each effect occurring (derived from case-study research data). The 'risks' associated with the disease for the producer are estimated in terms of an 'expected cost' (EC) which is merely the probability of various disease effects occurring multiplied by their respective financial valuations. More formally, the EC associated with the disease or with any disease-control strategy is estimated according to the following general expression:

$$EC = \sum_{i=1}^{n} XiP(Xi)$$

where Xi is the value of the ith possible outcome associated with the disease and P(Xi) is the probability of occurrence of the ith outcome. Also,

$$P(Xi) = Pci_1 * Pci_2 * \ldots\ldots\ldots Pci_n$$

where Pci_1 ...... Pci_n are conditional probabilities of the ith outcome.

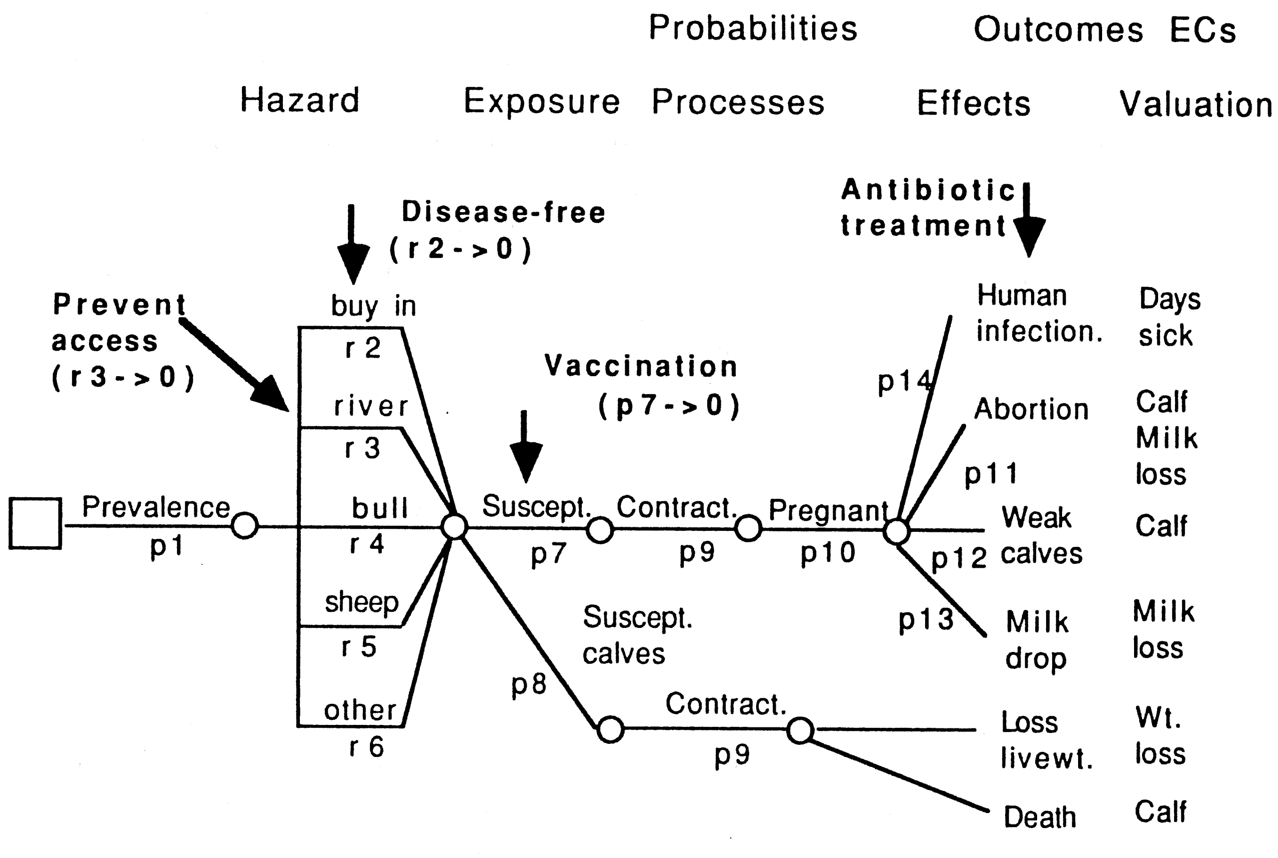

Fig. 1 Flow diagram of leptospirosis risk-assessment model

The values of many of the parameters contained in the model are herd specific, although may represent categories of herd types. For example, herd size, the number of calves in a calf rearing enterprise, average milk yield, the presence of risk factors etc. can all be varied and specified according to the characteristics of individual herds. More generally, herd types, such as 'closed herds', high yielding herds, herds which have access to a river etc., can be characterised in order to assess the risks faced by different herd types and the likely success of control strategies.

Control strategies for the disease can be considered simply in terms of their impacts on exposure processes (i.e. probabilities) and disease effects and hence on estimated ECs, together with the direct costs of implementing the strategies. For example, vaccination of all cows every year would reduce the susceptibility of cows to the disease such that p7 in the model would approach zero (depending on the efficacy of the vaccine) which would result in a lower EC, although the cost of administering the vaccine would need to be added which would increase EC. Thus expected costs for different strategies under various farm circumstances can be compared. Figure 1 has incorporated a number of possible control strategies and indicates how they would be considered by the model.

This spreadsheet model is a static risk-assessment model which does not consider the dynamic aspects of the disease or its financial implications for producers over time, for example, if the disease were to become endemic in a herd. In order to do this, a dynamic simulation computer model was built. A simple state-transition disease model was used which considered cows to be in one of three states at any one time - susceptible, infected (and infective) or resistant/immune. Cows move between states at different transition rates over time. A computer simulation software package, STELLA (Structural Thinking, Experiential Learning Laboratory with Animation; Richmond et al., 1987), was used to apply this simple dynamic model.

Detailed specifications of the two models are contained in the Notations, including the default values of parameters.

RESULTS

The static risk-assessment model and the dynamic state-transition model were used to consider a hypothetical 100-cow dairy herd under different situations. Table 1 shows some results from the risk-assessment model according to the presence of various risk factors associated with the dairy enterprise. These can be compared to annual costs associated with different disease-control strategies, such as vaccination. Vaccination of the herd, if assumed 100% efficacious in terms of preventing disease effects, would have an estimated annual cost of £400 (assuming a vaccination cost of £400 per cow per year). The annual expected costs associated with the disease take account of the likelihood of the herd being affected and of various disease effects occurring. However, even with a low probability, the unlikely may happen. Thus the estimated cost of the disease if it was introduced into the herd is estimated at £6292 for the first year following infection (under default values).

Table 1. Expected costs of leptospirosis according to presence of risk factors

Risk factors[a]	Expected cost (£s)
Buying cattle	1026
Access to river etc.	1258
Use of bull	975
Co-grazing	938
None of the above	63
All factors	4008

[a]Risk from other factors (r6) assumed always to be present

A number of different strategies can be explored using the model and many other analyses can be undertaken to test various assumptions or to take account of varying farm circumstances.

Figure 2 together with Table 2 show some results estimated by the dynamic model, again, for a hypothetical 100-cow dairy herd.

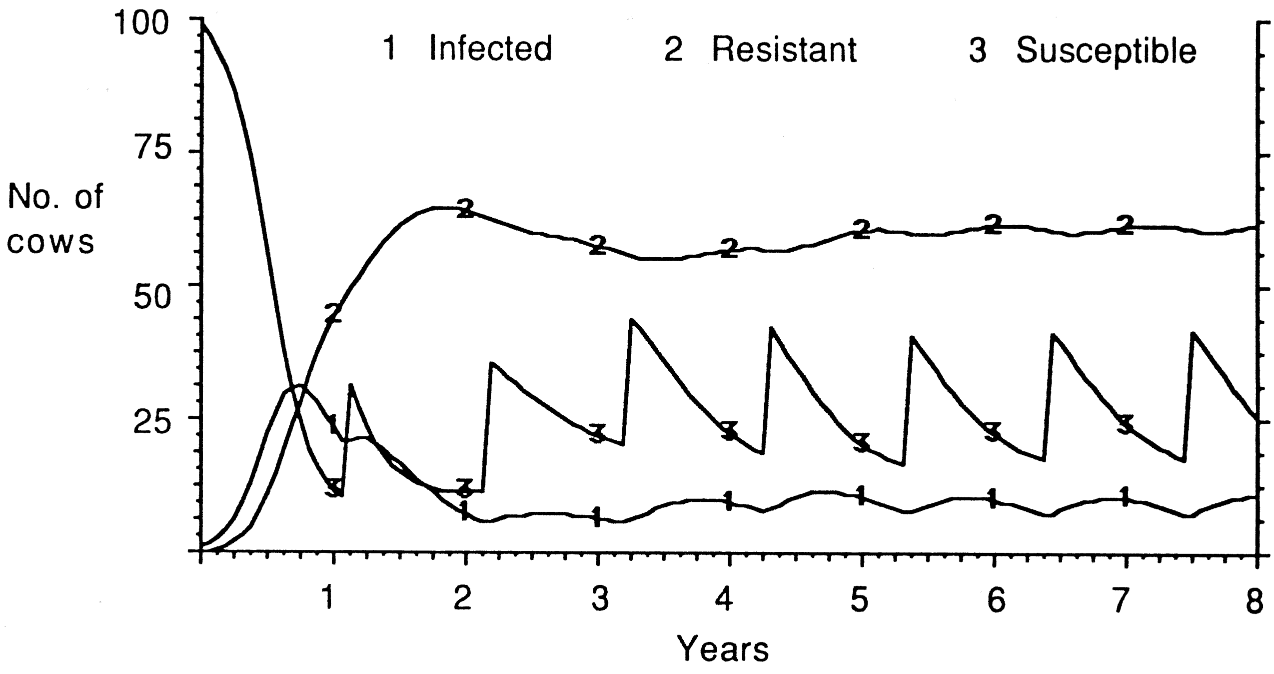

Fig. 2 Results of dynamic model under default values, showing numbers of infected, resistant and susceptible cows in the herd over time.

Simulation of the disease followed from the assumption that one cow in the herd became infected or was introduced into the herd, and that the rest of the herd was susceptible to the disease. The model simulates an epidemic in the first year following infection with estimated costs of over £6000 (comparable to those estimated by the static model). Subsequent losses are estimated at an average of over £2000 per annum over the following 7 years.

Table 2. Annual cost associated with leptospirosis estimated by the dynamic model under default values.

Year	Disease cost (£s per year)
1	6030
2	2119
3	1460
4	2165
5	2300
6	2107
7	2141
8	2186

It must be realised that the results relate to only one scenario or farm situation assuming the default values of the model. Many other scenarios can be explored and assumptions tested, together with various disease-control programmes. As an example, the model was used to explore the effect of ensuring that only 'leptospirosis-free' replacement heifers entered the herd each year (e.g. by vaccination and appropriate use of antibiotic). The simulation of this by the model was that after the high cost associated with initial infection, endemic infection fell to a very low level with annual disease costs of less than £200 for some time rising to over £500 with the waining of herd immunity. However, the model predicted a probability of around 50% that the disease could die out in the herd, assuming no reintroduction from external sources.

DISCUSSION

Results of the static risk-assessment model suggest that 'closed herds' with none of the risk factors identified by Pritchard et al (1989) face a low expected cost associated with L. hardjo. Those with any of the risk factors would be advised to explore ways of removing them or else to adopt a strategy such as vaccination. Risk-averse producers with none of the risk factors may still decide to vaccinate as an insurance policy.

Results of the dynamic state-transition model show that following possibly high costs in the first year after initial infection, disease costs associated with the endemic disease are likely to be around £2000 per annum and thus a policy such as annual vaccination may well be advisable following initial infection. Other possible strategies, such as combined vaccination and antibiotic treatment, could be explored using the model.

Both models make a number of assumptions about the prevalence of the disease, the importance of risk factors, the dissemination rate of the disease within a herd, the rate of immunity wane etc. These assumptions may be reasonable approximations or may require refinement. However, most of the values used were derived from empirical research and case-study data. Results are consistent between the two models, and with published case-studies of the effects and costs of the disease in dairy herds.

The usefulness of 'results' produced by any model intended to support decision makers depends on the degree to which the structure of the model, the parameters included, their mathematical relationships and their values, adequately represent the system and address the decision problem to which they refer. It also depends on how such a model is perceived by users and decision makers, in particular on the extent to which the model is credible, both in terms of its design and the results it produces. Models are simple representations of the real world and so by their very nature are not totally 'realistic'. The aim of model builders is to represent systems in as simple a way as is possible to address the problem or question in hand. Model builders and users need to be aware of the strengths and weaknesses of modelling and of particular models. All models suffer from the same potential weakness - that they fail to adequately represent a problem or that the assumptions used are unrealistic (or just plain wrong).

The models outlined in this paper potentially have the same weakness but are sufficiently transparent to enable critical appraisal and allow users to substitute their own assumptions in place of the default values. In this way, they allow the decision problem - i.e. what control strategy to adopt towards leptospirosis - to be explored. Their strength lies in this simplicity and transparency. Epidemiologists may feel that such simple models fail to capture the true complexities of disease, but nonetheless, they may be adequate to help explore decision problems and support decision makers. For veterinary advisers, they may have the added benefit of providing some visual or more tangible means of supporting and substantiating their advice to farmers.

CONCLUSION

The modelling approach outlined is a simple but flexible way of supporting livestock disease-control decision making. It helps to take account of two important aspects - risk and dynamics. The models are useful exploratory and research tools helping to think about risk factors, the implications of leptospirosis infection in dairy herds and the impact of possible disease-control strategy choices. They can be made relatively herd specific or can be used to represent different herd types. Their value lies particularly in their interactive use by the researcher, adviser or decision maker.

The models presented require further testing and refinement. It is intended to test their value to veterinary advisers and dairy farmers in the field. The extent to which they can meet the apparent information need of dairy producers found by Bennett (1991) remains to be assessed.

NOTATIONS

Probabilities and risk factors

p1 prevalence of leptospirosis-infected animals.
r2 risk ratio associated with buying replacement stock.
r3 risk ratio associated with access to a river.
r4 risk ratio associated with hiring a bull.
r5 risk ratio associated with co-grazing.
r6 risk ratio associated with other factors.
p7 proportion of the herd susceptible to the disease.
p8 proportion of any calf/beef animals susceptible to the disease.
p9 probability of susceptible animal contracting the disease if challenged.
p10 probability of cows being pregnant when infected.
p11 probability of infected, pregnant cows aborting.
p12 probability of infected, pregnant cows having weak calves.
p13 probability of cows suffering milk drop.
p14 probability of human infection from an infected herd.

Other parameters/variables

n1 number of dairy cows in herd.
n2 number of calves/beef animals in contact with dairy herd.
n3 number of workers in contact with dairy cows.
x1 loss in expected annual milk yield of a cow due to infection causing milk drop (proportion).
x2 average annual expected milk yield per cow.
x3 loss in liveweight in calves/beef animals due to infection.
x4 average days off work of a milker due to leptospirosis infection.

Effects of leptospirosis

a abortion.
b birth of weak calf.
c milk drop.
d loss of liveweight in calves/ beef animals.
e death of calves (eg. due to other diseases).
f effects of human infection.

Valuations

v1 value of abortion (a) = value of calf lost + value of milk loss.
v2 reduced value of calf because of weakness (b).
v3 value of milk = producer price for milk (per litre).
v4 value of milk loss due to milk drop (c).
v5 value of loss in liveweight per kg = average market price of beef animals per kg.
v6 value of loss in liveweight per infected animal (d).
v7 average value of youngstock dying from secondary infection (e).
v8 average cost of relief milker due to infection of regular milker.
v10 cost of vaccination per cow.

Expressions for calculating ECs of strategies

Let p1 (r2 + r3 + r4 + r5 + r6) = px.
Then px is a measure of the risk of the herd being exposed to the disease.
Let the EC of infection to dairy cows = y1
then y1 = px p7 p9 p10 (p11 v1 + p12 v2 + p13 v4) n1.
Let the EC of infection to youngstock/beef animals = y2
then y2 = px p8 (v6 + v7) n2.
Let the EC of infection to humans = y3
then y3 = px (p7 + p8) p9 p14 v9 n3.
Then EC of doing nothing about disease = y1 + y2 + y3.
EC of vaccination is calculated by the same expressions except that the cost of vaccination is added which = v10 n1.

Default values of parameters in risk-assessment spreadsheet model

p1 = 0.1 Allsup (1989) and Pritchard et al. (1989) report a proportion of these animals will be infected and infective. Therefore 0< p1< 0.215 assumed at 0.1.
r2 = 1.53 risk ratio from Bennett (1991). The herd-specific value will depend on whether animals are bought in, how many, where from etc.
r3 = 1.90 risk ratio from Bennett (1991).

r4	= 1.45	risk ratio from Bennett (1991).
r5	= 1.39	risk ratio from Bennett (1991).
r6	= 0.1	assumed risk ratio.
p7	= 1	i.e. all cows assumed initially susceptible to the disease.
p8	= 1	
p9	= 0.75	75% chance of a susceptible animal contracting the disease if challenged is assumed.
p10	= 0.78	(i.e. 280 days pregnancy/360 days in year).
p11	= 0.125	estimates vary from 0.05 derived from Pritchard (1986c) and 0.2 (Anon., 1989).
p12	= 0.01	unknown - default assumed.
p13	= 0.26	Pritchard (1986a) gives the possibility of up to 0.5.
p14	= 0.10	follows from evidence that 6% of milkers are affected and that there is evidence of infection in around 60% of herds (Pritchard, 1986a, 1986b, 1986c).
n1	= 100	
n2	= 0	
n3	= 2	
x1	= 0.2	milk drop quoted at causing a drop in expected annual milk yield per infected cow of 10-30% (Pritchard, 1986c).
x2	= 5020	average annual milk yield per cow given by Milk Marketing Board (1990).
x3	= 5.00	assumed average kilogrammes of weight loss in beef animals.
x4	= 2	
v1	= 400	(£s: updated from Bates et al., 1984 with a 28% reduction in 5020 litres expected annual milk yield at £0.195/litre, calf value £100, veterinary and AI charges £40).
v2	= 50	(£s). Calf value of £100 (Nix, 1991) assumed halved.
v3	= 0.195	(£s per litre). Nix (1991).
v5	= 1.2	(£s per kg). Nix (1991).
v7	= 10.25	(£s). Assuming that 5% of infected youngstock die at an average 3-months old valued at £205 (Nix, 1991).
v8	= 300	(£s).
v10	= 4	(£s).

Note that:

v4 = x1 x2 v3
v6 = x3 v5
v9 = x4 v8.

State-transition disease model

The proportion of cows infected/ive in the herd in any one time period is given by:

$$It = aSt\text{-}1 + It\text{-}1 - mIt\text{-}1 - yIt\text{-}1 \quad (1)$$

The proportion of cows in the herd susceptible in any one time period is given by;

$$St = St\text{-}1 - a\, St\text{-}1 + s\, Mt\text{-}1 + (x - w\, St\text{-}1) \quad (2)$$

The proportion of cows in the herd immune in any one time period is given by:

$$Mt = Mt\text{-}1 + mIt\text{-}1 - sMt\text{-}1 - zMt\text{-}1 \quad (3)$$

Also, $St + It + Mt = 1$ (4)

and, $a = f\,(It\text{-}1)$ where it is assumed initially that $a = b\, It\text{-}1$ (5)

where:

- It = proportion of the herd infected/infective during time t.
- St = proportion of the herd susceptible during time t.
- Mt = proportion of the herd immune during time t.
- It-1 = proportion of the herd infected/infective during time t-1.
- St-1 = proportion of the herd susceptible during time t-1.
- Mt-1 = proportion of the herd immune during time t-1.
- a = rate susceptible animals become infected/infective.
- m = rate infected/infective animals become immune.
- s = rateimmune animals become susceptible.
- b = dissemination rate of disease from infective animals.
- x = replacement rate.
- y = proportion of infected cows culled during one time period.
- w = proportion susceptible cows culled during one time period.
- z = proportion of immune cows culled during one time period.

<u>Default values of dynamic leptospirosis model and expressions used to calculate costs (£s).</u>

Initial number of susceptible cows	=	99
Initial number of infected cows	=	1
Initial number of resistant cows	=	0
Replacement_Rate 1	=	0.0625 (ie. 25% annual replacement rate).
Dissemination_Rate	=	0.031
Immunity_Rate	=	0.751
Immunty_Wane	=	0.051
Replacement_Pulse	=	Pulse (25,4,4) i.e.

assumed that 25 replacement heifers enter the herd all at once every 4 periods (1 year).

Note that these values were refined using the model. Initial values were chosen on the broad assumption of a relatively low Dissemination_Rate (since the rate of infection depended also on the number of infected animals), a relatively short (ie. around 3-4 months average period of cows being infected/ive and a relatively long period of immunity, hence a relatively high Immunity_Rate and relatively low Immunity_Wane.

Disease_Cost	= Infection_Rate (Milkdrop_Cost + Abort_Cost).
Milkdrop_Cost	= p10 p13 x1 x2 v3
Abort_Cost	= p10 p11 v1

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ECONOMIC SIMULATION OF AUJESZKY'S DISEASE CONTROL

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Aujeszky's Disease virus (ADV) is widely spread among pig farms in many countries. This herpes virus mainly affects the nervous system and respiratory tract, and is of great economic importance because of growth delay, mortality and abortion. Strategies to reduce the losses caused by the disease include vaccination programs, using genetically engineered vaccines that do not express one of the viral glycoproteins, e.g. glycoprotein gI. This makes it possible to discriminate between infected and vaccinated animals (Van Oirschot, 1988).

To gain insight into what vaccination strategy is best to apply, a lack of empirical data hinders a direct quantification of the elements to consider. Therefore, computer simulation was chosen as the method of research, making it possible to detect gaps in knowledge and to determine the impact of uncertain input values (Dykhuizen, 1992). The structure and input values of the model are mainly based on estimates Houben et al., 1993). The model named AUDIT (Aujeszky's disease transmission) is available on the PC, making it easy to do sensitivity analyses. Such analyses can help to set priorities for further research.

MODEL STRUCTURE AND CONTENT

Spread of the disease

The State Transition approach is used to simulate the evolution of the infection through time. Herds are considered to be in one of twenty mutually exclusive states, being the combination of four infection states (representing the amount of virus excreted by the total herd: none, moderate, normal or strong) and five protection states (protection is measured as the potential to resist excretion when the herd comes into contact with virus: optimal, good, reasonable, moderate and none). The optimal protection state can be reached only when a farm has been infected recently (i.e., by natural immunity to virulent virus).

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Each week, the probability of every transition is calculated and the proportion of herds in each state during the next week is thus derived. The basic formula to calculate the probability of infection is:

$$pi_t = 1 - e^{-DR * fi_{t-1}} \qquad (1)$$

where: pi_t = probability of infection in week t

DR = Dissemination Rate, representing the average number of herds to which the virus is delivered by each infected herd, irrespective of that herd's status

fi_{t-1} = fraction of farms infected (in the previous week)

This basic formula was expanded, in a stepwise manner, to include four aspects: infection state, protection state, type of herd (finishing or breeding), and possible reactivation of virus. Each of these aspects will be described briefly.

Infection state: Three levels of infection are included, differing in the amount of excretion of virus (i.e., moderate, normal and strong). This expands formula 1 as follows (see also De Jong and Diekmann, 1992):

$$pi_t = 1 - e^{-(DR_m * fi_{m,t-1} + DR_n * fi_{n,t-1} + DR_s * fi_{s,t-1})} \qquad (2)$$

where: $fi_{i,t-1}$ = fraction of farms with level i of virus excretion (i= m(oderate), n(ormal) or s(trong)) in the previous week (t-1)

other symbols as described previously

Protection state: To take into account that not-infected herds can have different protection states, the catch-on-factor (COF) has been introduced. COF_p is the probability that a not-infected herd with protection state p excretes virus after introduction of virus into the herd. So, to have a patent infection a herd has first to be exposed to the virus (with probability pi) and, second, a herd must actually excrete the virus (with probability COF). This probability is shown by formula 3:

$$pi_{p,t} = COF_p * pi_t \qquad (3)$$

where: $pi_{p,t}$ = probability of infection for a herd with protection state p (p= o(ptimal), g(ood), r(easonable), m(oderate) or n(ot)) in week t

pi_t = probability of becoming infected for a not-infected and not-protected herd in week t

COF_p = catch-on-factor for a herd with protection state p (p= o, g, r, m or n)

Herd type: An infected breeding herd can transmit virus to a finishing herd by airborne transmission (and vice versa) or by the flow of virus-excreting animals. The latter way has not been included in the model. Given the assumption that excreted virus will be proportionally distributed over finishing and breeding herds, formula 4 shows the probability of infection.

$$pi_{p,y,t} = COF_{p,y} * (1 - e^{exp}) \qquad (4)$$

$$exp = -(ff * (DR_{m,f} * fi_{m,f,t-1} + DR_{n,f} * fi_{n,f,t-1} + DR_{s,f} * fi_{s,f,t-1}) + (1-ff) * (DR_{m,b} * fi_{m,b,t-1} + DR_{n,b} * fi_{n,b,t-1} + DR_{s,b} * fi_{s,b,t-1}))$$

where: $pi_{p,y,t}$ = probability of becoming infected at least once in a week for a herd of type y (y=breeding or finishing), with protection state p in week t

$COF_{p,y}$ = catch-on-factor for a herd with protection state p and of type y

ff = fraction of finishing herds ($0 \leq ff \leq 1$)

$DR_{i,y}$ = dissemination rate for a herd with infection state i (i= m, n and s) and of type y

$fi_{i,y,t-1}$ = fraction infected farms with infection state i and of type y, in previous week

Reactivation: When pigs are latently infected with ADV, there is a chance of dissemination of the virus after reactivation of the virus. For gI- seronegative animals (no antibodies directed against glycoprotein gI) this chance is supposed to be zero. The farm - as modelling unit - is called gI-seronegative if all animals are gI-seronegative. In case a farm is not infected anymore it takes a certain time before becoming gI-seronegative, and all gI-seropositive animals have left.

To include reactivation in the model, it is necessary to estimate the total number of reactivations which will occur yearly (RY), if: (1) a fraction (FN) of the farms is not infected, (2) all the farms are gI-seropositive, and (3) the COF is 1. Assuming the number of reactivations to be a linear function of the previous factors, the probability that virus will spread on a farm of type y after reactivation (Rct_y) is:

$$Rct_y = Pos_y * \frac{RY_y}{52 * FN_y * B_y} \qquad (5)$$

where: Pos_y = fraction gI-seropositive herds

RY_y = estimated number of reactivations which Yearly occur on farms of type y (y=breeding or finishing) under specified conditions (see text)

FN_y = fraction not-infected type y farms on which RY_y is based (since only animals at not-infected farms can reactivate the farm)

B_y = number of type y farms

52 = number of weeks in a year

The combination of formula 4 and 5 gives the final formula (6) used to simulate the dynamic transmission in this model (from not-infected with protection state p to infected with protection state p).

$$pi_{p,y,t} = COF_{p,y} * (1 - e^{exp}) + Rct_y \quad (6)$$

where: symbols are as described previously

In formula 6 $pi_{b,y,t}$ can exceed 1 because of Rct_y. In that case $pi_{b,y,t}$ is made equal to 1.

Economic aspects

Costs included in the study are divided into costs of vaccination and costs due to production losses. Potential losses due to export bans, production losses for other species, costs involved with diagnosis and cost of eliminating infected animals are not (yet) included.

The parameters used to calculate the vaccination costs are: vaccination costs per animal (vaccine cost and labour), frequency of vaccination, number of visits of the veterinarian, number of animals and, for breeding herds, the sow replacement rate. The last parameter describes the costs involved with vaccination of replacement gilts (i.e., twice before first mating). Four different losses are being included, i.e. growth delay of fattening pigs, mortality of fattening pigs, abortion and piglet mortality.

In determining the potential profitability of ADV eradication, the costs of a program are translated into the disease-free period (DFP). This period represents the amount of losses which have to be avoided (i.e., the time a farm should remain free of the disease) to outweigh the program costs. DFP is calculated as follows (assuming a linear reduction in virus excretion):

$$DFP = \frac{TUC * (CCU + 0.5 * PLU)}{PLU} - TUC \quad (7)$$

where: DFP = number of disease free time units needed to outweigh the campaign costs

TUC = number of time units in the campaign

CCU = campaign costs per time unit

PLU = potential production losses per time unit (production losses which occur if none of the farms vaccinate against ADV)

Dividing formula 7 by TUC provides DFPU in formula 8:

$$DFPU = \frac{CCU + 0.5 * PLU}{PLU} - 1 = \frac{CCU}{PLU} - 0.5 \qquad (8)$$

where: DFPU = DFP per time Unit campaign

DFPU does not have any dimension because it is the ratio of the length of the disease free period to the length of the eradication campaign required to make the campaign profitable (break-even point). DFPU can be used to relate different strategies and to show the impact of other parameters. The DFPU can be used, however, only if a vaccination strategy leads to eradication of ADV.

Vaccination strategies and input values

In the model, vaccination strategies provide a minimum protection state. Strategy 0 means no vaccination which gives no protection (at least, none when no previous infection had occurred). If a finishing herd is vaccinated once a cycle (strategy 1), the minimum protection state is defined as moderate. When vaccinating twice a cycle (strategy 2), the minimum protection state is defined as reasonable. If sows are vaccinated with an inactivated vaccine once a cycle (strategy 1), the minimal protection state will be reasonable. Vaccinating all the sows with a live vaccine at the same moment three times a year (strategy 2) is estimated to give good protection (which however, still is less than optimal).

The major basic input values are summarized in Appendix A. Within the entire transition matrix, four submatrices are to be considered. Submatrix A includes the part in which farms remain not infected (dimension 5*5), submatrix B the part in which farms become infected (dimension 5*15), submatrix C the part in which farms become not infected (dimension 15*5) and submatrix D the part in which farms remain infected (dimension 15*15).

In the sensitivity analysis, two matrices have been defined with a different B submatrix and two with a different D submatrix. In these submatrices the value of the probabilities are changed, but the excluded transitions remain excluded. In the first B-alternative, the probability that a farm becomes more strongly infected the first week after infection has been reduced by 0.2 (B-0.2) and in the second increased by 0.2 (B+0.2). For the D-alternatives the probability to remain infected has been reduced by 0.2 (D-0.2) and subsequently increased by 0.2 (D+0.2).

MAJOR RESULTS

From the State Transition model first the Basic Reproduction Ratio (R_0) is calculated, indicating the number of secondary cases resulting from one single infectious herd. When $R_0<1$ the infection cannot spread and the population is effectively protected from the infection (De Jong and Diekmann, 1992).

Table 1. R_0 for different combinations of vaccination strategy (finishing/breeding) and transition matrices

matrix	vaccination strategy (finishing/breeding)								
	0/0	0/1	0/2	1/0	1/1	1/2	2/0	2/1	2/2
basic	6.0	3.8	3.7	3.9	1.7	1.6	2.6	0.4	0.3
B-0.2	6.0	3.8	3.7	3.8	1.5	1.4	2.5	0.3	0.2
B+0.2	6.0	3.8	3.7	4.1	1.9	1.8	2.6	0.4	0.3
D-0.2	4.3	2.7	2.6	2.7	1.2	1.1	1.8	0.3	0.2
D+0.2	10.0	6.3	6.1	7.0	3.3	3.2	4.2	0.5	0.3

B: part of transition matrix (Table A, Appendix A) which gives the distribution over infection states the week after infection (row 1-5, column 6-20). Decrease and increase of the probability of becoming more strongly infected during the first week of infection (B$\pm$0.2).

D: part of transition matrix (table A, appendix A) which determines if a farm remains infected (row 6-20, column 6-20). Decrease and increase of the probability of remaining infected (D$\pm$0.2).

In the basic situation, ADV seems not to be eradicated (i.e. $R_0>1$) without any vaccination on breeding farms and an intensive vaccination strategy on finishing farms, as shown in Table 1. Especially the difference between the strategies 2/0 and 2/1 turns out to be large, indicating a major impact from vaccinating breeding herds on the circulation of virus. A more intensive scheme on breeding farms turns out to be of little value. Table 1 also shows that the infection state of a farm during the first week of infection (submatrix B) does not have much effect on the R_0. A long duration of infection (submatrix D) has much more influence on R_0, but still does not change the R_0-value from above to below one or vice versa.

In Table 2, the equilibrium situation (i.e. when after a simulation period of 3 years the parameters do not change significantly) is shown for the infection state for finishing and for breeding herds.

Table 2. Equilibrium situation (after 3 years) for finishing and breeding herds (percentage infected) for different vaccination strategies

infection state	vaccination strategy (finishing/breeding) 0/0	0/1	0/2	1/0	1/1	1/2	2/0	2/1	2/2
finishing herds									
not	75.4	79.0	79.8	77.5	84.7	86.6	94.0	100.0	100.0
moderate	2.8	1.8	1.6	3.5	2.1	1.7	2.8	0.0	0.0
normal	3.5	2.3	2.1	5.1	3.2	2.7	3.2	0.0	0.0
strong	18.2	16.9	16.5	14.0	10.1	8.9	0.0	0.0	0.0
breeding herds									
not	75.4	91.0	97.8	76.2	93.4	98.6	82.9	100.0	100.0
moderate	2.8	4.2	1.5	2.6	3.1	1.0	1.0	0.0	0.0
normal	3.5	4.8	0.6	3.2	3.5	0.4	1.3	0.0	0.0
strong	18.2	0.0	0.0	18.0	0.0	0.0	14.8	0.0	0.0

The second vaccination strategy for finishing herds in combination with any positive vaccination strategy for breeding herds (2/1 or 2/2) reduces the percentage of infected herds to zero. In general the percentage moderately- and normally-infected herds turns out to be low and rather stable. The infection state of one type of farms has an influence on the infection state of the other type. This is especially the case in Table 2 where the percentage not-infected breeding herds increases with 9% if the finishing farms use strategy 2 (2/1) instead of 0 (0/1). This interaction also implies that it is not possible to eradicate the virus from the finishing farms without eradicating it from the breeding farms (strategy 2/0 versus 2/1 and 2/2 in Table 2).

In Table 3 the economic results are shown for one of the strategies which eradicate the virus, taking into account different fraction of the infected farms that show clinical symptoms (i.e. production losses).

Table 3. Profitability of the 2/1 vaccination strategy

Herds with clin. infect. (fin./breed.)	Vaccination costs Dfl/week	Potential losses Dfl/week	DFPU
30%/20%	1,794,516	3,321,588	0.04
25%/15%	1,794,516	2,122,749	0.35
20%/10%	1,794,516	923,910	1.44

A DFPU of 0.35 means that after an effective eradication campaign of, for instance, one year the virus has to stay away for at least 0.35 year (i.e. four months) to make the campaign profitable. The profitability highly depends on the percentage of infected farms with clinical symptoms, as shown in Table 3.

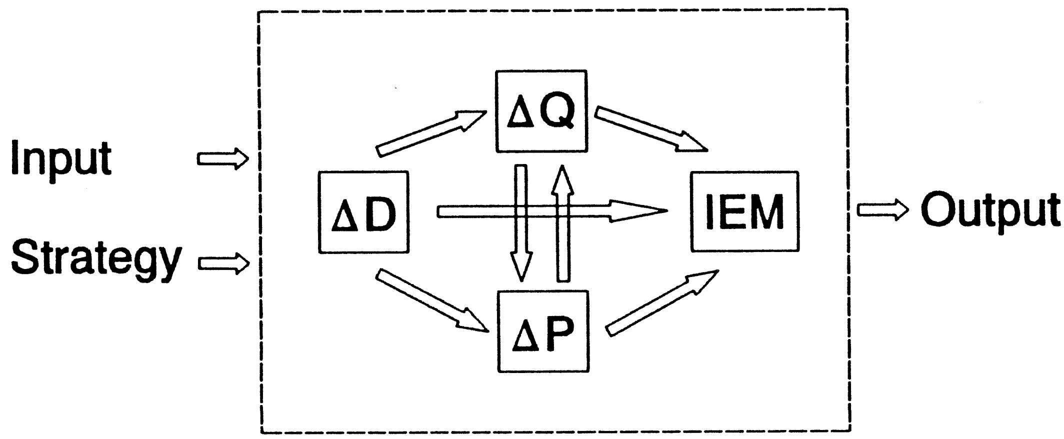
Several aspects were not yet included in this exploring study, such as the influence of maternal immunity, age, farm size, animal flow from top to base of the pig farming production pyramid, virulence and transmission characteristics of the virus, influence of season, and the potential impact of export restrictions. Further research is desired (and under way) to determine their impact on the ADV-transmission and on the profitability of ADV control schemes.

RESEARCH OUTLOOK

A further integration of the EC towards one common market makes a coordinated policy against contagious animal diseases increasingly important. In future, more restrict demands are to be expected considering control and eradication of a wide range of diseases, starting with Aujeszky's disease in swine, IBR in cattle and Newcastle disease in poultry (Dykhuizen, 1992). To anticipate these demands, a modelling environment is desired in which 'what-if' scenarios can be performed to explore the epidemiological and economic effects of the various diseases and control strategies. This requires input flexibility regarding (1) the type and density of farming in the region under consideration, (2) the type of disease, (3) the prevention and control strategy to apply, (4) the extent and segmentation of export markets, including intervention possibilities, (5) the market-specific probabilities of trade restrictions, and (6) the various price and demand/supply elasticities.

In The Netherlands, research is under way in which a basic economic framework is (further) developed for this type of analysis. Current thoughts on this framework are illustrated in Fig. 1.

Fig. 1 The basic economic framework



Where: ΔD = change(s) in disease-rate

ΔQ = change(s) in production

ΔP = change(s) in prices

IEM = integrated economic model

As shown in Fig. 1, four modules are considered with each having its own input and output. The starting distribution and the changes of the disease over time are simulated in "change(s) in disease-rate". Affected production sector(s) are described in "change(s) in production", offering the possibility to be linked with geographical information systems. "Change(s) in prices" is the third module, aiming to calculate the changes in prices as a result of changes in supply due to disease outbreaks, and taking into account price- and cross price elasticities. After the changes in production and prices are calculated for each of the disease control strategies under consideration, a final comparison is made in the "integrated economic model" module.

The basic approach presented in Fig. 1 will be worked out for two diseases, Aujeszky's disease in swine and IBR in cattle. Based on these experiences, the approach will finally be generalized to include other disease and control strategies. The system thus derived should be a flexible tool to support real-life policy making in animal disease control.

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APPENDIX A. MAJOR INPUT DATA

In the computer model AUDIT, about 900 variables can be changed, of which 800 are in the transition matrices. In this appendix, the basic values of the major parameters are presented.

Table A. Basic transition probabilities when no vaccination strategy is used.*

to→ from ↓	no infection					moderate infection					normal infection					strong infection				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.40	.35	.25	.	.	.	1.00	.	.	.	.	.	.	.	.	.	.	.	.	.
2	.	.50	.35	.15	.	.	.70	.	.	.	.	.30	.	.	.	.	.	.	.	.
3	.	.	.60	.35	.05	.	.	.30	.	.	.	.	.70	.	.	.	.	.	.	.
4	.	.	.	.70	.30	.	.	.	.	.	.	.	.	.30	.	.	.	.	.70	.
5	.	.	.	.	1.00	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1.00
6	.	.	.	.	.	1.00	.	.	.	.	.	.	.	.	.	.	.	.	.	.
7	.30	.40	.	.	.	.	.30	.	.	.	.	.	.	.	.	.	.	.	.	.
8	.	.20	.30	.	.	.	.10	.30	.	.	.	.	.10	.	.	.	.	.	.	.
9	.	.	.30	.15	.	.	.	.10	.25	.	.	.	.05	.10	.	.	.	.	.05	.
1.	.	.	.10	.25	.	.	.	.	.10	.20	.	.	.	.10	.15	.	.	.	.	.10
11	.	.	.	.	.	.	.	.	.	.	1.00	.	.	.	.	.	.	.	.	.
12	.25	.20	.	.	.	.	.20	.	.	.	.	.35	.	.	.	.	.	.	.	.
13	.	.20	.15	.	.	.	.10	.20	.	.	.	.05	.30	.	.	.	.	.	.	.
14	.	.05	.10	.	.	.	.05	.15	.20	.	.	.05	.05	.25	.	.	.	.	.10	.
15	.	.	.05	.	.	.	.	.10	.15	.15	.	.	.05	.05	.25	.	.	.	.	.20
16	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1.00	.	.	.	.
17	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1.00	.	.	.
18	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1.00	.	.
19	.25	.15	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.60	.
20	.30	.20	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.50

* 1, 6, 11, 16 = optimal protection; 2, 7, 12, 17 = good protection; 3, 8, 13, 18 = reasonable protection; 4, 9, 14, 19 = moderate protection; 5, 10, 15, 20 = no protection

- Dissemination Rate (DR):

  The number of farms to which virus is transmitted by each infectious farm depending on the infection state:

  moderate infection: 0.5 farms/week
  normal infection : 1.5 farms/week
  strong infection : 3.0 farms/week

- Catch-On-Factor (COF):

  The COFs for optimally protected and for not-protected farms are defined as 0 and 1, respectively. Because gI-seronegative farms can be found, the COF for well and reasonably protected farms has to be low. The basic values are set as follows:

optimal protection : 0.00
good protection : 0.05
reasonable protection: 0.15
moderate protection : 0.40
no protection : 1.00

- vaccination strategy:

  If a finishing herd has been vaccinated once a cycle (strategy 1) the minimum protection state will be moderate and the costs involved with this strategy will be Dfl. 1564. Vaccinating twice a cycle (strategy 2) increases the costs to Dfl. 2647 and the minimum protection state will be reasonable. If sows are vaccinated with an inactivated vaccine once a cycle (strategy 1) the minimal protection state will be reasonable and the costs are Dfl. 1248. Vaccinating all the sows with a live vaccine at the same moment three times a year (strategy 2) will by assumption give better protection (good) and is cheaper because of fewer visits of the veterinarian (Dfl. 944).

- production losses:

  Dutch swine farms have an average herd size of 99 sows and 262 fattening pigs, respectively. Assuming that 15% of the breeding herds and 25% of the finishing herds will have clinical symptoms after infection with ADV these clinically-infected farms will have the following production losses (per week):

	breeding herd		finishing herd	
infection state	# abortions	# dead piglets	# days growth delay	# dead fattening pigs
moderate	2	5	1	0
normal	3	10	2	0
strong	4	20	3	1

- potential economic losses (Dfl.):

  * one day growth delay for one fattening pig: 0.53
  * one dead fattening pig : 165.20
  * one abortion : 236.40
  * one dead piglet : 71.20

AUJESZKY'S DISEASE: ECONOMIC ASPECTS OF CONTROL STRATEGIES

D KOOIJ*

In recent decades there has been considerable effort aimed at controlling and eliminating Aujeszky's disease (AD) in numerous countries in the world. Four main control strategies can be defined. The first is 'doing nothing', which is not a plausible option for regions with a high pig population, but might be for areas with low pig density. The second strategy is vaccination, the third is eradication, and the final one is a combination of these two. There are, however, many methods for vaccinating as well as for eradicating Aujeszky's disease. Houben and Dijkhuizen (1990), for instance, identified 9 variations of vaccination strategies, ranging from no vaccination in either finishing or breeding herds, to twice a batch in finishing pigs and three times a year in breeding swine. Regarding eradication there are three basic clean-up strategies: (1) test and removal of positive animals; (2) complete depopulation-repopulation, and (3) offspring segregation (Thawley and Morrison, 1989). It is the presence of epidemiological risk and preventive factors, and subsequently the economics of the disease, which determine the control policy that is implemented on farms, in regions and countries.

Some countries with relatively small pig populations have been able to maintain freedom from AD without any particular control policy; this includes Norway, Finland, Austria and Australia, and some 20 states in the US. Denmark and Great Britain, by contrast, have been able to eradicate the disease. For countries attempting to control AD by vaccination, it was impossible to estimate the actual prevalence of the disease until the late 1980's since the serological tests could not distinguish between infected and vaccinated animals. The development of new vaccines having mutations or deletions in nonessential glycoprotein genes, including the so-called gI- and gX-deleted vaccines (Oirschot, 1988), plus the development of ELISA-tests made it possible to distinguish infected from vaccinated swine (Oirschot *et al.* 1990). At present gI-deleted vaccines are used as a tool to decrease the prevalence of AD, and sometimes in combination with a test-and-removal policy they can be employed to eliminate AD-virus from farms, regions and nations, as in Germany and The Netherlands (Mousing *et al.* 1991), Belgium (De Smet *et al.* 1992) and the US (Annelli, 1991; among others). Although a combination of vaccination and test-and-removal is applied both in EC-countries and US-states, there are differences between their AD-control programmes.

It is outside the scope of this paper to lay out precisely the AD-control policies of each region in the US and the EC. However a single control strategy for the entire EC is obviously not feasible, because of the different epidemiological characteristics of the disease in different regions. Each 'type' of region is likely to require a different approach. In areas of high pig density, for example, a strategy of vaccination in combination with test-and-removal might be implemented, whereas in lower density areas a depopulation-repopulation policy without vaccination might be sufficient. A region should, of course, not only be determined by pig density but also by pig-farm density, geographical

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characteristics, weather conditions, and other epidemiological risk and preventive factors. The appropriate AD-control strategy for any 'region-type' should also be based on the outcome of economic studies in which all relevant options are compared.

Since 1 January 1993, when the EC-Single Market with 'free' movement of animals came into effect, it is not efficient to eliminate AD from one area, while neighbouring areas have no strategy aimed at eradication. Besides, the AD-virus can be spread by air transmission (Donaldson *et al.* 1985; Mousing *et al.* 1991). In other words, coordination between regions is required to eradicate Aujeszky's disease from the EC.

ESTIMATED ECONOMIC COSTS OF AUJESZKY'S DISEASE

This paper sets out the economic aspects of the British AD-eradication programme, which until now have not been subject to a full examination. Basinger (1986) and Done (1987) provided some financial and economic estimations, Basinger calculating a benefit/cost ratio over ten years of 4:1, whereas Done's view on the financial aspects can be summarized as more negative. He pointed out that there were no critical studies available to the British pig industry comparing alternative AD control policies at national level. Muirhead (1983) calculated the output losses due to an AD-outbreak in 4 British breeder-feeder herds at £141.31 per sow per year, while more recently there have been some studies highlighting just the direct costs of the British eradication programme (Matthews, 1991; Thow, 1991).

Before proceeding further clear definitions of 'economic' terms should be set out. First, the total costs of a particular disease are made up of both direct and indirect costs. *Direct* costs consist of (1) output losses, e.g. caused by increased piglet mortality and reduced fertility, and (2) control expenditures as a result of, for instance, vaccination and disinfection (McInerney *et al.* 1992). Direct costs can be measured at both the farm and the national level. Direct costs at national level are the sum of those incurred at the farm level plus such things as research expenditures and surveillance costs. *Indirect* disease costs arise from wider adjustments in the economic system, such as changes in market prices, trade in pigs and pig products, and further downstream effects. The measurement of changes in the pig market uses concepts from the theory of welfare economics which provide, among other things, measures of consumers' and producers' surpluses (see Howe, 1992).

Estimations of the direct costs of Aujeszky's disease in other countries are not available except for The Netherlands and the USA. Based on a simulation study for The Netherlands (Houben and Dijkhuizen, 1990) the annual control expenditures were equivalent to some £20 million, and the yearly output losses were about £8.1m: this was for a control programme in which all breeding herds were vaccinated once a cycle and the finishing herds once a batch. The output losses in this study included four elements: (a) increased suckling mortality; (b) increased mortality of finishing pigs; (c) growth delay of finishing pigs, and (d) more abortions. Houben and Dijkhuizen compared this annual figure of £28.1 million with other vaccination strategies for which the total direct costs ranged from about £15.8 million to £42.4 million a year.

For the USA several studies have calculated the direct costs at the farm level of different AD control policies (Alderink, 1986; Zimmerman *et al.* 1989; Bech-Nielsen *et al.* 1992; Ebel *et al.* 1992a; among others). These studies reveal considerable variation in control programmes, the presence or absence of epidemiological risk factors, and the different methods used for calculating the costs; comparisons between them is therefore difficult. The costs varied from $1 per sow for a test-and-removal programme to $414 per sow for a vaccination programme in combination with test-and-removal. Since most studies mentioned estimated only the direct costs of AD, and only at the farm level; in many cases they were incomplete by including solely output losses. Some studies generated estimates at the level of the US pig industry by extrapolation, producing annual costs due to AD ranging from approximately $21 million to $72 million (see Ebel *et al.* 1992b). Only one study evaluated the indirect costs resulting from changes in the market caused by eradicating Aujeszky's disease (Ebel *et al.* 1992b). This indicated that the average producer in states with more than 5 million pigs gains from the US eradication scheme, but that the average producer in states with less than 5 million pigs loses. Furthermore, they indicated that owners of non-infected herds lose relatively little from a national eradication programme while infected herd owners gain. These results suggest that domestic consumers gain from a national AD-eradication programme, and that overall the US society in total gains also.

THE BRITISH AD ERADICATION PROGRAMME

The first report of Aujeszky's disease in Great Britain was in 1953, but the situation was not monitored very often during the following two decades. It was in the late 1970's that the disease started to spread in areas with large pig populations, but up to 1979 the number of outbreaks per year remained below 15. After a distinct increase in the number of AD-infected premises, pig producers agreed in a 1982 poll to start eradicating AD from Britain based on a mandatory industry-financed slaughter and compensation policy. The eradication programme started in March 1983 and was completed in October 1989 when the last AD-positive farm was depopulated. During those years a compulsory levy of £0.30 was raised on every pig slaughtered for human consumption and every pig exported. This levy was collected by the Meat and Livestock Commission and handed over to the Pig Disease Eradication Fund (PDEF), which was set up to administer the finances of the scheme (Matthews, 1991).

During the first 6 months of the AD eradication programme, a single seropositive blood sample was sufficient cause to depopulate the whole herd. From October 1983 it was considered sufficient to remove only the seropositive animals whenever the number of positive samples was low and clinical disease was absent. However, in the case of one or more animals with clinical Aujeszky's disease or a high number of positive samples, the whole premises were depopulated. Remarkably, the AD virus has been successfully eliminated from most partially depopulated premises (Thow, 1991). In addition to the compulsory slaughter of all herds having Aujeszky's disease, herd owners were required to cleanse and disinfect the pig premises to approved standards and not to repopulate for a month. In respect of re-stocking, no conditions were made for testing and accreditation of source herds as being AD-free, it being assumed that all herds might properly be regarded as free unless shown to be infected (Done, 1987).

On the completely depopulated premises animals which were clinically infected with the AD virus, unsalable young pigs and those on medication that could not be realistically withdrawn were all totally destroyed. The remainder were salvaged on the market for human consumption. Auctioneers carried out valuations of all animals, and PDEF paid the affected farmers the market value of their removed animals up to a maximum of £300 per pig (Matthews, 1991).

The numbers of herds which were totally and partially depopulated are shown in Table 1. Between March 1983 and October 1989 a total of 605 herds (out of an industry population of some 20,000 herds) were detected as AD-positive, three quarters of these occurring in the first year. A grand total of 440,190 pigs were valued and slaughtered, of which 330,793 were salvaged at slaughterhouses for human consumption. Of the 440,190 pigs the vast majority (432,280) came from totally depopulated herds. Most positive herds were found in north-west Wales, south-west England, East Anglia, Lincolnshire, Humberside, North Yorkshire, Lancashire, Greater Manchester, Cheshire and Shropshire, but it was even more remarkable how widespread the disease was over the whole of England and Wales, most counties having one or more AD-positive herds. The counties with most AD positive herds were generally more densely populated compared to the rest of Great Britain (Matthews, 1991). Remarkably, the Scottish pig industry has always remained free from AD. Northern Ireland, like the Republic of Ireland, is still not free of Aujeszky's disease.

Table 1. Number of herds slaughtered during the British AD eradication programme

Year	Total slaughter herds	Partial slaughter herds	Total
1983	443	11	454
1984	47	32	79
1985	12	27	39
1986	5	3	8
1987	6	4	10
1988	5	1	6
1989	5	4	9
1990	0	0	0
1991	0	0	0
Total	523	82	605

Source: Matthews, 1991

Seropositive herds were identified by blood sampling adult stock. During the first eight months of the programme known infected herds were confirmed and depopulated. Other types of investigation used were (1) testing all herds within 2 km of the infected premises, starting 10 days or more after depopulation so that seroconversion was possible; (2) movement tracing; (3) serological surveys of culled sows and boars at slaughter, and (4) serological surveys of communal boars. In January 1988 routine serological surveillance switched from culled sows to boars, since culled boars were considered an effective indicator of on-farm infection. Nowadays, serum sampling in culled boars is still carried out to maintain control. Besides the routine blood sampling at abattoirs, the Veterinary Investigation Service monitors material submitted to them by practitioners.

Although at the onset the predicted number of herds that might have to be depopulated was subject to uncertainty, the operation of the AD eradication scheme in veterinary terms was highly satisfactory. In 1984, however, there was continuing concern over the financial aspects, and in particular the low level of returns on healthy pigs from infected herds which were either marketed or salvaged through slaughterhouses. Besides the unexpectedly high number of premises which had to be depopulated in the first year of the scheme, the low salvage receipts was one of the major reasons for the 1984 debate in the House of Commons on the AD-eradication programme. The salvage receipts of pigs were lower than predicted at the outset as a result of lower prices received, which tended to be depressed at local markets by the sudden increase in supply at the time one or more premises were depopulated. Especially in the first year (1983) some markets had at certain times an oversupply with pigs resulting from the 443 completely depopulated farms. The following years the number of farms depopulated decreased rapidly, and the introduction of partial depopulation at the end of 1983 resulted in less oversupply problems.

Besides the oversupply effect, small pigs were difficult or even impossible to market, and the valuations of pigs for slaughter on the whole was higher than had been anticipated. As consequence of the miscalculated, overestimated salvage receipts, income from marketed pigs was almost £3 million less than the predicted figure of £13m.

COSTS OF THE BRITISH AD ERADICATION PROGRAMME

We now proceed to investigate the direct costs, i.e. output losses and control expenditures, and the indirect costs resulting from changes in the pig market for the British AD-eradication programme; the estimates include also the costs of keeping Britain free of the AD-virus after completion of the programme. An attempt is made to compare these costs with the alternative situation had the eradication not been carried out and AD had become an endemic disease controlled by vaccination.

The £10.4 million income from pigs salvaged was about 27 per cent of the total income of the PDEF, as can be seen in the Table 2. Because the £10.4m represents a revenue which would still have been received by producers if there had not been an eradication programme, the real financial cost of the programme to pig producers is the levy they paid, amounting £27.1m[1]. The £0.8 million miscellaneous income is a revenue received from the Ministry. Table 2 also shows how the £38.3m PDEF revenue was allocated among different expenditures. About 50% of these expenditures were

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1 Plus the extent to which some producers were undercompensated for their pigs that were slaughtered out (see below).

made in the first year, and the following years the disbursements of the programme became gradually less.

Table 2. Balance sheet of the British AD eradication (1983-1989)

EXPENDITURE	£	INCOME	£
Compensation	26,078,947	Salvage payments	10,368,000
Consequential loss payments	3,703,000	Producer levy	27,122,000
Payments of auctioneers	101,000	Miscellaneous income	835,947
Miscellaneous expenses	641,000		
Bank charges	7,152,000		
Surplus	650,000		
	38,325,947		38,325,947

Sources: Matthews, 1991 & Thow, 1991

The total value of pigs marketed and destroyed in the AD-eradication scheme, for which the market paid £10.4 million, was £26,078,947 - virtually all of which was paid to producers whose herds were totally slaughtered. Even so, because there was a maximum compensation payment of £300 per pig, part of the losses sustained by producers was not compensated (Matthews, 1991).

Besides the loss of underpaying culled pigs, there were also other losses for the farmer of which downtime, and consequently a loss of income, was the most important. For the first eight months of the campaign it was therefore agreed within the pig industry that consequential loss compensation would be made direct to affected farmers. The consequential loss was calculated as a fixed percentage of the assessed value of the culled pigs as provided by auctioneers. However, it was not intended to provide 100 per cent consequential loss compensation, the aim being to contribute about 75 per cent for the average commercial producer. To reach this level, it was estimated in 1982 that the fixed percentages of the herd value needed to be 35 per cent for breeders, 32 for breeder-feeders and 15 for feeders. These percentages resulted in consequential loss payments to the producers of £3.7 million in the first eight months. Herds slaughtered from 1984 onwards did not receive any such compensation.

It is difficult to estimate the true consequential loss suffered by producers. However, according to an Aujeszky's Study Group in 1985 commercial producer costings for an 18-month period after eradication show that consequential loss compensation paid was often little more than 50% of the actual consequential loss suffered, and not the target 75 per cent (see House of Commons report, 1985). It is therefore assumed in the calculations below that 50 per cent of the actual losses was compensated for the average producer, but it should be remembered that the situation differed between types of producers (in particular breeders fared much worse because of the £300 valuation limit on any one animal). Since the consequential loss payments were £3.7 million for the first eight months of the eradication programme, farmers are presumed to have suffered an additional £3.7m of uncompensated consequential loss during this period. By that time 342,000 pigs had been slaughtered in 430 infected herds, representing about 75% of the total pigs slaughtered during the whole eradication programme. Assuming that the consequential losses per pig in the first 8 months was equal to those in the rest of the eradication years, the consequential losses not compensated are estimated at £6.2m over the whole programme.

From the standpoint of economic analysis the compensation payments (including the extra £3.7m for consequential losses) are regarded as disease control expenditures. They are costs which had to be made to eradicate the Aujeszky's disease virus. The £6.2m producers' losses which were uncompensated are, from a national point of view, also judged as control expenditures. The £101,000 payment made to auctioneers was also part of the control expenditures. So too, were the miscellaneous expenses shown in Table 2, consisting of (1) payment to slaughtermen who had to slaughter non-saleable pigs such as young piglets, clinically diseased pigs and medicated pigs, (2) transport costs from farm to slaughterhouse or rendering plant, and (3) costs of disinfection carried out by Ministry staff after a farm was completely depopulated. The remarkably high bank charges were incurred on overdraft facilities up to £17 million which the PDEF had to secure as the levy was initially insufficient to pay the compensation costs which had to be met in the first year of the programme. The overdraft was reduced during the six years of the eradication programme, and after the levy collection ceased in October 1989 there was a surplus on the PDEF account of £650,000.

In addition to the expenditures shown in Table 2, the Ministry of Agriculture, Fisheries and Food (MAFF) made financial contributions towards the Aujeszky's disease eradication programme. The cost to MAFF in administration and veterinary involvement (salaries, travel, subsistence and laboratory expenses, etc.) are estimated to be in excess of £5 million (Thow 1991). Taken together, these data suggest that the total control expenditure of the British AD eradication programme was some £38.5 million. This is calculated as £38.3m PDEF expenditures, plus the MAFF expenditure of £5m, plus the £6.2m for uncompensated consequential losses, less the £10.4m receipts on salvaged animals, and the £0.65m surplus,

As explained earlier the total costs of a disease include not just control expenditures, but also the output losses. Partially depopulated herds, which are characterized by only a few positive animals and the absence of clinical disease, are assumed to have no significant output losses. In contrast, herds subject to complete depopulation might be preceded by reduced production due to effects of the disease. Output losses could occur due to reduced numbers of live births, increased mortality in suckling and fattening piglets, diminished growth rate in finishing hogs, and reduced fertility in sows (Muirhead, 1983; Houben and Dijkhuizen, 1990). Most of these losses, however, would occur more than one week after AD is first detected (Muirhead, 1983). Because depopulation took place within 48 hours of detecting the disease, we assume that no significant output losses occurred in the completely depopulated herds. The total costs of the eradication programme are therefore taken to be simply the control expenditures of £38.5 million spread over a period of 6.5 years

The direct financial costs to pig producers were the £27,122,000 they paid out for the levies plus £6.2 uncompensated consequential loss, making £33.3m overall. The remaining £5.2m was paid by the taxpayers. Although it is given in the balance of the Eradication scheme (Table 2), the £650,000 surplus is a 'left-over' not used by the eradication scheme, and is now to be used for other purposes as MAFF currently intends (Farmers Weekly, 20 November 1992).

So far, only the costs of *eradicating* Aujeszky's disease have been discussed; expenditures have also been necessary to keep Britain free of disease after the eradication programme was completed. These are borne exclusively by the government, and are basically the costs of serological surveillance. In 1990 and 1991, some 31,800 blood samples per year have been collected and tested for Aujeszky's disease. Assuming the costs per sample were £2, the total serological surveillance costs amount to £63,600 per year. The other governmental costs are considered to be low, compared with the eradication years, because research is at a very low level and administration is also on a low profile. However, the Veterinary Investigation Centres are still receiving blood samples for AD-testing. A rough estimate of the total yearly costs of keeping Britain free from Aujeszky's disease therefore might be in the order of £100,000.

MARKET ANALYSIS

This paper has so far considered only the direct costs of Aujeszky's disease - broadly speaking the "first round" effects, those associated with the pig production process. However, there are in addition a whole range of indirect costs and benefits representing the wider "downstream" effects of the disease within the economy. Some of these can be seen as changes in what are called producers' and consumers' surpluses. Howe (1992) presented the standard model used for such economic analyses, and this is now used to explore some of the other economic consequences of the Aujeszky's disease eradication programme in Britain.

Britain is about 70% self sufficient in pigmeat, the balance of domestic consumption being imported from within the EC (the EC's self sufficiency is about 102%). Denmark and The Netherlands are the two main exporters, trading with many community countries including the UK. Since the market for pig meat is virtually open, the price producers obtain and consumers pay is effectively uniform (except for transport costs) throughout the EC, and is equivalent to the world market price plus the Community's common external tariff.

Some of the most important implications of Aujeszky's disease and its control, as reflected on the market for pigmeat, are portrayed in Fig. 1. The supply curve for domestically produced pigmeat in Britain, assuming the disease to be endemic and without any control strategy, is shown as S, the domestic demand curve as D. The import supply curve is the horizontal line, indicating that Britain could obtain all required imports at the price P_i, since the level of UK demand has no influence on the world market price of pig meat. If the price was equal to P_{UK}, domestic supply would equal domestic demand and there would be no imports. However, if imports came in at price P_i, domestic supply is Q_s and demand Q_d, the difference being made by imported supplies of (Q_d-Q_s).

The effect of Aujeszky's disease eradication is to reduce the costs of pig production, so that the supply curve shifts downwards to S' when the programme is completed. The eradication programme therefore causes no change in the market price of pigmeat, which remains at P_i in the open market. Domestic consumers still purchase the quantity Q_d, but domestic producers can now supply the increased quantity Q'_s at the going price. The extra home production of $(Q'_s - Q_s)$ means that imports of pigmeat will be decreased by the same quantity. The income gains to the British producers, measured as the increase in their producers' surplus, is equivalent to the shaded area *A* in Fig. 1. By definition, this is identically equal to the economic loss suffered by overseas suppliers who lose some of their share of the UK market to British producers, who are now more competitive as a result of the AD-free status of the national herd. The rectangle *B* represents the saving in foreign exchange to the UK economy (a loss in revenue by overseas suppliers) due to the reduction in pigmeat imports.

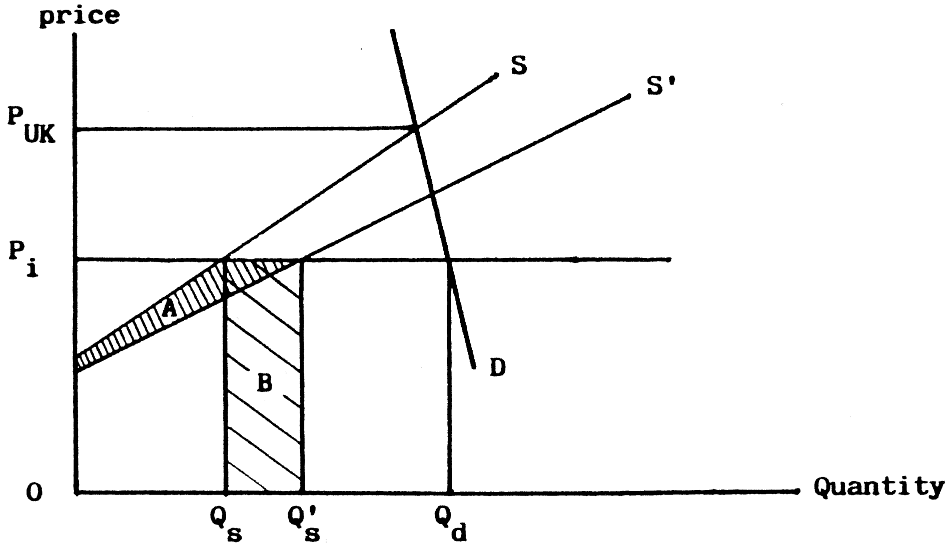

Fig. 1 The UK market for pigmeat before and after the AD-eradication

Although theoretically possible, the exact measurement of the change in producers' surplus is not attempted in this paper. The relatively small change in supply on the British market due to the AD-eradication programme makes it unreliable to estimate the exact adjustments in prices and quantities (even if data on price elasticities of demand and supply were available). It is above all hard to distinguish the effects of just AD-eradication on the real market when there are many other influences on both the domestic and the overseas pig markets. Furthermore, the pig price is also affected by other food markets, in particularly those for other meats such as beef, lamb and chicken. Extensive assumptions would have to be made to estimate market changes, which would not result in highly reliable outcomes. The foregoing model does, however, indicate the kind of economic analysis and economic data that are relevant if a full assessment of any disease eradication programme were to be attempted.

The general conclusion to be drawn is that after the completion of the AD eradication programme and the cessation of the AD-levy in October 1989, British pig producers were more competitive (had lower production costs) than when the disease was present in the national herd. The destruction of AD-positive animals during the eradication programme was a distinct short term loss for domestic producers and the British economy as a whole, particularly in the first year when 75% of the slaughterings took place. Following this, however, the gains of disease free status are realised every year at the cost of only relatively minor expenditures. It is the measurement of these gains that is the most difficult element of any benefit/cost calculation.

ALTERNATIVE CONTROL STRATEGIES FOR AUJESZKY'S DISEASE

Before concluding that the eradication programme was the optimal AD control policy it is necessary to compare its average annual costs with those of other possible strategies. It is difficult to predict the exact herd or pig prevalence of Aujeszky's disease in Britain in the alternative situation of vaccination, but some ideas will be pointed out. A MAFF study in 1982 indicated between 3500 and 5000 herds of the approximately 20,000 British herds would have been infected by the end of the century (Matthews, 1991). The average herd prevalence would consequently be about 20% by that time. However, on the basis of the widespread presence of the virus through the whole of England and Wales (as was found during the eradication programme), it is reasonable to presume that a stabilised herd prevalence of at least 20% would already have happened by the late 1980's. Furthermore, it is likely that the (approximately 7000) larger herds would be more frequently affected than smaller herds (Duffy *et al.* 1991; Hall *et al.* 1991). Also, in areas of high pig density 20% herd prevalence would probably have been reached a few years after 1983, so in these areas the average herd prevalence would almost certainly be much higher than 20% by the end of the 1980's. It is therefore concluded that voluntary AD-vaccination would have been introduced had the eradication programme not been implemented in 1983.

The simulation study of vaccination by Houben and Dijkhuizen (1990) in which all breeding pigs were vaccinated once a cycle and the finishing pigs once a batch, estimated annual disease costs of some £28.1m for the Netherlands. On this basis a similar vaccination strategy in Britain, with about half the number of pigs as the Netherlands, would have cost about £14m annually in the 1980's (assuming the British pig industry in general can be compared with the Dutch pig industry). The annual costs simulated for other vaccination strategies ranged from £15.8 to £42.4 million in The Netherlands, which become £7.9 to £21.2m in Britain.

Besides the direct costs of vaccination various indirect costs due to changes in the market would have arisen too. Although most pig farmers would have vaccinated their herds, some output losses would still have been suffered, and the supply curve would not have shifted downwards to the extent shown for complete eradication in Fig. 1. Consequently, domestic producers would have achieved lower gains and imports would have declined by less than shown. Hence, compared to the eradication policy British society as a whole would have lost, and exporting producers in the rest of the EC would have gained.

DISCUSSION AND CONCLUSIONS

The direct costs of the British AD-eradication programme, which lasted from March 1983 until October 1989, have been estimated at £38.5 million for the British economy as a whole. The direct costs for the pig industry were £33.3m and the total taxpayers' cost £5.2 million. Unfortunately these costs cannot be compared with any other AD-eradication scheme in which depopulation-repopulation was used (such as in Denmark) because no comparable economic data are available. A simple economic model (Fig. 1) is used to portray market changes in Britain, showing that gains in domestic producers' surplus were losses to overseas producers. In contrast to the economic model presented by Ebel *et al.* (1992b), the presented model takes into account both domestic and overseas production, and deals with the open market price. Using the model presented in Fig. 1, with US self sufficiency in pigmeat of approximately 94%, it can be concluded that domestic consumers in the US are likely not to gain to the extent Ebel *et al.* suggest in their paper.

In October 1989 the levy was terminated, AD had been eliminated from Britain and pig producers bear no further direct costs. The annual costs of keeping Britain free from AD is estimated to be £100,000, which is paid by MAFF, (i.e. it is taxpayers' money). As a result of a more competitive pig industry, British producers gain, but overseas producers lose. Only Great Britain and Denmark have been successful in eradicating Aujeszky's disease, and most other trading countries in the world are incurring relatively greater costs on controlling AD by some sort of vaccination policy.

If instead of the eradication programme a vaccination strategy had been started up in 1983, the costs of AD would gradually have been increased in the 1980's to a level possibly between £7.9 and £21.2 million, depending on the vaccination policy. Although the direct costs of a vaccination policy might have been lower in the first few years, they would soon have amounted to more than the costs of the eradication programme. When market effects are also taken into account it is easy to conclude that the eradication programme has been a good investment for British society as a whole in the long run.

The results of two other available economic studies on the British eradication experience (Basinger, 1986; Done, 1987) are somewhat different from the present study. Although Basinger's final conclusion (that the eradication programme would have higher net benefits than a vaccination programme) is identical with the conclusion of the present study, the way it was calculated is surely inadequate. Above all, it is dangerous to base the final conclusion solely on the fact that the overall benefit-cost ratio of the British eradication programme is 4:1, as is explained in McInerney (1991).

Although most elements are taken into account in the calculations of the direct and indirect costs, three further considerations have to be made. First, by eliminating the AD-virus it is likely that the risk of other diseases will be diminished[2]. The second consideration is about the positive image an eradication programme can have on the pig industry. It implies more welfare for the animals, because they do not suffer from AD and they are not injected for AD-vaccination - so adding a more positive attitude towards the pig industry from consumers who might buy more pork instead of other meat or food. The final consideration is that Aujeszky's disease virus can also infect other animals like cattle, sheep, dogs, cats and wild pigs, although the number of infected non-swine animals is very low (Pensaert *et al.* 1990). The virus is not extremely infectious, but is certainly fatal in non-porcine animals, and due to insufficient virus secretion the disease reaches a 'end-host' in these animals.

2 Literature is uncertain about the exact relationship between AD and other infections. Both Anderson *et al.* (1990) and Elbers *et al.* (1990) found a relationship between AD seropositivity and *Actinobacillus (Hæmophilus) pleuropneumoniae* infection. Elbers *et al.* (1990) could not demonstrate a relationship between AD and porcine influenza. In a study in 6 large Illinois herds, Aujeszky's disease did not in general appear to increase the risk of other viral and bacterial infections, although there was some evidence suggesting an increased infection risk for a limited number of associated diseases (Hall *et al.* 1991).

Because pigs are the infective hosts of the AD-virus, the eradication of AD from all swine will benefit other animals.

Other control strategies besides depopulation-repopulation and vaccination are available as well. The most obvious are (1) test-and-removal, (2) offspring segregation, and (3) a combination of preventive vaccination and test-and-removal. When the economics of different eradication strategies are compared, each must be weighed by its probability of success and by the likelihood of reinfection. One could argue that partial depopulation-repopulation, as used during the British eradication programme, is equivalent to test-and-removal of positive animals. The difficulty in analysing a pure test-and-removal policy is that some elements are unknown and questionable assumptions have to be made for such a comparison. The most important unknown fact is the spread of AD, and consequently the number of animals removed from premises, had the disease been eradicated by test-and-removal. It is also difficult to estimate how long such an eradication programme would have lasted. Studies in the US indicate that test-and-removal on individual farms often last more than one year before the herd is AD-free (Zimmerman *et al.* 1989; Bech-Nielsen *et al.* 1992). Hence, it is likely that the spread of AD would have been higher and a test-and-removal programme in Britain would have lasted longer than 6.5 years.

Farm level studies in the US suggest that test-and-removal results in less cost to the producer than does depopulation-repopulation (Alderink, 1986; Zimmerman *et al.* 1989). This would probably have been the case also on depopulated-repopulated British farms had the producers not been compensated. But calculations at farm level do not directly lead to conclusions at the national (or state or regional) level, for which additional costs need to be considered. Alderink (1986) estimated that the taxpayers' costs of test-and-removal are less than for depopulation-repopulation. This conclusion is possibly correct in the short run, but might not be for the long run. The higher costs of depopulation-repopulation compared with test-and-removal is associated with the fact that this study was conducted in five states of high pig density, where herd-prevalence of AD is among the highest in the US. Depopulation-repopulation is unlikely to be the most cost-effective policy in situations such as this, though it might be for less densely populated areas or areas with a low herd prevalence. Depending on other epidemiological factors, the AD-virus can actually disappear in less densely populated areas during the summer due to seasonal influences (De Smet *et al.* 1992).

Controlling AD through offspring segregation is uncommon in most countries except in the US, where it was estimated on average farms to be more expensive than test-and-removal, but to be cheaper than depopulation-repopulation (Alderink, 1986; Zimmerman *et al.* 1989). The fact that it requires higher management skills explains why it is not always successful, and why it is probably not a serious option for controlling AD in the EC. Because gI-deleted vaccines were not available until the late 1980's the policy of combining preventive vaccination and test-and-removal was not a realistic option for Britain at the start of its eradication programme in 1983. With the use of gI-deleted vaccines and ELISA-tests, which enable vaccinated and infected animals to be distinguished, the combination of continuous vaccination and test-and-removal is at present being attempted in several EC-countries. The economic optimization of current EC-control and eradication strategies remains to be addressed, but the analysis presented here suggests that depopulation-repopulation might be an option for certain regions in the EC, depending on epidemiological characteristics.

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IDENTIFICATION AND ANALYSIS OF THE RISK OF CONTAGIOUS AGALACTIA BEING INTRODUCED INTO THE UK

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Contagious agalactia is a transmissible disease syndrome of sheep and goats characterised by mastitis, arthritis and keratoconjunctivitis. The disease is associated with infection with several different mycoplasma species, namely: *Mycoplasma agalactiae* (Regalla 1985, OIE 1990a), *Mycoplasma mycoides subspecies mycoides LC* (Large Colony) (Kirchoff et al 1985, Okoh and Ocholi 1986) and *Mycoplasma capricolum* (Jones et al 1983, OIE 1990a) in sheep and goats. *Mycoplasma putrefaciens* infection has also been associated with contagious agalactia in goats (DaMassa et al 1987).

In countries where the disease is endemic it is of considerable economic importance. In Spain the annual economic loss has been estimated as 5000 million pesetas. These losses are due to a drop in milk production in dairy breeds and increased mortality in meat breeds.

The United Kingdom is considered to be free of contagious agalactia. A number of regulations, aimed at preventing the introduction of this disease into the UK, were in place up to the end of 1992. In Jan 1993, in association with free trade in sheep and goats, these regulations changed. The aim of this study was to identify and assess the risk of contagious agalactia being introduced into the UK under the old and new import controls.

METHODS

Data collection

An attempt was made to obtain the following information:

1. The geographical distribution and prevalence of disease in Europe: Information on the distribution of contagious agalactia was obtained from the Animal Health Yearbook (FAO 1989).

Information on prevalence was obtained from the International Office of Epizootics (OIE) 12, Rue de Prony, 75017 Paris, France

2. The sensitivity and specificity of diagnostic tests: Information on clinical signs, culture and immunological tests was collected using an abstracting database (MEDLINE, Cambridge Scientific Abstracts, Bethesda Maryland, USA). An EEC symposium on contagious agalactia held in Nice in 1985 (CEC 1985) proved a major source of information.

3. The origin and numbers of sheep and goats and their products imported into the UK: Information on animal importation between 1981-90 was obtained from the Ministry of Agriculture Fisheries and Food (MAFF), Tolworth, Surrey, UK.

Attempts were made to gather information on the annual importation of sheep and goat products from the Overseas Trade Statistics published by the Central Statistical Office (CSO 1991a).

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Each product has a commodity code and those relating to sheep and goat products were obtained from The Guide to the Classification for Overseas Trade Statistics (CSO 1991b).

*4.*Current and future regulations aimed at preventing the introduction of contagious agalactia into the UK.: Regulations concerning the import of sheep, goats, exotic small ruminants and sheep and goat produce and semen were examined. All the above information was obtained from MAFF, Tolworth, Surrey. Recent EC legislation, concerning intra-community trade in sheep and goats, was examined to see how the regulations would change in 1993.

Risk Analysis

The hazard and operating study technique (HAZOP) was used for risk identification and probability trees were used to quantify the risk of disease being introduced into the UK. (Dickson 1991)

RESULTS

Geographical distribution and prevalence

The distribution and prevalence of contagious agalactia in Europe is shown in Table 1.

Table 1: Contagious Agalactia in Europe (OIE 1990b)

Countries	Species	Occurrence	Number of outbreaks	Prevalence
Bulgaria	Ovi	+	1	0.0003% ($30/9x10^6$)
France	Ovi/Cap	+	...	...
Greece	Ovi	+ + + ubiq	221	0.09% ($15703/16x10^6$)
Italy	Ovi/Cap	+	24	0.007% ($871/13x10^6$)
Portugal	Ovi/Cap	+	...	...
Romania	Ovi Cap	+ + reg	9	0.003% ($491/19x10^6$)
Spain	Ovi	+ +	35	...
Switzerland	Cap	+ reg	15	0.09% (63/70,000)

Key:

Ovi	Ovine	+	Low sporadic occurance
Cap	Caprine	+ +	Enzootic
Ubiq	Ubiquitous	+ + +	High occurance
...	No information	reg	Regional

NB 1. In 1990 the disease was not reported in Belgium, Hungary, Netherlands, Norway, Poland, and U.K.

2. The disease has never been reported in Denmark, Finland, Germany, Iceland, Ireland, Luxemburg.

It is reported as endemic in Spain and Greece and sporadic in France, Italy, Portugal, Romania and Switzerland. The number of outbreaks reported in 1990 varied from 1 in Bulgaria to 221 in Greece. In five of these countries details of individual cases were available and were used in conjunction with published figures of total sheep and goat populations (FAO 1989) to estimate crude prevalence rates. These ranged from 0.03 cases/10,000 sheep and goats in Bulgaria to 9 cases/10,000 sheep and goats in Greece. The estimated prevalence in goats in Switzerland was also 9 cases/10,000 goats.

Evaluation of clinical and laboratory methods of diagnosis

The contagious agalactia syndrome can be acute or chronic. The acute disease occurs in flocks where no immunity has developed and usually results from the introduction of a carrier animal (Lambert 1987). The animals are dull, pyrexic and inappetant. Abortions may occur. Often some animals are dead before the three classical signs, mastitis, arthritis and keratoconjunctivitis, become apparent (Lambert 1987). Those that recover from the acute stages develop mastitis and a drop in milk yield.

The chronic disease occurs where contagious agalactia is endemic. Usually only a group of animals in the herd is affected. This is probably because recovered animals are immune. As the organism localises in the various tissues, signs of the disease become apparent. The disease may be mild or severe. Mild cases may not be noticed.

The four species of mycoplasma associated with contagious agalactia may all produce the classical signs of disease mastitis, although there are differences between them.

Mycoplasma agalactia: This infects sheep and goats. Infection causes the three typical signs of contagious agalactia but it is uncommon to see them all in the same animal. Infection may also result in abortion or death (OIE 1990a). There are few reports of disease epidemics because of its endemic status in infected countries.

Mycoplasma capricolum: This infects goats more commonly than sheep. Infection results in the typical contagious agalactia syndrome but respiratory disease also occurs (OIE 1990a). In sheep, vulvovaginitis has been reported in a flock with no other signs of disease (Jones 1983).

Mycoplasma mycoides subspecies mycoides LC: This usually infects goats. There has been one report of an outbreak in sheep (Okoh and Ocholi 1986). Infection is associated with a more severe disease then that seen with *Mycoplasma agalactiae* (Regalla 1985, Atalaia and Brandao 1986) and produces respiratory disease. In kids, the disease is severe with mortality rates of greater than 90% (Ruhnke et al 1983, DaMassa et al 1987).

Mycoplasma putrefaciens: This has only been reported in goats. The clinical signs are consistent with the contagious agalactia syndrome although arthritis has not always been noted and there have been no reports of ocular lesions.

Transmission

Transmission occurs via infective exudates and milk (Lambert 1987). The bacteria can also survive in compacted soil for long periods hence the Italians in the 1800's named contagious agalactia "the disease of the place" (Lambert 1987). It is thought that mycoplasmas can be transmitted in semen, although there have been no studies to confirm this. The incubation period of the disease is believed to be between 1 and 9 weeks (Pfutzner 1988). Carrier animals maybe those with a dormant infection, vaccinated animals protected from disease but not infection and treated animals which have recovered but are still harbouring the organism (Lambert 1987). It has also been suggested that ear mites may transmit the infection (DaMassa 1990).

Laboratory diagnosis

Contagious agalactia may be diagnosed by the isolation and identification of mycoplasmas or by the detection of antibody in the serum of an infected animal.

a. Isolation and identification: In most cases mycoplasmas are easy to isolate and identify with additional tests. However there are problems in identifying certain antigenic strains.

No comparative studies have done to evaluate the best technique for culturing these bacteria. A basic mycoplasmal media containing heart infusion broth, yeast extract (1-2%), and horse or pig serum (15-20%), with bacterial inhibitors, ampicillin (150 mg/litre) and thallous acetate is sufficient to isolate all four species causing contagious agalactia (OIE 1990a). This is currently used in the UK (Boughton personal communication). Identification of the different species from their colonies is difficult and requires considerable experience. Identification may be facilitated by biochemical characteristics of mycoplasmas isolated, growth inhibition and direct immunofluorescence tests.

The biochemical characteristics of the bacteria can help identification. However the characteristics of each species are not always consistent. This is thought to be due to the presence of different strains of each mycoplasma species. (Sarris and colleagues,1985 Gaillard-Perrin and Lefant 1985)

Growth inhibition tests and direct immunofluorescence tests are also widely used to help identify the mycoplasmas (OIE 1990a). However antigenic variation within each species occurs and some strains do not react well with their appropriate antisera. Sarris et al (1985) found that the growth inhibition zones with *Mycoplasma agalactiae* varied from 2-4 mm which further suggests that there is some degree of heterogeneity.

More research is being done on other diagnostic methods such as iso-enzyme composition (Erno et al 1985) and the use of DNA probes to alleviate the problems mentioned above. These techniques are not yet available for routine use in the laboratory.

b. Serological diagnosis: Two immunological tests are used, the complement fixation test (CFT) and the enzyme-linked immunosorbent assay (ELISA).
i. Complement fixation test: The CFT is widely used to diagnose contagious agalactia on the European mainland (OIE 1990a). Antigens are prepared from washed organisms. The test can detect infected animals although it does produce false negative results. There is no data on the sensitivity and specificity of this test.(OIE 1990a)
ii. ELISA: An enzyme-linked immunosorbent assay (ELISA) has been developed and is being evaluated by an EC study. The antigens used are sonicated mycoplasmas (Lambert and Cabasse 1985). It is expected that it will soon be available for routine diagnostic use.
iii.A comparison of the CFT and ELISA test: Lambert and Cabasse (1989) compared the CFT with the ELISA for contagious agalactia. The ELISA was shown to be more sensitive than the CFT. However no figures were available on the sensitivities and specificities of these tests. In 9 infected herds, 36-99% of the sera were positive with ELISA although only 2-22% gave positive results with CFT. Clinically normal animals also produced marginally positive titres with the ELISA. These animals may or may not be a source of infection to others. The ELISA is currently thought to be a better test for diagnosing the disease and for identifying carrier animals.

Current methods used to prevent the introduction of contagious agalactia into the UK

Contagious agalactia may be introduced into the UK via infected sheep, goats, semen and unpasteurised sheep and goat milk products. Regulations regarding import of these are considered below.

The importation of sheep

Over 15,000 sheep have been imported into the UK over the last 10 years (Table 2).

Table 2: The total number of sheep and goats imported into the UK between 1981 and 1990 (MAFF personal communication).

Country	Sheep	Goats	Total
Alaska	0	11	11
Australia	1	373	374
Belgium	94	0	94
Canada	19	568	587
Denmark	24	0	24
Eire	5155	1087	6242
Germany	64	53	117
France	7674	95	7769
Iceland	0	6	6
Netherlands	1694	33	1727
New Zealand	368	5937	6305
Sweden	63	0	63
Total	15156	8163	23319

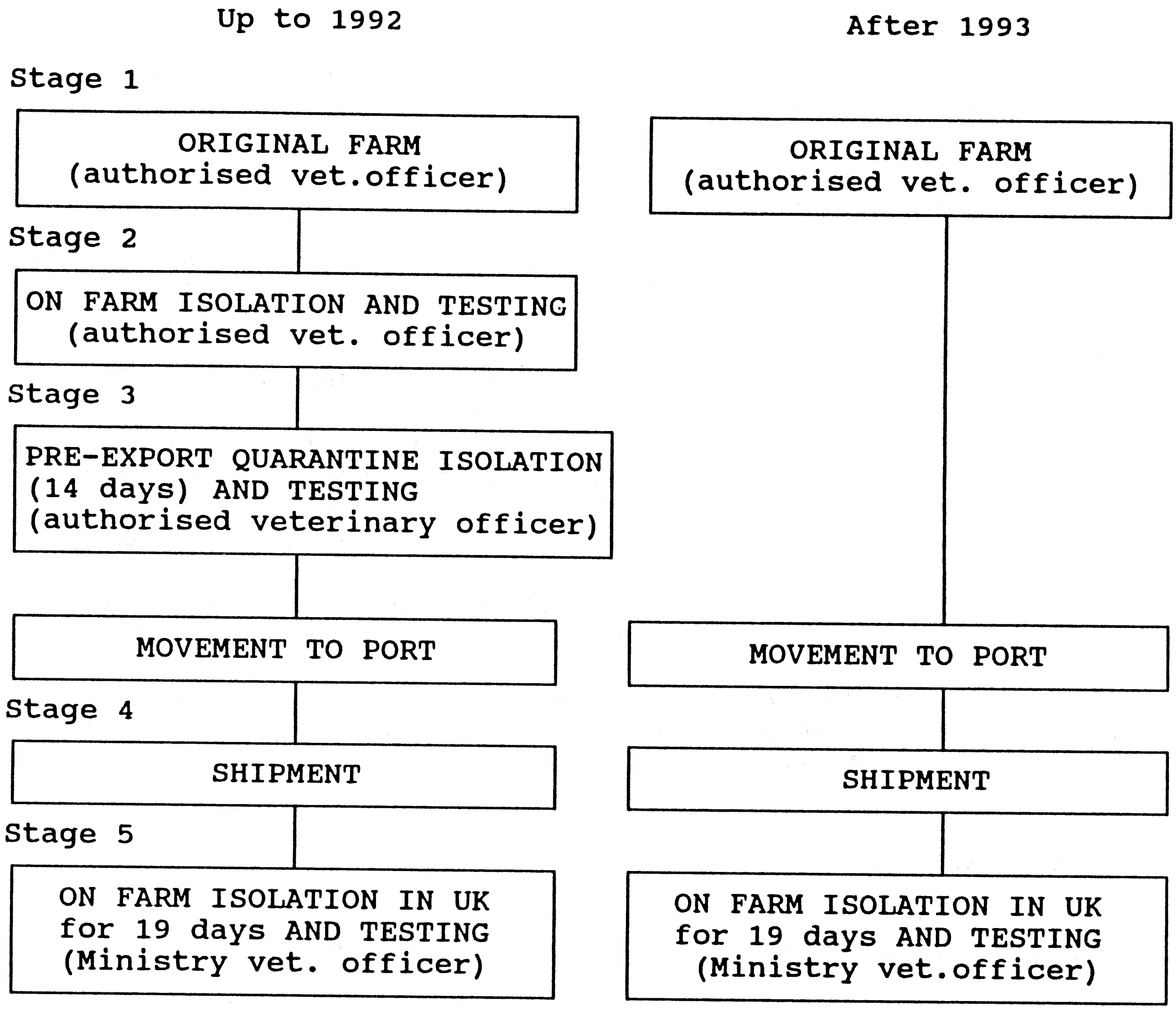
Imported sheep are subjected to a number of statutory health checks. These are illustrated in a flow diagram (Figure 1) and described below.

Stage 1: On the farm of origin: Sheep must be accompanied by a certificate signed by the local veterinary officer in the country of origin. This certificate accompanies sheep right through to arrival in the UK and states that:
For all countries: a. the animal was born in the country of origin
b. the premises of origin have been in existence for a minimum period of 12 months.
c. no sheep have been added to the flock for 12 months unless they have come from the country of origin or from the UK.
d. sheep have remained continuously on the original premises (for some countries of origin they can be exhibited at shows).
For countries that are free of contagious agalactia:
there has not been a recorded case of contagious agalactia for 3 years.
For other countries: a. the farm of origin has had no case of contagious agalactia for the last 3 years.
b. there has been no positively diagnosed case of contagious agalactia within a 10km radius of the premises for the last three years.

Stage 2: On farm isolation and testing: After certification, animals to be exported are isolated on the premises of origin for 30 days. In this period two CFTs for contagious agalactia are carried out. However only Mycoplasma agalactiae is tested for.

Stage 3: Pre-export quarantine, isolation and testing: For most countries sheep go straight from farm isolation to the port. Prior to movement, animals are inspected by an authorised veterinary officer. Vehicles for moving the sheep must be clean and disinfected. The animals must not be unloaded or come into contact with any others during transit.

Figure 1: Stages involved in sheep import into the U.K. and the persons responsible for each stage.



However sheep imported from Belgium or Canada go from the farm of origin to pre-export quarantine for 14 and 30 days respectively. Here they are retested for all three species causing contagious agalactia using a CFT, before being transported to the port.

Stage 4: Shipment : At the time of shipment sheep receive another veterinary inspection.

Stage 5: On farm isolation in UK: Once in the UK animals move to on farm isolation for at least 19 days where they are tested again for *Mycoplasma agalactiae* using CFT.

The importation of goats

Over 8,000 goats have been imported into the UK over the last 10 years. The origins of these goats are shown in Table 3. All the above regulations also apply to the import of goats. However there are some additional requirements. All goats over 12 months old must have a CFT for *Mycoplasma agalactiae, Mycoplasma capricolum, and Mycoplasma mycoides subspecies mycoides (LC)* during the 60 days prior to on farm isolation. After testing, no other goats can be added to the herd unless they have been shown to be free of contagious agalactia. Also any herd which has had contact with the herd of origin during the previous six months must have been screened for contagious agalactia.

The import of exotic small ruminants

The same regulations apply to exotic small ruminants which are imported into British zoos. However, only the subfamily caprinae is tested for contagious agalactia using a CFT for *Mycoplasma agalactiae, Mycoplasma capricolum, and Mycoplasma mycoides subspecies mycoides (LC).*

The import of sheep and goat produce.

In theory contagious agalactia could be introduced in meat, milk (heat-treated or "raw" milk) and milk products. It was found that the dairy commodity code numbers did not distinguish between different animal species so it was not possible to obtain import statistics on all sheep and goat produce.

Over nine months (from January to September) 2078 tonnes of sheep and goat meat was imported into the UK from other EEC countries.

There were no figures available on the amount of heat treated sheep and goats milk imported. Gaillard-Perrin (1985) showed that heat treating colostrum at 56°C for 20 minutes was sufficient to eliminate any *Mycoplasma capricolum and Mycoplasma mycoides subspecies mycoides (LC)* contamination. Hence heat treating milk can be expected to remove mycoplasmas.

"Raw milk" ie. sheep and goats milk that is not heat treated could pose a risk. There were no figures available on any imports. Currently there are no regulations governing its production.

It is considered that processing methods for yoghurt and cheese production kills any mycoplasmas initially in the milk (Boughton, personal communication). No figures were available on the quantities of these imported.

The importation of semen.

All imported semen must be accompanied by a certificate, signed by a government veterinary officer of the exporting country giving the folllowing details of donor animals:

1. the name and address of the approved semen production centre
2. the country, state of birth or date of entry into the exporting country (if appropriate).
3. Identity, breed, date of birth, and ear mark .
4. the dates of semen collection and the number of straws These must be marked with the identity of the donor, the date of collection, and the name of the semen production centre.

Further regulations concerning sheep and goat semen importation are formulated for each individual country. Currently, regulations exist for the Netherlands (sheep semen), Denmark (sheep semen) and Germany (goat semen). The content of these regulations is illustrated below:

Sheep semen imported from the Netherlands: Donor sheep must either be born in the exporting country or been imported at least 12 months before the first collection date. Donor sheep and teasers must have been kept continuously at the approved semen production centre for at least 2 months prior to collection.

Four months preceding first collection and 28 days after last collection all animals at the semen production centre must have been free of contagious agalactia. Also four months prior to first collection all animals at the centre must have a CFT for *Mycoplasma agalactiae , Mycoplasma capricolum, Mycoplasma mycoides subspecies mycoides (LC)* and during the same period no other animals can enter the premises unless they are tested for contagious agalactia.

The donor sheep and teasers must receive two injections of dihydrostreptomycin (25mg per Kg) at an interval of 14 days. The second injection must be given within 24 hours of collection.

At the time of collection an aliquot of fresh undiluted semen must be cultured to identify *Mycoplasma agalactiae, Mycoplasma capricolum and Mycoplasma mycoides subspecies mycoides (LC).*

The antibiotics listed must be added to the semen: dihydrostreptomycin, penicillin, lincomycin, and spectinomycin.

Sheep at the semen production centre must show no signs of contagious disease during the 28 days following collection.

Future control methods for contagious agalactia

In January 1993 regulations will be introduced to facilitate the free trade of livestock within the EEC. The directive 91/68/EEC concerning intra-community trade in sheep and goats includes no provision for mycoplasma testing of animals to be exported. A comparison of the controls before and after 1993 is shown in Figure 1. The only requirements for contagious agalactia control are that animals must have been born and reared in the EEC (or come from an approved third country) and that the premises of origin must have been clear of the disease for six months. There is a clause in directive 91/68/EEC which states that if a country is free of a particular disease additional approved control measures maybe introduced.

A draught of the new EEC directive on milk production specifies certain control regulations which concern the production of raw milk. The appropriate regulations are as follows; herds must be free of any disease likely to give rise to any "milk abnormal organoleptic characteristics", all animals in the herd must have no visible disorder, and no recognisable inflammation effecting the skin of the udder. These regulations can be expected to lower the risk of contagious agalactia being introduced to the UK through the importation of unpasteurised milk.

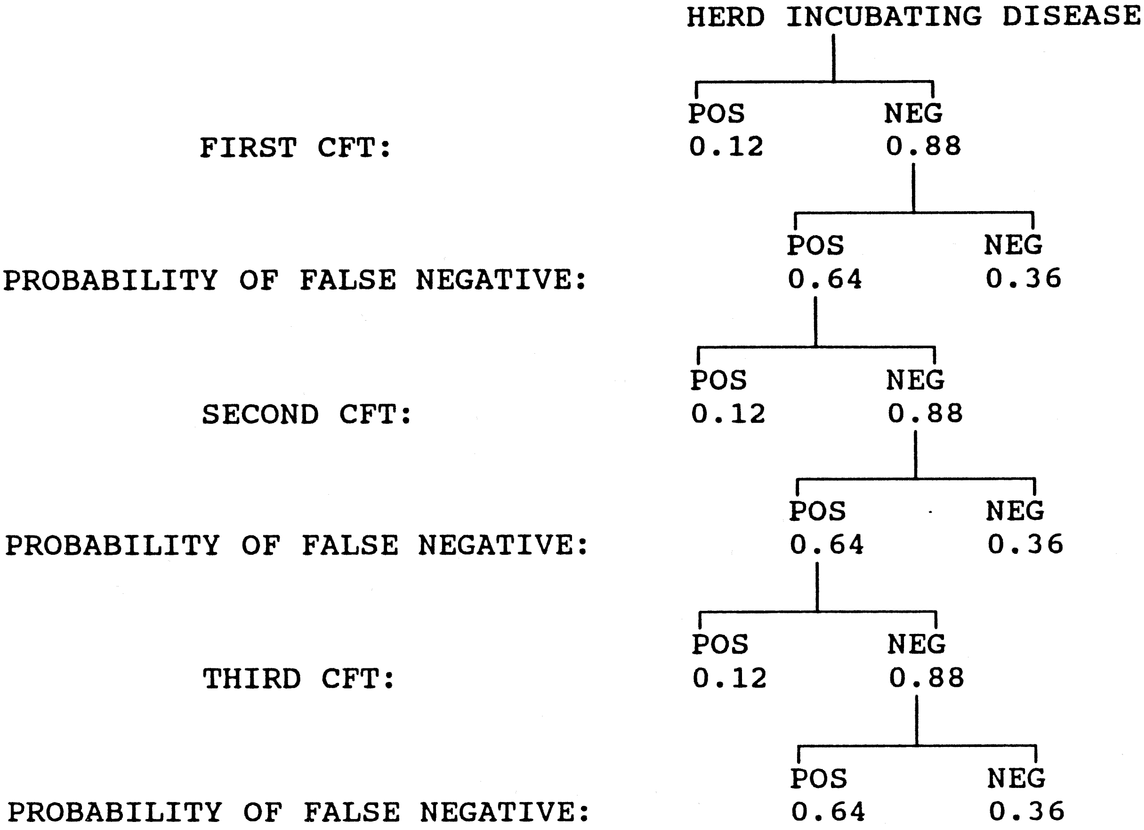
The new regulations governing semen production were not available at the time of this study Oct-Feb 1991-2.

Risk analysis

The possible causes of contagious agalactia being introduced into the UK were identified in the hazard and operating technique HAZOP. This involves dividing the importation process into stages, attempting to identify what could go wrong with the causes and consequences of such failure at each stage. Preventive measures are then suggested. This process is shown in Table 4.From this it can be concluded that the lack of sensitivity of the CFT, failure to detect carriers and human error are the major potential causes of disease introduction. Once introduced, lack of notification and veterinary awareness may lead to the establishment of the disease.

An attempt was made to quantify the risk of contagious agalactia being introduced into the UK based upon the failure of the CFT to identify a positive animal. Data from the comparison of a CFT with an ELISA in 9 infected herds (Lambert and Cabasse 1989) was used to estimate the sensitivity and specificity of the CFT. Between 2-22% (average 12%) of animals
and were CFT positive compared with 36-99% (average 68%) by ELISA. Assuming the ELISA to be the gold standard, this gives a sensitivity of 17.7% (12/68) and a predictive value of a negative test of 36.4% (32/88). A probability tree was constructed and is shown in Figure 2 (Dickens 1991)

Figure 2: Using a probability tree to estimate the chance of an infected imported sheep, failing the CFT each time (Dickson 1990)



If X = chance of a herd incubating the disease.

The chance of not detecting a carrier using CFT is $X \times (0.88)^3 \times (0.64)^3 = 0.18X$

If X = 1/5000.
Currently the chance of not detecting a carrier is 0.36×10^{-5} = 1 animal in 27,778

After 1993 the chance of not detecting a carrier is 1.13×10^{-5} = 1 animal in 8,878.
(if only one CFT is carried out).

The probability of a positive animal being missed by 3 CFTs was estimated as 0.15X, where X is the chance of a herd incubating the disease. If we assume that in a country with sporadic disease X is 1 herd in 5000, the chance of introduction of disease is 1 animal in 27,778. After 1993, with possibly of only one CFT the chance would be three four fold higher at 1 animal in 8,878.

DISCUSSION

Over 20,000 sheep and goats have been imported into the UK during the last 10 years (Table 3). The apparent freedom from contagious agalactia suggests that the regulations outlined above have been successful in preventing introduction of disease. However, closer examination of the data indicates that contagious agalactia occurs only in one of the exporting countries, France, where it is sporadic. The regulations have not been tested by import from countries where the disease is endemic.

More significantly, contagious agalactia is not a notifiable disease in the UK and it is therefore possible that its introduction may pass unnoticed. For example only when caseous lymphadenitis, a disease thought to be introduced to the UK through the import of infected goats from Germany (Gaisford 1990) was made a notifiable disease, it was discovered that the disease was already present in the UK (Robins 1991). Evidence from a report in 1983 of vulvovaginitis in sheep associated with *Mycoplasma capricolum* (Jones et al 1983) raises the possibility that the disease is already present in the UK.

Table 3: The total number of sheep and goats imported into the UK between 1981 and 1990 (MAFF personal communication).

Country	Sheep	Goats	Total
Alaska	0	11	11
Australia	1	373	374
Belgium	94	0	94
Canada	19	568	587
Denmark	24	0	24
Eire	5155	1087	6242
Germany	64	53	117
France	7674	95	7769
Iceland	0	6	6
Netherlands	1694	33	1727
New Zealand	368	5937	6305
Sweden	63	0	63
Total	15156	8163	23319

The disease could spread to the UK through import of infected sheep and goat produce and semen. Also by import of infected live sheep, goats and exotic ruminants. The import of raw sheep and goat milk poses a risk of infection but this can be considered very small for a number of reasons; there are regulations preventing the sale of raw milk from animals with visible mastitis, so little is actually imported into the UK and the chance of a sheep or goat coming in contact with mycoplasma contaminated milk must be very small. The thorough regulations governing semen import should be sufficient to prevent the import of mycoplasma contaminated semen. The most likely way that contagious agalactia could be introduced into the UK is by import of infected live animals.

Animals may be consistently misdiagnosed to be free of contagious agalactia by the CFT. Sheep are only tested for *Mycoplasma agalactiae*. It is possible that they could act as carrier animals for *Mycoplasma capricolum, and Mycoplasma mycoides subspecies mycoides (LC)*, and if imported pose a risk to British goats. Furthermore neither sheep nor goats are tested for *Mycoplasma putrefaciens.*

There are two further potential sources of carrier animals. Only members of the subfamily caprinae are tested for contagious agalactia so other exotic small ruminants could as carriers. All imported animals spend a minimum of 71 days in isolation but there is no agreed incubation period of the disease and it is possible that some animals may develop clinical signs after this period, again acting as carriers.

Finally "human error" may account for the admission of an infected animal. Infected animals may be misdiagnosed as free from contagious agalactia by a veterinary inspector or laboratory. Also healthy animals may be accidentally mixed with unhealthy animals. A recent example of "Human error" causing the breakdown of control measures was an outbreak of caseous lymphadenitis in a group of goats imported from Germany. At the time of export some animals had visible abscesses which were ignored by German and British veterinary inspectors. Later the abscesses regressed but reappeared in 1989. It then took a year before the condition was diagnosed in 1990, when 30 milking goats were affected (Harker1990).

The HAZOP analysis, suggests a number of potential improvements in the import controls for sheep, goats and exotic ruminants. The development of better diagnostic methods to overcome the antigenic variation within each species, such as the

Table 4: HAZOP table to identify the risks of contagious agalactia spreading to the UK (Dickson 1991)

STAGE	WHAT COULD GO WRONG?	CAUSES	CONSEQUENCES	PREVENTION
1.	carriers not detected	subclinical infection	source of infection	herd testing with ELISA
2	False neg. CFT	CFT not sensitive enough	"	use ELISA
	Accidental mixing with infected animals	human error	"	1. training 2. instruction 3. checks
3	presence of carriers	long incubation period	"	longer isolation
	"	failure at stage 1&2	"	as 1&2
	accidental mixing with infected animals	human error	"	as above
4	carrier animals not detected	subclinical infections	"	longer isolation
5	undetected presence of other mycoplasmas	no tests carried out	disease outbreak in UK	Test for all species
	CFT false negative	CFT not sensitve enough	"	use ELISA
In UK	failure to identify or notify presence of disease	Lack of awareness, not notifiable	infection becomes established	1. veterinary awareness 2. make notifiable disease

determination of iso-enzyme composition and the use of DNA probes would be beneficial. DNA probes are regularly used to detect mycoplasmas in tissue cultures. A more immediate measure would be to replace the CFT with the ELISA to detect infected animals. The ELISA is more sensitive, although it does not overcome the problem of antigenic variation.

Sheep, goats and exotic ruminants from all countries should be tested for all four species associated with contagious agalactia. Extending the isolation period would reduce the risk of not detecting a carrier animal. Good training, clear instructions, and spot checks would reduce the risk of "human error".

It is clear from above that the minimal regulations in directive 91/68/EEC would be insufficient to keep the UK free from contagious agalactia. The probability tree (Figure 2) demonstrated the possibility of a 3-4 fold increase in the risk of contagious agalactia being introduced to the UK after 1993. The high mortality and abortions would result in large costs to farmers. Furthermore the ease of disease spread, the difficulties in diagnosis and the lack of effective treatment or vaccines would mean the costs of controlling an outbreak would be high. If the UK can demonstrate that it is already free of contagious agalactia, by means of a survey, then additional regulations can be put forward to the Commission.

One role of the EEC is to promote free trade in animals and animal produce. This can only be beneficial to farmers by increasing potential markets. However disease control can act as a barrier to free trade. The importance of protecting the health of livestock has to be weighed against the advantages of a free market. Risk analysis has an important role in such assessment. In this preliminary study we have attempted to gather information which identifies and quantifies that risk for contagious agalactiae. Much of the information necessary to do this is unavailable at present and requires further research. One purpose of risk analysis is to identify priorities for such investigations.

AKNOWLEDGEMENTS

Many thanks to Christina Vilela, Laura Green, Gabriel Haggard, and Ben Nichols. Thanks are also due to all the people in MAFF, MLC, Customs and Excise who provided information for this study.

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BOVINE EPIDEMIOLOGY AND PREVENTIVE MEDICINE

OBSERVATIONS ON A CONGENITAL CHONDRODYSTROPHY OF CALVES

GEORGE J. GUNN*

A background level of congenital defects has always been accepted by the cattle industry and veterinary profession (Leipold 1986). However since 1985 there has been a growing awareness within the Scottish Agricultural College Veterinary Service (SAC VS) of a distinct, recurrent, congenital anomaly within the Scottish beef suckler herd. Head and limb abnormalities have been reported, Logue (1988) and Gunn (1992). The clinical abnormalities reported show a wide range within herds. Failure to define the problem using clinical description, gross pathology and at histopathology level has, in the past, resulted in some confusion.

In 1989 SAC Veterinary Services Inverness initiated a temporal study of severely affected local farms. Management changes were introduced, silage parameters monitored and each successive calf crop screened for signs associated with this problem. A detailed management questionnaire was produced for use on affected units. This was subsequently made available to other SAC VS centres. Following a review in 1991 two further facets were introduced to this study.

a) A survey of Scottish veterinary practices associated with cattle work.

b) A post-mortem survey was instigated in an attempt to define the problem.

In 1992 an additional survey to determine official awareness of any similar problem in the remainder of the United Kingdom was undertaken. This paper outlines the preliminary findings of this project.

DEFINITION

During 1991 all SAC VS Centres were supplied with a clinical description of the condition as observed in Inverness. This was accompanied by a range of photographs illustrating affected calves between 2 days and 15 months of age. A post-mortem protocol was provided which involved a gross description, evaluation of joint movement and retention of formalised samples including long bones, extensor muscles, flexor muscles and neural tissues. Whole brain was also

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collected from each calf. Fourteen seriously affected neonatal calves from ten farms were eventually included in this study with three aged matched controls. Two further, otherwise suitable, controls were excluded because hyperplastic changes were noted at histopath. screening of the thyroids. Five of the eight Scottish centres contributed data and samples.

For all fourteen affected calves the predominant clinical and post-mortem feature was shortening of the humerus with lateral bowing of the forelimb. Most were unable to stand unaided and this had been the reason for euthanasia. In most cases the proximal forelimb joints demonstrated restricted limb movement. The carpal joints were generally normal but a number were considered lax and yet others showed restricted movement. Many animals suffered pronation of the lower limb. The hind limbs were also affected with shortening of the femur but clinical changes were not always recognised. Sickle hocks were frequently reported as was restricted movement of the proximal joints.

At post-mortem examination the majority of pastern joints (fore and hind) showed a degree of laxity although this was not normally reported as a clinical feature. In a few cases movement of the pastern joints was restricted. The full length with the width of the distal extremity of each humerus was measured. In control calves the ratio was 2.6 - 2.8:1 whilst in affected calves the ratio was reduced to 1.7 - 2.1:1 ($p<0.0001$).

Affected calves had disproportionately large heads. Doming of the skull with brachygnathia superior was recorded for ten animals.

Consistent histopathological features of chondrodystrophy were noted in the growth plates of head of humerus. Other tissues are currently undergoing histopathological evaluation. It is however considered that the fundamental change in all these calves is a congenital chondrodystrophy and proposed that the range of associated features is dependent upon the severity of the chondrodystrophic lesions.

TEMPORAL STUDY

The sample of calves used to define this condition represented the more severely affected cases from each unit. Investigations have demonstrated that on most units the severely affected calves are considerably outnumbered by less dramatically affected animals. These may stand and suckle unaided and prove vigorous but never achieve full stature. The least affected calves may be less obvious but limb and head abnormalities persist. Often these animals are the poorest in the batch and 'finish badly'.

Several seriously affected units in the Highlands of Scotland have been monitored over the last few years. Each farm has been visited annually after calving and the management questionnaire completed.

Some preliminary results from this study are illustrated by Table 1. It is important to note that both spring and autumn calving herds have been involved, as illustrated. Where farms contain both spring and autumn calving herds only one is affected. It had been hoped that overlapping herd management histories would reveal a 'window' where the in-utero insult occurred. Unfortunately this has not been the case. It would seem calves are vulnerable for a wide period during gestation.

There does not appear to be a primary genetic component to this problem. On most units more than one bull has sired affected calves. Continental breeds are usually involved but these are the common sires for the Scottish suckled beef herd. All study herds comprise of beef/beef-cross or beef/dairy cross cows.

On most units cows can be identified which have produced more than one calf affected by congenital chondrodystrophy. This would tend to exclude the involvement of most infectious diseases and despite extensive testing for BVD virus and other agents there is no evidence that an infectious agent is involved.

No evidence of chemical contamination of feed or consistent use of feed additives has been found. No unusual poisonous plants have been identified on grass or silage parks. Silage has been monitored for quality and mineral/trace element status. No consistent deficiency has been identified in the silage or by biochemical assay on calf tissues.

During 1989 Farm A (see Table 1) was advised to alter the housed ration from silage and mineral supplement. This was achieved by a random division of the herd with the smaller group being fed the traditional diet of hay and turnips, outdoors. Cases were recorded from the housed group but none in the traditional group. Following this result and the publication of a paper, Ribble 1989, linking a similar problem to silage feeding all farms were advised to adjust housed rations during the winter of 1989 - 1990.

The aim of replacing 20% of silage in the ration with an alternative feedstuff was limited by lack of an economic alternative on many units. Despite this some control has been achieved on all units although this control is incomplete.

Work to determine the aetiology is ongoing but limited by funds. The temporal study which involved changes to the ration will be completed during 1993.

Table 1. Typical pattern of disease on affected units

Farm identification	Herd size	Calving season	No. of affected calves per calving	1986	1987	1988	1989	1990
A	80	April-May	Born	Unknown	5	10	23	1
A	80		Euthanased	Unknown	1	2	3	1
D	90	July-Sept.	Born	20	6	14	10	0
D	90		Euthanased	4	0	6	4	0
E	95	April-June	Born	-	12	4	10	2
E	95		Euthanased	-	5	0	3	0
F	100	Sept.-Oct.	Born	-	-	10	10	1
F	100		Euthanased	-	-	5	5	1

SCOTTISH VETERINARY PRACTICE SURVEY

Congenital chondrodystrophy had been reported by all SAC Veterinary Centres. In an attempt to ascertain the prevalence, a questionnaire was targeted to all veterinary practices in Scotland involved with cattle. This questionnaire provided a one page description of the condition with a selection of five photographs demonstrating a range of severely affected calves. The following questions were attached:-

1. Has your practice been aware of any cattle enterprise with abnormalities such as those described above?

YES/NO

2. Have any of your single-suckled beef clients reported this problem among their calves?

YES/NO

3. Could you give an estimate of the number of single suckled beef units, within your practice, which have had cases as described within the last 15 years?

NUMBER ----------

4. Could you estimate the number of single suckled beef units within your practice which have suffered more than two cases of the described condition in any year? Could you indicate in brackets afterwards the number of units where the condition recurred?

a) Within the last 15 years? NUMBER ---------

b) Within the last 10 years? NUMBER ---------

c) Within the last 5 years? NUMBER ---------

5. Could you list the owner names with farm names of the single suckled beef units affected and enumerated above in answer to question 4 c) i.e. those units which have suffered more than two cases in any year within the last five years? Could you indicate your consent to us approaching any of these farmers to complete our management questionnaire?

OWNERS NAME	UNIT/FARM NAME	CONSENT (YES/NO)

The questionnaires were delivered via local SAC VS Centres, April 1991. Telephone reminders were made by the veterinary centre during the summer 1991 with a further copy of the questionnaire mailed directly from SAC VS Inverness during October 1991. The last completed questionnaires were accepted during February 1992. The results of this survey are summarised by Table 2.

Table 2. Summary of results from the Scottish Veterinary Practice Survey (January 1992)

VI centre	No. of returns/ no. of cattle practices (%)	No. of herds affected within 15 years	No. of herds affected within 5 years
Aberdeen	14/24 (58%)	24	5
Auchincruive	27/42 (64%)	18	7
Dumfries	14/14 (100%)	17	9
Edinburgh	4/9 (44%)	9	1
Inverness	15/15 (100%)	>40	14
Perth	20/34 (59%)	18	7
St Boswells	7/7 (100%)	7	5
Thurso	7/7 (100%)	>16	8
TOTALS	**108/152 (71%)**	**>149**	**56**

UNITED KINGDOM SURVEY

A limited survey involving the remainder of the United Kingdom was carried out during the autumn 1992. The objective was to determine the level of official awareness of this problem. Descriptions, including photographs, were sent to appropriate organisations and agencies.

To supplement this survey five MAFF Veterinary Investigation Centres agreed to circulate descriptive questionnaires with photographs to selected cattle veterinary practices. Practices were given one month to respond.

This survey demonstrated that official awareness was poor however affected farms could be identified in England by some cattle veterinary practices. A comprehensive survey would be required to gain any real idea of prevalence.

It is suspected that the Scottish survey has identified only a limited proportion of affected farms. The serious recurrent outbreaks described above should be difficult to ignore yet we are aware of cases remaining unreported to the veterinary practice for some years. Where small numbers of seriously affected calves are born, and less pronounced cases go unrecognised, farmers appear to tolerate the associated losses. This may relate to two factors:-

i) Congenital deformities are generally attributed to a genetic cause and therefore considered outwith human control. Where action was taken the bull was culled.

ii) Reluctance to attract adverse comment from the farming community which may affect subsequent sales.

DISCUSSION

This paper attempts to define a complicated clinical condition which manifests itself through a range of skeletal defects. All these might relate to the congenital chondrodystrophy which has been defined here in terms of histopathological changes to the humerus and the gross changes to that bone.

A similar problem, Congenital Joint Laxity and Dwarfism (CJLD), was described by Ribble (1987 and 1989) in Canadian suckled beef herds and more recently reported on one farm in the Republic of Ireland, (Mee 1992). The histopathological changes described were similar but not identical to those reported in this paper. The clinical syndrome described as CJLD involved joint laxity as the predominant feature with disproportionate dwarfism present in 71% of calves and brachygnathia superior noted in only 24% of cases. CJLD is associated with silage feeding, (Proulx, 1992), as is almost certainly the case with the congenital chondrodystrophy described here. A long term objective of this study was to attempt to relate these two syndromes. In the light of the current findings it is felt they are similar but not identical. It would seem appropriate to describe the Scottish syndrome as a congenital chondrodystrophy. The epidemiology and aetiology are under investigation but the possibility of a multi-factorial aetiology must be considered.

The response rate for the Scottish Survey was considered excellent (71%) and given the scale of losses, on beef units monitored, appears to identify a significant problem. As discussed, without a direct survey of farmers it will always be difficult to ascertain the true prevalence. The impression from the industry is that this is considered a problem worthy of further research.

The veterinary practice return rate from the UK survey was poor but this probably relates to the timescale and resources available. It was inconceivable that this problem recognises the Scottish Border! Having demonstrated that the problem is recognised elsewhere it is hoped that with increased awareness and improved definition the true prevalence can be better assessed and further research to determine the aetiology initiated.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance of many of his colleagues within SAC and MAFF for their contribution to this project. In particular he acknowledges the contribution by Dr R. Munro, MAFF Lasswade. The Meat and Livestock Commission funded the UK survey. SAC is in receipt of funding from the Scottish Office Agriculture and Fisheries Department.

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METHODS OF PREDICTING BSE INCIDENCE

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Following the initial diagnosis of bovine spongiform encephalopathy (BSE) in 1986 (Wells and others 1987), the objectives of the epidemiological studies of the disease were to determine when the effective exposure of the cattle population in Great Britain to a scrapie-like agent commenced, to examine whether only specific age classes of animals, in terms of calves (animals less than one year of age), yearlings and adults, had been exposed and to determine whether exposure had been ephemeral, say for a period of one year only, or had continued. The expectation was that the fulfilment of these objectives would help in determining what events had led up to the unexpected exposure of cattle.

These objectives were first investigated in the early part of 1988, by means of a deterministic simulation model. This was necessarily simple as the number of affected animals and herds accumulated by this time was epidemiologically trivial, and initially a PC-based spreadsheet was used. The simulation considered merely annual events. Parameters were the probability of exposure for the three age classes; the age specific culling rates, which were originally derived from previous epidemiological studies of dairy herds in Great Britain; and the annual rate of recruitment of animals to the adult herd. Only animals which would survive to join the adult herd were included in the model. The other key parameter was the incubation period. Although the only relevant literature related to rodent models of scrapie, there was no evidence for a variation in this distribution with age at exposure. Therefore a constant incubation period, irrespective of the age at exposure, was assumed. The original incubation period distribution was estimated from the limited data on the age specific incidences for natural sheep scrapie (Dickinson 1976) and the age specific incidences of BSE then accumulated. Essentially it was assumed to be a log normal distribution, but necessarily curtailed to a range of 2 to 8 years of age because of the acknowledged limitations of the data available from the early stages of the epidemic (Wilesmith and others 1988). Finally, effective exposure of animals was assumed to be achieved by a single dose and not to be cumulative. The best parameter values and time of onset of exposure were judged by their resultant annual age specific incidences and the annual incidence.

The results of these initial simulation studies suggested that effective exposure commenced suddenly in the winter of 1981/82, was not ephemeral, and had continued until at least 1984. All age classes of animals had apparently been exposed but the majority of cases would have been exposed as calves (Wilesmith and others

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1988). Subsequent epidemiological studies, including modelling, have supported these findings and have indicated that exposure of the cattle population from the food borne source continued until July 1988 when a statutory ban on the feeding of ruminant derived protein to ruminants was enacted (Order 1988).

These early simulation studies were not intended to be used for predicting the future course of the epidemic in numerical terms. They did allow an assessment of the possible duration of the epidemic simply given no other source of infection other than food borne, but doubts over the current estimate of the incubation period distribution and more importantly the estimated changes in the probability of exposure with time in the early stages of the epidemic precluded any prediction of the future number of cases without surrounding such estimates with a series of caveats.

Since the first recognition of the disease in 1986, the epidemic has been monitored in some detail. BSE cases have been recorded on a computer database and for each suspect case reported an extensive questionnaire is completed (Wilesmith and others 1992). This includes information about the herd of origin and four dates which are important for epidemiological modelling. These are the date of birth of the animal, the date when clinical signs were first observed, the date reported (and therefore when subject to the statutory Form A restrictions) and the date of death, usually by compulsory slaughter. Data has therefore accumulated during the course of the epidemic to enable us to estimate the numbers of BSE cases expected in future years.

This paper describes a method used more recently to produce such predictions for budgetary purposes. It remains our preference as far as possible to use epidemiological modelling of the disease process rather than empirical fitting of curves to numbers of reported cases, as only a structural model of this nature can allow for the abrupt decrease in exposure of cattle from the food borne source that occurred in July 1988. The main effort has been directed towards forecasting cases by the month of onset of clinical disease (which it has been assumed is approximated by the date of the reported first observation of signs). For financial purposes these forecasts of actual cases are then converted into a forecast of numbers slaughtered (which includes a number of cattle which do not have BSE) each month. After describing the model we go on to discuss its strengths and weaknesses and some ideas for improvement and future development.

THE THREE-FACTOR MODEL

This model seems to be about the simplest that can approximate to what is thought to have occurred under our understanding of the disease progress to date.

Suppose that cattle become infected at an incidence rate equal to the product of two functions, one a function of time written $Y(t)$, and the other a function of age written $Z(a)$. These infected cattle begin to incubate and a third function $D(m)$ gives the proportion which would experience an onset of signs after a time interval m, in the absence of any intervening removal or culling. Provided any such culling has proceeded independently of BSE incubation then the incidence of signs in cattle of age a at time t is the sum:

$$I(a,t) = \sum_{m=o}^{a} Y(t-m)Z(a-m)D(m) \quad (1)$$

We assume that time is measured in discrete units, either months or years as convenient. It is important to note that by working in terms of incidences and assuming, reasonably, that culling acts independently then this formula remains valid whatever population fluctuations occur.

The functions Y, Z and D have straightforward interpretations. Y represents the rate of incorporation of infective material into cattle rations while Z represents the differential rate of infection of different ages of cattle at the same time, and D is simply the probability density function of the incubation period distribution.

Some of the assumptions in this formulation may not be exactly true. In particular the assumption of constant relative exposure of different ages ignores any differences in seasonal feeding pattern between calves and adults and also ignores the possibility that a high exposure of calves can effectively lower the subsequent incidence of infection in adults, since many of them will already be incubating. The assumption of instantaneous infection, with no cumulative dose effect, followed by an incubation period of length independent of age and time of infection is also open to uncertainty.

POPULATION MODEL

In order to turn observed numbers of cases into incidences for comparison with a model, or alternatively to turn predicted incidences into predicted numbers of cases, it is necessary to have an estimate of the population at risk at each age and time. For these purposes we are only interested in adult cattle since hardly any cases have been found in young stock. Only the structure of the population, that is the relative proportion of each age and any trend in time, is important since an arbitrary constant factor can be incorporated in any estimate of incidence.

A reasonable estimate can be formed from the information collected on the age structure of the rest of the herd at the time each BSE questionnaire is completed. The questionnaire actually records lactation numbers and these have been taken as indicative of ages, with age in years being one more than the lactation number. The result was taken to represent the survival distribution of cows from the age of 24 months, with the number given as n years old (lactation n+1) divided by the number of two year olds (lactation 1) being the proportion surviving to 12n months of age; no culling or removal was allowed for during the first 24 months of life. A close fit to the resulting survival curve was obtained by taking the proportion surviving to age a months to be $\exp(-k(a-24)^2)$, with k equal to 0.000243. (The integral to infinity is 56.9 which implies a 21.1% annual replacement rate).

The number of births each month can be taken as proportional to the distribution of month of birth among all the BSE cases in the database for which a month of birth was available, assuming that this distribution is repeated year after year, and that the total over any year is constant.

Thus the population of age a at time t was taken to be

$$P(a,t) = C \times B(t-a) \times \exp(-k(a-24)^2)$$

where B(m) is the proportion of births in month m, and C is a constant of proportionality (whose value did not need to be estimated directly).

This population model does not allow for any year to year fluctuations in population, or changes in calving pattern, nor for any seasonal influence on removal of animals. Estimating values from the database of BSE affected cases and their herds will clearly lead to some ascertainment bias in the characteristics estimated; this is of some concern in the matter of the birth month distribution as it may be that incidence is truly higher among calves born at certain times of the year, which fact will tend to be suppressed by using cases as indicative of the population at risk. For purposes of prediction this will not matter so long as these differences are sustained.

The fact that our main interest here is with prediction also mitigates any error in the age distribution. If we have underestimated the proportion of older animals our calculations of actual specific incidence will be too high in these groups, and thus incubation periods or age at infection will be overestimated. The later cases will however be subject to heavier culling which will tend to rectify the predictions.

IMPLEMENTING THE MODEL AND FITTING TO OBSERVED DATA

Given a series of infection incidences, Y, and of relative incidences by age, Z, and the incubation period distribution D it is a straightforward matter to produce a set of age specific incidences according to the model described above. It is not so simple to decide which values to take, and we describe first a method, best described as informal, which we have used and has produced plausible results and useful insights.

To start, we produced an estimate of the incubation period distribution, D, by inspecting the histogram of ages of cases occurring in the pre-order herds (herds that had reported a case before it became compulsory to do so), and drawing a smooth curve through them. The result is shown in Figure 1.

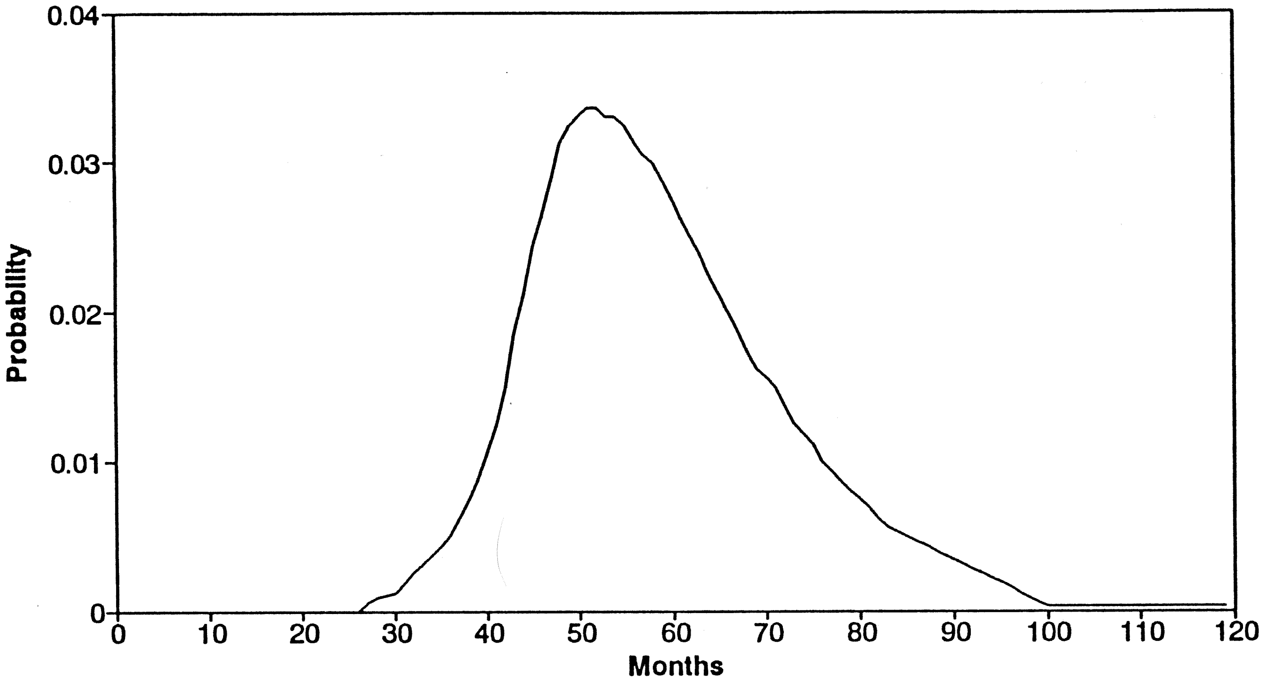

Fig. 1 A distribution used to represent incubation periods in BSE modelling

This age distribution was used directly as the incubation period distribution, ignoring any defect due to culling of older animals or to exposure having occurred at some time after birth. These two influences will tend to have opposing effects on the observed distribution in any case. Some allowance was made for the fact that long incubation periods could not be observed in recently born animals by considering birth cohorts separately.

The time related incidences of infection, Y, were assumed to be constant during any 12 month period July to June, so eight different values were used for successive one year periods starting in July 1981 and ending in June 1989, one year after the statutory ban on inclusion of ruminant derived protein in feed was introduced. The age-related incidences, Z, were assumed to have three values for calves, yearlings and adults, represented by months 0 to 11, 12 to 23 and 24 months and over, respectively.

There were two types of data obtained from the database of recorded cases which it was felt that the model should attempt to reproduce. The first was the age specific incidences observed each year for each age group and the second was the epidemic curve of total confirmed cases by month and year of clinical onset.

The age specific incidences calculated from the database are shown in Table 1. The denominator in each case was the total number of animals of appropriate age in herds that had reported a case at any time, at the last occasion when an age distribution was given for the herd; thus the denominator is the same at all years of incidence for any one age. BSE was made a notifiable disease in June 1988; the 1987/8 incidence is certainly unreliable and some cases were probably lost even after this date, due to the difficulty of recognising the condition. For these purposes we ignored the 1987/8 incidences and raised the 1988/9 incidences by five percent.

Table 1. Age specific incidences (percent) of BSE, calculated from the database

Year of incidence	Age (years) 3	4	5	6	7
1987/8	0.080	0.213	0.121	0.027	0.017
1988/9	0.212	0.881	0.815	0.310	0.080
1989/90	0.460	1.456	1.459	0.780	0.248
1990/1	1.051	2.452	1.801	0.971	0.466

The model was then arranged to produce age specific incidences in yearly groups as in Table 1, by combining each month's output weighted according to the population model. Given any two of the three distributions Y, Z and D the resulting incidences are a linear combination of the values of the third distribution, and this fact was used to determine the best set of values for Y and Z, by linear regression.

Taking, first, an arbitrary set of values for the elements of Y and thus keeping Y and D fixed, the three parameters in Z were in turn each set to one and the other two to zero. This produced three sets of age specific incidences, one corresponding to the effect of unit calfhood infection, one to unit yearling infection and one to unit adult infection. In a regression model (with zero intercept)

$$y = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + e$$

with the y's corresponding to the observed age specific incidences and x_1, x_2, x_3 corresponding to the model outputs, the estimated values of β_1, β_2, β_3, give the parameter values of Z which best fit the observations. This is a consequence of the linearity of the model; the effect of a certain combination of Z values is the same as the same combination of effects of the separate Z values.

Having determined Z we then determined the eight values of Y in the same way with Z fixed at its new value, and then back to Z again since different values would now be achieved and iterated between the two until both converged.

In the regressions negative coefficients were not allowed; when one was indicated it was set to zero and the regression recalculated without that term.

The result of this process was a set of age and time infection factors and a corresponding "best fit" set of age specific incidences; these are shown in Table 2. When these infection factors are put into the model together with the incubation period distribution and the population model, an estimated epidemic curve of monthly numbers of cases is produced. This is shown in Figure 2 together with the actual observed numbers of cases by month of onset. The "estimated" numbers are scaled by a factor sufficient to ensure that the total numbers observed and expected in the period January 1989 to December 1991 match. This raising factor is, essentially, the undetermined constant of the population model. Using that same factor the model output can be run on to give predictions for numbers of cases to be expected in future years.

Table 2. Fitted values for the incidence distributions and the resulting predictions of age specific incidences

Year	Y	Age (months)	Z
1981/2	0	0-11	1.721
1982/3	0.012		
1983/4	0.087	12-23	0.453
1984/5	0.154		
1985/6	0.180	over 23	0.0635
1986/7	0.275		
1987/8	0.883		
1988/9	0		

	Age (years)				
Year	3	4	5	6	7
1987/8	0.234	0.586	0.324	0.086	0.038
1988/9	0.313	1.028	0.879	0.316	0.102
1989/90	0.481	1.343	1.351	0.675	0.239
1990/1	1.114	2.402	1.913	1.015	0.459

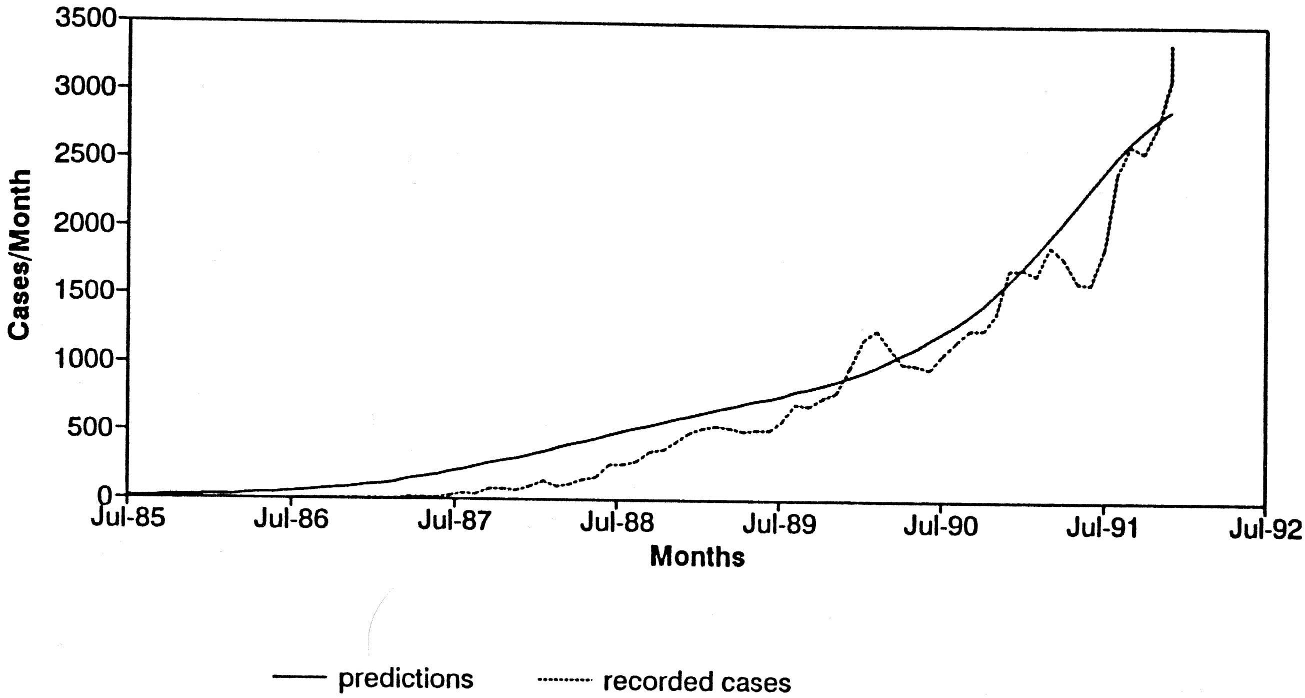

Fig. 2 Total BSE cases by month of onset to December 1991, and estimated numbers from the three-factor model

Before making any predictions a number of further points had to be considered; these were:

i) whether the incubation period distribution was appropriate
ii) how to allow for exposure after the feed ban
iii) the seasonality of onset of signs
iv) how to allow for animals slaughtered as suspects but not subsequently confirmed to be cases of BSE and therefore not included in the epidemic curve.

The adequacy of the incubation period distribution was checked only by shifting it a few months to left or right, and refitting the regression for Y and Z; no improvement in fit was found so no change was made, although for reasons to be discussed below this cannot be taken as providing strong support for it as the most likely distribution of incubation periods.

Although the regressions did not indicate that any exposure should be allowed for after the feed ban, they would barely have been expected to do so since the youngest animals in the age specific incidences considered (three year olds in 1990/1) would all have been born before the appropriate date. Some young cases, born after 18 July 1988, had already occurred. For the months of 1988/9 we therefore allowed a set of Y values tapering from the same value as those of 1987/8 at the start of the year to zero at the end. All such young cases are subject to detailed epidemiological investigation and analysis, and the results indicate that their occurrence can be attributed to exposure from feedstuffs in the food supply chain or remaining on farms which had been manufactured before 18 July 1988.

From inspection of the agreement between predictions and the epidemic curve in Figure 2, it is clear that there is considerable fluctuation in the epidemic curve which seems to be repeated from year to year. This fluctuation is clearly much greater than can be accounted for by any variation in occurrence of infection since the incubation period distribution is so broad as to smooth out any abrupt changes in the infection process. It was therefore necessary to apply a seasonal adjustment to the predicted numbers of cases in order to achieve a better monthly fit. This was done by empirical modelling of the curve, with the adjustments obtained being subsequently applied to the predictions for future months. The natural logarithm of numbers of cases with date of onset in each month from July 1989 to December 1991 was fitted by a quadratic regression on month number (from 1 to 30), with a separate indicator variable for each calendar month. The coefficients of these indicator variables, after adjustment so that they summed to zero, were then taken to be the logarithms of the quantities by which each month's model prediction should be multiplied. Figure 3 shows the modelled epidemic curve together with its predictions up to mid 1992, together with the actual numbers of recorded cases.

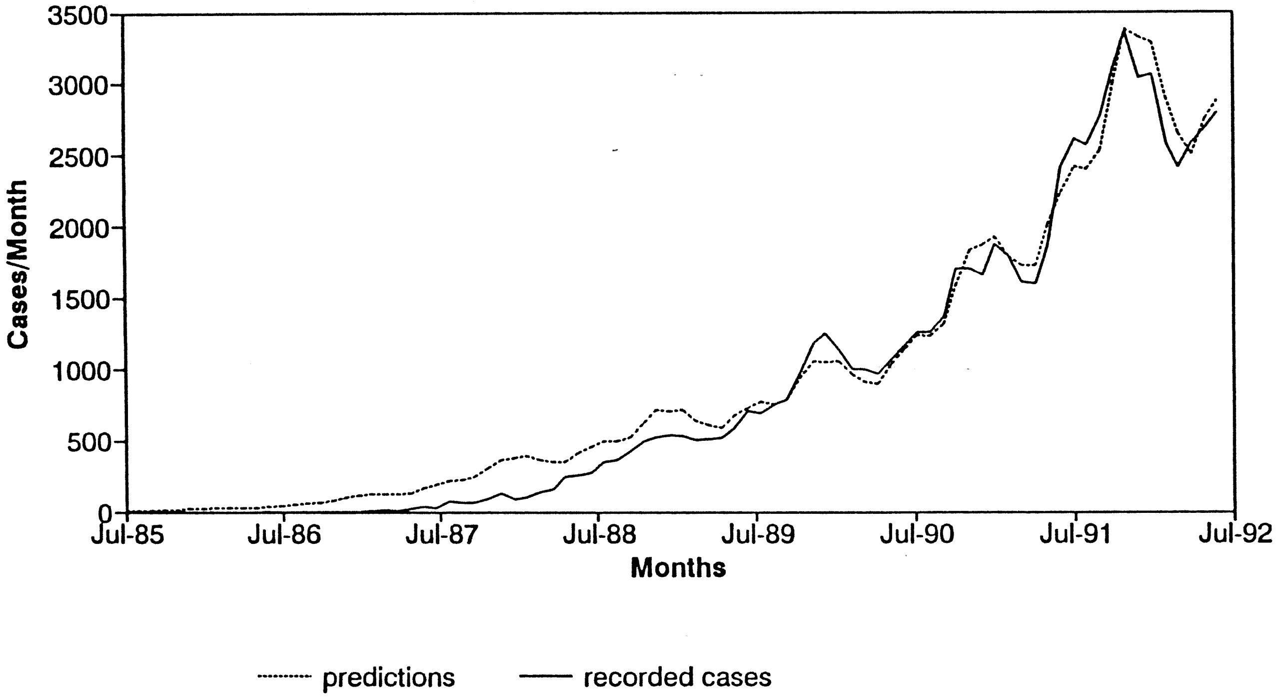

Fig. 3 Total BSE cases by month of onset to June 1992, and estimated and predicted numbers following seasonal adjustment

The final adjustment required is to predict numbers slaughtered each month. This was accomplished by moving the predictions on by one month and then raising by a factor to allow for fifteen percent of those slaughtered to be negative on histopathological examination, a negative rate typical of those experienced in past months.

CRITIQUE OF THE MODEL DESCRIBED

Perhaps the most obvious point about the model just described is that although the formulation in terms of three series appears completely flexible, in fitting it we constrained these series to annual changes in the case of time related infection, three age classes and a single shape of incubation period distribution - and then fitted the result to annual incidences. Nevertheless the result was to produce reasonably accurate monthly predictions.

There are two reasons why it is necessary to constrain the series in this model. Firstly, without constraint, estimates of successive monthly values tend to be excessively variable, whereas in practice one would not expect animals of adjacent ages at adjacent times to have very different incidence of infection or for the incubation period distribution to be other than smooth. We have in fact attempted to estimate the three series directly using methods described by Silverman et al (1990), taking monthly numbers of cases by month of age over three years from 1989 to 1991 and rotating the iteration between the three series, but without any smoothing, and found no evidence of any convergence in the estimates. This variability is at least partly due to the nature of the data arising from the combination of three quantities, each essentially unobservable on their own, and this is well known to lead to difficulties in direct estimation as described, in the context of AIDS prediction, by Jewell (1990). The solution may be to invoke a smoothing step into the iterations (Silverman et al, 1990), or a roughness penalty like Bacchetti (1990), or to use a strong parametric form as described by Cox and Medley (1989), or to block the parameters and the data as we have done.

A second difficulty with fitting a fully flexible set of monthly values arises from the shape of the curve of incidence of infection from which most of the data arise, which is roughly exponential with constant exponent. The model we have proposed can be considered a generalisation of the age-period/age-cohort type of model in which incidence at any age and time is the product of a factor due to age, and one due either to current time or one attached to the birth cohort concerned. These models were first discussed by Frost (1939), and more recently by Clayton and Schifflers (1987) who show that when incidence is changing in a steady exponential fashion (a "drift"), the two models are indistinguishable.

In the same way, if in our model (1) we put $Y(t) = \exp(kt)$, then since $\exp(k(t-m)) = \exp(k(t-a)) \exp(k(a-m))$ we have

$$I(a,t) = \exp(k(t-a)) \sum_{m=o}^{a} \exp(k(a-m)) Z(a-m) D(m)$$

which is the product of a cohort effect $\exp(k(t-a))$ and a function of age which is the convolution of D with $\exp(kx)Z(x)$. It follows that any functions whose convolution matches the observed age incidences in any cohort will serve as D and Z, and they are not separately determinable.

It is not exactly true that observed age specific incidences have followed the same pattern in each cohort, but they are close enough to make the separate determination of D and Z difficult. The consequence of this is that we cannot be certain how much infection has taken place in adulthood and how much close to birth. Our current preference is for an incubation period distribution rather longer than that given earlier, and hence a rather lower level of yearling and adult infection.

If we do assume that nearly all infection has taken place in the first month or two of life, then we will be able to expect all cohorts of cattle born after the feed ban to experience a similar pattern of relative incidences of signs and thereby use the first few cases appearing in the database to predict the total expected in that cohort in the future. This is an area of current development.

It will be noticed that the model completely overlooks the wide variation in incidence that has occurred between separate herds, and also contains no stochastic element to account for the fate of individual animals. Since the essential motor of the epidemic seems to have been through recycling of processed bovine material through feed, it seems appropriate to treat the national herd as freely mixing so that we would not expect stochastic or local effects to influence greatly the overall total of cases. An exception might be the saturation of high incidence herds where subsequent infection was effectively wasted on cattle already incubating the disease. A herd based model will however be useful for examining the possible influence of any alternative means of, or potentiating influence on transmission.

It is disappointing after modelling the general shape of the epidemic curve on epidemiological principles to have to descend to empirical methods to adjust for monthly incidences, and it is not clear how to improve these. It will be interesting to see if the adjustments remain the same when the epidemic is declining.

Another factor that cannot easily be predicted once the course of the epidemic is reversed is the number of cattle likely to be slaughtered and subsequently found negative. It seems plausible that these will also decline, but only some time after the number of positive cases starts to fall and that in the mean time an appreciably higher negative rate will be found. A further difficulty with predicting numbers slaughtered on the basis of predicted onsets is that our data for onsets is always up to six months out of date, as such a period will often elapse from the date the owner recollects as having first seen any signs to the time he reports the case and it is slaughtered. We therefore have to predict onsets starting from six months ago, and hence derive slaughters starting from the same time, when in fact we have reliable information on totals slaughtered almost up to date. We are presently working on methods to make best use of this information.

ACKNOWLEDGEMENTS

The authors would like to thank Sarah Peace, Helen Gartner and the BSE team in the department for maintaining the database, Charles Byrne for producing the illustrations and Dawn Cockle for typing the manuscript. We are also indebted to our colleagues in the State Veterinary Service for collecting the data on the cases and their herds. This work is funded by the Ministry of Agriculture, Fisheries and Food.

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PATHOGENESIS OF NON-INFECTIOUS HOOF DISORDERS OF CATTLE

S.S.SINGH, R.D.MURRAY and W.R.WARD*

Lameness in dairy cows is a major problem. It causes substantial economic loss to the farmer and is a significant welfare problem. In problem herds the incidence of lameness may be up to 50% (Greenough et al., 1981).

The terms pododermatitis aseptica, laminitis and coriitis have been used to describe non-infectious hoof disorders in cattle. Nilsson (1963) defined pododermatitis in cattle as diffuse aseptic inflammation of the corium. The term laminitis is characterised by significant arterio-venous shunting, thrombus formation and avascular necrosis of the laminae leading to separation of dermal and epidermal laminae, severe pain and in severe cases the hoof horn may come off. In chronic laminitis divergent rings on the wall are characteristic (Stashak, 1987). Maclean (1965) found that incidence of laminitis in cattle was 17% but the Compton Lameness survey implicated laminitis in only 5% of lameness cases (Russell et al., 1977).

The term subclinical laminitis was first described by Peterse (1978) and later Greenough (1985) described 'Subclinical laminitis syndrome' as of particular significance in dairy cattle. It is characterised by haemorrhage at the ulcer site and in the white line and is considered a risk factor in the occurrence of sole ulcer and white line disease (Bradley et al., 1989). In sagittal section of hooves with haemorrhage at the ulcer site (subclinical laminitis) changes of altered growth were present in the dorsal wall of hooves (Singh, 1991).

Endotoxins, histamine and lactic acid have been implicated in the aetiology of laminitis (Nilsson, 1963; Maclean, 1971; Telle & Preston, 1971). Endotoxins however are considered most significant. Feeding large quantities of carbohydrates to dairy cows is considered to predispose to laminitis (Roseberger, 1979). Dougherty et al., (1975) found that carbohydrated overloading in cattle led to absorption of endotoxins from the rumen and may be responsible for the hoof pathology. There is still controversy about the primary site of attack: many authors consider vascular changes as primary (Nilsson 1963; Maclean, 1971) while others consider the epidermis as the primary site of attack (Obel, 1948; Ekfalk et al., 1988).

In an early study it was found that in dairy cattle hooves with haemorrhage at the ulcer site, the arteriosclerosis was present at the ulcer site and there was no involvement of the laminae (Singh et al., 1992). Boosman et al. (1989) also reported that the laminae were not involved in such cases. Andersson & Bergman (1980) however considered arteriosclerotic changes as characteristic features of laminitis in cattle.

This study describes the role of changes in weight-bearing on the sole and the effect of endotoxins on the inflammatory response of the corium of the hooves.

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MATERIALS AND METHODS

Weight-bearing experiment

Three heifers and two bull calves of 12 - 18 months of age were used in this study. In two bull calves and a heifer a rubber chip of 1 cm thickness was fixed to the toe of the outer hind claws with a resin (Technovit, Kulzer Germany). Two heifers were used as controls. The animals were maintained on concrete for 6 - 8 hrs daily but otherwise kept on a straw yard. All the animals were slaughtered after 6 weeks. Sagittal and cross sections of hooves were cut and tissues from the ulcer site and abaxial wall were fixed in 10% formalin, and embedded, and sections were stained with haematoxylin and eosin (H&E) and Van Gieson elastin (VGE) stain for histopathology.

Endotoxin experiment

In a pilot study conducted on a bull calf weighing 370 kg, 2 mg of endotoxin (E.coli 0111:B4) was infused for one hour under general anaesthesia in the dorsal metatarsal artery of of the right hind foot. After 8 weeks the calf was killed and sagittal section of the hooves showed haemorrhages in the sole and the wall of injected and non-injected hooves.

Subsequently one bull calf weighing 240 kg and two heifers weighing 300 - 350 kg and aged 12 - 15 months were used for this study. All the hooves were examined for any gross lesions or haemorrhage. First a biopsy was taken from the sole (ulcer site) and the abaxial wall of the left foot in each case (Singh et al., 1993). Two mg of E. coli endotoxin diluted in 1 litre of Hartmann's solution was injected for one hour through an intravenous cannula in the jugular vein in standing animals without anaesthesia or sedation. The animals were kept under observation for 10 hrs and a continuous drip of Hartmann's solution (4 litres) was given during this period. Subsequent biopsies were performed from the right foot 5 and 15 day after the experiment. Two animals were killed after 5 weeks and one after 10 weeks. Sagittal and cross sections of hooves were cut and tissues from the sole, wall and coronary corium of the outer hind claw were fixed, processed, and sections were stained with H&E and VGE.

RESULTS

Weight-bearing study

Grossly in the experimental animals the haemorrhages were present at the ulcer site and a notch in the dorsal wall was evident. Histopathology of the ulcer site revealed parakeratosis and arteriosclerosis of the arterioles. The sole tubules contained non-keratinized material. The laminae did not shows any changes.

Endotoxin study

In the bull calf the coronary band and heel appeared red after 5 days. The intensity of redness in heifers was not as marked as in the bull calf but in one heifer perioplic separation was seen. In the bull calf after 10 weeks the haemorrhages were present in the wall and the sole of both claws of the right hind foot. The haemorrhages were less severe in the left foot (Biopsy was done from this foot and the animal was not putting its full weight on this foot when endotoxins were injected). Haemorrhages in the fore feet were less severe. In two heifers haemorrhages in the hind feet were present and in one heifer no haemorrhages were seen in the fore feet.

Histopathology of the hooves before the start of the experiment revealed a distinct germinal layer in the laminae and papillae. After 5 days histopathology showed presence of non-keratinized material in the tubules of the sole and exfoliation of epidermal cells was evident. In one animal the laminae showed some separation at the dermal and the epidermal junction. At 15 days the epidermal lining of the lamellae had regenerated and the non-keratinized material was evident in the lamellar horn and the tubules of the sole horn. The number of blood vessels in the laminae as well as in the papillae increased markedly as compared to the initial biopsy. Histopathological changes in the hooves of heifers were less marked than in the the bull calf. After slaughter histopathology of the hooves showed non-keratinisd material in the tubules of the sole horn, totally occluded blood vessels and hyperplastic changes in the laminae.

DISCUSSION

Acute and subclinical laminitis in cattle predispose to sole lesions (Bazeley & Pinsent, 1984; Greenough 1985). Endotoxin injection resulted in sole and wall haemorrhage and production of poor quality horn characterised by non-keratinized material in the tubules of the sole and the lamellar horn. A non-keratinized horn was also observed in weight-bearing experiment but this was localised to the ulcer site and there was no involvement of the laminae. Clinically lesions of so-called subclinical laminitis in dairy cattle are present in the outer hind claw primarily. In the endotoxin study the haemorrhages were present in the outer and the inner claws. Altering the weight bearing by fixing the chip to the toe resulted in haemorrhage at the ulcer site and arteriosclerosis of the arterioles. It can be said that the primary changes in weight-bearing are responsible for changes in the sole seen in so-called subclinical laminitis and endotoxins induce diffuse changes in the corium. It appears that the laminitis or diffuse pododermatitis and so-called subclinical laminitis are two different conditions.

The gross lesions were more severe in the hind feet in endotoxin experiment and the lesions were seen in the outer and inner claws. Low severity of lesions in the fore feet may be due to uniform weight-bearing between the outer and inner claws. Excessive stress/strain on the hind feet when the animal is walking or standing may be responsible for more haemorrhages in the hind feet.

Sole ulcers are more common in cattle after acute laminitis (Bazeley & Pinsent 1984). Lamintis can result in poor quality horn which may predispose to the compression by the plantar process of pedal bone in cattle. Alternately, following laminitis a slight change in weight-bearing can bring about quick changes at the sole-heel junction.

Rings on the dorsal wall are characteristic of chronic laminitis. Boosman et al. (1989) did not find any involvement of laminae in chronic laminitis in dairy cattle. Prolonged standing on a hard concrete surface may bring about changes in weight-bearing, and may even be responsible for wall growth changes.

Increased vascularity in the dermal papillae and laminae was seen initially and later occluded blood vessels in the corium were seen. These findings indicate that the vascular changes are primary in laminitis or pododermatitis and epidermal changes leading to poor quality horn formation occur afterwards.

The results of this study indicate that endotoxins can cause diffuse pododermatitis and overfeeding of rapidly fermentable carbohydrate and other diseases involving endotoxaemia may induce similar hoof pathology in cattle.

CONCLUSION

Laminitis may not correctly describe the lesions seen in the sole in so-called subclinical laminitis. Endotoxin can induce diffuse pododermatiti (laminitis) in cattle and the resultant poor quality horn production may predispose to other sole lesions. Primary changes in weight-bearing can cause vascular changes which may be responsible for haemorrhages at the ulcer site and development of sole lesons.

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AN EPIDEMIOLOGICAL STUDY OF DAIRY CATTLE LAMENESS

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Lameness in cattle is a major welfare problem in the United Kingdom and in many other parts of the world (Potter & Brown, 1990). The annual cost to the industry has been estimated at around £80 million (Esselmont, 1990). There have been many surveys carried out in many parts of the world which have sought to not only quantify the amount of lameness on different farms and identify the different lesions but also to attempt to identify some of the risk factors involved (for example, Baggott and Russell (1982); Faye and Lescourret (1989); Enevoldsen, Grohn and Thysen (1990); Tranter and Morris (1991); Groehn, Kaneene and Foster (1992)). All workers agree that a large number of risk factors may be associated with the apparent increase in the incidence of lameness which has occurred over the past 30 years including cow factors such as breeding, age, size, parity; environmental factors such as season, weather, length of tracks, cubicle design; nutritional factors such as protein, roughage: concentrate ratio, type of feeding, and behavioural including hierarchy and stockperson's ability.

The present study was designed to collect quantitative data on as many of these risk factors as possible on commercial farms in Britain in order to examine possible correlations between them and the quantity of lameness on the farms. The study was carried out on 37 farms in four areas: Wirral (9 farms), Cheshire (8), Somerset (11) and Dyfed, Wales (9) over a period of three years from Winter 1988 to Summer, 1991. After a winter for selecting farms and testing methods, the main study was commenced in Summer, 1989 and concluded in Summer, 1991. On most farms, therefore, records were available for 2.5 years i.e. 3 summers and 2 winters but the farms in Wales did not join the study until Winter 1989 and were thus involved for only 2 years. The data was divided into winter, housed periods (November to April inclusive) and summer, grazing period (May to October). Methods were devised to assess the quantity of lameness on the farms, establish the types of lameness involved, assess the feeding of the cows and arrive at quantitative assessments of the environment including cubicle design, cow comfort, state of walking surfaces including concrete and tracks to fields. Statistical techniques were devised to examine relationships between these risk factors and the quantity of lameness. The influence of breeding and genetics was assessed by the examination of individual cow records and the assessment of foot shape.

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This paper describes some of the methods used and provides examples of the range of results obtained. The enormous databank of epidemiological information built up over the study requires much more analysis and consideration, especially at the individual cow level.

MATERIALS AND METHODS

Quantifying lameness

Records of farmer and veterinary surgeon: An individual cow recording sheet was completed by farmer, veterinary surgeon or other worker whenever a cow's foot was picked up for trimming or examination. It identified the farm and cow, the person carrying out the examination and the date of examination, whether the cow was lame or not, and required an estimate of the degree of lameness, the recording of the limb involved and whether the lameness was foot or leg. In order to allow a diagnosis to be made even when the foot was not examined by a veterinary surgeon, a diagram of the foot allowed the claw involved and the site of the lesion to be identified and a description of the lesion to be made. The form also requested information on foot shape, treatment used and extent of foot paring. A new case of lameness was defined as the first occasion when a recording sheet is completed for an identified cow (excluding those which were trimmed but not lame), or when the same cow is lame on a different limb or the same limb 28 days or more since the last record. This method of quantifying lameness allows the calculation of an incidence rate which is defined as the number of new lameness cases over the stated period of time related to the mean cow population over the period.

Records of locomotion scores: The herds were visited for locomotion scoring at approximately monthly intervals during the year for the Wirral, Cheshire and Wales farms. Due to the distance of the Somerset farms from the Field Station, locomotion scoring was done on two occasions only during the winter period (November/December and March) and once in the summer period (May/June). The observations on the Wirral and Cheshire farms were carried out by one individual, those on the Welsh farms by two observers and those on the Somerset farms by a fourth observer who trained the other observers. The locomotion scoring was carried out as described by Manson and Leaver (1988). Scores from 1.0 to 5.0 were recorded against the freeze brand number of the cow in a rough notebook. The rough notes were transferred to a spreadsheet table. A score of 3.0 or above was recognised as lame. Locomotion scores were analysed in a variety of ways to provide mean scores for a herd, the distribution of different scores across the herd, the duration of lameness and the mean number of cows which are lame at any visit. For this paper, the method of quantifying lameness used is the calculation of a prevalence rate which is defined as the number of cows with a locomotion score of 3.0 or above related to the cow population scored on that occasion. A mean prevalence rate was then calculated for each summer and winter period of the study.

The farms were ranked in ascending order of incidence rates and prevalence rates for the five periods of the study and these 10 rankings used to determine possible associations with risk factors.

Feeding

Intake of feeds:

i) Intake of concentrate: Information was collected for each herd by means of a questionnaire completed annually at the beginning of the housing period and updated at the regular visits. This provided information about dietary components and times and methods of feeding. Individual cow allowances were estimated according to calving date (for flat rate systems) and weekly or monthly milk yield (for feeding to yield). The overall intake of concentrates by the herd has been calculated but the intake of individual cows will be examined later.

ii) Intake of forage: The herds were categorised according to the system of feeding forage into self-feed (the cows have to pull the silage from the clamp), easy-feed (silage is put in a ring feeder or trough), both self-feed and easy-feed and complete diet (the forage is fed mixed with concentrates). Measurement and observation of feed barrier design, space allowed and aspects of feeding behaviour were used as a means of deciding whether the forage was fed ad lib or restricted. Note was also taken on the availability of forages other than grass silage, such as maize silage, fodder beet, kale, hay, straw or treated straw.

The laboratory analysis of feed samples:

i) Analysis of concentrate: On-farm bulk stores of straights, concentrates, and forages other than grass silages, were sampled and analysed according to standard procedures.

ii) Analysis of grass silage: Material was collected by hand from a number of sites just behind the open pit face, in order to provide forage representative of that being offered that day. Fresh samples weighing about 1kg were dispatched in sealed plastic bags for immediate laboratory analysis. The chemical analysis was supported by visual assessment of forage quality which described the density of the clamp, the level of waste and variability, and the colour and temperature of material at the pit face.

iii) Intake of specific nutrients: The intake of Rapidly Fermentable Carbohydrate (RFC) and of Crude Protein (CP) was calculated by combining information on the intake and composition of each of the dietary components.

Environment

Methods were devised to provide data on the design, condition and dimensions of the cubicles, with details of the beds and bedding and an assessment of the ability of the cows to lie, rise and stand comfortably in the cubicles. Methods to assess the texture of the indoor and outdoor walking surfaces were also devised. The only sophisticated equipment used was a digital levelmeter (Levelman DL-1000, Suehiro Tool Company Limited), which recorded slopes/falls in degrees from the horizontal. Various instruments for assessing the texture of the walking surfaces were tested but none proved useful. We finally resorted to developing scoring systems based on eye and feel observations. This allowed quick scoring of a large number of surfaces variously covered with slurry, mud or stones, and reliability was achieved by training pairs of observers and by frequent cross-checking between pairs.

Cubicles: The design and dimensions of one representative cubicle in each set of cubicles on each farm were recorded in the first winter and any subsequent major alterations noted. The presence or absence of head rails and brisket boards were also noted and the available borrowing-space was assessed by observing cows in the cubicles.

Beds and Bedding: The cubicle bedding was scored at least twice each winter, on all the farms. Five cubicles in each set, or house, were selected with random numbers. The beds were firstly classified as either soft-based (e.g. used straw, soil or sand) or hard-based (cement), and the bedding was then scored into three categories from satisfactory to absent. Allowance was made for the presence of mats. The slope of the beds was assessed visually.

Cow comfort (cubicles): This data was obtained on the same visits as the bedding scoring. Five cows in each set of cubicles were observed lying, rising and standing, and restrictions in movement scored from 1 to 5, with increasing degrees of restriction.

Walking surfaces:

Indoors:

Textures: These were scored once each winter, whilst the cows were housed. Five or more sites were randomly selected in each of the following areas: parlour and collecting yard, loafing, feed troughs, cubicle houses, silage bays if present and one at each water trough and, after scraping off excess slurry, they were scored by eye and feel on a score of 1 to 5, from very smooth to very rough.

Slopes/falls: These were assessed once only, in the first winter. Five or more sites were randomly selected in the same areas as above. Two readings of the level meter were taken at right angles (sideways and forwards), and the results grouped into four classes, with increasing steepness.

Outdoors:

Textures: Four areas were selected for scoring; fields, surroundings to water-troughs (or ponds), gateways and tracks. The tracks varied considerably in length, both within and between farms, and so a random selection of 5 sites was chosen for each approximate 100 metres, with a maximum of 5 such sets of scores per track. Precedence for scoring was given to any so-called "cow-walks", and sites obviously not used by the cows were not scored. Only one 'average' score was given for each field, because of their general uniformity within each field, and only one score was given for water troughs (or ponds) and gateways, unless the areas were extensive and very variable, in which case five scores were allocated. Scoring was based on eye and feel, and on a 1-5 scale, as for the indoor textures.

RESULTS

The results of the survey are voluminous and examples have been chosen to indicate their range.

Quantity of lameness

Incidence of lameness derived from records completed by farmers and veterinary surgeons: The Wirral farms are identified as 1 - 9, Cheshire as 11 - 20 (excluding 14 & 19), Somerset as 21 - 31 and Wales as 32 - 40. The totals of the mean herd sizes of these 4 areas were 915, 1,084, 1,639 and 592 dairy cows respectively, a grand total of 4,230 cows, and the total numbers of new incidents of lameness in the 4 areas were 795, 2,802, 2,593 and 331, respectively, a grand total of 6,521.

Figure 1 shows the mean lameness incidence for a year i.e. a standard period from November to October inclusive, allowing for the differing times for which farms were in the study. The incidence rate for a year varied from as low as 9.3 in Farm 35 to as high as 200.7 incidents per 100 cows in Farm 18.

Prevalence of lameness from locomotion scores: The data have been pooled and the mean prevalence rate over the whole period of the study calculated and presented in ranked order in Fig. 2. This indicates a range of mean prevalence of lame cows over 2 to 2.5 years of as low as 2.0 on Farm 31 to as high as 53.9 on Farm 18.

Fig 1. Ranked mean annual incidence rate

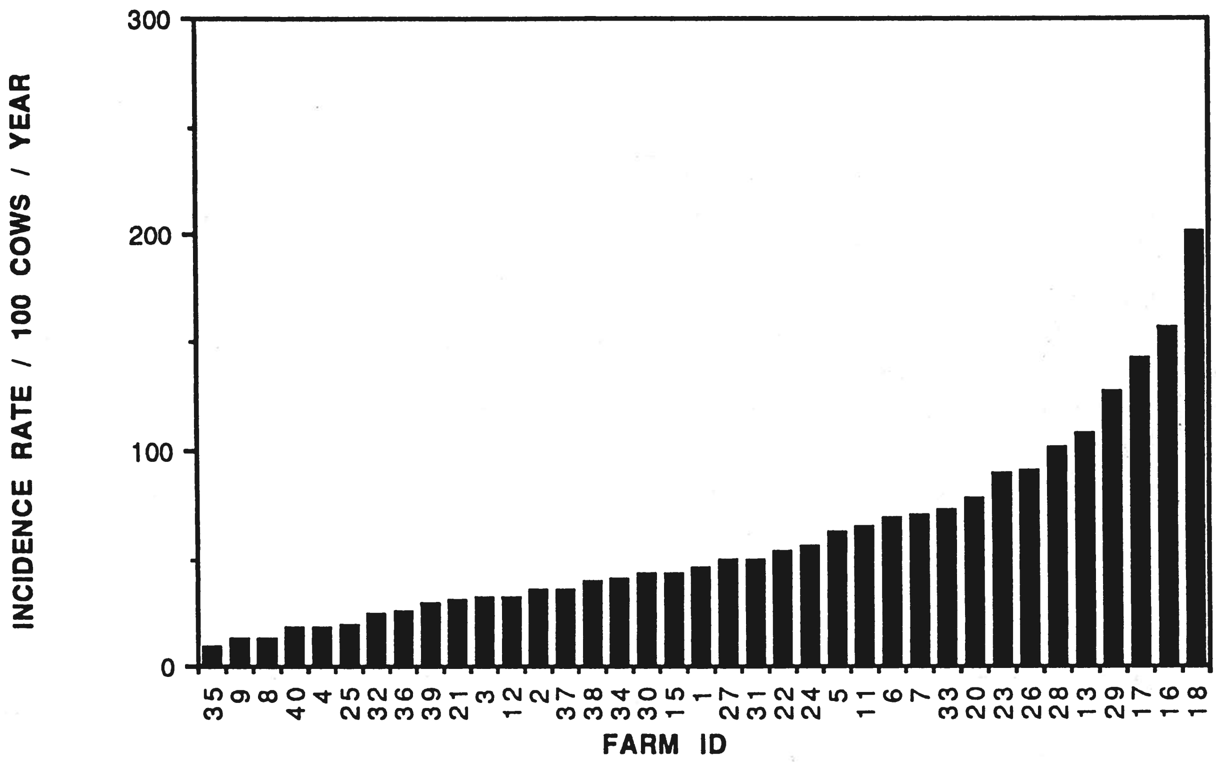
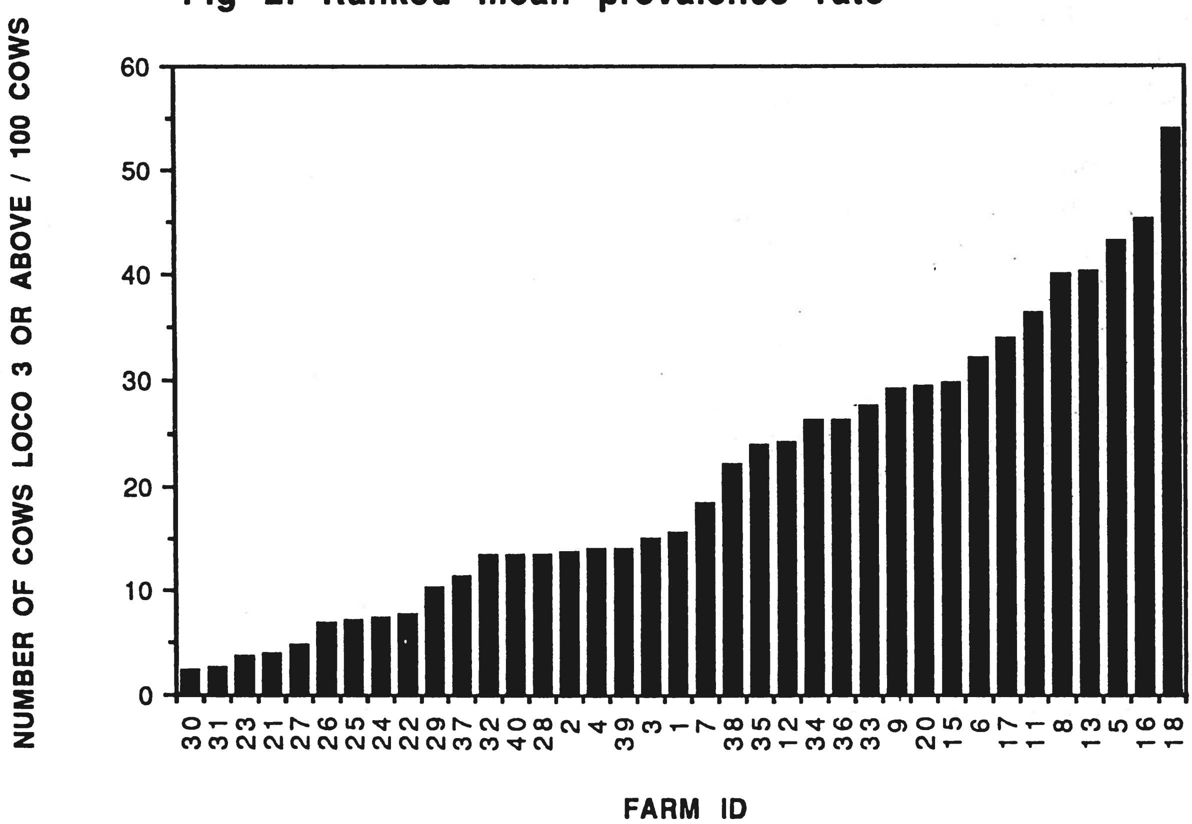


Fig 2. Ranked mean prevalence rate



Feeding

Systems of feeding concentrate: Fifteen farms on flat-rate feeding were compared with 22 feeding to yield. The farms on flat-rate feeding had 1,799 lame feet from 1,814 cows (50 lame feet per 100 cows per winter) whereas the farms feeding to yield had 1,319 lame feet from 2,408 cows (27 lame feet per 100 cows per winter).

Type of forage: Using locomotion score as a measure of prevalence, there were significant differences between farms feeding different forages ($p<0.001$). Using lameness records as a measure of incidence, there were again significant differences between farms feeding different forages in winter 1 ($p<0.001$) and in winter 2 ($p<0.05$).

Composition of forage: Since grass clamp silage was the most commonly fed forage, the composition of this alone was therefore compared with the prevalence and incidence of lameness. There were significant differences ($p<0.001$) in the prevalence and the incidence of lameness between farms with high and low dry matter (DM) grass clamp silage. In winter 1 the prevalence of lameness was significantly higher ($p<0.001$) on farms with a grass clamp silage high in crude protein (CP) than on farms with low CP silage. In the same winter, the incidence of lameness was non-significantly higher on farms with high CP silage. In winter 2, the incidence of lameness was significantly higher ($p<0.001$) on farms with a grass clamp silage high in crude protein (CP) than on farms with low CP silage, and the prevalence was non-significantly higher on farms with high CP silage.

Types of concentrate: There were significant differences in the prevalence of lameness between farms feeding different concentrates ($p<0.01$) in both winters.

Environment

Cubicles: One hundred and seventy cubicles on the 37 farms were assessed. Eighty seven percent (87%) of the cubicles were considered to be too short (<230cm), 50% too wide (>122cm) or too narrow (<115cm), 91% of the top partition rails were also classified as too low (<111cm), and 70% of the bottom rails too high (>40cm) or too low (<34cm). Sixty percent of the cubicles contained a head rail and 96% of the bottom partition rails were rigid, both of which intentionally restricted space. Some borrowing space was available in 82% of the cubicles, but 6%, such as those with 3 wooden rails and/or solid front walls, had no extra space available, and only 12% permitted real freedom.

The height of the kerb was consistently significant ($p<0.05$). The higher the kerb the worse were the lameness and locomotion rankings, with the stronger relationship between the kerb height and the locomotion ranking. The presence of a headrail appears to improve the locomotion and lameness rankings ($p<0.05$). The higher the bottom rail the better were the locomotion and lameness rankings ($p<0.05$), although this relationship showed up intermittently.

<u>Beds and bedding:</u> Two thousand, one hundred and eighteen beds were assessed during the two winters. Seventy-five percent had a cement base and 25% were made of softer material. Sixty-three percent of the beds were classified as having too little bedding and 11% next to none.

<u>Cow comfort:</u> One thousand, five hundred and sixty cows were observed lying in the cubicles and 1,950 rising and standing. Eighteen percent of the cows lying appeared to be moderately or severely restricted, 33% when rising and 55% when standing. The locomotion and lameness rankings were weakly (if at all) related to the comfort of the cows, as represented by the mean comfort lying, rising or standing. Wherever one of the comfort variables was significant at the 5% level, the higher the score (representing the greater the discomfort), the worse is the lameness or locomotion ranking.

<u>Walking surfaces:</u>
<u>Indoors:</u> Three thousand, one hundred and ninety-one sites were scored over the two winters. In general, the surfaces scored higher (i.e. they were rougher) in the second winter than in the first; 25% were classified as satisfactory in the first winter and 34% in the second; 55% and 33% were classified as smooth or very smooth, 20% and 33% rough or very rough. In general, the walking surfaces in the silage bays were the roughest (54% rough or very rough in the first winter and 72% in the second), and the parlour and collecting yards the smoothest (54% smooth or very smooth in the first winter and 37% in the second).

Those herds with floors recorded as smooth, or very smooth, have significantly worse lameness rankings in both winters ($p<0.01$). This relationship was hardly apparent in the locomotion rankings with just one significance level less than 5%. There was no discernible relationship between rough and very rough indoor floors and the lameness and locomotion rankings.

<u>Outdoors:</u> Three thousand, three hundred and thirty-five sites were scored over the two summers, the majority (2,180) on the tracks leading to and from the fields. Overall, the scores in the two summers were very similar, but there was variation within the seasons, associated with local weather conditions and wear and tear. Farms varied greatly in their length of tracks. Overall, only about 25% of the outdoor surfaces were classified as satisfactory, whilst about 70% were classified as too rough, and about one third of those were very rough. Perhaps surprisingly, about a third of the fields were classified as rough.

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MEASURING FERTILITY IN DAIRY HERDS

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The use of calving index as a measure of herd fertility ignores the proportion of the herd that is culled, generally for failing to conceive. It is more important to consider the total cost of long calving intervals, high culling rate and even low pregnancy rates in an integrated index that reflects inefficient management, than to have to cope with balancing a number of separate physical indicators.

In a study of 91 herds calving in 1988 - 1989 (14524 cows) a full range of physical indices were examined. The average herd calving interval was 380.3 days, with a culling rate of 23.1%. Of the cows calving, 76.9 per cent recalved. When this was adjusted for the calving interval (CIA Calving Rate), this was 73.8 per cent.

In quartiles split on the basis of CIA Calving Rate, the top quartile achieved 82% (CIA Calving Rate), with a calving index of 375.2, and a culling rate of 16.7%. These standards were achieved by serving 91.9% of the cows after calving, at an interval to first service of 67.2 days. The submission rate for A.I. in the first 24 days after the earliest service date was 57.5%, the overall pregnancy rate being 51.2%. The result was that 92.1% of those served, and 85.3% of those calved, conceived again, with an average of 1.9 serves per conception.

Assessing fertility performance on a financial basis, with costs attributed to calving interval, culling rate and pregnancy rate (Fertex, Fertility Index), the average herd was losing £62 / cow / year, compared with target levels. In the top quartile of herds (on the basis of CIA Calving Rate), the average loss per cow was only £10.60 per cow, whereas in the lowest quartile the cost was £121.91 / cow. Clear guidelines are given to help farmers and advisers raise the standard of fertility management in herds.

INTRODUCTION

Generally speaking, in the U.K., the efficiency of the fertility of dairy herds has been measured by the calving index. As this is the average interval between successive calvings in a herd over a 12 month period, it ignores important factors such as the rate of culling for failure to conceive.

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Table 1. Calculation of the cost of a cull cow

		£
Price Cull Cow, Sold	300	
Purchase, or Transfer Price, Heifer	700	
Depreciation Cost	400	400
Lower Production from Heifer Lacation 1000 Litres at Margin / Litre of 14p		140
Smaller Calf, less valuable crossbred from Heifer instead of one possible from the Cow (difference)		50
		590

The cost of culling a cow that fails to conceive within the serving season, in terms of herd depreciation, lower yield and less calf income, is calculated to be £590 (Table 1), so it is important to include culling rates in any fertility index. The most efficient dairy herd will have a calving index of 355 to 365 days, and a total culling rate of 18% (Gartner and Herbert, 1979).

Calving index is affected by such factors as the proportion of the herd the farmer decides not to serve (i.e. set barren), the close season for serving cows, the interval to the earliest service date, the heat detection rate, the overall pregnancy rate, and the length of the serving season allowed for individuals and for the herd. Long intervals and high culling rates may have more to do with the farmer's policy and rules that he applies in this regard, than with heat detection and pregnancy rate.

Looking at the U.K. calving index (12,000 herds) (Warren, 1984), the National Milk Record's (NMR) results show a figure of 384 days. A separate study of 285 herds on NMR, showed the mean interval to first service to be 74 days (Poole and Mabey, 1984), and an average rate of pregnancy to an assumed conception of 57%. Heat detection rates were calculated to be 44%, but the method used seems to underestimate the level of performance in this regard. Other surveys place heat detection rates between 50% and 60% (Peters and Ball, 1987; Boyd and Reed, 1961; Drew, 1982).

Separate studies indicate that actual replacement rates are around 25% (22.7% Beynon, 1978; 25% Wray, 1980; 26.9% Spooner, 1978), and these authors show that about one third of culled cows are sold for infertility. Since the arrival of quota controls in 1984, farmers may have changed their practice to accommodate the falling herd quota allocated to them.

Perhaps because of the use of non return rates in A.I., and also because of limited data about fertility and of culling events in herds recorded on National Milk Records, there are few performance figures for fertility based on actual performance that can be used by advisers and veterinarians as targets which are achievable. There is a need for the analysis of an integrated set of individual cow fertility data, that reflects a whole season's management, in a sufficiently large sample of well recorded herds.

MATERIALS AND METHODS

Data for the cows calving in the 1988 - 1989 season were drawn from farms and veterinary practices using the micro computer based recording scheme developed at the University of Reading (DAISY - The Dairy Information System. Esslemont R.J., et al 1991).

All the herds had been using the scheme for at least 2 years, so there was no missing data for the season in question. The records covered calvings, services (A.I. and natural), pregnancy diagnosis (by rectal palpation), drying off and culling, for all first lactation heifers and mature cows calving between the 1st July, 1988, and the 30th June, 1989. All these animals have since either recalved, or have been culled.

The original records were kept by the herdsman in a duplicate book, the top copy of which passed to the computer in the farm office or at the veterinary practice. There the records were entered on an individual animal basis into the DAISY software on the computer. A considerable number of checks are incorporated into the DAISY programs, to help ensure that the data quality entering the computer is of a high standard in terms of logic, accuracy and consistency (Eddy, 1982).

The herdsmen and veterinarians receive action lists and other analytical reports to help in the management of the cows in the herd. Apart from fertility records, extra data of any type can be entered for individual animals, and usually covers calving difficulties, calf mortality, metabolic disorders, veterinary treatments, mastitis and lameness.

Based on their use of DAISY being at least five years, and the level of experience, selected bureaux sites were invited to send in to Reading, copies of their completed herd records on diskette for the season in question. The data and health coding was checked and corrected, to allow a common approach to the analysis of all the herd records.

The sites have already received a set of performance indices (on a confidential basis) for their own herds. The data has since been processed through two special DAISY reports that analyse the herd's fertility and health. The first produces a full set of fertility indices for the cows calving in the season in question (Table 3). The results from this report have recently been validated by the analysis of raw data from the same period in the same herds on a commercial statistical program (SAS, 1990. SAS Statistical Analysis System, SAS Institute Inc., Box 8000, Cary, North Carolina).

The second report analyses all the main disease and treatment data held for the cows calving in the period. This includes the rate of calf mortality, twinning and abortion. The incidence of milk fever, vulval discharge / endometritis, calving difficulty, retained afterbirth, mastitis and lameness is also summarised. Treatments for "oestrus - not - observed" and for "failure to conceive" are analysed.

This report also shows frequency distribution tables and charts for fertility indices, including the inter - service intervals in days (Table 4). The results covering health and disease will be dealt with in a separate paper.

Calving interval adjusted calving rate CIA calving rate

The Calving Interval Adjusted Calving Rate is the proportion of the herd that recalve in a twelve month period. This is calculated as :

$$\% \text{ of the herd recalving} \times \frac{365}{\text{Herd Calving Index}}$$

Table 2. Method of calculation of fertility index (Fertex), with examples for three herds (A, B, C)

Parameter	"Standard" Used	Penalty or Bonus
Mean Calving Interval	360 Days	£3/Day
Culling Rate	22%	£590/1%
Inseminations per Conception	2.0	£18 per Insemination

Examples of calculations of herd fertex

	Results	Calculation	£/cow	£/100 cows
Herd A				
Calving Interval (days)	386	-(386-360)x3	- 78	- 7800
Culling Rate (%)	31	-(31-22)x590	- 53	- 5310
Inseminations per Conception	2.1	-(2.1-2.0)x18	- 1.8	- 180
	FERTEX SCORE		- 132.8	- 13290

	Results	Calculation	£/cow	£/100 cows
Herd B				
Calving Interval (days)	358	(358-360)x3	+ 6	+ 600
Culling Rate (%)	18	(22-18)x590	+ 23.6	+ 2360
Inseminations per Conception	1.8	(2.0-1.8)x18	+ 3.6	+ 360
	FERTEX SCORE		+ 33.2	+ 3320
Herd C				
Calving Interval (days)	372	-(372-360)x3	-36	-3600
Culling Rate (%)	17	+(18-17)x590	+ 5.9	+ 590
Inseminations per Conception	2.0	=(2-2)x18	0	0
	FERTEX SCORE		- 30.1	- 3010

Table 3. Frequency distribution showing average herd performance of main fertility, 91 herds. Quartiles based on calving - interval - adjusted calving rate (CIACR). (p.p. = post partum)

	Number of Herds				
	91 Herds Average	Worst 23	23	Best 23	22
No. heifers calving	36.1	41.7	38.2	34.8	29.3
No. cows calving	128.5	122.7	127.2	125.3	118.6
Total no. calvings	159.6	164.3	165.4	160.1	147.9
Cows served of calved (%)	88.3	85.5	87.5	88.5	91.9
Calving to first service (days)	71.7	75.4	74.4	69.5	67.2
Cows served under 40 days p.p. (%)	5.6	5.57	5.73	4.6	7.0
Cows served over 100 days p.p. (%)	11.2	15.2	14.1	7.9	7.3
1st Service 24 day Submission Rate (%)	51.9	44.9	50.8	54.5	57.5
1st Service Pregnancy Rate (%)	50.5	48.8	50.4	51.7	50.9
Overall Pregnancy Rate (%)	49.4	47.0	49.0	50.5	51.2
Cows Conceiving of Served (%)	89.5	86.4	89.4	90.4	92.1
Cows Conceiving of Calved (%)	79.8	74.4	79.1	80.5	85.3
Interval Calving to Conception (days)	98.9	104.8	101.6	95.2	93.9
Average Days Open	128.9	139.0	134.4	126.9	114.7
Cows Conceiving more than 120 days post partum (%)	23.6	28.5	24.1	21.1	20.7

Services per Conception	1.98	2.10	2.00	1.93	1.90
Cows Dried off of Calved (%)	77.2	70.6	79.6	79.3	79.6
Mean Lactation Length (days)	309.3	313.8	313.6	312.7	296.3
Cows Recalved (%)	76.9	69.4	76.4	78.8	83.3
Mean Dry Period (days)	65.6	68.3	67.3	63.3	63.3
Mean Calving Interval (days)	380.3	386.5	382.6	376.8	375.2
Total Culling Rate (%)	23.1	30.6	28.6	21.1	16.7
Calving-Interval-Adjusted-Calving-Rate (CIACR) (%)	73.8	65.5	72.8	76.3	81.0
Fertex Score (£/100 Cows)	-6226	-12191	-7364	-4064	-1060

Table 4. Inter Service Intervals;
91 Herds in Quartiles by Calving - Interval - Adjusted Calving Rate.

	Number of Herds				
	91 Herds Average	Worst 23	23	Best 23	22
% Cows Reserved at					
< 6 Days	2.9	3.0	2.5	3.2	2.9
7 - 12 Days	2.7	2.4	3.3	2.2	2.8
13 - 17 Days	3.7	3.9	3.8	3.7	3.5
18 - 24 Days	36.0	34.9	35.1	37.1	37.0
25 - 30 Days	14.7	13.2	14.9	15.0	15.9
31 - 35 Days	3.8	3.2	4.0	4.2	3.7
36 - 48 Days	12.9	13.8	13.6	11.7	12.5
49 - 71 Days	14.1	15.3	12.8	14.7	13.7
72 - 96 Days	4.6	5.5	4.2	5.3	4.3
> 96 Days	4.3	4.7	5.8	3.0	3.7
18 to 30 Days (%)	50.7	48.1	50.0	52.0	52.9
< 18 Days (%)	9.3	9.4	9.6	9.4	9.7

Fertex, fertility index

This index has been devised to integrate the estimated financial loss in a cow or a 100 cow herd, caused by long calving intervals, high culling rates or low pregnancy rates (Esslemont, 1991). Herds are rewarded or penalised (Table 2), showing figures for a poor herd (herd A), a good herd (herd B), and a reasonable herd (herd C).

Days open

This is an average of days from calving to conception for the cows conceiving, and days from calving to culling for those that did not conceive.

Results

Data from 91 herds (18 DAISY sites, 10 in Veterinary Practices, 6 on farms, 2 run by Consultants), a total of 14524 cows, average herd size 159.6 cows, range 48 to 473), was considered to be of sufficient quality to be included. On average, 22.6% of the animals in a herd were first lactation heifers.

Interval to first service

The farms served 88.3% of the herd after calving, at an average of 71.7 days post partum, with 5.6% of those served receiving the insemination at less than 40 days post partum, and 11.2% being served at later than 100 days post partum (Table 3).

Heat detection first service

Taking into account each herd's rules for serving cows (days left to earliest service date, close season for serving), 51.9% of the cows were served in the first possible 24 days after the earliest service date (1st service 24 day submission rate).

Pregnancy rate and heat detection (returns to service)

The pregnancy rate to first service averaged 50.5%, and to all services, 49.4%. In terms of the percentage of the animals recorded as returning to service within the expected oestrus interval (18 to 30 days), the heat detection rate is 50.7% (Table 4).

Proportion finally conceiving and re-calving

The proportion of cows that became pregnant was 89.5% of those that received at least one service, and 79.8% of those that calved (on average only 0.83% of these animals were in calf to an unrecorded service).

Calving to conception interval, days open, culling rate

The average interval from calving to conception was 98.9 days, and the mean days open (calving to conception for those conceiving, and calving to culling for those that did not), was 128.9 days. Nearly a quarter (23.2%) of the cows conceiving did so at over 120 days post partum.

The mean number of services per conception (for the cows conceiving), was 1.98. The lactation length was 309.2 days (for cows dried off, excluding those culled without being dried off). On average, a total of 79.8% cows conceived (77.2% were dried off), and 76.9% recalved; 3.8% of cows in calf did not actually recalve.

Calving interval, culling rate

The dry period averaged 65.5 days, and the calving interval was 380.3 days. A total of 23.1% of the cows were culled. The culls include those cows that died on the farm (1.6% of the cows calving).

Accuracy of heat detection

In terms of accuracy of heat detection, 9.3% of the cows returning to service were served less than 18 days after the previous occasion (Table 4). The ratio of returns to service at 18 - 24 days (one cycle), to those at 36 - 48 days (2 cycles), was 2.81 : 1. The target is 7 : 1.

Quartile analysis

The 91 herds were allocated to quartiles based on the Calving - Interval - Adjusted Calving Rate (CIA Calving Rate).

The top quartile achieves a CIA Calving Rate of 81.0%, with the worst herds only reaching 66.5%. The better group cull only 16.7% of the herd (with a 375.3 day calving index), as opposed to 30.6% (and 386.5 days), in the worst group.

The top herds (compared with the worst group) achieve these results by serving 91.9% of the herd (versus 85.5%), at a mean interval to first service of 67.2 days (versus 75.4 days). They do this by having a higher first service 24 day submission rate of 57.5% (versus 44.9%), leaving, in their case, only 7.3% being served after 100 days post partum (versus 15.2%).

Pregnancy rate to first service is a little different in the four groups, with the overall pregnancy rate at 51.2% in the top group, compared to 47.0% in the bottom quarter.

The detection rate of returns to service (% reserved at 18 to 30 days), also differs to a similar extent (Table 4).

The effect of the higher standards is that in the top quartile 92.1% of the cows originally served get back in calf (instead of 86.4%), and this means that 85.3% of the cows calved get pregnant (versus 74.4%). The top group actually achieve a calving to conception of 93.8 days (versus 104.7 days), with the days open being only 114.7 days (versus 139.0 days).

The recalving rate in the top group is 83.3%, as opposed to 69.4% in the worst quartile. This, and the shorter calving interval in the best group, leads to a CIA Calving Rate of 81.0%, as opposed to 65.5%.

In terms of Fertex, the average herd is "losing" £6226 per 100 cows, while in the top quartile each herd is, on average, over £5000 better off at minus £1050. The worst group of herds are losing £5965 more than the average herd, as the former have a score of minus £12,191. The top group is £11,131 better off (per 100 cows) than the worst group. This is £111 per cow, and this should be reflected in the profitability of the herd.

DISCUSSION

Both in terms of CIA Calving Rate and Fertex, because of the higher proportion served after calving, the interval to first service, and the 24 day submission rate, the top quartile perform well. The success of these herds has less to do with overall pregnancy rate and the detection rate of returns to service. However, the fact that the top group are also slightly better at both these indices remains a further contribution to their performance.

Some herds do achieve a positive Fertex Score (five out of the ninety one). The Fertex Score emphasises the importance of a low culling rate. This parameter has been overlooked in many of the recording systems, and only calving index is mentioned in this regard in the National Milk Recording Scheme (NMR) in the U.K. (NMR, 1990).

The top quartile have only about a day shorter calving interval compared with the third quartile, but, by having about four culls less per 100 cows, have a Fertex Score that is £30/cow or £3000/100 cows better.

The Fertex Score could be refined by adding other elements, such as the cost of certain veterinary treatments. It could be improved by considering only the cows culled for failing to conceive, instead of measuring the total culling rate.

The component of the Fertex calculating the calving interval could consider only the proportion of the herd recalving instead of all cows. Generally such refinements and sophistication may make it more difficult to understand such an index, and hence harder to use.

The principles and calculations on which Fertex is presently built are generally sound enough to give farmers and advisers clear warning that something may be wrong, and that it may pay at least to examine the underlying factors.

The CIA Calving Rate may offer a first step in examining the fertility performance of a herd, and it requires relatively little information to be able to extract this important index.

There are very few surveys of herd fertility that look at proportions of the herd involved in the various indices, and that deal with the main intervals for those conceiving, as well as the culling rate for those that do not. NMR figures deal only with calving interval, and indicate an average of 384 days (Warren, 1984). This is some four days longer than the average in the herds studied. The shorter interval may reflect a greater effort to improve performance in the herds on the more intensive DAISY scheme.

The calving to conception interval in the 91 herds is also four days shorter than that recorded in the 255 Checkmate herds (Poole and Mabey, 1984). In general, pregnancy rates have been over estimated by using non - return rates in the past. The Checkmate results show 57% assumed in calf to first service on the basis of a 120 day non return rate (Poole and Maby, 1984).

This is some seven percentage points higher than the results in this study, where pregnancy diagnosis has been used, and where animals returning to heat or service, even after that inspection, will have had their status adjusted in the records. The overall pregnancy rate of 49.4% is one of the lowest surveyed (Warren, 1984) in the U.K., and gives cause for further investigation.

It is not that the mean culling rate differs widely fron other surveys, but the very wide spread in such performance found in the present survey that is interesting. The present study goes on to show that culling is associated with fertility management.

Heat detection remains a weak area in U.K. dairying, and average rates of 50 to 55% are confirmed in this study. It is perhaps better to use a wider span of return intervals than even 18 to 30 days to check return heat detection rates. Certainly, only 75% of normal returns are covered if 18 to 24 days are used as the indicator (Warren, 1984).

In this study, if the returns from 13 to 30 days are used as the indicator, the average rate is 54.4%, and the herds in the best quartile achieve only 56.9%.

This study of a complete set of records for many aspects of fertility management shows that success is achieved by ensuring the interval to first service is kept low, and that the proportions of the herd that are served and that are finally got in calf is kept high. It is the integration of all the important parameters into sufficiently successful standards of performance that lead to a high CIA Calving Rate, and to a positive Fertex Score.

Those working as dairy farm advisers can help their clients by ensuring that individual animals are closely monitored, and that indices are calculated as the breeding season progresses. This allows the level of success to be determined while there is still time to make alterations.

The indices that are important are, the proportion served of calved (target 95%), the mean interval to first service (target 65 days), the overall pregnancy rate (target 55%), first service 24 day submission rate (target 70%), returns heat detection (target, 13 to 30 days, 65%).

CONCLUSION

There are now clearer pointers to ways of reducing losses in the national, and individual, dairy herd. By concentrating on raising the proportion of the herd served after calving, reducing the interval to first service (partly by raising the first service submission rate, but also by shortening the interval post partum to the earliest service date), farmers will raise the efficiency of milk production on their farms. Greater selection can then be applied in terms of choosing replacements; fewer unproductive cows and heifers will be kept, and more cows will have longer productive lives.

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ACKNOWLEDGEMENTS

The data for this study has been kindly provided by farmers and veterinarians. I am grateful to them, and to Erik Pasman, Research Fellow at the University of Reading, who has helped in the validation and tabulation of the material.

OVINE EPIDEMIOLOGY
AND PREVENTIVE MEDICINE

THE PREVALENCE AND CURRENT METHODS OF CONTROL OF SHEEP BLOWFLY STRIKE IN ENGLAND AND WALES

N.P. FRENCH*, R. WALL* AND K.L. MORGAN*

Blowfly strike is the cutaneous infestation of sheep by the larvae of blowflies. Current anxiety about the use of insecticides, coupled with concern about the traditional practice of tail docking, have prompted a re-evaluation of the methods of preventing blowfly strike. This paper describes the findings of three studies, each looking at different aspects of the epidemiology and control of blowfly strike in England and Wales.

METHODS

Prevalence study

Full details of the design and analysis of the prevalence study are given elsewhere (French et al., 1992). Briefly, a two page self administered questionnaire was sent to a random sample of 2451 sheep farmers, stratified into 5 regions (Fig. 1). The study population was all farmers in England and Wales with 50 or more sheep. Questions were asked about the blowfly seasons of 1988 and 1989.

Longitudinal study

A subsample of the 1988/89 survey (749 farmers), who had indicated a willingness to participate in a further study, were sent questionnaires in the form of recording sheets in April 1991. They were asked to record each case of blowfly strike, when and where on the body it occurred, and to give details of insecticide use, worming and shearing. Return envelopes were sent on 30.10.91 followed by 2 reminders.

Tail docking trial

A total of 3200 lambs on 7 farms in the south west of England were included in an intervention study of tail docking. On each farm, half of the lambs in the cohort were docked and half undocked. As each lamb reached docking age (usually within 48 hours of birth), they were ear tagged and then systematically allocated to docked and undocked groups according to whether the tag number was odd or even.

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Both health and production variables were monitored throughout the period of study. A thorough post mortem examination was carried out on all dead lambs and throughout the blowfly season all cases of blowfly strike observed by the farmers were recorded. Growth rates were measured to 1st worming and weaning and the presence and degree of faecal and urine staining were recorded at regular intervals. In this paper the relationship between tail docking and blowfly strike and tail docking and mortality will be described. In the analysis, cumulative survival rates were calculated for each week after tagging (Kirkwood, 1988). For incidence rates, the numerator was the number of new cases in each week and the denominator was the number of lamb-weeks of observation. Multivariate odds ratios (OR's) were obtained from logistic regression models using EGRET (SRC, Washington, Seattle)

RESULTS

Blowfly strike prevalence

The response rate to this survey was 74.2% and the usable return rate 66.8%. Details of the assessment of survey quality (repeatability, validity and non response) are given elsewhere (French et al,. 1992).

The proportion of all farmers reporting at least one case of strike in 1988 and 1989 was 77.5% and 80.0% respectively. Regionally this ranged from 58.6% in both years in the north of England to 89.9% in the south east of England in 1989 (Fig. 2). Although blowfly strike was reported by most of the sheep farmers surveyed, the annual proportion of sheep affected was low. The within flock prevalences were 1.5% and 1.6% of sheep struck in 1988 and 1989 respectively. These also showed a characteristic regional pattern, ranging from 0.7% of sheep in the north to 2.8% of sheep in the south west of England in 1989 (Fig. 3).

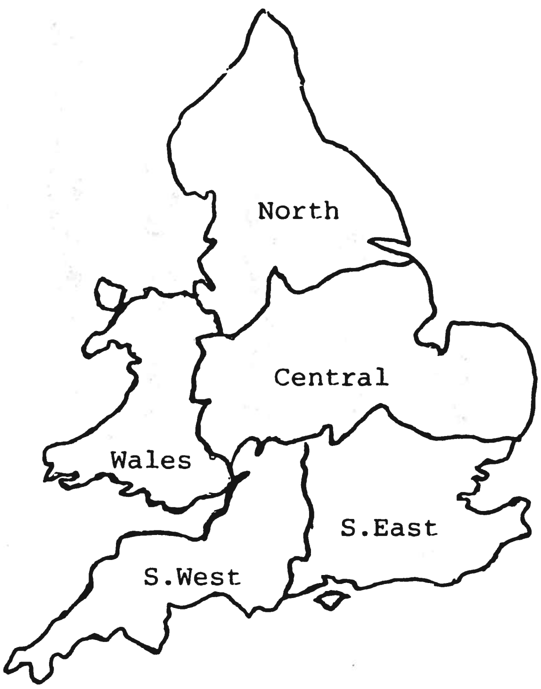

Fig 1. The 5 regions into which the sample of farmers was stratified.

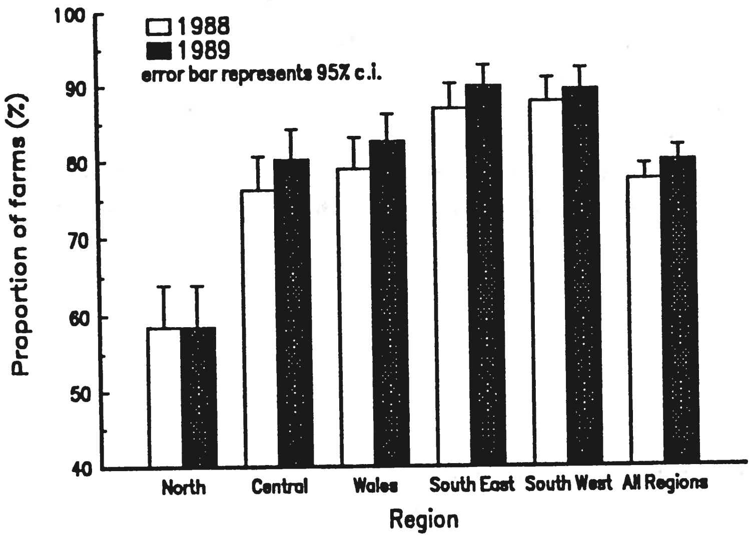

Fig 2. The proportion of farmers reporting strike (at least one case in 1988 and 1989)

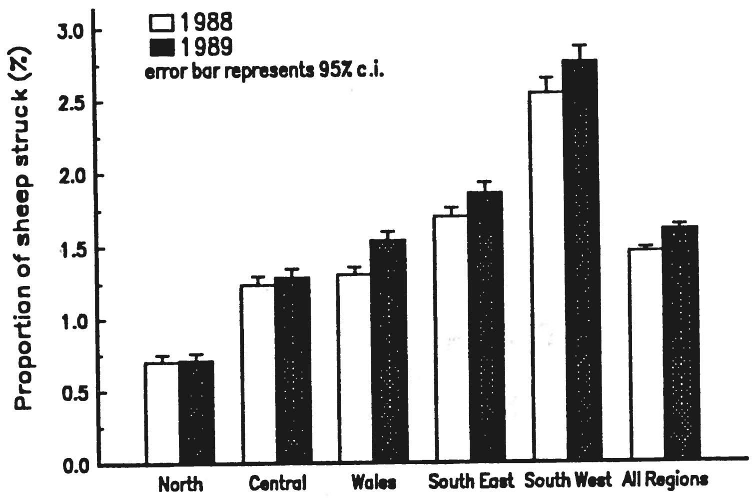

Fig 3. The proportion of sheep with strike in 1988 and 1989

<u>Blowfly strike control</u>

Farmers were asked about the methods they used specifically to control blowfly strike in 1988/89. Dipping was the most common, reported by 88.9% of farmers, followed by tail docking (75.2%), dagging or crutching (61.5%), spraying with organophosphates (OP's) (23.8%), and the use of Vetrazin (cyromazine, Ciba Geigy) (8.6%). The 3.9% of "others" included the use of regular worming, Jeyes fluid, and Maggot Oil (Battle, Hayward and Bower). These proportions refer to blowfly strike control only, some of these practices were carried out for reasons other than strike control. For example, dipping and tail docking were reported in total by

99.0% and 92.1% of farmers respectively.

Table 1. Methods of controlling blowfly strike in 1988/89 in England and Wales: the proportion of farmers reporting the of use of each method **specifically to control blowfly strike.**

Method of control	%	95 % confidence interval
Dipping	88.9	87.4 - 90.4
Tail Docking	75.2	73.1 - 77.3
Dagging or crutching	61.5	59.2 - 63.9
Spraying with OP's	23.8	21.7 - 25.8
Vetrazin (cyromazine)	8.6	7.3 - 10.0
Other	3.9	2.9 - 4.8

<u>Tail docking</u>

<u>Method of docking</u>. Rubber rings were by far the most commonly used method of tail amputation, reported by 86.4% of farmers. Of the remainder, 7.9% did not dock at all, 3.2% used knifes and 2.0% used either clippers, hot irons or Burdizzos. The age of lambs ranged from 1 day to 2 months, however, 90.3% of farmers reported docking within 48hours of birth.

<u>Tail docking and health - mortality:</u> In the field intervention study on tail docking, comparisons of the survival rates of docked and undocked lambs were carried out. The survival curves were similar on all farms. Figure 4 shows the survival curves for docked and undocked lambs on all farms for the period from tagging to 11 weeks, (after which the first lambs left the study to be slaughtered). The mortality rate of all lambs was greatest within the first week of life resulting in the sharp decline in the survival rate during this period. The decline continues over the following weeks and, although the two curves converge around 3 weeks after tagging, the survival rate of undocked lambs was higher throughout the period of study. The mortality of docked lambs was greater than undocked lambs on 5 of the 7 farms. However the difference between the groups was small (5.2% of docked lambs died between tagging and sale compared to 4.8% of undocked lambs, $p = 0.61$). The multivariate odds ratio was 0.90 (95% c.i. 0.65 - 1.25) (table 2).

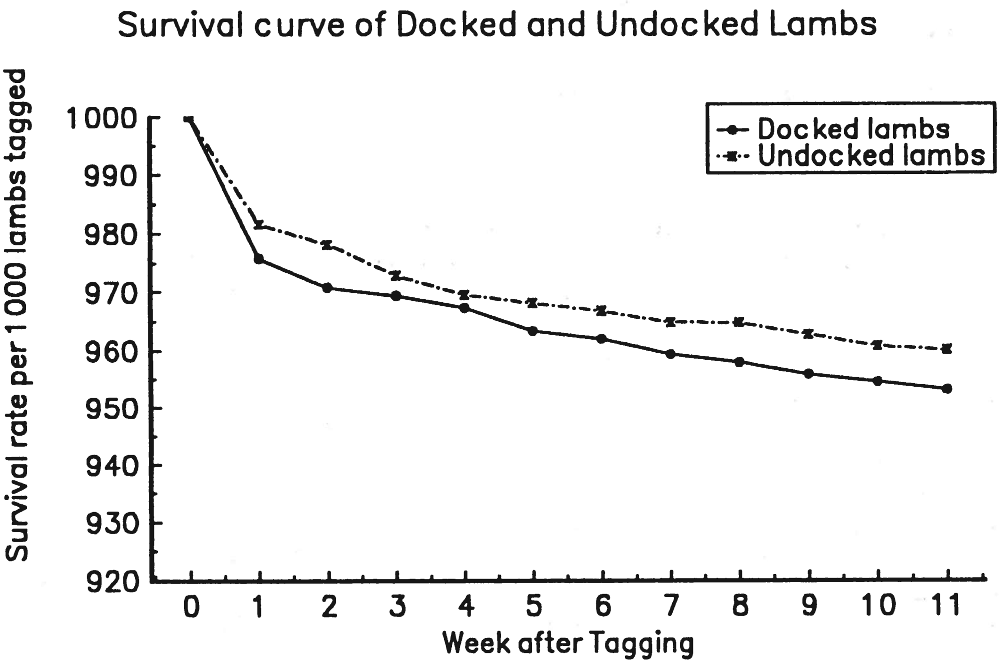

Fig 4. The weekly survival rates of docked and undocked lambs from tagging to 11 weeks of age, when the first lambs were slaughtered.

Table 2. The relationships between tail docking and two health variables; mortality between tagging and sale and blowfly strike.

Outcome variable	Proportion (%) of lambs		Multivariate O.R.	95% c.i.
	Docked	Undocked		
Death between tagging and sale	5.2	4.8	0.90[a]	0.65 - 1.25
Blowfly strike	1.3	6.5	4.80[b]	2.99 - 7.70

[a] adjusted for sex
[b] adjusted for sex and faecal soiling.

Tail docking and health - blowfly strike: The weekly incidence of blowfly strike was consistently higher in undocked lambs compared to docked lambs (Fig. 5). The incidence of strike was higher in undocked lambs on 6 of the 7 farms, the remaining farm had no cases throughout the fly season. The relationship was highly significant, only 1.3% of docked lambs were struck compared to 6.5% of undocked lambs (multivariate odds ratio 4.80, 95% c.i. 2.99 - 7.70, $p<0.001$) (Table 2).

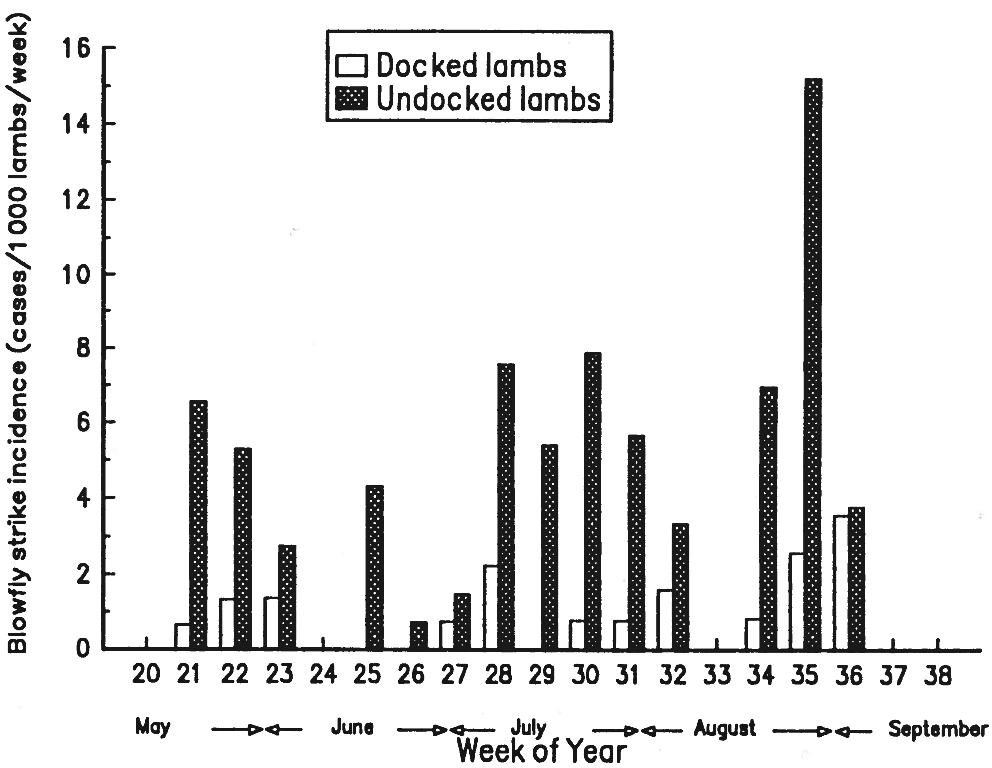

Fig 5. The weekly incidence of blowfly strike in docked and undocked lambs.

Insecticide use

In the 3 years studied (1988, 1989 and 1991), dipping was compulsory for the control of another sheep ectoparasite *Psoroptes ovis*, the cause of sheep scab. However, there was one important change in compulsory dipping policy that occurred between 1988 and 1989. In 1988 there were 2 compulsory dips, one in mid summer and one late autumn. In 1989, the compulsion to dip mid summer was removed, leaving only the autumn dip as mandatory. In all regions there followed a decline in the use of summer dipping with a subsequent increase in the use of spraying insecticide.

Longitudinal survey. Of the 749 farmers sent recording sheets, 542 replied (72.4%). Of these 495 were partially usable and 453 fully usable (usable return rate 60.5%). By 1991, more than half of the farmers that had participated in the longitudinal survey, had ceased the summer dipping of ewes and lambs (50.6% of farmers reported dipping just once in 1991, during the compulsory dipping period.) Conversely, spraying with insecticide had gained in popularity. Some 39.8% of the farmers in the 1991 survey reported applying insecticide by spraying (including pour-on) compared to 20.7% of the same group of farmers in 1988.

With the exception of flumethrin, all the dips licensed for the control of sheep scab contained the organophosphates diazinon and propetamphos. These two chemicals accounted for 89.3% of compulsory dips and 87.0% of summer dips in 1991 (Table 3). There was a greater range of non organophosphate spray or pour-on preparations available for the control of blowflies, including Vetrazin (cyromazine). This product was first available in the UK in 1989 and accounted for 29.1% of the spray or pour-on preparations in the 1991 survey. However, in spite of these alternative products, 53.9% of preparations used, were organophosphates (Table 4).

Table 3 .The proportion of different insecticides used in summer, compulsory and all dips

	Insecticide use (% of dips)		
Insecticide	Summer	Comp	All
[a]Diazinon	47.7	52.9	50.7
[a]Propetamphos	39.3	36.4	37.6
[b]Flumethrin	0.3	5.3	3.1
[a]Chlorphenvinphos	5.1	0.2	2.1
[b]Cypermethrin	0.6	0.0	0.2
Unknown	7.0	5.1	6.3

[a] Organophosphate dips
[b] Pyrethroid dips

Table 4 The proportion of different insecticides used for spraying sheep (including "pour on").

Insecticide	% of sprays
[a]Cyromazine	29.1
[b]Diazinon	25.9
[b]Chlorphenvinphos	15.4
[b]Propetamphos	11.9
[c]Cypermethrin	1.0
[b]Coumaphos	0.7
Jeyes Fluid	0.5
Gamma BHC	0.2
[c]Deltamethrin	0.2
Unknown	14.9

[a] Insect growth inhibitor - Vetrazin Ciba Geigy
[b] Organophosphate
[c] Pyrethroid

<u>The timing of insecticide application</u>: Figure 6 shows the seasonal pattern of sheep dipping in 1991, from the longitudinal survey. The proportion of sheep dipped in each week showed a distinctive bimodal pattern, with a small mid summer peak and a larger autumn peak. The smaller peak in dipping activity occurred in July and corresponded with the largest peak in blowfly strike incidence. The proportion of sheep sprayed in each week also

followed the pattern of flystrike incidence throughout the summer. On most of the farms surveyed (64.5%), insecticide was applied after the first cases of strike had been recorded. On 49.2% of farms, cases of blowfly strike had been observed more than one week before dipping or spraying was employed.

The compulsory dipping period started on 22.09.91 (week 39) and ended on 02.11.91 and can be seen as the larger peak in autumn. In the first 2 weeks of the compulsory dipping period, 39.7% of ewes and 43.9% of lambs were reported to have been dipped

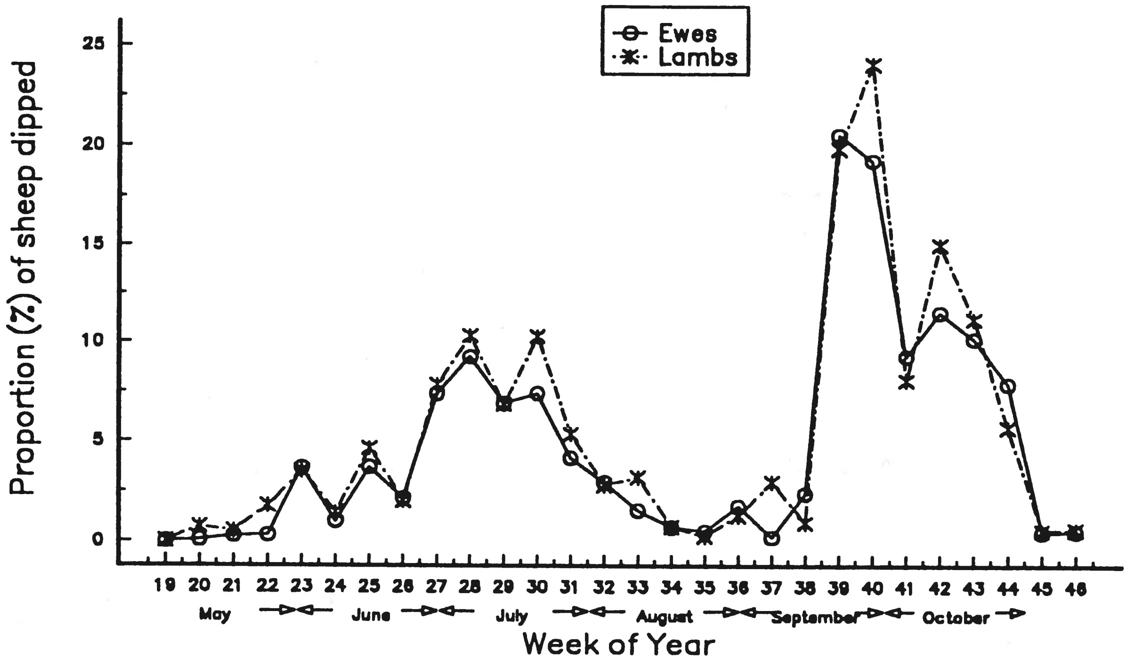

Fig 6. The proportion of sheep dipped in each week in England and Wales

CONCLUSIONS

Blowfly strike occurs on a large proportion of sheep farms in England and Wales, although the proportion of sheep affected is low. There is a distinct regional pattern, with the north of the region experiencing fewer cases than the south and west. Control of the problem relies largely on the use of insecticides in response to an initial challenge, and the use of measures such as tail docking and partial breech shearing to control faecal soiling.

There is concern about the welfare aspects of tail docking. Recent studies have demonstrated the behavioural and physiological responses of lambs to the acute pain associated with tail amputation (Wood & Malony 1992). The effect of different lengths of docked tail on susceptibility to blowfly strike has been examined in Australia (Riches, 1941), however none of these studies appear to have included undocked lambs as controls. In addition, there have been few studies investigating the effects of docking on health and productivity. The intervention study of tail docking, conducted in the south west of England, clearly showed an increased risk of strike in undocked lambs compared to docked lambs. As far as the authors are aware, this is the first published report of this finding. The study also found no significant difference between docked and undocked lambs in terms of mortality. However, mortality was higher in docked lambs on 5 of the 7 farms, suggesting there is a need for further examination of the effects of this procedure on mortality and morbidity.

There is much concern in the sheep industry about the use of insecticides, particularly organophosphates. There is no longer compulsory dipping for the control of sheep scab in the United Kingdom. However, in 1991 when the autumn dip was still mandatory, around 40% of the sheep population on the study farms were dipped within a 2 week period. The contamination of natural watercourses with insecticides, associated with sheep dipping, has already been reported (Littlejohn & Melvin, 1991). The short, intense periods of dipping activity reported here may result in an increased risk of environmental contamination and should be a serious consideration if such a policy were to be reintroduced.

Many sheep farmers are concerned about the possible effects of exposure to sheep dips on their own health. In a recent report, 154 of 227 reported human suspected adverse reactions were associated with the use of sheep dips (VMD, 1992). This reason alone may account for much of the observed shift away from dipping towards spraying and the use of pour on preparations. However, 53.9% of the preparations used for spraying contained OP's. This may reflect a higher cost of alternatives, a lack of awareness of the type of insecticide farmers were using, or the narrow range of activity of products such as the insect growth inhibitor Vetrazin (specific for blowflies only).

The seasonal pattern of insecticide use, reported in the 1991 survey, suggested that most farmers dipped and sprayed in mid summer, in response to a blowfly strike problem. Used in this way, insecticides will control strike by reducing sheep susceptibility, but are unlikely to have much effect on fly abundance. In Britain, *L. sericata* abundance follows a distinctive seasonal pattern. The first, small generation of flies that emerge in the spring give rise to much larger fly waves later in the season (Wall et al,. 1992). Using insecticide in advance of a strike problem, when fly abundance is low, may be a more efficient way of reducing blowfly abundance and hence strike incidence (McKenzie & Anderson, 1990).

The studies described in this paper describe the prevalence and geographical distribution of blowfly strike in England and Wales and give an assessment of the methods currently used to control the problem. They were conducted at a time when compulsory dipping policy was changing. With procedures such as dipping and tail docking being increasingly questioned, there is clearly a need for the development of alternative control strategies.

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THE SHEEP BLOWFLY, *LUCILIA SERICATA*: ITS ECOLOGY AND FUTURE METHODS OF CONTROL

R. WALL, N.P. FRENCH* & K.L. MORGAN*

The range of powerful insecticides currently available provide the means of controlling the vast majority of insect pests and parasites of veterinary importance. However, reliance on these chemicals brings with it a number of associated problems. These include the development of resistance by the target pest species, a variety of unintentional effects on non-target organisms and the environment, the presence of pesticide residues in food and high costs both of development and deployment. As a result, there is growing concern that in the future the judicious use of chemicals must be supplemented by the development of a range of non-insecticidal techniques for pest and parasite control (Strong & Wall, 1990).

The collection of detailed information relating to the behaviour, physiology and genetics of the species to be controlled is an essential first step in the development of any such novel control technique. In addition, basic ecological information is also needed relating to the seasonal fluctuations, rates of population increase and, in particular, the nature of the factors limiting abundance.

The aim of the work described in this paper was to examine the ecology of the sheep blowfly *Lucilia sericata* Meigen (Diptera: Calliphoridae) and to provide the background information necessary to allow new approaches to flystrike control to be considered.

BLOWFLIES AND FLY-STRIKE

In temperate Northern Europe, sheep blowfly-strike is caused predominantly by *L. sericata* (MacLeod, 1943; Wall *et al.*, 1992a); a metallic-green, medium-sized fly of about 5-10 mm in length. Adult female *L. sericata* lay batches of about 200 eggs in the fleece of sheep, close to the skin, often choosing breech areas soiled by faeces (Cragg, 1955). After hatching, the larvae pass through three instars, feeding on epidermal tissues and skin secretions (Evans, 1936).

The feeding activity of the larvae causes extensive tissue damage and allows invasion of the wound by other insects and bacteria. Attack by blowfly maggots results in considerable distress to the struck animal, reduced weight gain, loss of fertility (Heath *et al.*, 1987) and, if untreated rapidly leads to death from chronic ammonia toxicity

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(Guerrini, 1988). Mortality rates of up to 10% have been recorded in severe epidemics (Liebisch *et al.*, 1983).

On completion of feeding, third instar larvae migrate away from the strike focus, eventually dropping to the ground where, after a period of dispersal, they pupariate. Adult flies emerge at the end of pupation when metamorphosis is complete. As their oocytes develop, adult females mate, seek out the initial protein meal which is required to complete the maturation of their first batch of eggs, and subsequently search for a suitable oviposition site to begin the cycle once again (Fig. 1).

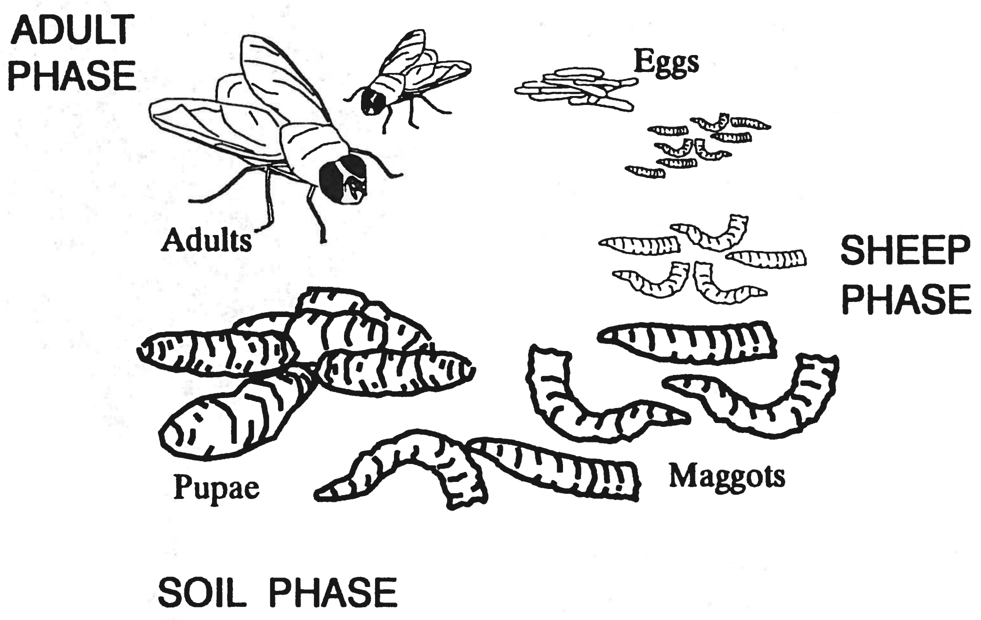


Figure 1. The life-cycle of the sheep blowfly *Lucilia sericata*.

The first generation of *L. sericata* emerge in spring and flies are present until the end of summer. In temperate Northern habitats, the offspring of the final generation to emerge in late August or early September cease development mid-way through the third instar wandering phase. These larvae diapause overwinter in the ground (Davies, 1929). In early Spring, when diapause has been broken, they migrate to the surface and by the end of March can be found in the top 1 cm (Davies, 1934). They then complete a short period of pre-puparial development and pupate, before emerging as the year's first cohort of adults.

METHODS

A variety of trap types have been used previously to catch blowflies in Britain (Holdaway, 1933; Cragg & Rammage, 1945; MacLeod & Donnelly, 1956). However, in the present study simple, sticky targets were used to sample field populations of *L. sericata*.

Targets

Targets were constructed from 41 cm sided squares of aluminium sheet, covered by white polyester cloth. A mounting bracket was bolted to one corner and a piece of 1.3 cm diameter dowelling was inserted into this bracket. In the field, the completed target formed a vertical diamond with the base about 20 cm above ground level (Fig. 2).

Both sides of all targets were coated in Oecotak[R] A5 (Oecos Ltd.) a polybutene based, non-setting adhesive (Ryan & Molyneux, 1981). Each target was baited with a drinks can half filled with lambs liver covered by sodium sulphide solution (approximately 10% w/v). Bait cans were wired to the target and a netting cover was fitted over each can top and held in place with an elastic band, to exclude insects.

Previous work has shown that the number of *L. sericata* caught by these targets is positively related to target surface area and is dependent on target colour. This work found that white followed by yellow coloured targets consistently caught the greatest numbers of *L. sericata* while red followed by blue caught the least. More detailed analysis of these data showed that catch was related negatively to reflectivity in the 300-450 nm (ultra-violet/blue) band of the spectrum and positively to the reflectivity in the 450-580 nm (blue-green-yellow) band (Wall *et al.*, 1992b).

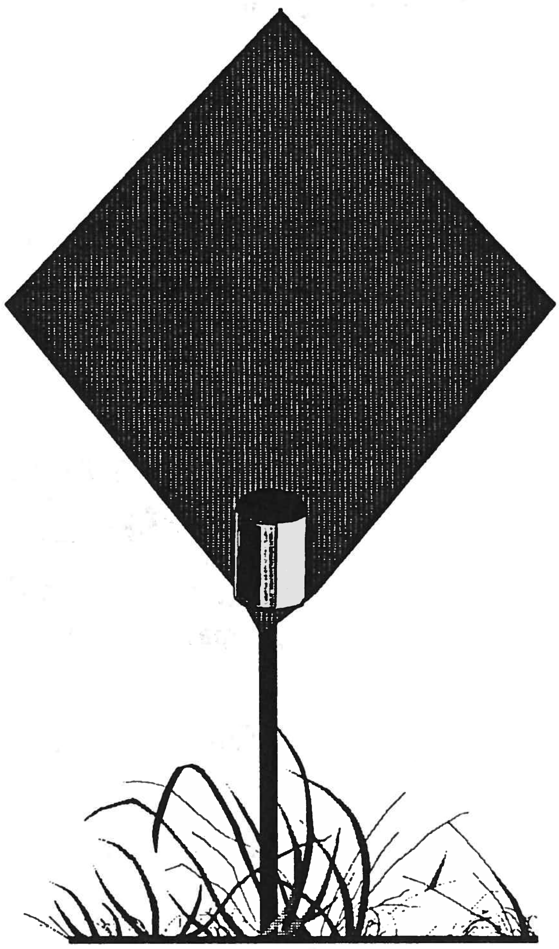


Figure 2. A blowfly target

Population sampling

The targets described were used to examine the distribution and relative seasonal abundance of *L. sericata* populations in sheep pastures over three years. Field work was carried out at the University of Bristol farm at Langford near Bristol.

In 1990, two sites, approximately 1.5 km apart, were sampled simultaneously. Site 1 was at the southern end of the farm. In this year the pasture at site 1 was used for silage and was grazed only intermittently by cattle and sheep from late summer onwards. For the purposes of this study, therefore, site 1 is classified as a low sheep availability area. In the Spring of 1990, the University flock of approximately 250 ewes and their lambs were turned out into fields at the northern end of the farm - site 2, which was classified as a high sheep availability area. The ewes grazed fields in this area almost continuously until late summer and intermittently thereafter. Lambs remained with the ewes until weaning in May/June after which they were removed and generally grazed fields lying between the two sites. In 1991 the pattern of pasture use was similar, but in 1992 pastures at site 2 were grazed more heavily and earlier in the season.

In 1990, six targets were put out in a randomised sequence 100-150 m apart, around the edges of two, approximately 2 hectare fields at site 1. An identical six targets were also put out in two similarly sized fields at site 2. In 1991 six targets were put out in a similar manner around the edges of the same two fields at site 1 only. Finally, in 1992, five targets were put out around the edges of two fields at site 2 only.

In all years targets were examined at approximately 72 hour intervals. At each inspection all green-coloured Diptera were removed, returned to the laboratory and washed in white spirit to remove the polybutene. All *Lucilia* were counted and *L. sericata* were identified and sexed. At approximately 10 day intervals the liver bait was renewed, all targets were cleared of fly corpses and fresh Oecotak was applied. Shade temperature was measured at 30 min. intervals throughout the spring, summer and autumn of each year at a computer-linked weather station.

At Wyndhurst farm, in 1990 all ewes were dipped in diazinon organophosphate insecticide (Topclip^R, Ciba-Geigy) in mid July and late September. In the same year all lambs were treated with a pour-on cyromazine larvicide (Vetrazin^R, Ciba-Geigy) in April. In 1991, all lambs were treated with cyromazine at the end of May and July and all ewes were dipped in diazinon organophosphate in September. In 1992, both lambs and ewes were given only a single treatment with cyromazine in mid August.

RESULTS

Target catches

In 1990, the targets at site 1, caught a total of 4,776 *Lucilia*, 646 (13.5%) of which were *L. sericata*. Of the *L. sericata* caught 469 (71.8%) were female. Over the same period at site 2, the six identical targets caught a total of 9,873 *Lucilia* spp., 1,644 (16.6%) of which were *L. sericata* and 1,230 (74.8%) of the *L. sericata* caught were female.

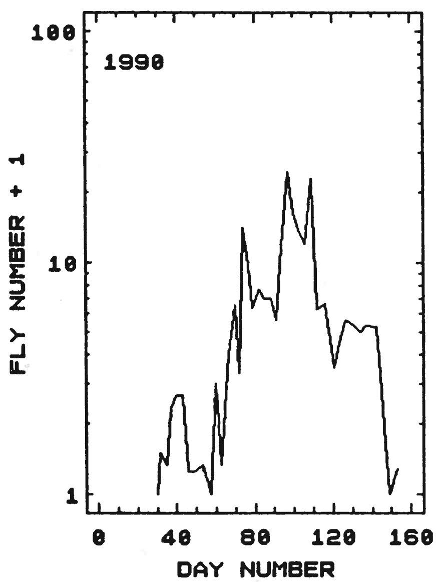
To quantify distribution of flies in the field, the variance of the number of *L. sericata* caught by each individual target in 1990 was plotted against its mean catch on $\log_{10}$ scales. The slope of this regression gives an estimate of the index of aggregation (Taylor's Power Law, b) (Southwood, 1976). Over the entire field season, the index of aggregation calculated was 1.59 at site 1 and 1.57 at site 2. This indicates that the distribution of flies in the field, reflected by the target catches, was distinctly aggregated or contagious. The index of aggregation increased only slightly over the course of the field season. Logarithmic transformations ($\log_{10}(n+1)$), therefore, have been applied to the data to stabilise the variance for subsequent statistical analyses.

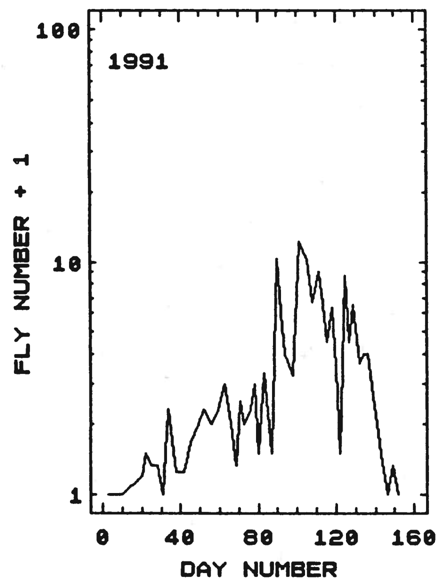
Similar aggregated distributions have been noted in previous trapping studies. They may be due to habitat preferences within the vegetational mosaic, as suggested by MacLeod and Donnelly (1956, 1957) or to the existence of flushes of emerging adults originating from a single strike, resulting in temporary local population concentrations as suggested by Wall *et al*., (1992b).

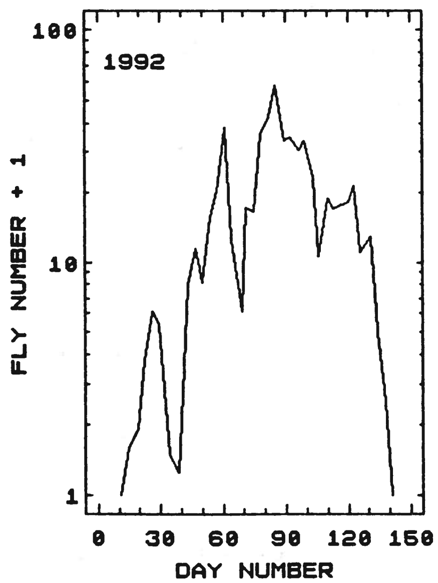
Seasonal abundance

The number of *L. sericata* collected at each inspection at each site were pooled and divided by the number of days since the last inspection to give a daily catch value and adjust for differences in sample interval. Target catches made in 1992 were multiplied by 1.2 to correct for the fact that 5 rather than 6 targets were used in that year.

In 1990, targets were first deployed on 25th May. However, temperature measurements and the pattern of sheep fly-strikes at Wyndhurst that year indicated that the first cohort of adults had already emerged in the field before this date. At site 1, the target catches show that in 1990 the population increased in abundance throughout the spring, reached its maximum size by about day 90 before declining at the end of the field season (Fig. 3.). The pattern of fly abundance recorded at site 2 in 1990 will be discussed later as a special case. In 1991, the targets were first deployed on the 3rd of May and the first *L. sericata* were caught on the 20th of May (Fig. 4). The numbers of *L. sericata* caught remained low throughout spring, eventually rising to peak at about day 100, before falling rapidly at the end of the season. In 1992, the targets were first deployed on the 7th of May and the first *L. sericata* were caught on the 15th of May (Fig. 5). The *L. sericata* population increased more rapidly than in the previous year, reached its peak by about day 100 and declined slowly at the end of the season. The numbers of flies caught per day in 1992 at Site 2, was significantly higher than at Site 1 in the previous 2 years.







Numbers of *Lucilia sericata* caught per day (+1), where day 1 is the 1st of May.

Figure 3 = 1990,
Figure 4 = 1991,
Figure 5 = 1992.

MODELLING THE PATTERN OF SEASONAL ABUNDANCE

To attempt to account for the changes in abundance seen over each of the three years of the study, a model which could simulate seasonal blowfly population growth was constructed (Wall *et al.*, 1992c, 1993a,b). The first stage in the development of this model was the examination of the effects of temperature on the rate of life-cycle development.

Effects of temperature

In the climatically stable environment experienced in the fleece, egg incubation takes between 10-12 hours and completion of the larval feeding stage 2.5 days, regardless of changes in ambient temperature (Wall *et al.*, 1992c). Once off the sheep the duration of each subsequent life-cycle stage becomes far more variable, since the rates of growth and development are highly dependent on the ambient temperature experienced.

Analysis of the rate of development of each post-feeding *L. sericata* life-cycle stage at a range of temperatures in the laboratory, allows the duration of each to be quantified in a temperature-independent manner. This is done by plotting the reciprocal of the time taken for 50% of individuals to complete each developmental stage against a range of temperatures, examined experimentally. Linear extrapolation of the positive regression is used to provide an estimate of the theoretical base-temperature (Van Kirk & Aliniazee, 1981; Collier & Finch, 1985). This is the temperature below which no development occurs. The difference between the base and the ambient temperature, multiplied by the time required for 50% of individuals to complete the developmental stage at any given temperature, gives the number of day-degrees that are necessary for completion of that stage (Hughes, 1962; Collier & Finch, 1985; Wall *et al.*, 1992c).

Such analysis shows that all pre-adult stages require a base-temperature of approximately 9°C. Completion of the larval wandering stage requires an average of 45 day degrees and pupation an average of 126 day degrees above 9°C. The period of post-diapause larval development, prior to spring pupation, requires 28 day-degrees above 9°C. The base temperature for oocyte maturation is approximately 11°C and 62 day-degrees above this are required for development of the first egg batch and 27 for the second and any subsequent egg batches (Wall *et al.*, 1992c).

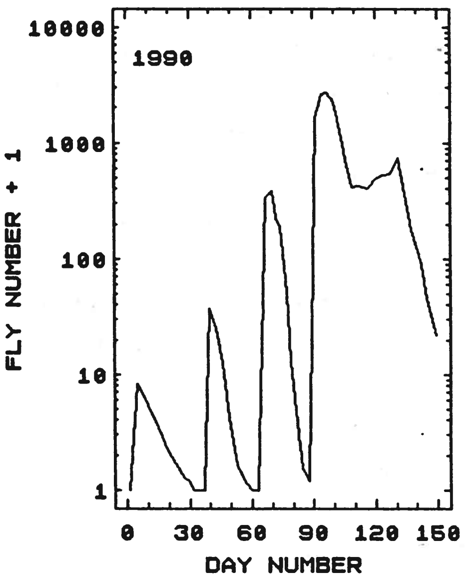
Model development

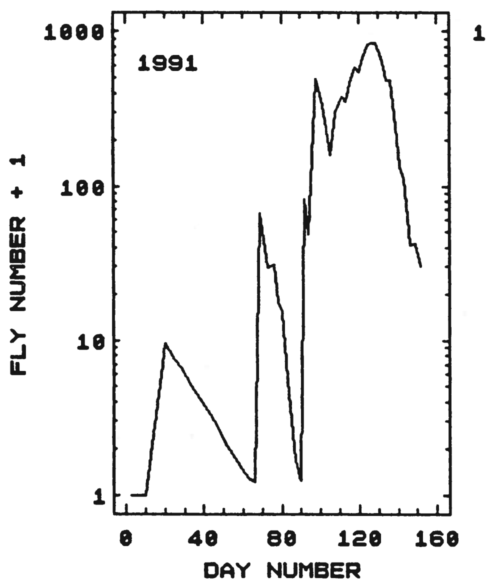
The base-temperatures and day-degree requirements can now be used to construct the simulation model. Initially, a third order polynomial is fitted to the average daily temperatures recorded during each year of the study, and the equation is used by the model to calculate the number of day-degrees available to each life-cycle stage on each day during each year. Using this data, the date of spring emergence and the rates of development of each life-cycle stage are computed and the dates of subsequent emergence and ovipositions determined.

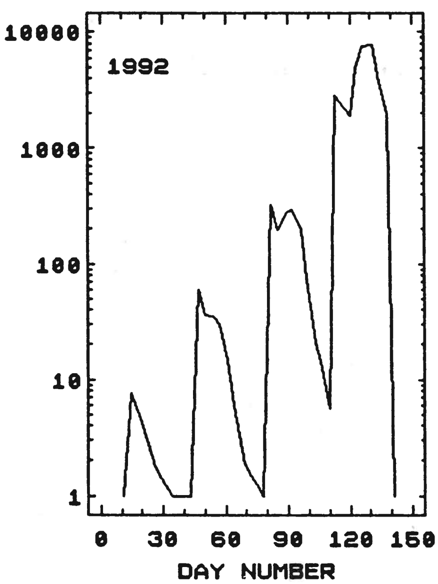
A daily rate of adult mortality is imposed which allows 8% of females reach a first oviposition, 3.5% reach a second and 1% reach a third. This mortality schedule is based on *L. sericata* population age-distributions observed in the field. All reproducing adult females are allowed to produce 200 eggs at each oviposition. As a result, the number of individuals entering each successive generation is the product of the number females surviving to each oviposition and the number of eggs oviposited. The simulation imposes a standard 50% egg to adult mortality and assumes that surviving larvae give rise to equal numbers of male and female adults. For more detail about the construction and operation of the model see Wall *et al.*,(1992c, 1993a,b). The model output gives an estimate of the expected relative abundance of *L. sericata* on each day of each of the three field seasons (A_1).

Model simulations

In the simulations, for 1990 the date of spring emergence was taken as the 1st of May, based on the first reports of flystrike by farmers. In the subsequent 2 years, the first emergence date was taken as the day on which the first *L. sericata* were captured in the field. The results show that in 1990, the *L. sericata* population would have been expected to pass through four discrete generations, increasing exponentially to reach its peak in the fourth generation by day 100 (Fig. 6). A relatively small number of individuals forming a fifth generation also would have been expected. However, most of the offspring from the fourth generation of adults would have entered diapause. In 1991, because of the lower spring and autumn temperatures recorded, only three generations of adults would have been expected to emerge in the field, reaching peak abundance in the third generation by day 130 (Fig. 7). In 1992, once again four generations would have been expected, with peak abundance achieved by the fourth generation at about day 130 (Fig. 8).





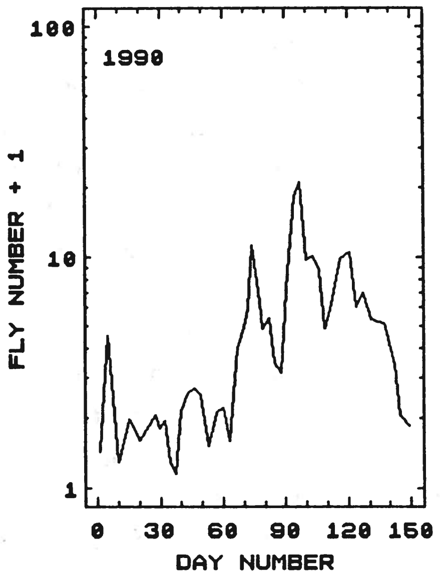


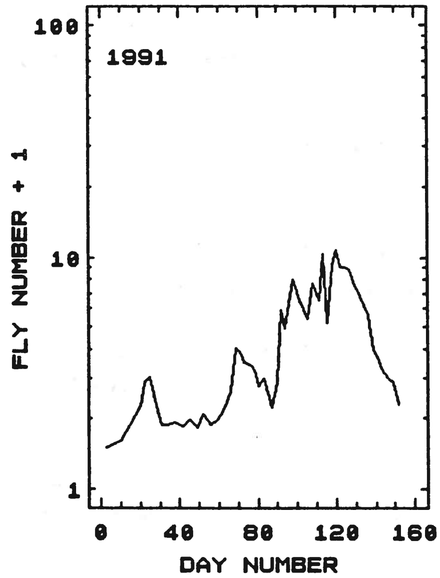
Expected relative abundance (+1) of *Lucilia sericata* plotted against day number, where day 1 is the 1st of May.

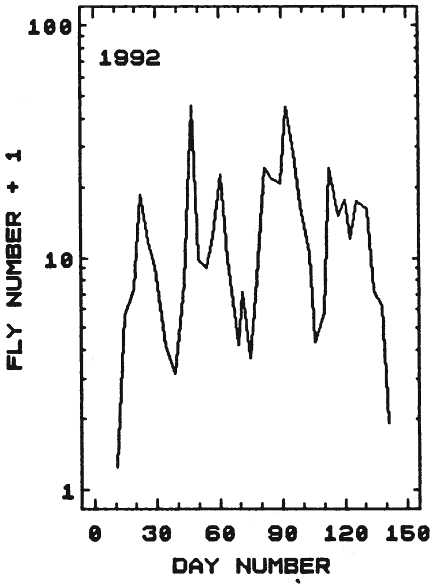
Figure 6 = 1990, **Figure 7** = 1991, **Figure 8** = 1992.

However, the number of flies caught is dependent not only on the underlying dynamics of the population, which determines how many flies are available for capture, but also in the short-term on the levels of fly activity. Such activity levels are strongly dependent on the variation in temperature over each catching interval (Vogt *et al.*, 1983). For example, even during a period of high relative abundance, low temperatures may depress fly activity and result in a low target catch. It is necessary to correct for this effect, therefore, before the simulation model output can be compared directly with the number of *L. sericata* caught in each year.

To assess the effects of daily variation in temperature on catch, the expected relative abundance (A_1) derived from the simulation model and the average temperature (T) over the 2-4 day intervals between catches are regressed as independent variables against the number of *L. sericata* caught. The resulting regression constant and coefficients are then used to determine the expected catch (A_2) in each year. The resulting expected catch for 1990, 1991 and 1992 are shown in Figs 9, 10 and 11. The expected catch (A_2) is able to account for 67.3%, 52% and 49% of the variance in observed catches made in 1990, 1991 and 1992, shows in Figs 3-5. The predictive ability of the model can be validated by using the regression constant and coefficients calculated for any one year to explain the catch in subsequent years (Wall *et al.*, 1993b).







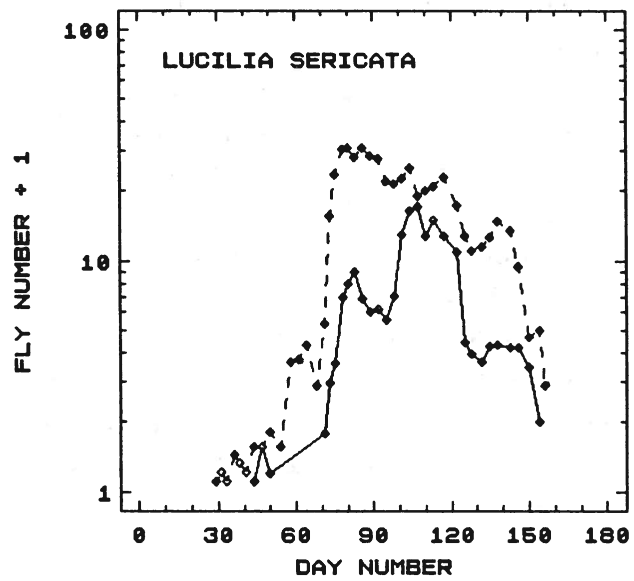
Expected catch (A_2) (+1) of *Lucilia sericata* plotted against day number, where day 1 is the 1st of May.

Figure 9 = 1990,
Figure 10 = 1991,
Figure 11 = 1992.

Effects of dipping on fly abundance

The catches of *L. sericata* made in 1990 at sites 1 and 2 are compared in Fig. 12. As shown previously, at site 1 the pattern of increasing *L. sericata* abundance can be adequately explained as the passage of successive generations, peaking at days 50, 90 and 120. At site 2, the high sheep availability site, the absolute numbers of *L. sericata* caught were initially higher than at site 1 and the *L. sericata* population increased more rapidly, eventually being some 3 times higher by day 90. However, contrary to the predictions of the day-degree model and in contrast to the pattern of increasing abundance seen at site 1, after day 80-90 the *L. sericata* population at site 2 started to decline steadily. At day 90, the population at site 2 had fallen to equal that at site 1.

The difference in the pattern of abundance of *L. sericata* between the two sites in 1990 can be explained by the availability and susceptibility of sheep in that year. The higher *L. sericata* density and population growth rate was associated with the relatively high availability of sheep at site 2 but not at site 1 and the onset of the unexpected fall in the *L. sericata* population at site 2 coincides closely with the date on which all the ewes were first dipped in 1990. That the decline in *L. sericata* population was not due to any change in suitability of the site for flies can shown by comparison of the pattern of abundance of *Lucilia* species excluding *L. sericata*. At both sites in 1990, the *Lucilia* abundance shows two major peaks, at about day 90 and days 140 (Fig. 13). At neither site did the numbers of *Lucilia*, excluding *L. sericata*, show any consistent decline as seen in the *L. sericata* population at site 2.



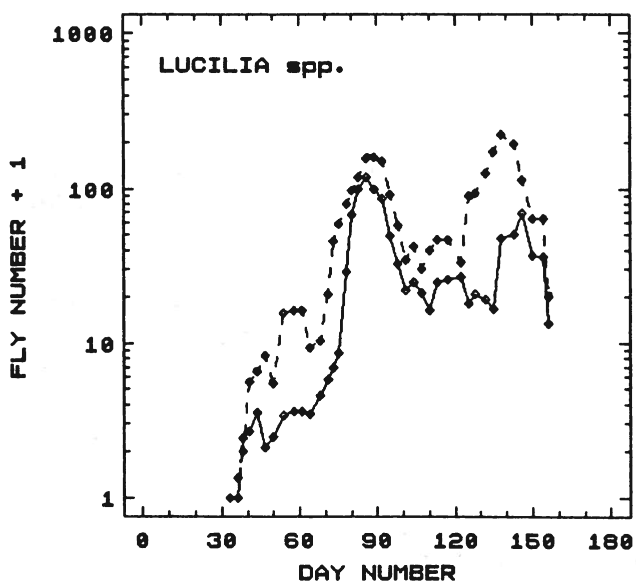


Figure 12. Number (+1) of *Lucilia sericata* caught per day in 1990.

Figure 13. Number (+1) of *Lucilia spp.*, excluding *L. sericata*, caught per day in 1990.

Open symbols = site 1, solid symbols = site 2. All data smoothed by 3 point sliding means.

DISCUSSION - FUTURE CONTROL

In England and Wales most of the control methods currently used aim to reduce sheep susceptibility to blowfly-strike by killing eggs and feeding larvae and to reduce the number or suitability of available oviposition sites on the sheep. This is achieved through the direct application of insecticide or other larvicide such as cyromazine, or by procedures such as tail docking or dagging. Little consideration has previously been given to the effects of these management practices on *L. sericata* populations or the possibility of strike control by blowfly population suppression.

The results of the present studies have shown that *L. sericata* exist at low population densities relative to other species of Calliphorid blowflies; only 13-16% of the total number of *Lucilia* spp. caught were *L. sericata*. This supports previous findings which have shown that trap catches of Calliphorid blowflies are generally composed predominantly (50-90%) of *Calliphora vicina* R.D. and that *L. sericata* may be up to 7 times less abundant than *L. caesar* (MacLeod & Donnelly, 1957). The results have also shown that the numbers of *L. sericata* caught were relatively higher in areas grazed more heavily by sheep and that in these areas *L. sericata* were distributed in an aggregated or contagious pattern throughout the season. The decline in the *L. sericata* population in the sheep pastures following dipping suggests that *L. sericata* is highly dependent on sheep as its living host. The fact that dipping did not appear to result in any decline in the *L. sericata* population in the low sheep availability pastures, even though the two sites were only 1.5 km apart, also suggests that dispersal may be slow.

Clearly these conclusions need to be supported by wider scale replication. Nevertheless, the low population densities of adult *L. sericata* relative to other *Lucilia* species, their aggregated distributions and dependence on sheep as a host, suggest that it may be possible to suppress *L. sericata* populations in sheep pastures without large-scale immigration. The success of this type of control would depend critically on the density-dependence of the factors limiting *L. sericata* abundance, which might be relaxed as densities were reduced. The nature of these factors are unknown at present for *L. sericata*. Successful control of fly-strike by *L. cuprina* in Australia by trapping adult flies has been reported previously, but this approach was found to be too labour intensive and expensive to be of practical value in strike control at that time (Mackerras *et al.*, 1936). The form of target catching device developed in the present study is considerably simpler in design and hence easier and less expensive to construct and deploy than conventional blowfly traps or bait systems (Wall *et al.*, 1992b). The further development of simple, visual targets for *L. sericata*, impregnated with insecticide, particularly if baited with long-lived, concentrated, synthetic odours, therefore, may have considerable potential for blowfly population suppression.

In Britain insecticidal treatment for blowfly strike usually occurs in late July or early August in response to high blowfly populations and rising strike levels (French *et al.*, 1992). Hence, treatment usually occurs after high blowfly populations and problem strike levels have been reached. It is, therefore, relatively inefficient, has minimal impact on the fly population and must protect the sheep through a period of high strike challenge. The model developed here was shown to be capable of simulating blowfly population dynamics with a relatively high degree of accuracy. Using this model it has been possible to explore a range of control options. This analysis has shown that early Spring control, with conventional insecticide or with targets to kill adult flies, would maintain the blowfly population at a substantially lower density than a similar percentage kill at any other time in the season (Wall *et al.*, 1993a). The effectiveness of such strategic early-season mortality was first suggested for use in Australia by Mackerras *et al.* (1936) and has subsequently been supported by work in Australia (McKenzie & Anderson, 1990). The use of early-season strategic control depends on being able to predict the timing of first Spring emergence, This is now possible, using the model developed here given appropriate temperature measurements.

In conclusion, the work reported here has gone some way in the development of a simple and effective target catching system and has developed a simulation model which can be used to predict fluctuations in blowfly abundance and explore the effects of a range of control options. The results suggest that the management of blowfly populations may present a range of viable alternative methods for fly-strike control. Such a management policy is now possible and its implementation would mark a new approach to the control of blowfly strike.

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BLUETONGUE VIRUS VECTORS: A EUROPEAN PERSPECTIVE

P. RAWLINGS*

Bluetongue (BT) is an arthropod-borne virus disease of sheep and other ruminants. Serious outbreaks of the disease have occurred in Europe, notably in Spain and Portugal between 1956-60 (Campano Lopez & Sanchez Botija, 1958). During this period no entomological investigations were carried out to determine the identity of the arthropod vector(s) responsible for the transmission of the disease agent. However, elsewhere it had already been established that BTV and the related African horse sickness (AHS) virus were usually transmitted by various species of biting midge of the genus *Culicoides* (Du Toit, 1944).

In 1987 a serious outbreak of AHS started in central Spain (Lubroth, 1988) and spread in succeeding years to southern Spain (Anon, 1990) and Portugal and thence to Morocco (Anon, 1992). Vectors studies showed that the abundance and distribution of one particular species of *Culicoides* (*C. imicola*) closely followed the patterns of AHS incidence in Iberia, and AHSV was isolated from this same species on a number of occasions during the course of the disease outbreaks (Mellor *et al*, 1990, Mellor, 1991). It appeared that the principle vector of AHS in Iberia was the same species which was responsible for both these diseases in Africa (Du Toit, 1944; Mellor *et al*, 1984; Walker & Davies, 1971; Wetzel *et al*, 1970) and BT in the eastern Mediterranean (Braverman, 1989). By implication, *C. imicola* was also then presumed to be the vector responsible for the BT outbreak in the 1950s, which occurred in similar districts to the AHS outbreak 30 years later (Mellor, 1993).

However, during the AHS outbreak in the late 1980s, AHSV was also isolated from mixed samples of two other species of *Culicoides*, *C. obsoletus* and *C. pulicaris* (Mellor *et al*, 1990). Furthermore, *C. obsoletus* had previously been shown to be infected with BT virus in Cyprus (Mellor & Pitzolis, 1979). It seems probable that *C. obsoletus* was also involved in the AHS and BT outbreaks in Iberia. Perhaps significantly, *C. obsoletus* and *C. imicola* belong to the same sub-genus, *Avaritia*, along with other European members of the *obsoletus* group (*C. chiopterus*, *C. dewulfi* and *C. scoticus*) (Kremer & Rebholz, 1977).

The probability that *C. obsoletus* is involved in BT transmission affects the potential significance of this exotic virus disease for Europe. Although *C. imicola* appears to be an efficient vector (Venter *et al*, 1991) of both BTV and AHSV wherever it occurs, its mainland Europe distribution is quite restricted (Fig. 1). The ability of *C. imicola* adults to survive the northern winters is very limited; this species being mainly tropical. The initial outbreak of AHS near Madrid was not able to overwinter whereas the subsequent outbreaks in the warmer southern provinces of Cadiz, Huelva and Seville did. The viraemia of AHS-infected hosts is short (<27days; Erasmus, 1973), so unless adult *Culicoides* are present almost all the year round, AHS epizootics will not persist from year to year. In the case of BT, viraemia in sheep is again short lived (generally five to 10 days, perhaps as long as 30 days) but it can persist up to 100 days in cattle (Gard, 1987). For the disease to overwinter in

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palaearctic climates either the viraemia needs to be long or infected adult *Culicoides* to be present for much of the winter period so that new adults can be infected before the short-lived viraemias die away. If overwintering occurs, the virus can infect additional susceptible animals and spread to new areas once the new vector season begins. In this event, an epizootic may appear to end in the autumn but then resurgence occurs as *Culicoides* abundance rises the following year.

THE ROLE OF *C. obsoletus* IN BLUETONGUE VIRUS TRANSMISSION

Distribution

A European resurgence of BT solely within the known range of *C. imicola* could be contained. However, should *C. obsoletus* also be involved in transmission, containment would be impossible since this species has a virtually pan-European distribution. This species has been recorded from the whole of the forest zone of Europe and the former USSR (Remm, 1988), and from most of the Mediterranean countries; from Portugal (Mellor *et al*, 1985) and Spain (Mellor *et al*, 1983) right through to Cyprus (Mellor & Pitzolis, 1979), Rhodes (Boorman, 1986a), Lesbos (Boorman & Wilkinson, 1983), Turkey (Jennings *et al*, 1983) and Israel (Braverman & Galun, 1973) at the eastern end (Fig. 1). Nevertheless, it seems unlikely that adult *C. obsoletus* will be able to overwinter over most of this area because of the severity of the northern winters.

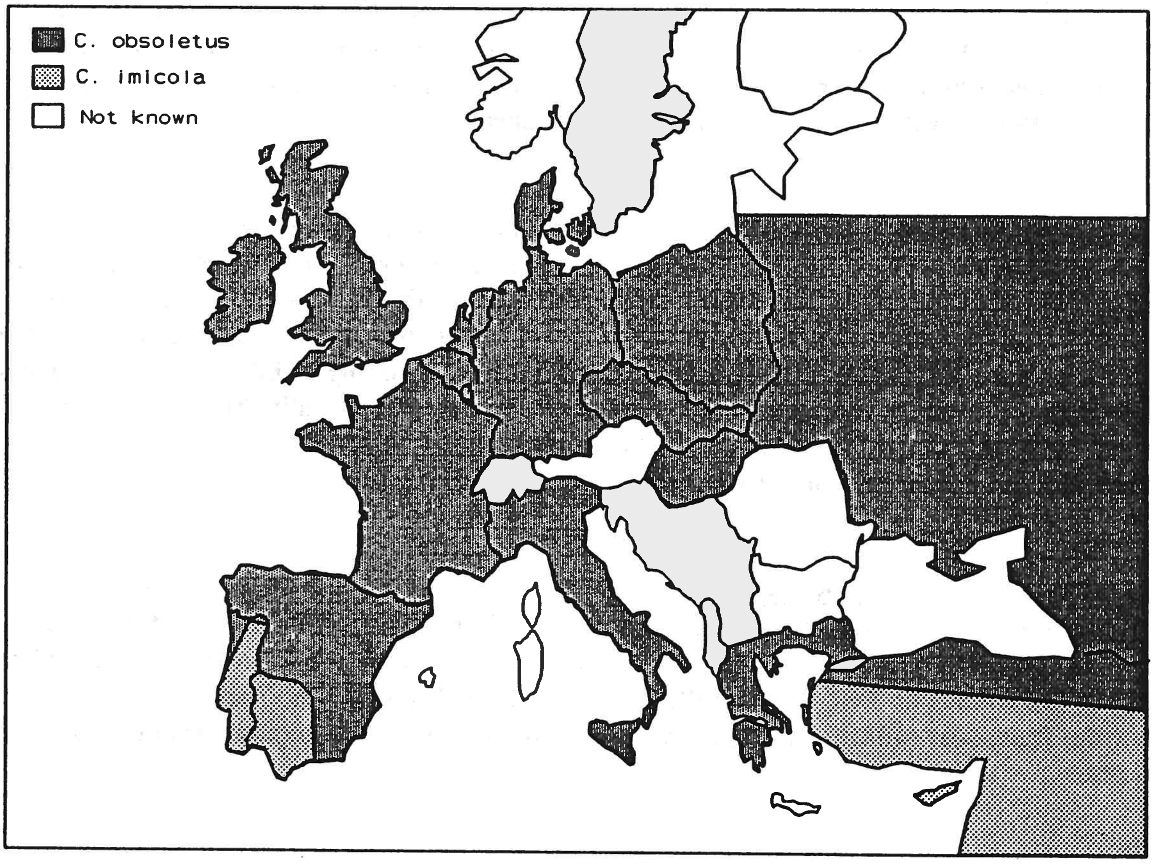

Fig. 1 European distribution of *C. obsoletus* and *C. imicola*

Overwintering

Little is known about the survival of adult *C. obsoletus* over winter in Europe. It is possible that some adults do survive right through from October to March or that new adults emerge during brief warm winter spell. It is also possible that no adults at all are present for some part of the winter period. In the absence of such behavioural and observational data, the conditions which permit adult *C. obsoletus* to be on the wing during the winter months is being investigated by analysing data from light trap collections gathered at the Institute for Animal Health, Pirbright, Surrey. It may be possible to extrapolate these results to a European map to demonstrate those areas in which the climatic conditions are sufficiently mild to enable *C. obsoletus* survive in adult form all the year round thereby creating a series of potential enzootic zones for BT and AHS.

In Britain, *C. obsoletus* occurs in most counties of England and Wales (Boorman, 1986b). Studies on Ceratopogonids have been carried out at Pirbright for a number of years. Daily light trap collections for every month of any year, however, are not, as yet, available, although this is being rectified. Detailed data on numbers and dates of males of *C. obsoletus*, sensu stricto, trapped between the beginning of May and the end of October for 1980, 1981 and 1992 are available. In 1981 trapping was continued at daily intervals until 8 December and for 1982 information on captures of *C. obsoletus* group males is available from mid-September to 18 December. These collections show that many *C. obsoletus* (>20) can still be trapped as late as 24 or 25 November (1992 and 1982, respectively) and individuals have been caught as late as 2, 14 and 15 December (1981, 1982 and 1992, respectively). In 1981 and 1982 the capture of the last individual *C. obsoletus* was quickly followed by termination of the trapping effort. There is, therefore, no long sequence of daily trapping data available to indicate that *Culicoides* were not on the wing. On the other hand, collections just prior to the end of trapping caught only small numbers of insects at all and very few *Culicoides*. The 1992-93 collections were continued throughout the winter but upto 12 January (1993) no further *C. obsoletus* had been captured subsequent to 15 December.

There is a decline of the adult population of *C. obsoletus* in winter which is probably largely, if not entirely, determined by some aspect of coldness. Precisely what function of low ambient temperatures is killing off, or at least preventing the flight of the adult population is not known. The survival of adults until mid-December in 1982 and 1992 at Pirbright indicates that the coldness of these two winters had not become sufficiently severe or long-lasting to kill all adults by that stage. The analysis investigates the possible causes of adult *C. obsoletus* mortality by looking at the severity and timing of single cold-events, either the lowest mean, minimum and maximum daily temperatures reached, or the largest falls of these parameters.

Lowest daily temperatures as single cold-events: Meteorological data from a weather station near Pirbright (Wisley) on the absolute coldness reached in mean, maximum and minimum daily temperature for the period when adult *C. obsoletus* could still be caught in light traps, and for the whole of the winters of 1981-82 and 1982-83 are shown in Table 1. The Table also lists comparable data from Dale, near Milford Haven, Dyfed; a location with one of the most amenable winter climates in Britain.

Table 1. Lowest daily temperatures reached for first part of winter (until date of termination of trapping) and the whole of winter at Wisley and Dale, 1981-82 and 1982-83.

	Pirbright(Wisley)			Dale (Warm Winters)		
	Mean	Min	Max	Mean	Min	Max
1.10.81-08.12.81	-0.3	-0.5	0.0	3.7	1.3	6.0
1.10.81-31.03.82	-6.6	-15.1	-2.3	-2.8	-5.2	-2.0
1.10.82-17.12.82	0.1	-3.4	3.5	2.6	1.0	4.3
1.10.82-31.03.83	-0.9	-7.0	1.4	0.7	-2.9	2.1

These data confirm that Dale is not only warmer than the Pirbright area in winter (which is why it was selected for comparison) but also that the lowest daily mean and minimum temperatures reached at Wisley by mid-December 1982 were never reached at Dale throughout the winter of 1982-83. During the winter of 1981-82, the lowest mean daily temperature at Dale over the whole of that winter were lower than those in the first part of the winter at Wisley, but only for four days in January.

Temperature falls as single cold-events: Table 2 shows the severity of temperature falls over 24h at these two meteorological stations. At Dale, unlike Wisley, all temperature falls were heavily buffered by its coastal climate.

Table 2. Largest falls in temperatures over 24h for the first part of winter and the whole of winter at Wisley and Dale, 1981-82 and 1982-83.

	Pirbright(Wisley)			Dale (Warm Winters)		
	Mean	Min	Max	Mean	Min	Max
1.10.81-08.12.81	7.5	8.9	7.1	5.1	5.1	5.1
1.10.81-31.03.82	8.3	8.9	8.4	7.1	7.0	7.3
1.10.82-17.12.82	5.7	10.1	6.0	3.5	3.9	3.8
1.10.82-31.03.83	5.7	10.1	6.0	3.5	5.8	4.1

In the 1982-83 winter in the Pirbright area, the largest temperature falls all occurred in the first part of the winter but either very early on (27 October; mean temperature drop of 5.7°C and minimum fall of 10.1°C) or at the end (16 December; 6.0°C maximum temperature fall). The largest mean and minimum temperature fall were therefore more than a month before the numbers of *C. obsoletus* in light trap collection started to tail off but the largest maximum temperature fall the day before trapping ended and two days after the last individual *C. obsoletus* was captured. In 1981 the largest temperature falls of the maximum and mean temperature in the first part of the winter (24 November) were surpassed later in the winter (on 6 January) but by little more than 1°C.

Analysis of single cold-events: If a single cold event is responsible for the disappearance of adult *C. obsoletus* from light trap collections at Pirbright, the event should follow the last capture of *Culicoides* in light traps, or should occur at about the same date as the last capture (because of the shortness of the period between the last capture and the end of trapping). Also, if a single cold event is determining adult survival it is reasonable to assume that the same event would kill off adults every year when it occurs. In 1981 the lowest daily temperatures recorded at Wisley for the first part of the winter did coincide with the last day of trapping and after the last capture of *C. obsoletus*. In 1982, though, the lowest daily temperatures occurred two weeks before the last capture of *C. obsoletus* and there were minimum temperatures lower than the lowest minimum for 1981 (-0.5°C) for four consecutive days at the end of November. Similarly, in 1992, minimum temperatures lower than -0.5°C were recorded on ten days in October, three days in November and five days in December - up to the last record of *Culicoides* capture. The coincidence of the lowest daily minimum temperatures and the disappearance of *C. obsoletus* in 1981 is not supported by data from the following years. Thus, it appears that low daily minimum temperatures are not the single cold-event killing off adult *Culicoides* at Pirbright.

In 1981 at Pirbright (Wisley) the lowest daily maximum temperature recorded in the first part of winter was 0°C and was 3.5°C in 1982. Despite the large differences in these two lowest maxima there were no days in 1981 before 8 December (when the 0°C maximum was recorded), and 1992 (up to 16 December), on which the maximum was lower than 3.5°C. Even though October 1992 was obviously cool (Anon, 1993), as shown by the exceptionally small rise in the Pirbright day-degree line (see below and Fig. 2), the lowest daily maximum upto the date of the last capture of *C. obsoletus* was 6.1°C. Low daily maximum temperatures, therefore, appear to be a possible cause of adult *Culicoides* mortality and a lack of low daily maxima an indication that *Culicoides* may still be on the wing. The largest falls in daily maximum temperature also coincide with the dates of last capture of adult midges at Pirbright, whereas the largest temperature falls for both mean and minimum daily temperature in 1982 occurred 48 days before the last *C. obsoletus* was recorded. At places like Dale, there were very few single cold-events throughout the winters of 1981-82 and 1982-83 in excess of that which continued to allow *C. obsoletus* to be still on the wing at Pirbright until mid-December. In 1982-83 there was never an occasion when the daily maximum was below that recorded in the first part of the winter at Wisley and in 1981-82 there were only two days.

Cumulative cold-events: It may not be a single cold-event, but a series of such events that prevents the overwintering of adult *Culicoides*. An accumulation of poor survival conditions could be responsible. Cumulative survival conditions can be roughly assessed by measuring the mean monthly temperatures but these take no account of transient temperature rises which may be of sufficient duration to allow adults to fly and feed and thereby allow the possibility of virus transmission. A coldness day-degree model was therefore used to compare winters at Wisley and with Dale. For each day where the mean temperature was between 8 and 10°C the status quo was maintained. If the mean temperature was higher than 10°C then the difference between the daily maximum and 10°C was added to the accumulated day-degrees. If the mean temperature was less than 8°C then the deficit of the mean was subtracted from the day-degrees. The status quo figure of 8°C was used because mean temperature for December falls below this value for each of the four years analysed. The data for Dale and Wisley for winters between 1980 and 1983 and the winter of 1992-93 are plotted in Fig. 2. The relative height of the peaks indicates the warmth of the autumn each year at each site. The sharpness of the falls of the graphs indicates the degree of severity of cold weather. At both Wisley and Dale increasing coldness (as indicated by the bar-line graphs descending), and thus poor survivorship conditions for adult *Culicoides*, are consistently present from late November-early December onwards for the winters 1980 to 1983. At Dale, though, the severity of cold is buffered right through to mid-February in 1981 and to the end of January in 1983. Conversely, near Pirbright the coldness continues to worsen almost relentlessly, recovering slightly only near the end of March.

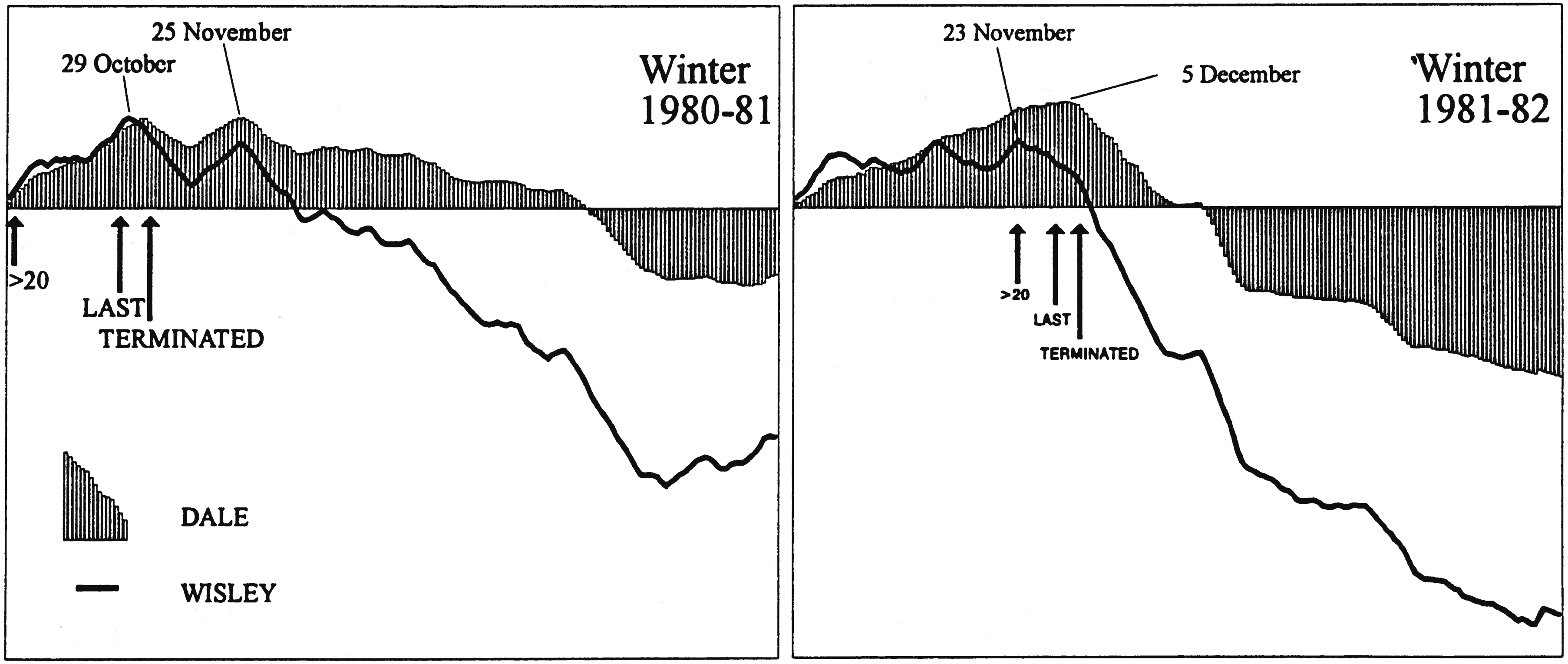

Fig. 2a. Accumulated coldness profiles for the Pirbright area and British locations with warm winter climates. Each winter runs from 1 October to 31 March.

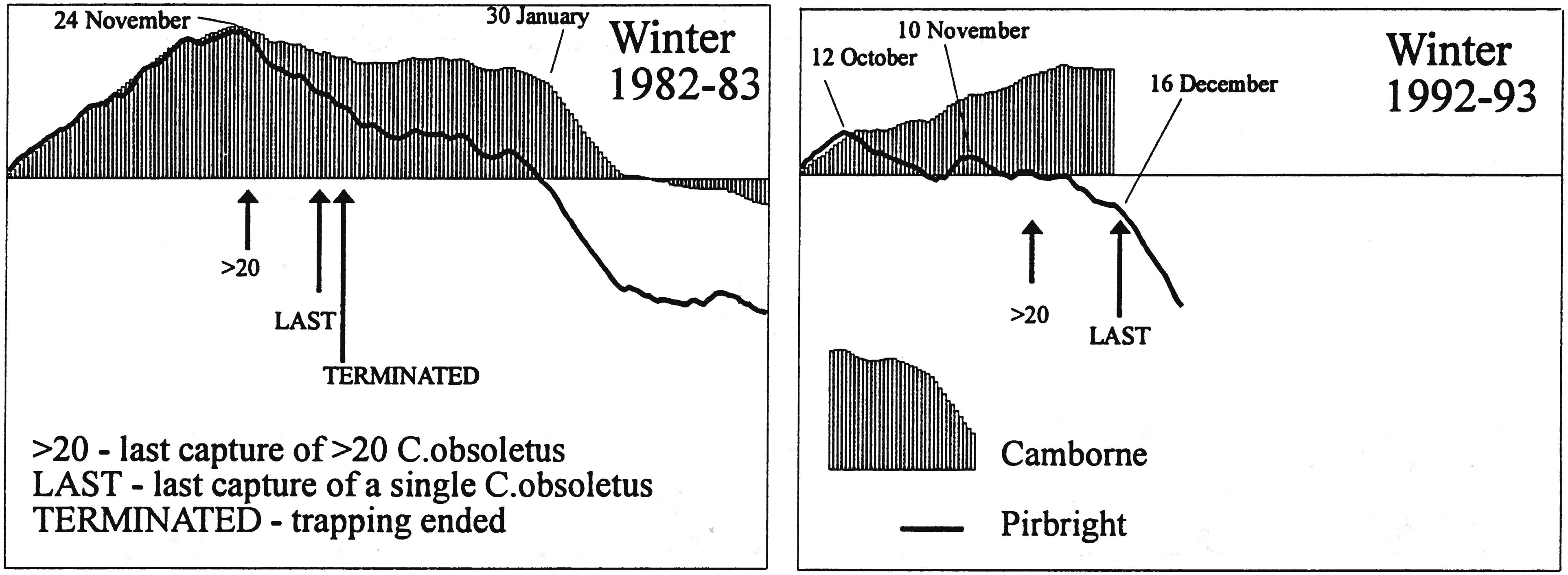

Fig 2b. Accumulated coldness profiles for the Pirbright area and British locations with warm winter climates. 1982-83 runs from 1 October to 31 March and 1992 up to 31 December.

EPIDEMIOLOGICAL CONCLUSIONS

These preliminary data based on winter temperatures and collections of *Culicoides* over parts of four different winters near Pirbright serves to indicate that adults of palaearctic species like *C. obsoletus* may die or become inactive in the winter because of the cumulative effect of cold-events and/or when daily maximum temperatures fall below 3.5°C. These sets of conditions become significant in the Pirbright area around the end of November. In warm winter zones like Dale there is also a 'downturn' in adult survivorship conditions at the end of November but in some years severe coldness does not set in for another two months. From the coldness day-degree model this suggests that adult *C. obsoletus* could be absent for as little as 20-30 days in warmer western zones of Britain. Even in colder areas of southern England, like Pirbright, the midge "season" begins in the last week of March or first week in April (Boorman, 1986). If the main cause of adult *Culicoides* death in the winter is a single cold-event, then daily maxima below 3.5°C or falls in maximum daily temperature over 24h of more than 6°C appear to be the factors most likely to cause adult mortality. In these instances, adult *Culicoides* could be present throughout the winter in warm western zones as such low daily maxima or severe temperature falls are seldom if ever found in these localities. Using either the coldness day-degree or the low daily maxima model, virtually continuous transmission of bluetongue virus by *C. obsoletus* would be likely in any area with a winter climate as mild as that at Dale.

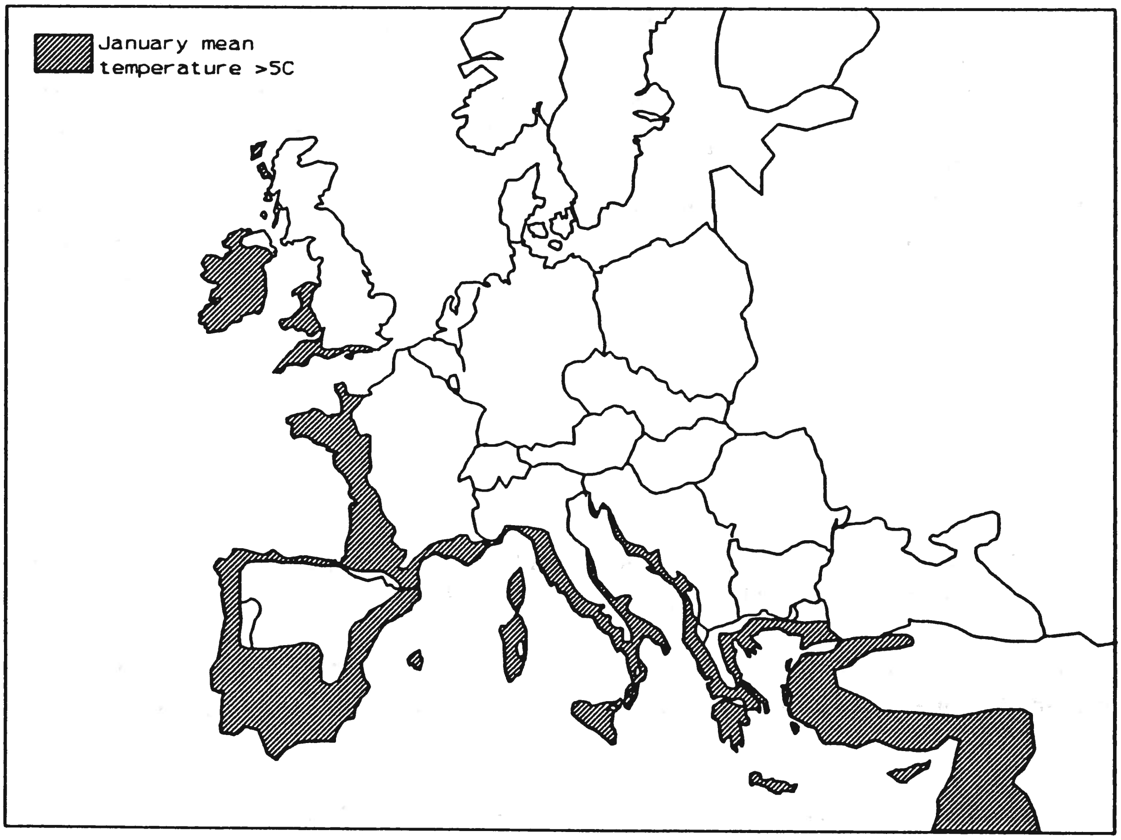

Fig. 3. European distribution of areas with mean January temperature >5°C

Over the whole of Europe, the most readily available marker of the degree of mildness of climate, such as that found at Dale, is mean monthly temperature. At Dale between 1980 and 1983 mean monthly temperature only fell below 5°C in one month; February 1983 (3.6°C). Mean temperatures in the Pirbright area for December 1980, 1981 and 1982 were 5.7, 1.4 and 5.0°C, respectively, and 5.6°C for 1992. Mid-December appears to be the latest (from the continuing 1992-93 trapping) that adult *C. obsoletus* are flying in the type of climates found in central southern England and it is during this period that mean temperatures generally fall below 5°C. Figure 3 shows the distribution of places in Europe in which the long-term average mean temperature for January is 5°C or more (Wallen, 1970). For inland areas January is usually the coldest month and February for coastal sites, but the difference in means of the two months is usually less than 1°C in Britain so January is a good representative of the coldest mean monthly temperature over most of Britain and Europe. As expected, all the non-mountainous Mediterranean areas and Portugal could support all-year round adult populations of *C. obsoletus* but so could all the north Spanish and west coast of France, most of Ireland and the west and south coasts of England and Wales. This extends the potential danger from BT and AHS outbreaks far beyond the limited European range of *C. imicola*.

The distribution by country of this potentially important vector of bluetongue and African horse sickness viruses is not thoroughly documented and little is known of the detailed distribution within each country. Changes in distribution of many insect species are likely to occur with global warming. The distribution of *C. imicola* may extend further north in mainland Europe but the greatest danger to livestock health lies in possible intersection of the ranges of the palaearctic vector species of *Culicoides*, *C. imicola* and infected hosts. Not only are species in the sub-genus *Avaritia*, like *C. obsoletus*, potential vectors but so also are the European representatives of the sub-genus *Monoculicoides*, namely *C. nubeculosus*, *C. puncticollis*, *C. riethi*, *C. stigma*. In North America, *C. variipennis* from the *Monoculicoides* is the major vector of BT and epizootic haemorrhagic disease of deer. The importance of the other members of *Avaritia* and *Monoculicoides* as potential vectors has been played down since they seem to be largely refractory to infection with BT virus (Mellor, 1990). Recent laboratory studies at Pirbright, however, show that the frequency of susceptibility to infection with BT or AHS virus in *C. variipennis* and *C. nubeculosus* can be easily raised by selecting from known susceptible females. It is likely, therefore, that wild populations of potential vector species of *Culicoides* will show wide variations in susceptibility to BT virus infection and some populations will be efficient vectors of these important viruses.

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SURVEILLANCE SYSTEMS

THE DEVELOPMENT OF NON-NOTIFIABLE DISEASE SURVEILLANCE IN SCOTLAND

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Disease surveillance has been described as an active intelligence and accounting process intended to continually monitor the overall disease and health of a population (Schwabe et al., 1977). These authors listed the components of such a scheme as the collection of disease data; the collation and analysis of the data and the expression, interpretation and prompt dissemination of disease intelligence information to all those that need to know. In Great Britain most reliance for non-notifiable disease surveillance has been placed on the diagnostic laboratory. In England and Wales the Ministry of Agriculture Fisheries and Food (MAFF) veterinary investigation centres (VIC) have filled that role while in Scotland an essentially similar service has been provided by the Scottish Agricultural College Veterinary Services (SAC VS). Harmonisation between the two services has resulted from close co-operation while surveillance data from both organisations are combined in the Veterinary Investigation Diagnosis Analysis (VIDA) recording system run in conjunction with the Epidemiology Unit of the Central Veterinary Laboratory, Weybridge.

The attractiveness of diagnostic laboratory data rests in both the precision and objectivity of the information, but these very features can be a limitation when laboratory results are viewed outwith the clinical or farm context. For such a system to work there must be close contact between the laboratory veterinary surgeons and both the referring veterinary surgeons and the owners or managers of the livestock units. This close contact not only serves to qualify the value of the diagnostic information but also to provide an informal but effective means of disseminating intelligence "to these who need to know". The laboratory-based veterinary surgeons must be aware of their role in surveillance and have the ability not only to collect the requisite information, but to collate, analyse and interpret the fruits of the surveillance. This paper describes the disease surveillance role of SAC VS and by referring to a specific prevalence study outlines the limitations of the collected data and describes the developments planned to overcome or account for these limitations.

Non-notifiable disease surveillance in Scotland

SAC VS, through eight geographically spread centres, provides laboratory diagnostic services and general farm animal health consultancy to veterinary practices in Scotland. In recent years the range of activities has increased to embrace fish farming, game birds and companion animals. The close contact between laboratory veterinary surgeons, many of whom have recognised expertise in farm animal health and

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production, and the veterinary surgeons in practice ensures that a representative view of the current disease situation, at least as observed by the practitioner if not the flock or herd manager, is achieved. Examples of the effectiveness of this surveillance range from reports defining disease conditions such as enzootic abortion of ewes (Stamp et al., 1950, Linklater & Dyson, 1979), *Salmonella montevideo* infection of ewes (Linklater, 1983), mucosal disease (Barber et al., 1985) and listeriosis (Low & Renton, 1985) to descriptions of unusual or emerging diseases eg. nutritional myopathy (Greig & Hunter, 1980) and acute myopathy in horses (Hosie et al., 1986). Close links with Moredun Research Institute has led to more in depth studies being carried out e.g. ovine listeriosis (Low et al., 1992) and ovine nephropathy (Angus et al., 1989). Further examples of SAC VS surveillance are to be found in the proceedings of this society: adventitious bursitis in pigs (Smith, 1992) and congenital chondrodystrophy in suckled calves (Gunn, 1993).

Less formal presentations of surveillance information appear in the form of monthly reports in the Veterinary Record. These offer a basic account of the disease conditions observed over a particular month and draw attention to novel conditions or disease incidents of interest. In a similar fashion the individual VIC annual reports produced in the past allowed SAC VS client practitioners to have surveillance data specific to their own geographic area. Finally, presentations made directly to veterinary surgeons or livestock producers are routinely employed as a further route of surveillance intelligence dissemination.

Data recording and sources of bias

As mentioned above the VIDA system is used to record diagnoses arrived at after appropriate examinations have been carried out on the material submitted to the VIC. The essential bones of VIDA are lists of diagnoses, two of which can be recorded for each submission. Beyond this, recorded information is limited to species, age, sex, type of specimen submitted, date of submission and county of origin. Summaries of these data are published each year whilst searches can be requested on any of the diagnostic codes or other recorded variables. Use of these have tended to be limited to background information in the production of specific reports on disease investigations, clinical trials or promotional literature for medicinal products. When used in these contexts little effort has been made to qualify the value of these data and yet clearly such surveillance data has obvious bias. For example the number of recorded incidents of mucosal disease increased from 546 in 1984 to 883 in 1985. This can properly be explained by the implementation of new diagnostic techniques, a better understanding of the disease itself and consequently greater awareness by veterinary surgeons working with cattle.

The cost of veterinary intervention and diagnostic procedures relative to the value of the affected stock affects the submission of diagnostic material to the laboratories. The value of an animal varies between species and within species from year to year, but usually in a way that can be quantified and therefore accounted for. This factor compounded by the effect of distance from the livestock unit to the laboratories ensures that a relatively incomplete picture of disease problems encountered in animal productions systems of the upland and hill regions is obtained compared to the more intensive systems such as milk production or early lamb production.

One of the most significant failings of the VIDA system is the inability to accurately identify the number of units from which diagnostic material has been submitted or to identify the number of units on which a specific diagnosis was reached for any given time period. Yet the identity of the farm from which the sample originated will always have been recorded at the VIC. Until recently this information only existed as a paper record making retrieval time consuming. In 1987 SAC VS began to install micro-computer networks in the VIC's and to use an in-house designed laboratory information management software. It is now possible to link diagnoses to farms at the VIC level, but not at the level of VIDA. Similarly the populations at risk are known, but never related to diagnostic data.

Despite these limitations VIDA data provides the most extensive disease data base available in Great Britain, but a data base that is certainly under-used and occasionally misused. This is a frustrating position for the majority of veterinary surgeons working with VIDA and in an effort to test the system it was decided to explore the use of VIDA data to examine one particular disease. Enzootic abortion of ewes (EAE) was chosen for a variety of reasons: the condition is well understood; it is economically important; diagnostic tests are well defined.

EAE PREVALENCE STUDY

The major aim of this study (Leonard et al., 1993) was to describe the extent of the condition throughout the flocks of Scotland by using data that was routinely recorded by VICs in conjunction with VIDA data. Through this exercise the limitations of the present diagnostic data could be explored and ways to improve the system identified.

Material and Methods

Diagnostic data from ovine abortions collected over a five year period beginning in December 1986 and continuing until May 1991 were examined. All positive EAE diagnoses and examinations of all abortion material recorded using the VIDA system were retrieved and matched by their unique number to the information on submitting flocks recorded at each VIC. In turn these data were related to the number of flocks at risk as indicated by Scottish Office Agriculture and Fisheries Department (SOAFD) census data. Figures were available for each local authority area and these were then combined to give the number of flocks served by each VIC. Only 1988, 1989 and 1990 data were available and the mean of these was taken to give a measure of the population at risk.

The definition of prevalence used was: period prevalence is a measure of the total number of cases of a disease that has existed in a population during a period of study (Thrusfield, 1986), i.e. flock prevalence of EAE was the number of flocks where a diagnosis of EAE was made on one or more occasion during the period December 1986 to May 1991 inclusive, divided by the total number of units with breeding ewes in Scotland as described by the SOAFD census data. The data were compiled for each centre and on an all Scotland basis.

Results

Table I details the number of flocks and average flock size served by each of the eight VICs. Thirty-one per cent of all flocks in Scotland submitted material for ovine abortion diagnosis during the five years under study and in 28% of these flocks a diagnosis of EAE was made on one or more occasion. Thus an overall prevalence of 8.8% was obtained ranging from 1.8% at Inverness to 25% at St. Boswells (Table 2).

Table 1. The ewe flock population by area serviced by SAC Veterinary Investigation Centres (VIC) and the percentage of flocks that submitted material for abortion diagnosis during the period from December 1986 to June 1991

VIC	The no. of holdings with ewes	Average no. of ewes per holding	The no. of holdings that submitted abortion material expressed as a percentage of the number of holdings with ewes
Thurso	2494	129	26.6%
Inverness	3773	152	14.0%
Aberdeen	1813	151	37.0%
Perth	1311	349	59.1%
Edinburgh	1037	358	49.0%
Ayr	2714	303	20.9%
St. Boswells	874	501	54.9%
Dumfries	1394	354	38.7%
Scotland	15410	243	30.7%

Table 2. The EAE flock prevalence in the period December 1986 to June 1991

VIC	Number of flocks with EAE	Number of flocks with EAE expressed as a percentage of flocks that submitted material	EAE flock prevalence: The number of flocks with EAE expressed as a percentage of the total flocks
		%	%
Thurso	85	12.8	3.4
Inverness	68	12.8	1.8
Aberdeen	287	43.0	15.8
Perth	198	25.5	15.1
Edinburgh	152	29.9	14.7
Ayr	117	20.7	4.3
St. Boswells	222	46.2	25.4
Dumfries	196	36.3	14.1
Scotland	1325	28.0	8.8

Discussion

Leonard et al. (1993) discussed the significance of these findings and the possible sources of bias, but from a disease surveillance point of view the significant conclusion was that by using VIDA data in conjunction with other information available to SAC VS, a more quantitative statement could be made about a disease than had previously been possible for any common non-notifiable disease in Scotland. This study did identify certain areas that could be improved. Firstly the criteria used to define a diagnosis must be clearly identified. In the case of EAE these are obvious as chlamydia are easily detected by direct microscopy of suitably stained smears from placentae and aborted ewes produce a strong detectable humoral antibody response. In contrast the diagnostic criteria for leptospirosis in cattle are not so clear. The detection of L.hardjo antigen in abortion material is difficult throwing emphasis onto serological examination, but the concentration of maternal antibody to L.hardjo at the time of abortion is extremely variable. Cross reaction to other leptospiral antibody further interferes with the diagnostic worth of serology in this condition. No guidelines exist within VIDA to resolve this problem and no confidence could be placed in an estimated herd prevalence for leptospirosis in cattle. A cursory glance through VIDA diagnoses would reveal many similar ill-defined entities. The Office International des Epizooties (OIE) have produced diagnostic criteria for a number of economically important diseases including leptospirosis and these could be adopted. Where gaps occur it would be a simple matter to construct diagnostic criteria based on similar principles.

The second major problem is the failure to clearly identify the number of occasions on which a diagnosis was attempted, but was not achieved. In the case of EAE the laboratory submission is clearly described as abortion material or sera for toxoplasma and EAE antibody screening and it can be assumed that appropriate tests for EAE diagnosis are carried out. This is not the case for a disease like scrapie where the submitted material is a carcase for post mortem examination and the appropriate test for scrapie is carried out in only a minority of occasions and then only positive outcomes are recorded. By using the above methodology it would only be possible to identify the number of flocks where a diagnosis of scrapie had been reached, not the number of flocks where the disease had been considered in the differential diagnosis and the appropriate examinations carried out. Therefore once again little confidence could be placed in a statement of the flock prevalence of scrapie when the number of flocks examined was unknown.

To overcome this deficit SAC VS have constructed a clinical history coding system which covers all species and the clinical history or reason for submission can be sorted into one of 15 clinical history codes. Hence in addition to the scrapie diagnosis code recorded for the submitted ewe carcase a clinical history coding of nervous signs will have been recorded also if the appropriate history had been supplied.

In future it should be possible to present disease surveillance data in the form of disease diagnoses broken down by clinical history and subdivided further by age, type of specimen and therefore range of examinations that could be carried out. Disease diagnostic criteria will be defined; the population at risk will be defined; the number of livestock units where a diagnosis was reached or sought will be defined. As SAC VS is only one part of an organisation which embraces considerable animal production and economic expertise it should be possible to use this expertise to place laboratory disease surveillance data in the context of the contemporary market and production pressures. Surveillance intelligence can then be disseminated with an explanation of the sources of bias that profoundly affect this type of information.

CONCLUSION

SAC VS is now in a position to provide the components of disease surveillance, as defined by Schwabe et al. (1977), the collection of disease data; the collation and analysis of data and the expression, interpretation and prompt dissemination of disease intelligence and to take this beyond the static position occupied for the past decade and on to a position more compatible with the current knowledge of animal disease and the availability of efficient computer hardware and software. If this improvement is realised it will increase the potential for animal disease control in Scotland and provide more accurate information to help the allocation of resources available for animal disease research.

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DO WE NEED A EUROPEAN SURVEILLANCE SYSTEM?

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The European Community is now an open market and the veterinary legislation programme that allows animals and animal products to move freely without internal frontier checks is virtually complete. The next step is to underpin this legislation by developping a coherent Community-wide approach to the prevention of animal diseases. One element of this strategy, contingency plans for dealing with outbreaks of foot and mouth disease and other emergencies, is already in place. The other element that needs to be addressed is disease surveillance.

PRESENT COMMUNITY NOTIFICATION PROCEDURES

A paper presented at the last meeting of the Society (Scudamore 1992) described the disease control programmes operating within the Community and the framework of veterinary controls that is designed to maintain the high health status of the Community's herds and flocks. These controls include disease notification for a list of diseases that approximates to the O.I.E. list 'A'. (Council Directive 82/894/EEC as amended) and a requirement that Member States shall 'notify other Member States and the Commission of any outbreak in its territory, ... of any zoonoses, disease or other cause likely to constitute a serious hazard to animals and to public health' (Council Directive 90/425/EEC).

In addition to these notification requirements Member States engaged in eradication programmes, such as those for Tuberculosis and Brucellosis report their progress to the Commission. The recently agreed Council Directive for the prevention of zoonoses requires Member States to report annually to the Commission the trends and sources of the (zoonotic) infections recorded during the previous year.

By and large these arrangements have operated satisfactorily. The Commission has an accurate record of outbreaks of O.I.E. list 'A' diseases via the computerised animal disease notification system (A.D.N.S.), and 'new' diseases such as Porcine Reproductive and Respiratory Syndrome (P.R.R.S.) have been reported promptly. The form of the proposed zoonosis reporting system has yet to be decided and a more formal reporting arrangement for reporting endemic diseases that are subject to mandatory or voluntary control and/or eradication measures on a herd or flock basis is desirable.

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There are pressures for a review of the existing disease notification arrangements. EFTA countries whose trade is intimate with that of the Community through the proposed European Economic area arrangements want to operate a notification system that is compatible with ADNS. The O.I.E. is presently reviewing its own reporting system and compatability with other systems must be one of its considerations.

THE OBJECTIVES OF FUTURE SURVEILLANCE

Beyond these immediate issues the question arises as to whether the Community legislative requirements for notification are satisfactorily going to safeguard the future animal health status of a major and growing world trade block, one which is committed to free movement within its borders.

A more important question is whether the myriad processes by which disease is reported - veterinary visits to farms, diagnostic laboratory reports, abattoir surveillance and so on are in good order within the Community and if they are whether they can be adapted to form a Community surveillance system.

Surveillance can be a costly process and one that is susceptible to one of the failings of bureaucracy - collecting information to no purpose in a self-perpetuating system. It is important therefore that its objectives are clear.

Firstly, disease surveillance should provide the Community with satisfactory intelligence about animal diseases that might pose a threat either to the livestock industry or to public health. Secondly, it should also allow the Community's trading partners to take a view of the health status of our herds and flocks and the food products that come from them.

The first statement implies that surveillance should be confined to diseases and other conditions which are important, in other words, diseases that are or might come under some form of official control. The second requires that the methods of collecting data and the presentation of the results are 'transparent' and this implies a formal process as opposed to anecdotal reporting.

These primary objectives determine the scope of any surveillance system, but the detailed data that is to be collected depends on the customer's requirements. The customer in this case is the Commission together with the governmental authorities in the Member States; they jointly fund disease control programmes and provide the compensation following outbreaks of disease. Their requirements have not been formalised but they can be stated a follows:-

- **An early warning of primary outbreaks of disease and other new events that constitute an emergency.** All Member States have contingency plans for dealing with disease emergencies but they depend crucially on the early detection of disease outbreaks before they give rise to widespread epidemics. This means 'disease awareness' at the farm level. Herd owners, veterinarians and others involved with livestock must be able to recognise unusual conditions and be motivated to report them so that the authorities can react promptly. (A recent example of this process is the reporting that led to the identification of Classical Swine Fever in four widely spread pig units in Northern Germany).

- **Comprehensive but basic disease data that are readily accessible.** For the more important diseases such as tuberculosis these should provide as complete a record of incidence as possible. For the less important conditions that are only potential candidates for official control, e.g. Infectious Bovine Rhinotrachectis (I.B.R.) the data should be sufficient to inform the authorities as to whether the disease is of major or minor importance and whether the prevalence is increasing or decreasing. Information of this kind may not be epidemiologically exact but it does allow the authorities to take a 'broad view' of the disease situation and provides them with a starting point in considering possible disease control programmes. (The V.I.D.A. system is a good example of 'broad view' reporting).

- **Detailed assessments of particular disease situations.** The 'broad view' mentioned above may identify particular disease situations that need to be examined in depth. Such examinations usually take the form of statistically valid surveys and authorities carry out such surveys before planning control or eradication programmes. (An example of such an exercise is the recent survey carried out by the Italian authorities to determine the approximate prevalence of contagious Bovine Pleuropneumonia (CBPP) in the national herd. This preceded the preparation of an eradication plan). It is important that the infrastructure for such surveys is established; this includes creating a data bank that provides background statistics such as population data and setting up administrative arrangements such as access to farms and to abattoirs.

TWO POSSIBLE APPROACHES

If we are to create a recognisable Community animal disease surveillance system it must meet the requirements outlined above:

- reporting confined to 'important diseases'
- a relatively formal system that is 'transparent'
- an early warning system for 'new events'
- continuous, comprehensive but basic disease data
- well established survey facilities
- 'least cost'.

There appears to be two possible approaches to the problem of providing a range of information at 'least cost' from a territory covering 2,253 million square kilometres and containing 8,644,300 agricultural holdings that range from the large intensive units of Northern Europe to the small peasant holdings characteristic of the Mediterranean littoral (see tables 1 & 2).

TABLE 1
NATIONAL ANIMAL POPULATIONS (million head) 1987

	B	DK	D	GR	E	F	IRL	I	L	NL	P	UK	TOTAL
Cattle	3,07	2,35	15,23	0,68	5,36	21,86	6,76	8,91	0,22	4,89	1,39	12,09	82,8
Sheep	0,19	0,10	1,10	7,78	19,89	10,41	4,96	8,14	0,006	0,98	2,24	38,53	94,5
Pigs	5,84	9,27	23,99	0,91	12,74	11,78	0,91	8,79	0,075	14,35	2,36	7,90	98,92
Poultry	23,24	15,54	66,70	29,75	125,34	224,91	7,84	144,35	0,10	98,67	31,50	138,92	908,9

SOURCE: Eurostat

TABLE 2
LIVESTOCK HOLDINGS IN MEMBER STATES 1987
(Thousands)

	B	DK	D	GR	E	F	IRL	I	L	NL	P	UK	TOTAL
Number of AG holdings	92,6	86,9	705,1	953,3	1,791,6	981,8	217,0	2,784,1	4,2	132,0	635,5	260,1	8,644,3
Holdings with animals	76,2	66,2	576,1	651,0	872,6	772,5	188,7	1,066,0	3,5	94,4	535,3	189,1	5,091,5
Holdings with cattle	63,2	40,7	418,3	81,7	428,8	526,9	180,5	439,0	3,0	70,3	243,8	153,9	2,650,0
Holdings with sheep	8,9	5,4	38,8	191,0	161,0	145,0	45,9	176,2	0,3	20,4	113,9	91,4	998,0
Holdings with pigs	26,3	37,7	365,9	87,7	466,3	210,6	4,9	420,3	1,0	35,4	318,9	21,3	1,996,3
Holdings with poultry	20,1	15,5	286,3	577,9	582,5	598,0	50,1	751,4	1,9	7,1	458,4	55,3	3,402,4

SOURCE: Eurostat

The first is a 'gradualist' approach that brings together the existing surveillance facilities and systems in the Member States into a coherent community structure: this will take time.

The second is to create a formal disease reporting system 'de novo'. This again will take some time, but would be less dependant on present facilities some of which are less than perfect.

THE "GRADUALIST" APPROACH

All Member States have well established diagnostic facilities and data or information gathering arrangements. These include diagnostic laboratories, abattoirs, veterinary practices and national or regional veterinary field services. All are possible contributers to a Community surveillance system.

Diagnostic Laboratories

Member States diagnostic laboratories (see Fig.1) form the backbone of a surveillance system partly because they examine a wide range of material and partly because they underpin other investigations carried out by the veterinary services. Most of the laboratories form part of the national or regional veterinary services but increasingly private sector funding is involved and in some countries such as Denmark the majority of laboratories are run by producer organisations.

Most if not all of these laboratories produce records of some sort ranging from a brief annual report to extensive disease recording systems such as VIDA II.

Diagnostic laboratories contribute to reporting 'new events' and whilst they cannot produce a definitive record of disease prevalence, they also provide a 'broad view'. If European diagnostic laboratories are to contribute to a formal Community surveillance system then they have to agree on a common method for recording and collating disease events. This is in itself no small task. Inevitably there will be some additional cost and whilst this could be absorbed by a public funded laboratory which sees surveillance as part of its function, it could be a problem for the private or producer funded laboratories. On the other hand a formal surveillance output would enhance the justification for diagnostic laboratories many of which are under financial pressures.

F I G. 1

PUBLICLY FUNDED VETERINARY DIAGNOSTIC FACILITIES IN THE EUROPEAN COMMUNITY

Note: All Member States maintain one or more central research laboratory that to a greater or lesser extent carry out diagnostic work. Most of the laboratories listed below carry out veterinary public health examinations as well as animal health investigations.

BELGIUM	8 provincial laboratories
DENMARK	Regional veterinary diagnostic laboratories established by producers organisations
GERMANY	(1) Veterinary investigation laboratories - one or more in each of the 16 Länder (2) Laboratories forming part of the animal health service established by the farming organisations (45 laboratories are approved for the diagnosis of viral diseases)
GREECE	13 regional veterinary diagnostic laboratories
SPAIN	(1) 12 regional veterinary laboratories (2) A number of provincial laboratories (3) 17 other laboratories approved for testing samples for eradication schemes
FRANCE	92 departmental laboratories
IRELAND	5 regional laboratories
ITALY	10 veterinary research institutes
LUXEMGOURG	State laboratory for veterinary medicine
NETHERLANDS	(1) 4 regional laboratories for animal health services (2) 12 district laboratories for public health
PORTUGAL	(1) Laboratories coming under the regional directorates for agriculture. (2) Other approved diagnostic facilities are located in public or private laboratories
UNITED KINGDOM	(1) 26 veterinary investigation centres (including 2 laboratories in Northern Ireland). (2) Various private laboratories approved for certain purposes.

Abattoirs

There are about 7000 abattoirs in the Community of which over 1200 are EC approved (Table 3). The veterinary authorities have access for surveillance and they use this to carry out gross pathological examinations, e.g. CBPP in Italy, Spain and Portugal or for serological sampling, e.g. SVD surveys in the United Kingdom and the Netherlands. Serological sampling poses statistical problems which have been discussed at a previous meeting of the society (Richards and Norris, 1986). Coordinating abattoir surveillance on a Community-wide basis should not be an insuperable task; it can contribute to the detection of new events, the 'broad view' and to the execution of surveys.

Veterinarians On-Farm

Two kinds of veterinarians visit livestock holdings on a regular or occasional basis: private practitioners and officials from veterinary services.

The number of veterinarians in these two categories in the Member States is shown in Table 4 and it can be seen that the Community livestock holdings are remarkably well served - the ratio of general practicioners to livestock holdings is of the order of 1 : 116, although a large proportion of practices are largely or entirely small animal units and thus do not contribute to farm animal surveillance.

Several attempts have been made in various parts of the world to set up general practice disease recording systems and none have lasted for more than a few years. It is probably too much to expect busy general practictioners to devote a great deal of their time to detailed disease recording apart from participating in the herd recording systems that are used in the better pig and dairy cattle herds. Nevertheless, veterinary visits to farms are a vital part of an early warning system and the main means by which we identify primary outbreaks of foot and mouth disease and classical swine fever before they spread to become major epidemics. There has been considerable concern in certain parts of the Community that the abandonment of FMD vaccination would reduce the number of farm visits to the point where veterinary surveillance become ineffective. If ways are to be found to encourage veterinary surveillance on farms it is probably by developing the relationship between general practitioners and diagnostic laboratories. This has been particularly fruitful in the UK and has accounted for the early identification of Aflatoxicosis, B.S.E. and other 'new events'.

Official veterinarians visit farms to carry out tests for diseases such as Tuberculosis, Brucellosis, and Enzootic bovine leucosis. The veterinary authorities should be in a good position to provide accurate prevalence data for this group of infections.

It is worth repeating that the Community has excellent on-farm surveillance through veterinary visits and the legislative base is already

TABLE 3

	EEC Approved Abattoirs	Total Abattoirs
BELGIUM	93	160
DENMARK	51	273
GERMANY	299	350
GREECE	7	430
SPAIN	46	476
FRANCE	358	558
IRELAND	45	854
ITALY	153	2640
LUXEMBOURG	6	6
NETHERLANDS	105	153
PORTUGAL	1	221
UNITED KINGDOM	73	852
TOTAL	1237	6973

TABLE 4

VETERINARIANS IN THE MEMBER STATES OF THE EUROPEAN COMMUNITY (AS AT DECEMBER 1989)

Member State	Total of Active Veterinarians	Practitioners	Veterinary Functionaries
BELGIUM	3,315	2,929	386
DENMARK	2,220	1,198	596
GERMANY	11,009	7,514	1,794
SPAIN	10,038	3,428	5,422
FRANCE	8,660	7,588	588
GREECE	2,492	552	1,331
IRELAND	1,694	1,288	312
ITALY	12,233	11,828	405
LUXEMBOURG	60	43	12
NETHERLANDS	2,496	1,751	386
PORTUGAL	1,707	310	1,102
UNITED KINGDOM	7,510	5,414	625
TOTAL	63,434	43,843	12,959

in place for the authorities to carry out checks on holdings (Directive 90/425/EEC); this kind of surveillance is the key factor in dealing with emergency disease solutions. Pig and cattle holdings are visited regularly and the poultry industry is also well served. It is only in the sheep and goat sector that visits are so occasional as to threaten effective surveillance. The Community does not have large areas of land where animals are kept under range conditions and rarely see a veterinarian. This distinguishes it from many other parts of the world where authorities are overcoming the problem of inadequate surveillance by establishing a formal monitoring system based on herd sampling.

FORMAL MONITORING SYSTEMS

The best example of a formal monitoring system is the U.S.D.A. national animal health monitoring system (NAHMS) and its evolution has been described in a paper presented to the 1990 meeting of the society (Pointon & Hueston, 1990). The early pilot projects were limited to the administration of a general farm questionnaire to a selected sample of livestock holdings and the monitoring of farm records of disease occurrences and their cost on subsequent regular visits to the sample farms.

In 1989 NAHMS entered its second phase, the establishment of a national animal health information programme that has two elements: active surveillance through visits to a sample of holdings and passive surveillance through the collection of animal health information from existing sources such as diagnostic laboratories, abattoirs, research institutes and federal agricultural statistics agencies. It would appear that the authorities recognise the value of informal surveillance procedures to supplement formal monitoring. The whole system, which is still in its early days, is of considerable interest to European authorities as it tries to grapple with the problems of maintaining surveillance over a large territory and a diverse livestock industry.

DISCUSSION

I have outlined the possible objectives of a European surveillance system that will supplement the present A.D.N.S. notification system and the different approaches that might be employed to implement it. Whatever system develops it must satisfy the requirements outlined earlier in the paper.

The advantage of a gradualist approach is that it is relatively cheap (it relies on existing facilities), and it provides a broad view of the current disease situation. Most importantly it harnesses a variety of disease intelligence resources to provide an early warning of 'new events'. This is crucial to the Community which is presently free of FMD and a whole range of other exotic diseases and where other important diseases such as classical swine fever are a rarity. Its disadvantage is that it is informal and therefore possibly not 'transparent' to our trading partners.

The advantage of a formal monitoring system relying on enquiries on a sample of holdings is that it is transparent. It may provide a broad view of disease events that can be integrated with economic studies to calculate losses but it seems unlikely to be effective in identifying a primary outbreak of FMD or Rinderpest - there is still no substitute for the contacts and the diagnostic skill of the veterinary practitioner and the good sense of the livestock farmer.

I have not answered the question in the title of this paper - Do we need a European surveillance system? Of course we already have informal surveillance systems and they serve us well, but as the dust settles after the opening of the single market I would guess that we will need something more formal for our own security and something more demonstrable for our trading partners.

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OPEN SESSION

THE USE OF A GEOGRAPHICAL INFORMATION SYSTEM (GIS) IN THE CONTROL AND EPIDEMIOLOGY OF BOVINE TUBERCULOSIS IN SOUTH-WEST ENGLAND

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Geographic information systems (GIS) have gained increasing popularity since the mid-1980s with the greater availability of suitably-priced hardware and software, the development of a large body of data referenced to the environment, the recognition of their commercial applications and the self-generating pressure from surging sales (Maguire, 1991).

They are now an accepted means of managing geographically referenced data, especially by such enterprises as utility companies and local authorities where there is a need for storing and accessing large quantities of data relating to well-defined objects, such as the route of underground power cables or the position of specific man-hole covers. GIS are also being used as planning and modelling tools, especially for resource management, for example in managing damage to forestry caused by moose (Saarenmaa & Nikula, 1989). However, there are few reports of their use in the veterinary field, although suggestions for their application have been advanced (Sanson *et al.*, 1991). Notable exceptions are a study of brucellosis in southern California (Campbell, 1987), a report of the epidemiology of bovine tuberculosis in the common brushtail possum (Pfeiffer *et al.*, 1991) and an evaluation of GIS as a replacement for conventional mapping in tuberculosis research in Southern Ireland (Hammond & Lynch, 1992).

Acting on a recommendation from a Research Visiting Group attending the MAFF Central Veterinary Laboratory in 1991 that the Epidemiology Department should add GIS to the tools available for epidemiological analysis, the Department bought PC ARC/INFO (Environmental Systems Research Institute, Redlands, CA) and the required hardware. It was decided that the testing ground for the system should be part of an appraisal of past and future tuberculosis control strategies in south-west England.

In the autumn of 1975, statutory badger removal operations were started in south-west England in an attempt to control cattle tuberculosis. Since then more than 10 thousand badgers, with an infection prevalence of about 12.5%, have been killed and 2500km^2 of land involved in such operations. Initially, badger setts were cleared with HCN gas, monitored and, where necessary, re-gassed for 12 months. Areas for control were delineated where possible using geographical barriers, such as major rivers and roads, so that the instigating herd as well as other nearby herds with a recent occurrence of tuberculosis were included. The average size of individual control areas was 7km^2. Not all of a designated area would necessarily be cleared at one

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time, so that controlled land could be surrounded by infected badger populations which were potential immigrants to the gassed areas until they too were controlled, which could have been up to six years later. Despite this, the incidence of infected herds in gassed areas was reduced by 40% from that expected, based on the incidence history in the same areas from the mid 1960's to the start of gassing (Dunnet *et al*., 1986).

Coincident with the start of badger control, two areas were delineated for intervention studies. Here, setts were re-gassed for up to two years before allowing recolonization. The incidence of tuberculosis in cattle herds in these areas was reduced to levels not previously achieved and to date *Mycobacterium bovis* has not been confirmed again (Report, 1990). These studies perhaps provide the strongest evidence for a causal link between *M.bovis* infection in badgers and tuberculosis breakdowns in cattle herds.

Cage trapping and shooting badgers replaced gassing in 1982. Most designated areas were still centred on herds with recent reactors, but now social group territories were delineated by bait marking (Kruuk, 1978) prior to control such that a strategy of centrifugal clearance of infected badger populations was attempted until a 'ring' of uninfected social groups had been removed. The mean size of controlled areas was similar to that during the previous strategy. Analysis of the results of this 'centrifugal' policy proved difficult because of the large overlap with previously gassed areas and the relatively short time the strategy was in place.

The Dunnet Committee reviewed the tuberculosis problem in cattle and badgers and reported in 1986 that the exceptional costs of the centrifugal strategy were not justified. It recommended that an 'interim' strategy be adopted until a serological test to detect *M.bovis* infection in the live badger was developed for use in a future control strategy. Under the interim strategy badgers could only be trapped and shot on land used by the herd in which *M.bovis* infection had been confirmed and where epidemiological investigations had ruled out sources other than badgers. Costs were reduced by abandoning social group delineation and the need for confirming infection in the local badger population prior to control. However, control still only took place after disclosure of infection in a herd.

A serological test, initially a blocking ELISA and now transposed to an indirect ELISA in kit form, suitable for lay staff to use in the field with minimum laboratory equipment, has been developed at the MAFF Central Veterinary Laboratory and is being evaluated in a practicality field trial using a mobile laboratory. The availability of such a test for the first time creates the possibility of adopting a pre-emptive approach to controlling cattle tuberculosis.

This paper describes how the GIS has been used to help in epidemiological analysis of tuberculosis in south-west England and to address the applied problem of where the ELISA would best be deployed.

MATERIALS AND METHODS

For this study, 'south-west England' consists of the counties of Avon, Cornwall, Devon, Dorset, Gloucestershire, Somerset and Wiltshire.

The geographic information system

The software used throughout this study was PC ARC/INFO (ESRI, Redlands, CA), a vector-based, multi-module product for map creation, editing, plotting and data management, accessed through a central control programme. The hardware comprised a 486 PC, with high resolution screen, linked to a 36x48inch digitizer and 8 pen plotter.

Sources of data

Herd TB testing histories: 1) The national ('Tuberculosis in Cattle') database, containing summaries of all herd tuberculin test results from 1986 to June 1992, recording the herd holding number (CPHH number, amalgamating county, parish, herd and holding numbers), Ordnance Survey (OS) grid reference of the main farm premises, the number of animals tested, the type of test and interpretation criteria, the numbers of reactors, inconclusive reactors and dangerous contacts slaughtered and their bacteriological culture results.

2) CVL Bacteriology Department 'TB50' database containing all culture results for samples submitted from reactors, inconclusive reactors and dangerous contacts slaughtered from 1985 to June 1992. This was used principally to validate entries of reactor herds in the national database.

3) A database (the 'TB74' file) summarizing test data for herds partly or wholly within badger control areas. The herd CPHH, numbers of cattle tested, and the number of reactors in each calendar year from 1960 to 1985 were recorded.

4) Quarterly returns from Animal Health Offices listing new herd breakdowns from 1979 to 1985 and lists of herds with visible-lesion reactors in each year from 1972 to 1978 compiled during earlier research.

These sources were combined to create a summary record for each reactor herd detailing whether there were reactors in each year from 1960 to June 1992.

Records were validated by various procedures. a) OS grid references and parish numbers were checked against CAMAP6 (Edinburgh University Department of Geography) which rasterizes county parishes to km squares. b) Obvious anomalies were detected using the GIS. c) Programmes were written to check for unusually high herd or holding parts of the CPHH numbers. d) Different CPHHs with the same km square OS grid reference were identified.

Potential errors detected by the above means were checked against lists of ordered CPH numbers by county referenced to name and address and against alphabetical lists of names and addresses by county referenced to CPH number (supplied by MAFF Agricultural Census Branch) and by reference to OS paper maps. CPHHs were also cross-referenced to the CVL BSE and the MAFF badger control databases.

Badger control operation data: The MAFF badger control database provided information on all badger control operations from 1975 to June 1992, including a record of all badgers caught, their OS grid reference and *M.bovis* status, and the areas by km square which were controlled each year during each of the control strategies. Km squares were coded according to the types of control performed in them.

A file was created containing records of herds with confirmed breakdowns between 1986 and June 1992, differentiating between those deemed to have a badger-associated origin and those with other causes. Breakdowns were taken as confirmed if severe interpretation of skin test results was applied and/or if *M.bovis* was cultured from slaughtered animals. A breakdown was considered ended once there was a year free from reactors after the last year in which reactors were detected.

Digital map data

Digitized map information at a scale of 1:250,000 was purchased from Bartholomew Times, Edinburgh.

Analyses

Mean centre and standard distances, standard deviational ellipses, nearest neighbour indices and Moran's I coefficient for spatial autocorrelation of point data were derived for each county using Fortran programmes (Ebdon, 1985). The x and y coordinates were expressed as four digit numbers, the first representing the 100km square, the second the 10km square and so on according to the conventions noted for the grid in Fig.1.

Using the GIS to create 1, 2.5, 5 and 10 km buffer zones around km squares previously subjected to statutory badger control, the distribution of badger-related herd breakdowns was determined from 1986 to June 1992 in relation to the distance from past control areas. Logistic regression indicated that year of breakdown did not significantly affect this distribution.

Km squares were ranked according to the number of herds detected with skin test reactors each year from 1976 to 1992 inclusive, weighted such that the more recent the breakdown the greater the contribution to the overall score. The squares were further weighted according to the type of badger control which had taken place in them. Using the badger-related herd breakdown distribution information the top-ranked km squares were selected provided they were within 5kms of km squares where previous badger control had taken place. One km wide buffer zones were created around these squares. If these zones incorporated previously selected squares, extra squares from the ranked list

Table 1. Spatial statistics for all herds with i) skin testing histories, ii) reactor animals and iii) confirmed badger-related tuberculosis breakdowns in south-west England, during the period from 1986 to June 1992.

County	Herd category	Mean centre coordinates x	y	Standard distance (km)	Standard deviational ellipse y axis rotation (degrees)	x axis length (km)	y axis length (km)
Avon	i) all	3597	1715	16.1	51.7	18.1	27.5
	ii) reactor	3685	1768	14.7	28.4	17.2	23.8
	iii) badger	3723	1790	10.7	6.1	10.5	18.8
Cornwall	i) all	1960	581	34.9	52.3	21.9	66.5
	ii) reactor	1988	623	38.5	50.7	23.8	73.3
	iii) badger	1986	642	38.9	47.8	24.8	73.8
Devon	i) all	2723	990	35.1	22.4	52.2	46.6
	ii) reactor	2579	988	31.6	21.8	53.7	33.4
	iii) badger	2517	974	27.0	38.5	50.3	19.5
Dorset	i) all	3727	1031	22.8	84.1	23.4	39.7
	ii) reactor	3601	1016	20.6	79.6	15.5	38.2
	iii) badger	3667	1035	28.2	3.0	34.8	44.4
Gloucs.	i) all	3855	2141	20.8	65.5	23.2	35.3
	ii) reactor	3833	2092	18.1	67.1	23.2	27.8
	iii) badger	3836	2039	14.7	32.2	18.1	23.2
Somerset	i) all	3387	1332	25.9	81.5	24.5	46.1
	ii) reactor	3450	1362	22.3	74.2	24.8	37.1
	iii) badger	3493	1495	25.9	25.2	5.1	0.5
Wilts.	i) all	4004	1640	24.2	2.9	25.3	42.0
	ii) reactor	3980	1688	20.3	88.1	33.3	23.3
	iii) badger	3594	1737	19.0	74.4	30.4	22.8

were added and further buffer zones created until a total of approximately 900km squares had been delineated.

Areas totalling 901 km squares were selected by MAFF staff in the State Veterinary Service with responsibility for control of cattle tuberculosis in south-west England. For the purposes of this study, these areas were simply defined by a single map reference point and a circular buffer zone covering an area as large as that suggested by the field staff. No attempt was made to delineate the areas more accurately.

RESULTS

The following measures were derived for each county using data covering the period 1986 to June 1992 (Tables 1 and 2):

1) The mean centre, standard distance and details for describing standard deviational ellipse for all herds, herds with reactors and herds with badger-related breakdowns;

2) Nearest neighbour indices based on area and their c values for non-reactor herds, herds with reactors and herds with badger-related breakdowns;

3) Moran's I statistic for spatial autocorrelation and the corresponding z value from the randomization significance test, comparing all non-reactor herds with reactor herds and with herds with badger-related breakdowns.

Table 2. Nearest neighbour indices and Moran's I statistics for all herds with i) skin testing histories with no reactors, ii) any reactor animals and iii) confirmed badger-related tuberculosis breakdowns in south-west England, during the period from 1986 to June 1992.

County	Herd category	Nearest neighbour analysis Index	c value	Spatial autocorrelation Moran's I statistic	z value
Avon	i) non-reactor	0.82	-13.24	n/a	n/a
	ii) reactor	0.91	-1.92	0.0319	16.54
	iii) badger	0.55	-6.53	0.0390	19.25
Cornwall	i) non-reactor	0.89	-15.32	n/a	n/a
	ii) reactor	0.92	-3.22	0.0116	14.55
	iii) badger	0.66	-9.39	0.0006	0.97
Devon	i) non-reactor	0.81	-32.60	n/a	n/a
	ii) reactor	0.66	-12.59	0.0256	38.18
	iii) badger	0.37	-12.89	0.0370	54.41
Dorset	i) non-reactor	0.79	-19.51	n/a	n/a
	ii) reactor	0.77	-5.21	0.0229	16.97
	iii) badger	1.30	2.65	0.0098	7.14
Gloucs.	i) non-reactor	0.81	-17.03	n/a	n/a
	ii) reactor	0.81	-5.50	0.0095	7.27
	iii) badger	0.75	-4.45	0.0177	12.34
Somerset	i) non-reactor	0.84	-19.47	n/a	n/a
	ii) reactor	0.76	-4.28	0.0050	5.55
	iii) badger	0.12	-4.12	0.0130	14.41
Wilts.	i) non-reactor	0.76	-20.86	n/a	n/a
	ii) reactor	0.84	-3.82	0.0041	2.81
	iii) badger	0.57	-5.39	0.0069	4.42

Table 3. The odds of badger-related tuberculosis breakdowns occurring related to distance from past badger control areas, based on 529 breakdowns during the period from 1986 to June 1992.

Distance to nearest past badger control (km)	Odds	Odds ratio	Exact 95% confidence intervals
0	1.242	92.58	43.25-235.04
>0 to 1	0.216	16.11	7.40-41.53
>1 to 2.5	0.216	16.11	7.40-41.53
>2.5 to 5	0.048	3.54	1.46-9.82
>5 to 10	0.033	2.48	0.96-7.12
>10	0.013	n/a	n/a

The odds, related odds ratios and exact 95% confidence limits of badger-related breakdowns occurring within different distances of past statutory badger control based on confirmed breakdowns during 1986 to June 1992 are listed in Table 3.

Kilometer squares in which there has been statutory badger control up to June 1992 are shown in Fig.1. They have been

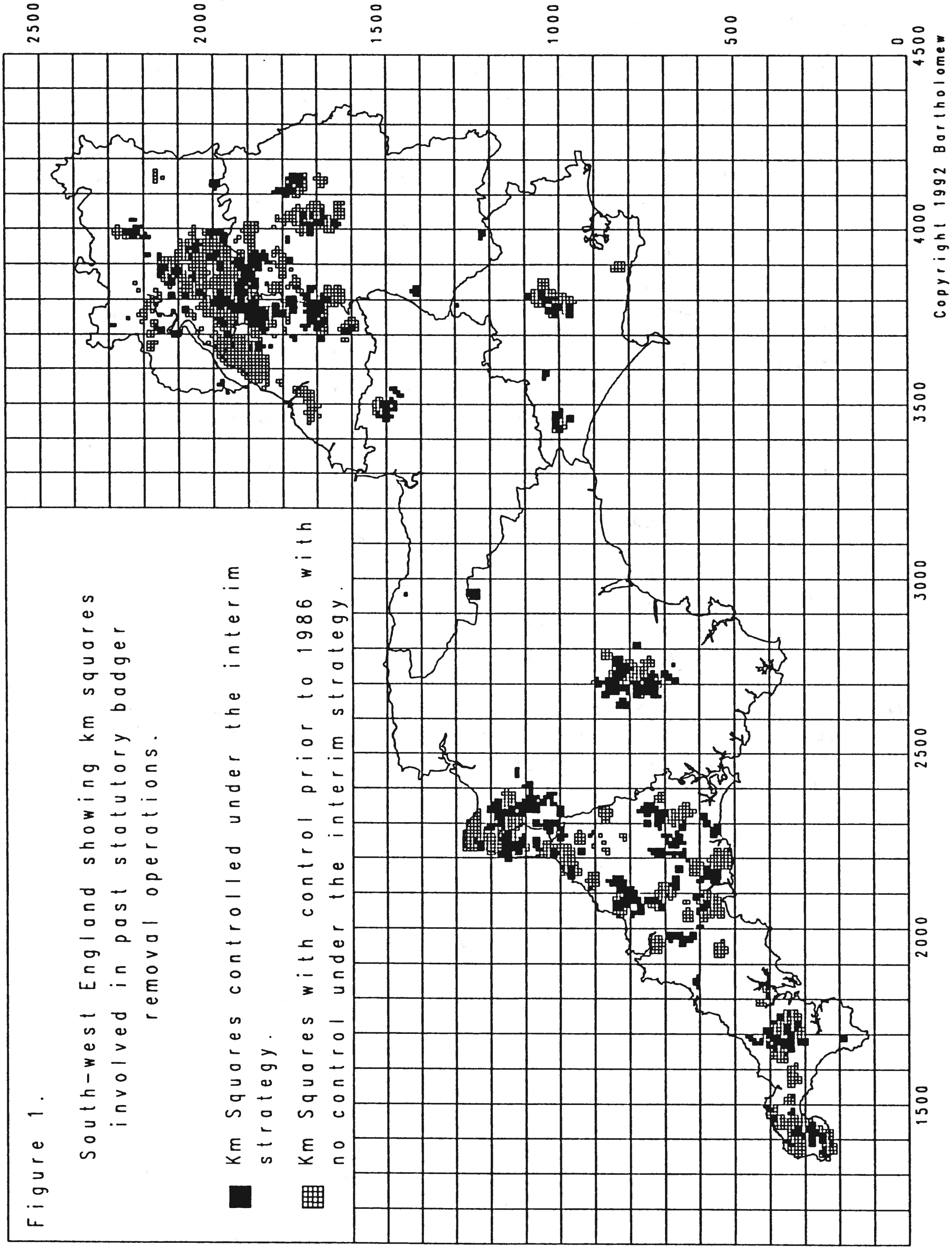

Figure 1.

South-west England showing km squares involved in past statutory badger removal operations.

subdivided into those with or without control during the interim strategy. Areas suggested for pre-emptive control from analysis of past data using the GIS, totalling 913km^2, are mapped in Fig.2. These may be compared with the areas suggested by field staff in south-west England (Fig.3), and with areas centred on herds suffering badger-related breakdowns during 1991 to June 1992, totalling approximately 900km^2 (Fig.4).

DISCUSSION

Despite the significant decline in badger-related herd breakdowns after 1975 when gassing was introduced to control infected badger populations (Dunnet *et al*., 1986), the annual number of confirmed breakdowns has been increasing, especially since 1985, such that it is projected that the pre-1976 level of breakdowns will be reached by the end of 1995 (unpublished findings). This does not necessarily imply that the interim strategy has failed, indeed the re-breakdown rate has been significantly less during the last seven years than that prior to the start of badger control (unpublished findings). However, the restrictions placed on the extent of trapping have probably hindered any reduction in the number of breakdowns on previously unaffected farms. The availability of a test to detect infection in live badgers allows, for the first time, a control strategy which incorporates the element of pre-emptive selection. At the same time its use should reduce the number of apparently uninfected badgers which are killed every year during statutory control operations. Up to 1991, of the 9943 badgers killed in control operations since the start of badger removals, infection has been confirmed in 1521 animals (Report, 1991).

The present study was undertaken to assess the worth of GIS to the CVL Epidemiology Department and in the process perhaps help MAFF in defining the areas where resources should be deployed in bovine tuberculosis control in south-west England should pre-emptive badger control replace the current strategy.

The first step was to assemble the necessary data, given that databases for herd skin testing records and badger control operations were already in existence. Inaccuracies in the data related especially to the herd identification (CPHH) number and the OS grid reference. CPHH numbers were found with wrong or non-existent county or parish parts when located using the OS reference. If the name and address were known then in many cases it was possible to correct the number. Incorrect herd and holding parts of the CPHH were considered less important for locational purposes. Two or occasionally more CPHHs were found with the same OS reference. Often this was apparently correct, but sometimes one of the references or CPHHs proved incorrect. Two CPHHs could refer to the same farm, one being an out of date number which had been officially changed to the other. Records in this case had to be merged.

Incorrect OS references were a particular problem, perhaps of more importance than CPHH errors. Analyses involving areas, such as creating buffer zones around specific points or the

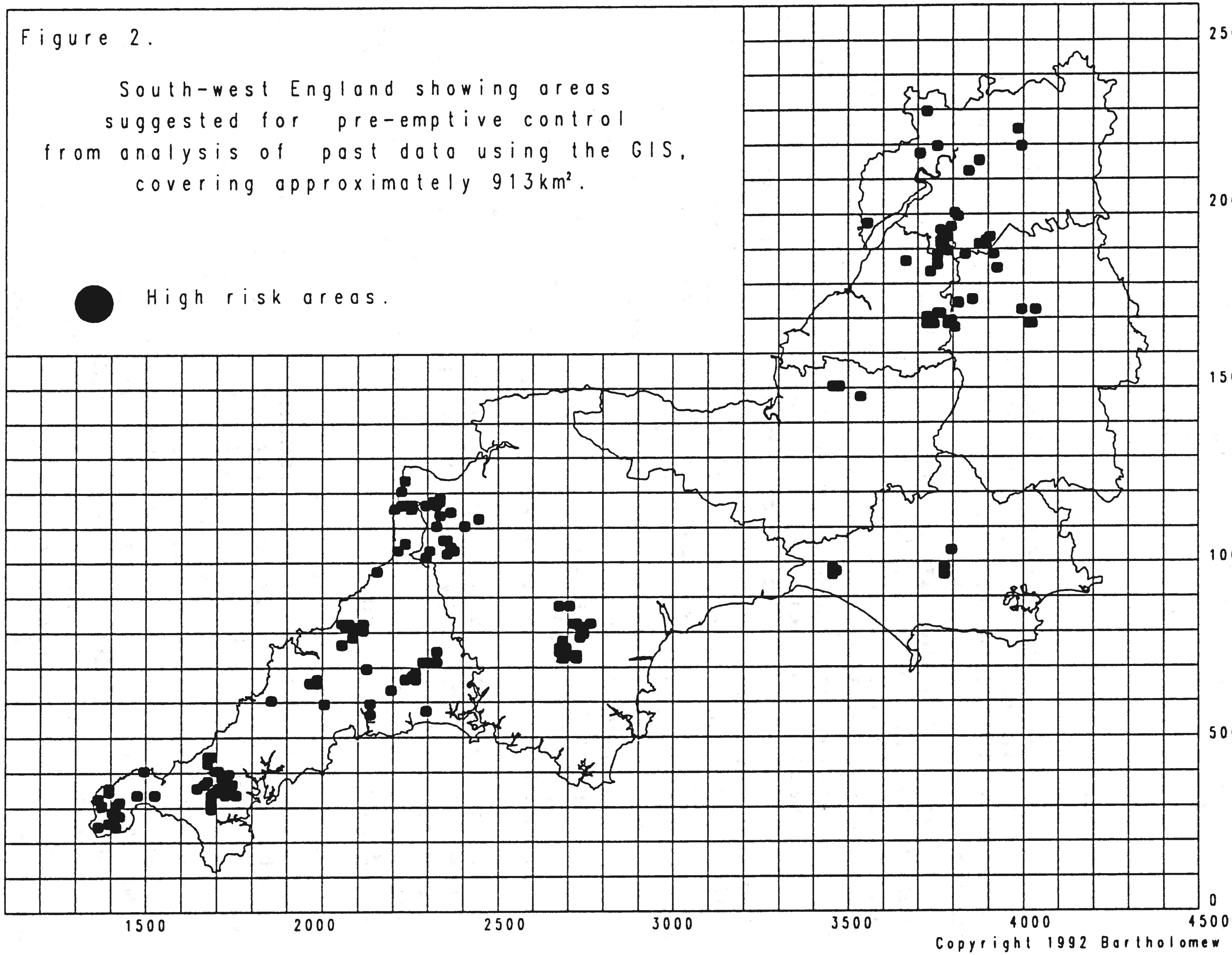

Figure 2.

South-west England showing areas suggested for pre-emptive control from analysis of past data using the GIS, covering approximately 913km².

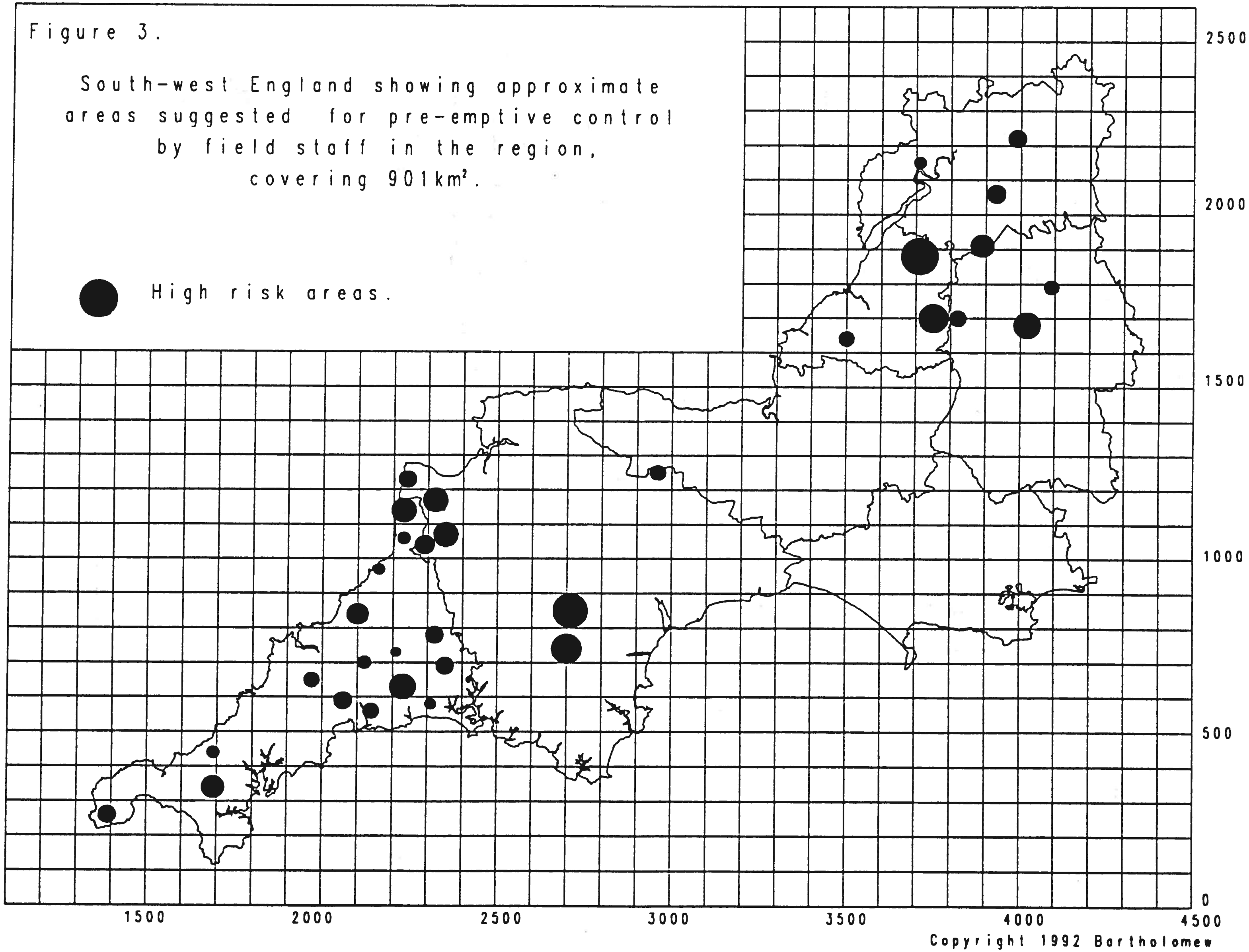

Figure 3.

South-west England showing approximate areas suggested for pre-emptive control by field staff in the region, covering 901km².

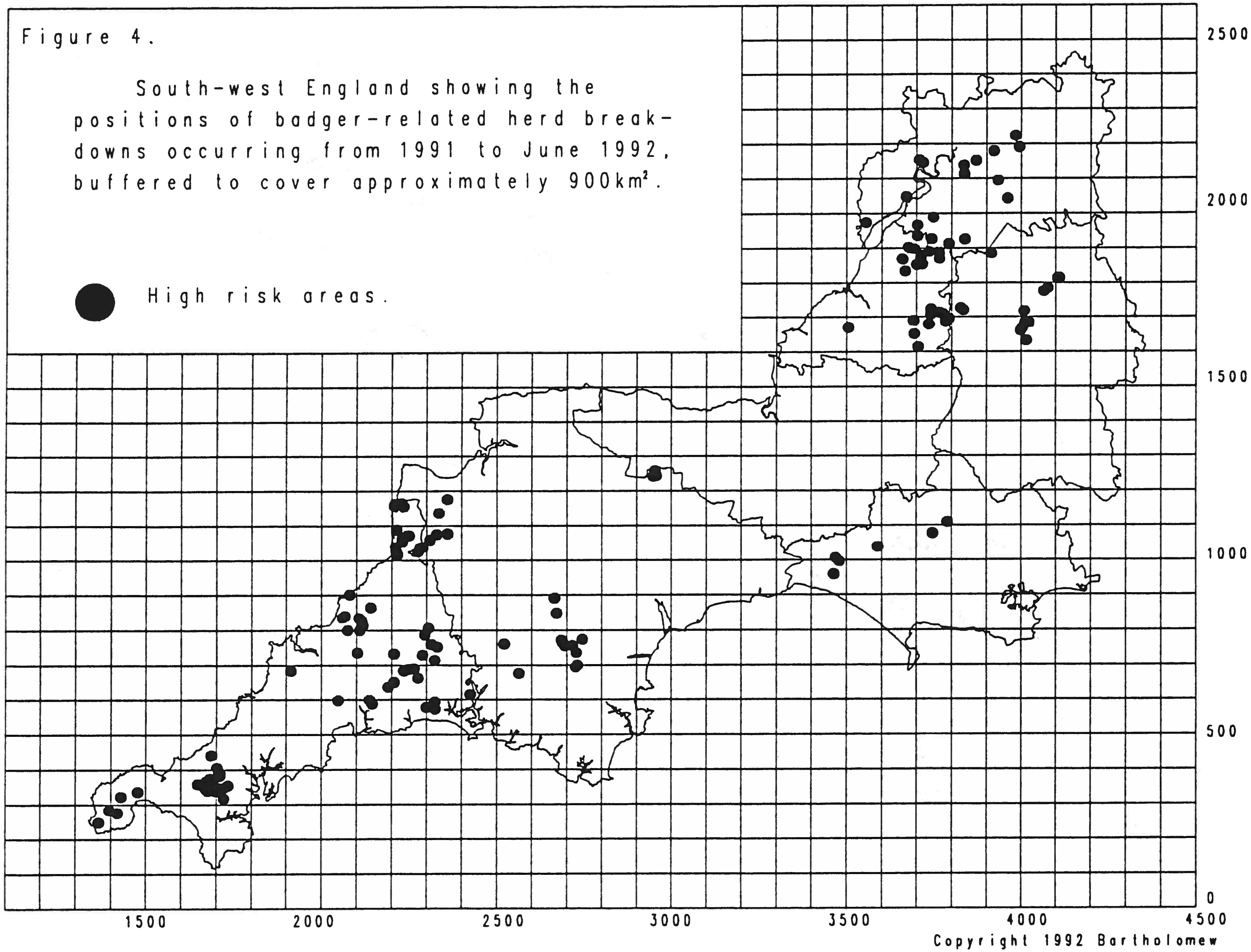

Figure 4.

South-west England showing the positions of badger-related herd break-downs occurring from 1991 to June 1992, buffered to cover approximately 900km².

derivation of spatial statistics, would be affected by wayward points increasing the area size. Points located in incorrect counties (or in the Bristol Channel!) were identified visually using the GIS, but shifts within county were more difficult to identify. Inaccuracies related to the two letter prefix, or the numerical part, where the northing was often placed before the easting. In other examples the reference bore little relation to anything at all!

Another problem, related to the skin testing forms filled in by the local veterinary inspectors and Animal Health Offices, was where the OS reference and CPHH were for the owner's main herd or correspondence address. These could be correct for the address given but the herd in question could be located elsewhere. Often, several herds would be owned by the same person and so had the same CPHH apart from the holding part. However, the same OS reference was often given for each.

The present study highlighted these limitations of the present information gathering and storage arrangements and steps are at present being taken to rectify them.

An obvious problem with the study was trying to marry different data sources with somewhat dissimilar information to give a coherent record over time. This meant that few items were recorded standardly from the inception of badger control to the present, with the result that badger-related herd breakdowns could only be identified with any certainty from 1986 onwards.

The spatial statistics presented here (Tables 1 and 2) are simple and quick to derive and helped to summarize the datasets. The mean centre provides an estimate of where the centre of a spatial distribution is. For example, the differences in the coordinates for all herds and reactor herds, especially those with badger-related breakdowns, in Devon could indicate that the distribution between the two was different, and the direction of the difference is suggested. The amount of dispersion of the points is concisely summarized by the standard distance, although outlying points will have a disproportionate effect on the result. Also, the distribution of points may be different according to direction and this is lost in the standard distance. However, the standard deviational ellipse summarizes a distribution with its long axis directed to where the maximum dispersion is occurring. The lengths of the axes represent the degree of dispersion. For Gloucester and Avon , the direction and area of the ellipse indicate a different distribution for badger-related breakdown herds from other herds, whereas the distribution of problem herds in Cornwall is apparently similar to that for all herds in the county.

The nearest-neighbour index has a value ranging from zero, indicating maximum clustering, to 2.15, representing a completely dispersed pattern. A random distribution has a value of 1.0. Slight clustering was apparent in non-reactor herds in all counties. However, of particular interest was the accentuated clustering of badger-related breakdown herds, especially in Avon, Devon, Somerset and Wiltshire. Moran's spatial autocorrelation coefficient, I, gives a measure of the probability that the spatial arrangement of a set of points could have occurred by chance. Especially in Avon, Devon, Gloucester and Somerset, significance tests for the I coefficient suggest that the distribution of the badger-related breakdown herds was not due to chance.

Although these spatial statistics are of use in summarizing data and indicating where something unexpected has happened, they can only be regarded as an initial attempt to answer the fundamental question posed in the introduction to this paper, which was where to deploy badger control resources to best effect if a change in strategy to incorporate the diagnostic test for badgers were undertaken. The areas selected in Fig.2 can only be taken as a preliminary and somewhat crude attempt to delineate areas of particular high risk of cattle breakdowns. The weighting used at present has over-emphasized the importance of more recent non-badger related breakdowns and should be refined to take full advantage of the overlaying, buffering and filtering capabilities of the GIS and should include further variables not available at the present time, such as measures of badger density, land classification and herd density.

The degree of correlation between the more recent badger-related breakdowns (Fig.4) and the areas picked by field staff for control (Fig.3) was to be expected. However, their experience also led other areas to be selected which to some extent was intuitive. The initial selection using the GIS included several km squares which the field staff did not consider as priority areas, especially in Somerset and Dorset. The reasons for these differences will be investigated and any future breakdowns in the areas monitored.

In conclusion, the present study has probably raised more questions than it has answered, especially relating to validity of the data and how to improve its collection and storage. The GIS is obviously a powerful tool which we are only just beginning to understand and exploit. Its limitations can be seen in the paucity of statistical functions built into the software and the time consumed performing some routines, but its strengths are also obvious in its presentational and selective capabilities. At present the technological advances which have made geographic information systems more accessible and more readily applicable to problem solving have outstripped the applied statistical methodology which is needed before they can develop their full potential. However, this situation is unlikely to persist for long.

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THE EPIDEMIOLOGIST/PRACTITIONER PARTNERSHIP IN RESEARCH

Jean-Pierre Vaillancourt *

The growing concerns for the environment, animal welfare and health in general in today's society are creating opportunities for veterinarians. Indeed, the role of veterinarians, the only professional in direct contact with the animals and their owners on a regular basis, is enhanced by the increased awareness of the benefits of disease control and preventive and production medicine. However, with new opportunities come new challenges. External forces such as free trade in North America and the General Agreement on Tariffs and Trades will have a profound impact on the food animal industry. In North America, small farms with low overhead may survive, but most will probably be integrated to larger operations. The integrated approach will improve the competitiveness of these farms via different business and production structures. However, any intervention intended to improve productivity under intensive conditions will also need to address concerns for animal welfare, the environment and food safety. This will require new approaches and insight (Meek, 1991).

To tackle all these issues requires a holistic approach. Hence, a need for objective methods to assess diagnostic procedures and prevention and intervention strategies (Bonnett, 1991). Companion animals also stand to benefit greatly from a preventive medicine/health management approach (Bonnett, 1991). However, this paper will focus on the food animal sector.

> "The veterinarian with deep emotional ties to his or her stethoscope and with strong convictions regarding clinical impressions will not seriously impact modern agriculture" (Jim and Guichon, 1991).

Indeed, in addition to a solid foundation in diseases, veterinarians will now be expected to have a background in animal production and behaviour, production economics, system analysis and information management. In this context, the epidemiologist should be a natural partner to the veterinary practitioner. The widespread computerization of veterinary practices and of farm operations offer a great opportunity for the development of field-based data collection and ongoing health monitoring systems (Bonnett, 1991). The epidemiologist is uniquely qualified to assist practitioners in optimizing their use of field data. An analogy could be made between epidemiologists and pathologists. The pathologist can assist the practitioner in interpreting lesions. The same way, the epidemiologist can assist the practitioner in interpreting production and health related data.

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ADDRESSING THE NEEDS OF THOSE INVOLVED WITH FOOD ANIMALS

Producers want information that will allow them to make daily decisions (management of animals) and to prevent or correct health and production problems. Practitioners must be in tune with the industry and the community they are serving. They want to respond to their clients needs by providing the expertise to assist them in their decisions. Similarly, epidemiologists must be aware of the producers' needs in order to focus their investigations accordingly. To stay in business, all three need to be financially solvent and accountable to society. To achieve this, they need valid information.

The validity of field investigations depends on an array of factors, such as the study design, the quality of measurements, the sampling strategy and the analytical procedure employed. Of all these, data quality is probably the most limiting factor. We can draw a parallel between this and the quality of samples submitted to diagnostic laboratories. Only valid data can generate useful results. Practitioners, in collaboration with the animal owners, can provide such information. The validity of this information will, in large part, depend on its perceived importance by those who are collecting it. Therefore, the information must also be useful to the animal owners. In other words, the practitioners have to be able to market the importance of data collection and both the practitioner and the producer must be rewarded for their participation. While epidemiologists have the skills to analyze the information, the investigation, from the design to the interpretation of the results, must be a "team" effort.

PREVENTIVE MEDICINE: THE CONNECTION BETWEEN PRACTITIONERS AND EPIDEMIOLOGISTS

Making preventive medicine a paying proposition to the producer is certainly a major incentive to foster collaboration between practitioners and epidemiologists. The same way practitioners often rely on diagnostic laboratories to assist them in solving problems, anyone who wants to do preventive work would benefit from interacting with an "epidemiology laboratory".

There are three levels of organization related to preventive medicine: the within-animal level (disease), the within-herd level (between-animal) and the between-herd level (Bigras-Poulin and Harvey, 1987). The information required to address issues at all three levels can be divided in seven sections: 1) animals; 2) management; 3) agents (bacteria, virus, parasite, etc.); 4) feeding and nutrition; 5) diseases; 6) environment (buildings); 7) the manager (Tillon et al., 1981; Bigras-Poulin and Harvey, 1987). Virtually all the information can be collected by producers and veterinarians. However, a single practitioner or even a clinic with several veterinarians normally do not follow enough herds to be able to adequately investigate the between-herd variations. Epidemiologists, on the other hand, in collaboration with several clinics, can have access to sufficient data.

The best approach to offer a complete preventive medicine programme would integrate on-farm monitoring, activity scheduling reports, health status and prediction reports, periodical questionnaire interviews conducted by the veterinarians, farm comparison and evaluation reports, and continuous analysis of the preventive medicine database for interrelationships between various factors (Bigras-Poulin and Harvey, 1987). These are important components of an effective partnership responding to the expectations of each partner. Such an approach is presently implemented by a group of researchers at the University of Montreal. One example of the originality of their approach is the financing. Veterinarians from 39 clinics have formed a research society and raised several hundred thousands in tax-deductible dollars. This fund is partially used to grant a research and development contract to the University. This contract gives to the society all the rights of commercialization of the softwares developed during the research project. About 500 dairy herds will be included in this project. The selection of the clinics and the herds was not based on a sampling scheme (Bouchard et al., 1991). Although this is a limitation, the approach is addressing the two major issues associated with this type of partnership: finance and collection of data relevant to all participants.

The structure of the partnership depends essentially on the people involved. There is not one single approach that can claim to be effective and viable under any circumstances.

Another approach is proposed partly based on work done at Ploufragan, France (Tillon et al., 1981):

Three different levels of cooperation could be established (Figure 1). In order to be representative of the overall population, randomization is normally used when sampling a part of this population. This is often done at different levels (animals, herds, regions) and is usually a major consideration in the design of any epidemiologic study. However, a large disparity exists between producers in their ability to collect information (Vaillancourt et al., 1992). Data quality should be a primary concern over representativeness of the information per se.

Those who are best at recording information could be asked to participate closely with practitioners and epidemiologists in establishing a nucleus of herds that would be constantly monitored (Figure 1). The development of a privileged relationship with the producers is critical. This high level of interaction is essential to the establishment of a detailed preventive medicine programme (primary level). A second group of farmers should be sought and asked to participate at a secondary level. This would be a larger group of operations with whom the epidemiologists could communicate on a regular basis via their veterinarians and other support personnel. Although also not selected at random, this group would provide a greater number of data on a restricted number of variables of potential interest based on the investigation at the primary level (secondary level). As we become more knowledgeable on a particular topic, it would be more feasible to involve more farms in an investigation focusing on key variables based on the work accomplished at the primary and secondary levels. The randomized selection of herds at this level would then be possible. These three levels of cooperation could constitute a regional unit. Once well established, several of these units could be linked. Government veterinarians and epidemiologists could work in close cooperation with each regional unit to establish this link. It could provide them, at relatively low cost, with baseline information on the health status of the "national herd". The ideal situation, of course, would be to develop regional units considering from the start the needs of a "national network". For example, addressing issues such as the standardization of data collection (categorization, indices, etc.). The National Animal Health Monitoring System (NAHMS) in the United States is an example of such a network. NAHMS is design to gather information based on random sampling. However, regional units developed with the priorities

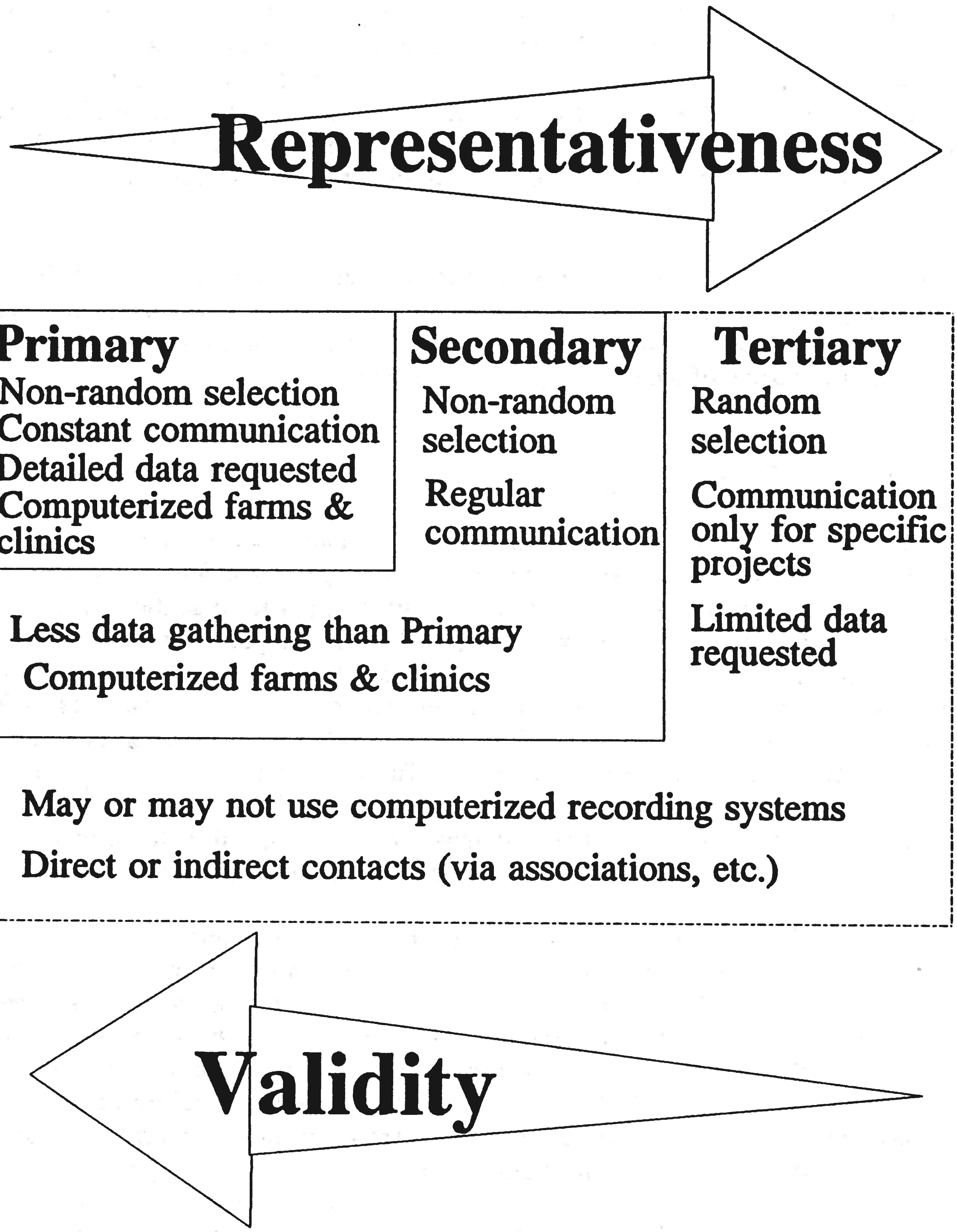

Fig. 1 Major characteristics of a three-level regional unit.

of the local people in mind could be more viable on the long run.

The "regional unit" concept developed at Ploufragan was successful during the first few years of its existence. However, it is no longer fully operational. It appears that the relationship between practitioners and epidemiologists or field-based researchers could not be maintained. One possible reason for this current situation is the apparent conflict between the need to observe versus the need for immediate action when a problem arises. To produce a sustainable partnership, epidemiologist will have to use recording schemes that will allow them to monitor interventions and quickly assess the outcomes without interfering with practicing veterinarians.

Success will ultimately depend on two points: whether the partnership responds to the needs of the people involved, and whether an effective communication system can be developed and maintained that allows for the timely transfer of up-to-date information and for a continued exchange of ideas among the participants.

A LONG TERM VISION

Different forms of partnership can be established. Although epidemiologists as full time private consultants could be part of the agri-food landscape in the future, the short term reality is that most epidemiologists involved in a partnership with practitioners will likely have an University affiliation. The partnership will need support from Universities or institutions not as much for the research environment as for the maintenance of a "communication system" that goes beyond the day-to-day contacts between partners. Indeed, a system should be in place to train veterinarians in population medicine so that they can effectively communicate with epidemiologists. To assist the food animal industry, Universities, governments and the private sector must contribute to the development of integrated research-training programmes. It must have the capability to respond to the different levels of problems encountered by the agri-food industry (Figure 2).

Most animal industries are essentially facing three types of problems or challenges: acute (such as infectious disease epidemics); endemic issues requiring immediate attention (hatchability and egg quality in poultry; behavioral problems associated with intensive production, etc.); and long term issues leading to new developments that are vital to the more distant future of the agri-food industry (improvement of genetic lines, alteration of the nutrients in eggs, etc.) (Figure 2). These different types of problems call for different types of investigations that could be "nested" in the preventive medicine programme described above. An integration of research and training programmes is essential because a system must be in place to effectively channel the information resulting from investigations to the individuals who can best use it. This includes people who want to become part of an animal production industry as well as those who want to acquire new skills or stay up-to-date. In addition to promotions and bonuses based on performance (productivity, herd health status), similar rewards could be based on efforts to stay informed. Such a reward system would certainly contribute to support collaboration between producers and the practitioner/epidemiologist partnership.

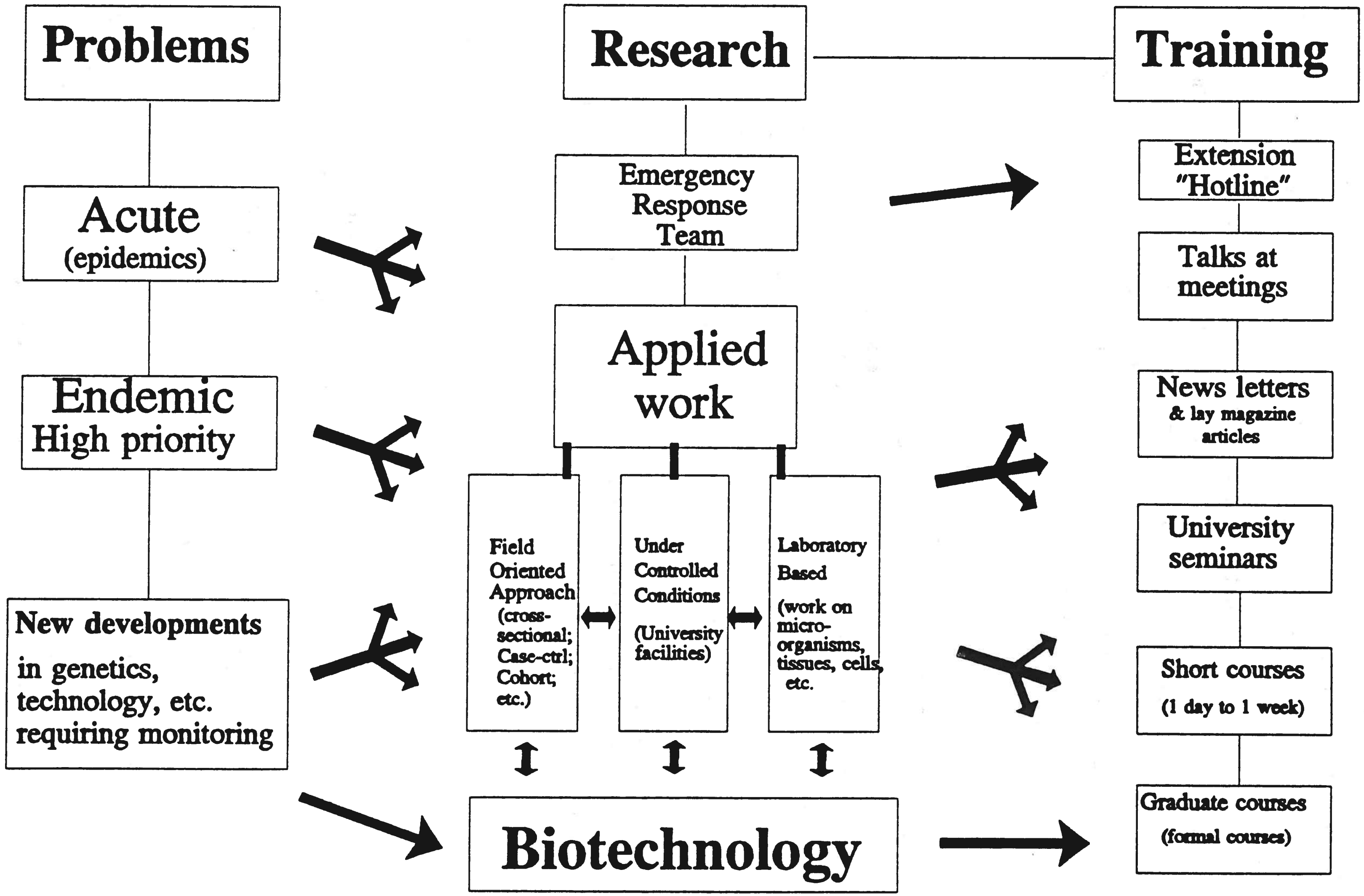

Fig. 2 Elements of a research-training programme

Research and the acquisition of knowledge by academicians or government based organizations will only benefit the agri-food industry, and ultimately society, if the information is made available in a timely fashion and if it is properly transmitted. Although several structures are already in place to achieve this goal, and good results have been achieved in the past, a lot of original work is still required in this area. In order to optimize the transmission and application of knowledge, the value of education per se will have to be recognized and promoted by everyone involved in animal production and in satellite organizations such as the provincial and federal governments and Universities. Although this may seem like stating the obvious, the fact is that not enough is being accomplished in this area. For example, we already have the knowledge to keep preweaning mortality in pigs well below 10% without requiring expensive sophisticated equipment. Yet, mortality in pigs before weaning averages between 15 and 20% in most developed countries! Although not one single factor can be entirely responsible for this situation, the lack of appropriate transfer of information is certainly a major aspect of this problem.

Professors and staff from Universities and other institutions will have to assume the leadership in establishing an integrated approach to training that will include managing undergraduate education, post-graduate training and research, continuing education and extension without the traditional limitations imposed by departmental structures. Indeed, the critical mass of individuals needed to support an adequate training programme for a specific animal industry usually cannot be found in only one department or college. Therefore, training programmes requiring participation from individuals from different departments or colleges (veterinary medicine, economics, engineering, food science, agriculture, etc.) should be encouraged. They would respond to the needs of the food animal industry and of society.

The epidemiologists who are committed to a specific animal industry and who have the knowledge and expertise of health managers will likely be the most effective individuals to participate in a partnership with practitioners and in establishing training programmes tailored to the needs of their partners.

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DECISION SUPPORT SYSTEMS IN ANIMAL HEALTH

R S MORRIS[1], R L SANSON[1], J S MCKENZIE[1] and W E MARSH[2]

Computers offer a valuable tool for epidemiological investigation and for management of animal health services at both farm and national level. The nature of information systems is continuing to evolve rapidly as the mobility and capacity of the computer hardware becomes greater and greater, and as new forms of software become readily accessible. Earlier concepts of the objectives of information management were embodied in names such as "databank" and "registry". The analysis of data was handled quite separately from entry and storage, frequently not even on the same computer.

Since then the conceptual framework for information management has matured (Thrusfield 1983, 1986), and the capability to handle more powerful and especially more integrated information management systems has grown and changed in the light of experience. Currently information management efforts are directed towards "decision support". The two key concepts in this approach are that the focus is on the decision-makers (at both policy and implementation levels) rather than on the system itself, and that as far as possible the components of the decision support system are seamlessly integrated so that a single interface is used to access all features of the system without regard to which component of the system is actually providing the answers.

This trend will be illustrated with examples from national disease control and from health management systems at farm level. EpiMAN is a decision support system for control of major diseases which require national control or eradication procedures. The first implementation of the approach has been for exotic disease control. The system incorporates a core database with links to a geographical information system (GIS), so that all information about livestock herds and disease occurrence can be linked directly back to the farm location. Expert systems process incoming data immediately and guide outbreak managers on priorities for allocating personnel. Other components of the expert system answer technical questions on demand. Simulation models incorporated into the system predict both the short-term consequences of individual outbreaks as sources of infection, and the longer-term merits of alternative control policies which might be under consideration. An "epidemiologist's workbench" gives the epidemiologist access to both standard menu-selected reports on demand and the capacity to formulate advanced analyses using built-in software. The system is totally mobile, and can be set up anywhere in the country. The approach embodied in EpiMAN is progressively being extended to endemic disease control programmes, other exotic diseases and quality assurance procedures such as chemical residue control. The nature of EpiMAN makes it ideally suited for use as a training tool, as well as an operational tool.

A similar approach is being adopted at farm level. PigCHAMP was developed at the University of Minnesota as a records analysis program for pig herds, and is now being expanded to incorporate farm financial data, abattoir information, expert systems and simulation models, all accessible through a common interface. Modules originating at different research centres can be incorporated into the total system, and the user can choose which components to pay for and use, according to need. DairyMAN is an equivalent system for dairy herds developed at Massey University, which is being enhanced with a whole farm simulation model and with expert systems. It is also integrated with the national dairy herd improvement system.

These examples will be used to illustrate the nature and value of decision support systems.

DECISION SUPPORT SYSTEMS

Decision support systems (DSS) are interactive computer-based systems that help decision makers utilize data and models to solve unstructured problems (Sprague & Carlson, 1982).

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They exhibit the following characteristics:

They tend to be aimed at less well structured, underspecified problems.
They combine the use of models and analytic techniques with traditional data access and retrieval functions;
They typically focus on features that make them easy to use by non-computer people in an interactive mode;
They emphasize flexibility and adaptability to accommodate changes in the environment and decision-making approach of the user. Individual decision support systems can comprise part of an overall national animal health information system (Morris, 1991).

The purpose of a DSS is to provide a set of tools to help in the interpretation of data. The DSS should give decision makers an appreciation of the risks implicit in particular decisions, and the factors which can be varied to modify those risks. One approach is to use an expert system with a database management system (DBMS) (Tou, 1980).

An ideal application area for DSS in animal health is in emergency response systems, where typically decision-makers have to cope with large volumes of diverse and often imperfect data, inadequate time and resources are available to devote to complex problem-solving, and the outcomes of decisions can have far-reaching consequences. Berke and Stubbs (1989) present a thorough argument in favour of DSS for hurricane mitigation planning. Successful control and eradication of a foot and mouth disease (FMD) epidemic is contingent on the rapid identification and elimination of all virus sources. This involves an understanding of the dynamics of the disease, combined with adequate procedures that identify, record and deal with all events that may contribute to further spread of the disease. The EpiMAN project was initiated to develop a DSS to be used by MAF should an FMD outbreak ever occur in New Zealand.

DESCRIPTION OF EPIMAN

EpiMAN is a system for national control of major animal diseases, initially concentrating on FMD. It was developed in New Zealand as part of national preparedness for any future outbreak of this major exotic disease, but is now under consideration for adoption in a number of other countries. The system runs on a pair of linked Sun workstations (database server and graphics workstation), to which personal computers are networked. Replaceable hard disk cartridges are used to allow rapid switching to different diseases and areas. Fast printing of colour maps and of reports is provided. The whole system is designed for easy and rapid transport by air or land, and immediate service at the operational site.

A key function of the DSS is management of the large volume of data typically generated during an emergency. A computerised DBMS is ideally suited to such a task. The need to have a bird's eye view of the situation, the need for presentation of status reports in formats that are easy to comprehend, and the need to understand the dynamics of the disease in a spatial context, led to the evaluation and subsequent adoption of a geographic information system (GIS) in EpiMAN. It is noteworthy that an analysis of FMD outbreaks in unvaccinated populations in Europe from 1965 to 1982 (Lorenz 1986) showed that although the median outbreak size was 29 farms, the mean size was 1048, because 30% of the outbreaks were massive. An important objective of EpiMAN is to make massive outbreaks much less likely.

Computer simulation models are programs which seek to represent the dynamics of real world systems. Models can be linked to information systems to provide procedures for the evaluation of management options based on an analysis of the current situation (Marsh, 1986; Saarenmaa & Nikula, 1989). In this manner, the information collection system serves to provide parameter estimates for the model. These estimates are updated as new information is acquired, and the model can be re-run to assess the new situation.

New Zealand has never had an outbreak of FMD. Consequently, there are very few veterinarians in the country with the experience or knowledge of FMD to fully understand the epidemiology of the disease. A FMD epidemic would place a severe demand on suitably qualified manpower resources to run all facets of the Emergency Headquarters (EHQ) operational procedures. Expert systems, which can emulate aspects of human reasoning, have an obvious role to play in interpreting epidemic data and aiding in the decision making process.

Figure 1 shows the structure of EpiMAN. The core of the system is a comprehensive database, consisting of spatial data, textual data and epidemiological knowledge of FMD (contained within the FMD models and expert systems). The epidemic-related tabular data and farm profile information associated with farms in the infected area (IA) is stored in the DBMS. Associated with this are the digital maps of the IA which are stored and managed by the GIS. The models of FMD spread and the expert systems operate on these spatial and textual datasets, using a set of epidemiological parameters which describe aspects of the behaviour of FMD. Initially these variables have a set of default values, but are modified through immediate statistical analyses of the spatial and temporal patterns of the particular epidemic.

Details of these various components are discussed below.

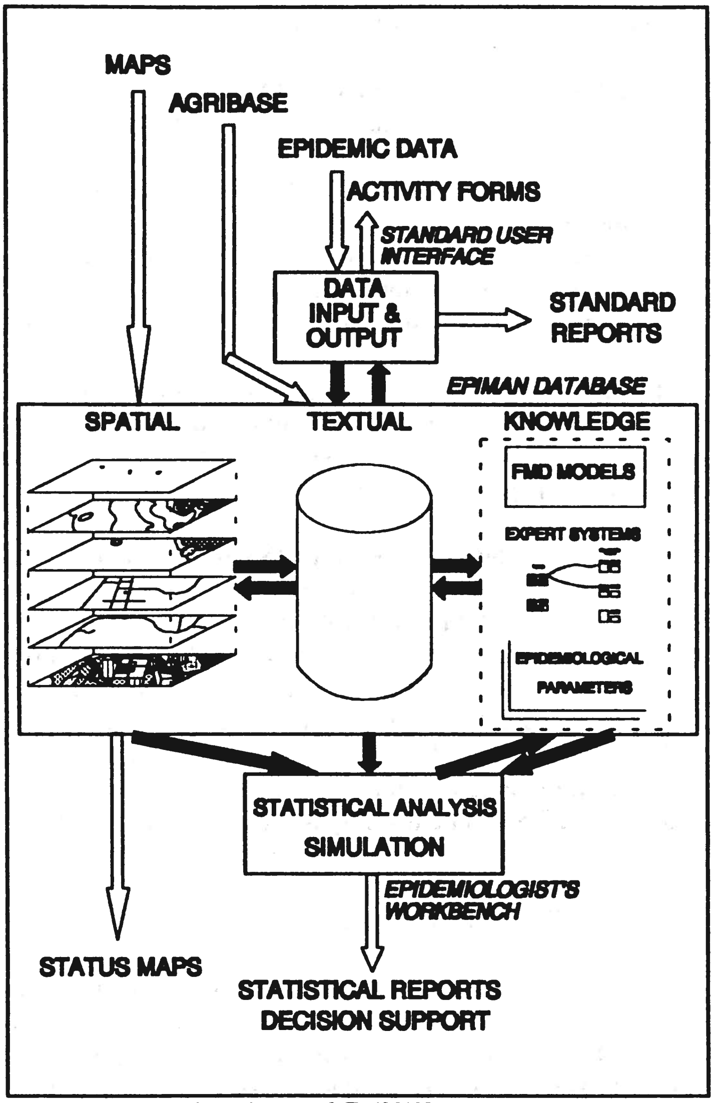

Figure 1 The structure of EpiMAN.

Core textual database

To understand the information processing tasks assisted by EpiMAN, a brief description of the control philosophy adopted by MAF, and the responsibilities of the specific operational sections of the EHQ is necessary.

If a FMD outbreak occurred in New Zealand, an exotic diseases and pests responses programme (EDPR) would be activated, involving slaughter and disposal of all livestock on infected premises followed by thorough cleaning and disinfection (C&D), urgent investigation of all properties directly or indirectly associated with infected premises (IPs) followed by active surveillance on those livestock units judged to be at risk of FMD, coupled with stringent movement control within the IA. The goals are rapid elimination of all virus sources, surveillance of all at-risk properties to facilitate early diagnosis, and prevention of further spread through strict movement control.

The EHQ is the field operations control centre during the eradication campaign. It is intended to be as close as possible to the focus of infection to facilitate the directing of control procedures. A key consideration during the design of the EpiMAN system was to construct the database such that a complete national picture would be available at the EHQ, with secondary access from other sites as required.

Whenever a new IP is discovered, the information derived from the investigation is reported to the EHQ where the data is transferred into the DBMS *via* computer input screens. An on-farm FMD virus production model (FMDVPM) is run using details of the clinical report as input. This model recreates the buildup of infection on the farm and quantifies virus release to the atmosphere, and into milk in the case of dairy farms. The outputs are then accessible to the rest of the system. Up-to-date weather data collected from an existing weather station, the IP or from a specially erected weather recording site is stored in the database to allow the prediction of wind-borne spread.

All movement information is analyzed by the tracing expert system, which ranks movements in priority order. The Tracing Group (TG) identifies all properties and vehicles that have been in direct or indirect contact with the IP. C&D Order forms are issued for vehicles and plant and equipment requiring C&D. C&D is overseen by the Movement Control Group (MCG), which also has responsibility for the issuing of movement permits within the IA.

The Disease Investigation Group (DIG) is responsible for surveillance on all at-risk properties, which include contiguous properties, all livestock units within a 3 km Patrol Zone, owners' other properties, premises associated with movements off an IP, and livestock holdings exposed to windborne plumes of FMDV.

For every farm which comes under detailed consideration, a special Control Form, which contains a map of the particular property, and relevant farm details is printed by the system. The Control Forms are assessed by the DIG manager who decides if field investigations are required. Information presented on the form includes the date and nature of all episodes that placed the property at risk, a summary risk rating, the earliest date one would expect to see clinical signs if disease were to become established, and the date by which the event can be discounted if no clinical signs appear. This information is furnished by an expert system which processes all incoming data. The DIG manager decides on the exact action to be taken in light of the information presented.

The database is capable of containing information on all livestock units in the outbreak zones. This is however not essential for the operation of the system, which can work with much simpler data such as grid locations of affected and at risk farms, but extends the power of the system to enable the assessment of risk factors and the prediction of disease spread. To facilitate this, consideration is being given to creation of a national agricultural index system (Agribase) that will contain basic farm profile information on every commercial farm in the country. Each farm will have a unique farm identification number, the FarmID. The FarmID is the key field throughout the EpiMAN system, and provides the link between the GIS and the DBMS.

The recent development of low-cost hand-held geopositioners intended for navigation offers another attractively simple way of dealing with location information. These allow the user to stand at an outbreak site and instantly determine the exact location by satellite telemetry (at no cost). This information can then be fed into the database where it is immediately linked to its map location, removing the need for locating farms on paper maps to enter their geographical locations.

Spatial database

EpiMAN employs the Arc/Info[3] GIS operating on a UNIX workstation to manage the spatial aspects of the system. The map layers used by the system are depicted in Figure 2. The base layer is a farm-based map layer. Each farm is related to the Oracle DBMS *via* the FarmID, which is the key field within the GIS and the EpiMAN DBMS. This means that any changes to the records in the DBMS can be readily displayed and manipulated by the GIS.

A range of graphical and other reports can be provided from the GIS. Various overview maps can be generated, showing the location of all infected and at-risk properties - some suitable for use by the Chief Veterinary Officer and the media, others intended for use in the EHQ for assignment of duties. Local maps can also be produced as a result of the risk evaluation by the expert system, showing farms to be visited plus surrounding properties.

Although the use of individual property boundary information gives the system maximum power to support decision-making, various less detailed methods can be used to come close to this level of detail. The nature of the GIS means that, provided each map coverage is "registered" through a reference point,

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[3]Environmental Systems Research Institute, Redlands, California, USA.

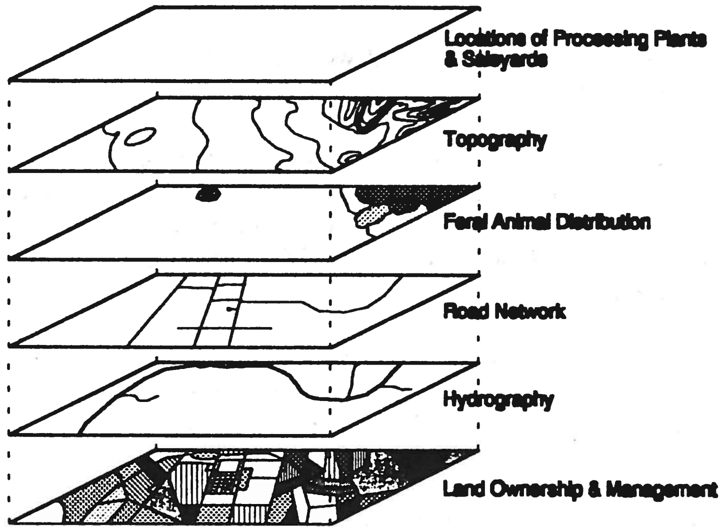

Figure 2 Major map themes used in EpiMAN

maps of different types can be overlaid on each other for visual or analytical assessment. For example a standard paper map can be optically scanned and presented on the screen with outbreak and other data visually superimposed on it so that disease data can be related to geographical features in a familiar way. Thus advanced digital map data is not essential. Where digital map data is available it can be used to recreate a 3-dimensional image of the land surface in the area, again allowing this data to be displayed in relation to outbreak information.

FMD models

On-farm virus production model

When a new IP is discovered, there is an urgent need to evaluate what opportunities there have been for further spread of disease from the moment of virus arrival on the property to the time of diagnosis. The probability of spread for each opportunity is directly proportional to the build up of infection on the farm and the consequent release of virus into the environment.

A Monte-Carlo simulation model that resimulates the sequence of events on the farm, and quantifies the degree of environmental excretion of FMDV has been developed and incorporated into the EpiMAN DSS. The model simulates the spread of infection among animals of the first species infected on the farm, and then to other species on the same farm, reports the numbers of animals infected/clinical/carriers on a daily basis, and computes the total quantity of FMDV liberated into the atmosphere on a daily basis; and in the case of dairy farms, the daily concentration of FMDV expected in the farm milk supply.

Meteorological spread model

The on-farm model simulates the release of FMDV into the atmosphere as discussed above. The meteorological model is then run. The technique used is to solve the Gaussian plume dispersion equation (Hanna *et al.*, 1982). This uses weather parameters to estimate lateral and vertical dispersion, and then calculate the concentrations of virus at various points downwind. A 20x20 km grid, consisting of 50x50 m cells is constructed over the farm. Virus concentration at each of the cell centres is calculated. The model starts from the centre of the farm, and moves down the direction of each plume. The cells lateral to the plume core are also considered, until the concentration is effectively zero. The concentration of FMDV for each cell is accumulated for each day, as it is assumed that if there is insufficient virus to infect an animal over a 24-hour period, virus will be inactivated. The grid concentrations are then processed by the GIS to identify properties at risk.

Inter-farm spread model

A true DSS should allow a manager to conduct a series of what-if scenarios to investigate the likely consequences of major policy options. In terms of managing a FMD epidemic using a stamping-out philosophy, strategies include changing the size of the IA, adjusting the size of the patrol zone (standstill zone) around IPs, instigating pre-emptive slaughter (dangerous contact slaughter) and implementing a ring vaccination buffer. In order to test these major control options adequately, a spatial simulation model has been developed that operates on the actual geographic data.

Three infection processes are modelled - local spread, movement related spread and recrudescence. To investigate alternative control options, the user can alter the patrol zones, change the size of the IA, instigate a dangerous contact slaughter policy, and create a vaccination buffer. The entire epidemic can be resimulated with the alternative policies in operation, or the user has the opportunity to implement changes during a particular simulation run. If the control procedures are adequate, the disease is eradicated. If not, the dissemination rate remains high and the disease eventually becomes endemic. Outputs of the model are the numbers of farms diagnosed per day (or per week), the dissemination rate, the length of the epidemic, and the number of farms to be patrolled on each day throughout the epidemic.

Expert systems

Development of a system to assign priorities to tracing movements

One of the bottlenecks identified in the operation of the EHQ was the follow-up work associated with traces involving movements of people, animals or materials on to or off IPs in the period leading up to diagnosis. In the New Zealand Temuka FMD scare of 1981, in addition to investigating the sources of garbage fed to the pigs, some 50 direct movements had to be traced (Ryan *et al.*, 1981). A recent study in New Zealand has shown that the number of traces which would need to be assessed per farm would be over 50. In a large epidemic involving multiple IPs being identified daily, such as the UK 1967/68 epidemic where there were 80 new farms identified as infected per day at the height of the emergency (Northumberland Report, Part I, 1968), the number of traces to investigate would quickly place an overwhelming demand on manpower resources.

Investigation of traces involves first establishing whether or not there is a risk of FMD having been transferred with the particular movement. An expert system assigns risk ratings varying from very high to nil to each of the traces and presents this information to the TG. The traces are assigned a risk rating, ranging from very high to nil risk. The assignment of risk ratings is based on a set of decision rules which have been incorporated into the expert system. The principal issues to consider in the assignment of risk are date of movement, whether on to or off the farm, type of conveyor and whether there was any direct contact with susceptible animals. The second step involves a team of telephonists confirming the movement, the fate of the moved items (in particular whether or not they have been transferred to another property) and whether or not there are any signs of disease. This process identifies at-risk properties, and potentially contaminated equipment and vehicles.

Rating of at-risk farms and patrol requirements

There are numerous circumstances that place farms at risk of contracting FMD. These include being involved in a trace from an infected farm, proximity to an infected farm, being exposed to an airborne plume of FMD virus and being on a dairy tanker route from an infected farm to the factory. An essential part of managing an emergency is ensuring all events or circumstances that place properties at risk are investigated and that these farms are monitored according to the degree of risk. Very often, there will be multiple incidents that constitute risk to a particular property. For example, a dairy farm neighbouring an infected dairy farm could easily be at risk through all of the above reasons. A summary indicator of risk would be a valuable management tool to allow the DIG Manager to plan the daily patrol schedule, especially where manpower resources are limited. It is also important to know when farms are likely to exhibit clinical signs if infection is present, and when the farm can be safely taken off the At-Risk file. An expert system has been developed to conduct these tasks.

There are several components to this system. The first stage records the specific event or situation that places a farm at-risk. Each of these episodes is recorded as an episode in the DBMS. For each episode, a risk rating is applied, the earliest date at which clinical signs can be expected is derived and the date by which the episode can be discounted if no clinical signs have appeared computed. A summary entry is then recorded for each property into an At-Risk file, where a combined risk value is derived for the farm, the earliest date by which clinical signs can be expected recorded, the date at which it can be recommended that the farm be removed from the patrol list and the optimum patrol frequency entered.

Technical information data base

During a FMD emergency, the range of possible scenarios and the complexity of interacting factors, invariably leads managers to have to make decisions regarding the eradication of the disease, where the circumstances of the particular farm are atypical. In these situations, there will inevitably be additional technical information on some aspect of FMD that would aid the decision maker. Although there is a vast literature store on the epidemiology of FMD, a ready source of technical information on FMD at the EHQ would be a real help. This perceived need has lead to the development of a knowledge-based technical reference system on the epidemiology of FMD. The system is known as FMDHELP and has been developed using the expert system shell Nexpert *Object*. Basically the user selects one of the broad categories of subjects relating to FMD for which technical information is desired. The user is then presented with a list of sub-headings within that subject to choose from. On selection of one of these, a file of specific information is shown on screen, which the user can scroll through at leisure. The system then returns the user to the front menu containing the major categories.

EPIDEMIOLOGIST'S WORKBENCH

At the peak of an exotic disease emergency it would be difficult to spend time designing and conducting analyses to evaluate the effectiveness of the eradication effort. Hence EpiMAN contains a set of tools which have been designed in advance either to conduct standard analyses or to carry out particular forms of analysis on the data files, with specific details being provided by the epidemiologist at the time. All of these procedures will be accessible through a menu system, described as the workbench. They will be carried out by a statistical package which has advanced analytical and graphing capabilities.

For example, the system will be able to automatically build a graphical network on request to represent its best assessment of the epidemiological links between the various IPs detected to date, and will reassess the network each time a new IP is found. The shape of the epidemic curve and the estimated dissemination rate will be calculated, and a forward extrapolation will be made from this. A series of detailed indicators will also be calculated to assess changes in the mechanisms of spread which appear to be operating as the outbreak develops, and to evaluate the extent to which new IPs are failing to be predicted in advance by earlier "at risk" lists, which would indicate that unexpected transmission patterns are occurring. Survival analysis and proportional hazards regression will be used to assess factors influencing the development of local clusters of IPs.

EXTENSION TO OTHER NATIONAL ANIMAL HEALTH PROGRAMMES

A substantial amount of work was required during the initial design of EpiMAN to prototype various alternatives and choose how best to develop an integrated system. Two of the major design criteria were that the system be capable of operating on various hardware platforms, and that it be adaptable to other tasks beyond FMD.

It is proposed to extend the exotic disease capabilities of EpiMAN beyond vesicular diseases to cover various groups of diseases which share common features, so that there will eventually be up to 5 variants of EpiMAN to cover the range of epidemic diseases. Many of the features will be common, but specialized aspects for rabies or insect-borne diseases can be handled by disease-specific modules which would replace the vesicular disease module when required.

The system can also be adapted for use in control of endemic diseases. In New Zealand tuberculosis (TB) has become established in the Australian brush-tailed possum, and this means that control of the disease involves wildlife as well as domestic cattle and deer. A version of EpiMAN is being designed to use the geographical capabilities of the system to manage the wildlife and domestic animal aspects of tuberculosis jointly, using vegetation and landform information which determine possum ecology to handle possum control aspects, while in another overlay domestic stock TB control is managed within property boundaries, taking into account stock movement information.

A computer simulation model of TB has been developed in which the epidemiology of the disease is simulated on the actual geography of the area, at micro-, meso- and macro-scale, using a three-tiered modelling approach. The model uses parameter estimates derived from detailed epidemiological studies currently being conducted on the disease (Pfeiffer and Morris 1991).

The completed system will be able to conduct management procedures and analyses comparable to those described for FMD, but targeted to the longer-term needs of an endemic disease control programme. Work on the various constituent parts of the system is currently underway. Because the control effort for TB takes place through local area disease control managers, it is envisaged that the components of the system required for local control programme management will be made available at district offices, including the reduced form of Arc/Info called ArcView, which enables simpler GIS procedures to be carried out purely by menu selection, on a PC.

Because of its large international trade in animal products, New Zealand places great importance on its international standing as "clean and green", and hence on the maintenance of quality assurance procedures for products leaving the country. Another capability of EpiMAN is to manage data concerning such quality assurance procedures as chemical residue testing and meat inspection findings, linking this back to the farm and area of origin so that sound claims can be made about the status of product going to various markets. Development of this aspect of the system is envisaged for the near future.

Because much of the data is common to these various systems and removable disk cartridges are being used for system-specific data, the same equipment and purchased software can be applied to widely different problems over the same period, ensuring that users are familiar with it in various applications. It will also make it possible to have the system permanently ready to handle an exotic disease emergency immediately, should one arise.

DECISION SUPPORT SYSTEMS FOR FARM USE

Herd information systems are currently expanding in scope to become decision support systems, much as national disease information systems are evolving in the same direction. In both cases this results in part from the development of an increasing range of computer programs which all use the same data. There is pressure from users to avoid re-entry of the same data, and both hardware and software developments are making this easier to achieve. In technical terms, this linking of software and the capacity for different programs to access the same datafile is called "seamless integration". With appropriate care separate pieces of software can be integrated by sharing a common interface and menu system, so that a single main menu gives access to alternative programs, and transfer of data from one program to the other is transparent to the user. Both may make use of a single data file, as long as the programs respect the rules concerning file opening and closing, and especially obey the same rules concerning file modification. Increasingly, software is moving towards complying with the Common User Access rules, which means that all programs look and act in similar and consistent ways. Two examples will be given of herd systems which are developing the features of decision support systems.

Pig herd decision support

The pig records system PigCHAMP was developed in the US at the University of Minnesota in the 80s, and has now become the most widely used system of its kind in the world. Initially it dealt only with the breeding herd, but it has since expanded to cover the growing herd and analysis of efficiency of the whole herd, and to include an overall financial analysis of the herd, and an interface to a farm accounting package so that accounting data can be shared between the programs. A comprehensive database evaluation module within PigCHAMP allows the user to go beyond pre-defined reports to produce a variety of types of graphical and text reports on over 200 variables, with user-selected inclusion and exclusion criteria. In this way great flexibility to produce epidemiologically valid reports can be achieved without sacrificing simplicity of access.

There is also a direct interface through a PigCHAMP menu item to a simulation model of the pig breeding enterprise, PigORACLE. This allows current herd productivity data and herd composition to be used to create a forward prediction for the next six years of physical and financial performance of the herd, and then to vary the price and performance assumptions and evaluate the sensitivity of performance to these changes. Equivalent models for the growing herd have become available in recent years (Black and Barron, 1988), and there are plans to link one or more of these growth models to PigCHAMP to allow evaluations of feed formulation and management to be conducted within the overall herd information system. These models of growth are technically very complex, and make available to the user a synthesis of experimental data and field experience in the form of a predictive model for the growing pig.

Expert systems are also being added to the total system at present. CHESS (Computerised Herd Evaluation System for Sows) assesses the performance of a single breeding herd in relation to its own previous performance and in relation to performance of a peer group of herds over a single time period and over a series of time periods. It reports back likely sources of suboptimal performance, which can then be investigated further (Huirne *et al* 1992). It is currently being interfaced directly to PigCHAMP, so that CHESS evaluations can be run as a PigCHAMP menu selection, using peer group data for a chosen "comparison group" of herds. PigCHAMP is able to do comparative analyses on up to 200 herds, which will generate the peer group data for such analyses. If reproductive performance in the herd is found to be suboptimal, then a second expert system PigFIX (Fertility Investigation eXpert) is being developed (Wongnarkpet, Morris and Stern 1993) to automatically run and analyze various reproductive reports available within PigCHAMP. It will then guide the user to issues which deserve priority in herd investigations. A third system, PorkCHOP (Dijkhuizen *et al* 1986; Huirne *et al* 1991) evaluates herd culling and replacement policy, and recommends both a overall policy for the herd dependent on its performance, and will assess what action is economically optimal for individual culling decisions.

The system is also being extended to incorporate other data. For example, both carcase data and slaughter inspection data can now be returned to farm files electronically, and used in a comparative evaluation of occurrence of lesions in the particular herd versus its peers. Other complementary modules of a similar nature are planned for the future.

Electronic identification by transponder is gradually emerging as a practical technology for animal recognition, and is likely to become widely used over the next decade. Already in use and likely to become more widely accepted is the use of electronic identification in combination with hand-held data loggers/computers, in some cases with FM radio exchange of data with the computer which is storing the primary records, and which is located in the farm office. In this way seamless integration can occur throughout the process from animal recognition to report production and evaluation!

Dairy herd decision support

A similar process is occurring in dairy herds. In North America programs such as DairyCHAMP are developing the same degree of functional integration, while in New Zealand and Australia DairyMAN is designed to provide comprehensive support for pasture-based dairy herds.

DairyMAN contains a core information system which handles production, reproduction and health data, and analyzes it in both report and graphical formats.

The system is now fully integrated with the national dairy herd recording and artificial insemination system, so that data can be downloaded from the national database to create (and in most cases maintain) the farm database. Plans are in hand to upload data from the farm to the national database as well. Work has commenced on an expert system DairyFIX (McKay *et al* 1988) which will evaluate herd performance in much the same way as PigFIX will do for pig herds. In other places expert systems are already employed for purposes such as analysis of lactation curves (Fourdraine *et al* 1992).

There are special problems with modelling pasture-based livestock production, which make development of a model of a grazing farm much more difficult than one of a housed enterprise such as a pig farm. However a model, FarmORACLE, has been developed which simulates a farm comprising a paddock layout specified by the user, together with agronomic details for each paddock. All major grazing species in New Zealand can be allowed for, and the dairy herd which is simulated can be the one stored in DairyMAN. Farm management can be simulated with appropriate management decisions and paddock rotations, with output consisting of financial and physical performance indices (Butler and Morris, 1993).

As milking parlour management and data gathering become increasingly automated, increasing use is being made of integration between different methods of measurement of production, mastitis, oestrous activity and other variables of interest to the farmer (Devir 1992). Because of the large flow of information which arises from such systems and the difficulty in discriminating abnormal from normal patterns, such techniques as neural net analysis are being used in an effort to distill the data down into useful management aids (Neilen *et al* 1992).

CONCLUSIONS

Developments in hardware and in software design over the last two decades have laid the foundations for information management in animal health to move gradually from what can now be seen as relatively primitive beginnings to tightly integrated systems which provide very powerful support for management, evaluation of options and decision-making in both national disease control programmes and in herd management systems. In many ways these represent the embodiment of the current state of epidemiological thinking in the form of integrated processing and analysis systems which use the techniques of epidemiology within practical management systems. In this way current epidemiological thinking becomes accessible to decision-makers without the need for them to have direct involvement in determining how the data are analyzed and presented to them.

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A SURVEY OF ANIMAL HUSBANDRY IN THE DARTMOOR NATIONAL PARK

A R LEWIS*

Since the earliest designation in the 1950s, the National Parks in the United Kingdom have been at the centre of a debate over the balance between intensive farming and the National Park purpose. In the uplands this debate has focused on the preservation of heather moorland and provision for public access. In the Dartmoor National Park, the Dartmoor Commons Act 1985 established that account should be taken of the National Park purposes of (i) enhancement of the natural beauty of the landscape and (ii) public recreation in the regulation of animal husbandry on common grazing land within the Park.

From the animal health point of view the main features of the area are the large size and low density of the animal populations, semi-natural vegetation and severe climate.

This paper presents:

(i) A description of common grazing land within the Dartmoor National Park.

(ii) Analysis of a farmer questionnaire survey of the use of common grazings by sheep and cattle under traditional Dartmoor husbandry;

(iii) A description of the management of reproduction of sheep flocks and cattle herds by movement between farms and the commons;

(iv) Discussion of the epidemiological importance of developments in animal husbandry on Dartmoor since 1985.

ANIMAL HUSBANDRY IN THE DARTMOOR NATIONAL PARK

The Dartmoor National Park, designated in 1951, is an area of upland 94,627 ha in extent and classified as severely disadvantaged land within the Less Favoured Area. Figure 1 (Atkinson 1991) illustrates that in 1988 the size of farm holdings within the Park was comparable with that in the remainder of the county outside the Less Favoured Area. The major landscapes associated with farming and animal husbandry within the National Park (Atkinson 1991) are:

(i) Moorland used for extensive grazing covering 48,254 ha, 51% of the area of Park. SSSIs managed to conserve heather moorland cover 30% of the area of the Park;

(ii) Woodland covering 8664 ha, 9% of the Park area;

(iii) Improved farmland covers 36,889 ha, 40% of the total Park area.

Common land, predominantly moorland, which is the basis of traditional animal husbandry, comprises 37,028 ha or 37% of the area of the National

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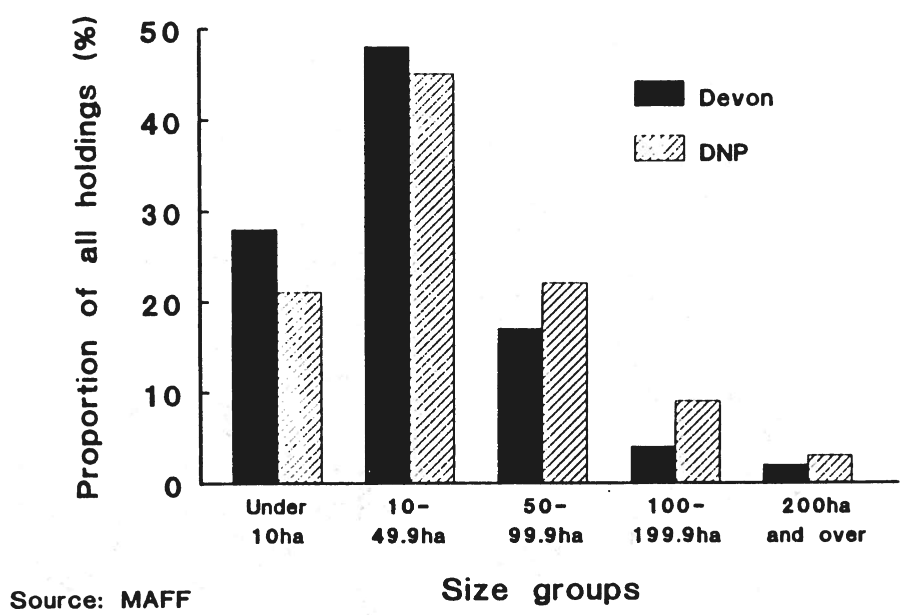

Fig 1. Dartmoor National Park (DNP) and County of Devon, 1988: farm holdings by size

Park (Fig 2.). Together with the area to which the public have access under management agreements, this constitutes the largest public open space in England and Wales (Atkinson 1991).

The farming tradition on Dartmoor, based on grazing rights on the commons attached to occupation of the surrounding farms, is regulated by a statutory body, the Dartmoor Commoners' Council, established under the Dartmoor Commons Act 1985. The livestock populations registered in 1985 as grazing the Dartmoor commons were 50,000 sheep, 10,000 cattle and 2250 Dartmoor ponies.

The farmers' rights to graze the commons with sheep, cattle and ponies have been in existance since the early Middle Ages. Such grazing rights form the basis of animal husbandry on other surviving areas of common land, such as the New Forest which has similar status to a National Park. The origin of common rights on Dartmoor lies in the way in which settlement and exploitation of marginal land and upland developed historically. This was contemporary with the establishment of parish boundaries (Pearce 1985). Three features of the modern Dartmoor landscape reflect the medieval origins of modern animal husbandry (Fig 2).

(i) The large size of the central parish of Dartmoor Forest, originally a Royal Forest protected by medieval Forest Law;

(ii) The elongated shape of the parishes surrounding Dartmoor to the south and east. Each parish extends from the farmed area onto the higher marginal land (Fig 2); and

(iii) The combination of common land and farmland within the modern parish boundaries around the perimeter of the Dartmoor National Park.

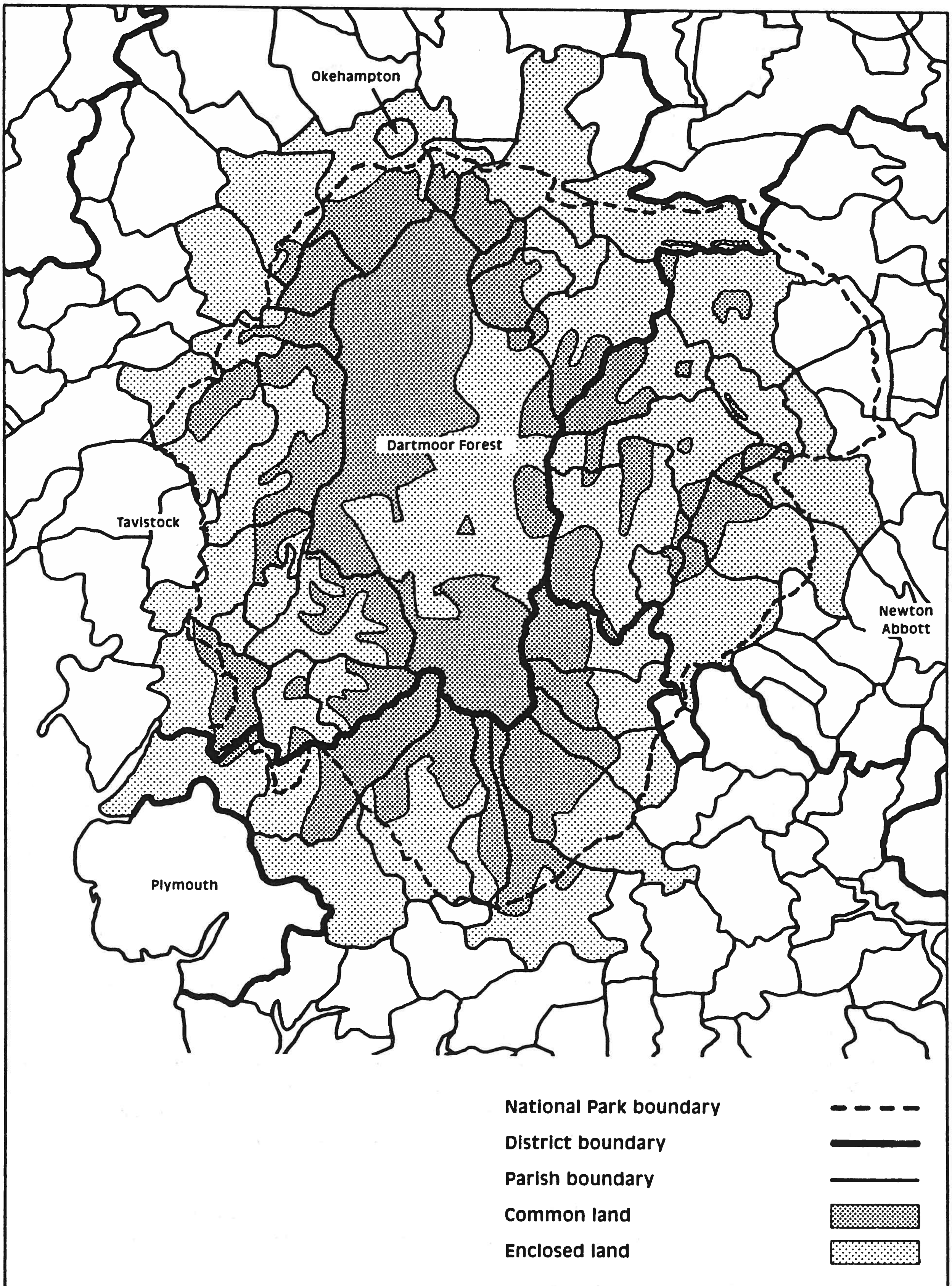

Fig. 2 Common land in relation to parish boundaries in the Dartmoor National Park

 992/418 ADAS Cartography, Gloucester. GL3 1AG.

The boundary between farmland and common land occurs at an altitude of 300 m above sea level around the whole perimeter of the central Dartmoor commons. (Fig 2). Within this central area the altitude in the northern section of the National Park rises to 600 m above sea level at its highest point.

Boundaries

The boundaries established between farmland and common land in each parish are traditional stone walls, sometimes topped with a low fence or hedge. It is the farmers legal responsibility to fence against the common. The parish boundaries which lie between adjacent areas of common land, or farmland, are defined mainly by natural features such as minor rivers or watersheds. The major rivers draining Dartmoor to the south and east, the Teign, the Dart and the Plym, in part form the boundaries of administrative districts where these fall within the National Park (Fig 2). The 'quarters' are 4 areas into which the parishes which include the Dartmoor commons are divided for electoral purposes, and the boundaries between them are parish boundaries.

Regulation of Animal Husbandry

Regulations (Dartmoor Commoners Council 1990) drafted under the authority of the Dartmoor Commons Act 1985, by which 'proper' standards of livestock husbandry on the Dartmoor Commons are enforced, were confirmed in 1990. A central purpose of the Regulations is stated to be:

> 'the control of stallions, rams and other entire commonable animals and to prescribe conditions under which entire commonable animals may be de-pastured on the commons' (Dartmoor Commons Act 1985).

The Regulations have excluded bulls over the age of 6 months from the commons, and excluded rams and ram lambs from the commons between 31 July and 10 November. This is an important example of the way in which husbandry and reproductive management of sheep flocks and suckler cow herds in the National Park is achieved by control of animal movements between farmland and the commons.

MATERIAL AND METHODS

The purpose of this study has been to determine (i) the breeds of cattle and sheep established in traditional Dartmoor husbandry, (ii) the movements between farmland and common land necessary for nutritional and reproductive management, and (iii) to examine the health and welfare of sheep and cattle on the Dartmoor commons. Consideration of the remoteness of the area determined that the study should be carried out by farmer questionnaire.

The questionnaire survey was carried out on farms within the Dartmoor National Park having grazing rights on the Dartmoor commons, the farms included being equally distributed between the 4 'quarters' of Dartmoor. The questionnaire was completed by a Veterinary Officer who interviewed the farmer at the time of a farm visit to inspect either the sheep or cattle on the farm and carry out routine herd testing for notifiable disease or investigation of animal welfare under statutory programmes.

TABLE 1: FARMER QUESTIONNAIRE SURVEY OF SHEEP HUSBANDRY IN THE DARTMOOR NATIONAL PARK

1. Date

2. Name

3. Total Stock Cattle Sheep Ponies

4. Breed of Ewe

   (i) Number of Ewes

   (ii) Ewe Replacements - % Reared

   - % Purchased

   (iii) Month of Lambing

   (iv) Lambing on Moor

   (v) Lambing on Farm

5. Breed(s) of Rams

   (i) Number of Rams

   (ii) % Rams Reared

   (iii) % Rams Purchased

   (iv) Tupping on Moorland

   (v) Tupping on Farm

6. Months of Year on Moorland Grazing

   (i) Ewes

   (ii) Hoggs

   (iii) Rams

   (iv) Wethers

   (v) Maximum Distance from Home Farm

7. Supplementary Feeding Practises

8. Stock Handling

   (i) Sheep Identification

   (ii) Month of Shearing

   (iii) Anthelmintic Treatments

   (iv) Month of Summer Dipping

   (v) Body Condition Scores

TABLE 2. FARMER QUESTIONNAIRE SURVEY OF CATTLE HUSBANDRY IN THE DARTMOOR NATIONAL PARK

1. Date

2. Name

3. Total Stock - Cattle Sheep Ponies

4. Breed of Suckler Cow

   (i) Number of cows

   (ii) Number of Heifers

   (iii) % of Females Reared

   (iv) % of Females Purchased

   (v) Month of Calving

   (vi) Calving on Moor

   (vii) Calving on Farm

5. Breed(s) of Bull in Suckler Herd

   (i) Number per Breed

   (ii) % of Bulls Reared

   (iii) % of Bulls Purchased

6. Months per Year on Moorland Grazing

   (i) Cows

   (ii) Heifers

   (iii) Calves

7. Supplementary Feeding Practises

8. Stock Handling

   (i) Cow Identification

   (ii) Location of Handling Race/Crush

   (iii) Preferred Month for Herd Tests.

Between 8 and 16 questionnaires, each relating separately to sheep flocks or suckler herds, were completed each year between September 1987 and January 1992. While the purpose of farm visits was concerned with statutory duties, farmer interest in the survey was stimulated by the opportunity for advice on farm animal welfare legislation, by support given by the Dartmoor Commoners Council and by the circulation of an annual report dealing with the assessment of animal welfare.

The information for this survey recorded on the questionnaire is listed in Table 1 (sheep) and Table 2 (cattle). In designing the questionnaire each breeding cow herd or ewe flock was considered as a husbandry unit.

RESULTS

Survey Sample and Interpretation of Results

Over the 5 year period, the survey was extended to 52 separate sheep and cattle holdings, 22 per cent of holdings having registered grazing rights on the commons of Dartmoor. The total number of sheep on holdings included in the survey was 15,500, approximately 30% of the total number of sheep within the Dartmoor National Park for which registered rights of common were held at the inception of the survey; the number of cattle on holdings included in the survey was 2850, which was 28% of the number of cattle within the National Park for which registered rights of common were held.

In presenting the results of the survey, each breeding flock or herd has been considered as a separate unit irrespective of either the size of the flock or herd or the number of separate flocks/herds per holding. This method of analysis was adopted for the following reasons:

(i) Traditional animal husbandry on the commons of Dartmoor and the Regulations to which animal husbandry in the National Park must conform, are primarily directed at flock and herd management;

(ii) Many Dartmoor farm Holdings support more than one breed or sheep or cattle. This practice reflects the specialisation of animal husbandry for the Dartmoor environment, and each breeding flock or herd merits separate consideration.

(iii) It is flock and herd husbandry on Dartmoor, particularly the rearing of female replacements, which is of epidemiological importance and most relevant to the purpose of this survey.

Established Breeds in Dartmoor Animal Husbandry

The proportion of different breeds of ewe and suckler cows represented in the sample of Dartmoor holdings are illustrated in Fig 3 and Fig 4. The hill breeds, Scotch Blackface sheep and Galloway cows, predominate, representing 40% and 30% of the samples respectively. Traditional Devon breeds, the Dartmoor sheep and South Devon cattle (both 16% of the sample of breeds) are also strongly represented. Cross breeding with less hardy cattle breeds, Hereford, Limousin and Charolais represented 40% of suckler herds. Mules and crosses with Texel, Suffolk or with Dorset Horn breeds represented 15% of sheep flocks.

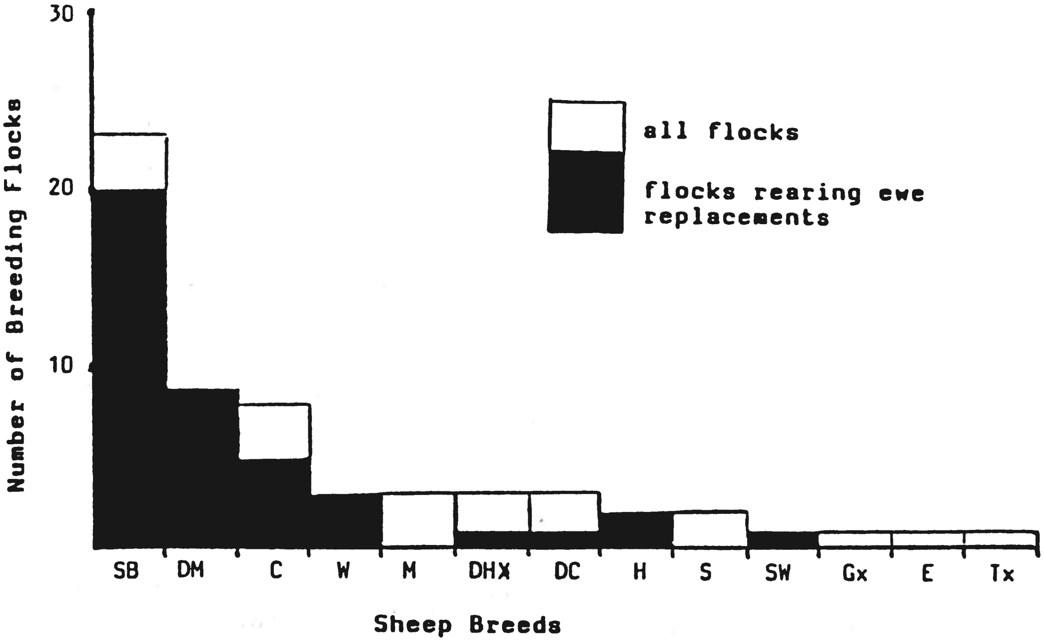

Fig 3. Dartmoor National Park: Survey of Sheep Breeds

Breed Abbreviations

x - Crossbred

SB - Scotch Blackface
DM - Dartmoor
C - Cheviot
W - Welsh Mountain

M - Mule
DH - Dorset Horn
H - Herdwick
DC - Devon Closewool
SW - Swaledale

S - Suffolk
G - Gritstone
E - Exmoor Horn
T - Texel

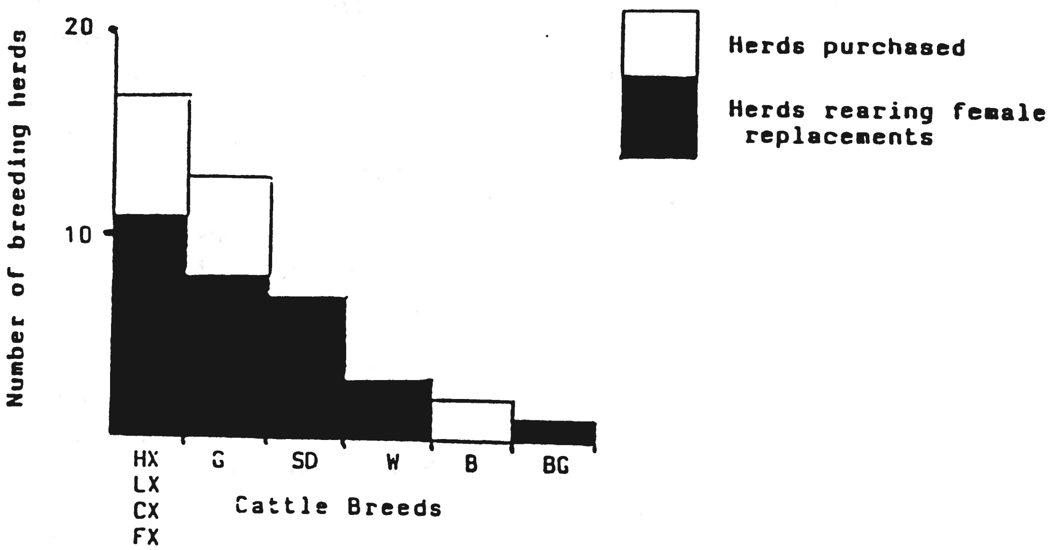

Fig 4. Dartmoor National Park: Survey of Cattle Breeds

Breed abbreviations

X - Crossbred

H - Hereford
L - Limousin
C - Charolais
F - Friesian

G - Galloway
SD - South Devon
W - Welsh Black
B - Blue Grey
BG - Belted Galloway

Season of Births and use of Common Grazing by Sheep and Cattle

The number of flocks and herds reported to use common grazing in each month of the year is related to the number of flocks or herds in the survey lambing or calving in Fig 5 and Fig 6.

Sheep

There is a lambing peak in April when a minimum number of flocks was reported to use the common grazing (Fig 5). Thereafter, from May to October, flocks of ewes with lambs graze the commons; in October and November lambs are weaned and ewes are mated; flocks of in-lamb ewes then graze the commons from December to March (Fig 5).

Cattle

The most important use of common grazing by cattle herds in the survey was grazing by spring-calving cows and calves in summer and autumn, from June to December (Fig 6), by which latter time calves have been weaned. Supplementary feeding of in-calf cows is practised from January until they calve. In-calf cows may be put out on common grazing in winter, but they will have access to supplementary feeding.

Reproductive Management of Sheep Flocks and Cattle Herds

Sheep

Replacement ewes were reared in 70% of all flocks and in 87% of flocks of hill breeds in the survey. Rams were mainly purchased; a minority were reared.

Early lambing began in late February and March but there was only a single report in this survey of a flock lambing too early because a stray ram had served ewes. The regulation restricting access of rams to common land before 10 November is reflected in the high proportion of flocks which lamb in April, particularly flocks rearing ewe replacements (Fig 5). Flocks are shepherded at lambing time; more than 90% of flocks in the survey were gathered into fields or moorland enclosures (newtakes); shelter and protection from foxes is provided and assistance is given to ewes; lambs are handled for docking, castration or fostering. Lambing in all flocks is largely complete by May.

Flocks of ewes and lambs will return to the commons when lambing is complete. The lambing percentage in typical flocks is estimated to be 120%. Ewes suckling twin lambs are retained on farm land and not returned to moorland grazing. A twin lamb will not be selected for rearing as a ewe replacement.

Flocks of ewes and lambs are gathered off common grazings and returned to the home farm on at least 2 occasions during the summer months before they are finally gathered for weaning of ewe lambs and mating of ewes in October and November. Routine flock husbandry when flocks are gathered consists of (i) shearing (not including replacement ewe lambs) and grease paint marking between May and July; (ii) dipping against myiasis, undertaken by 100% of flocks, in July or August; (iii)

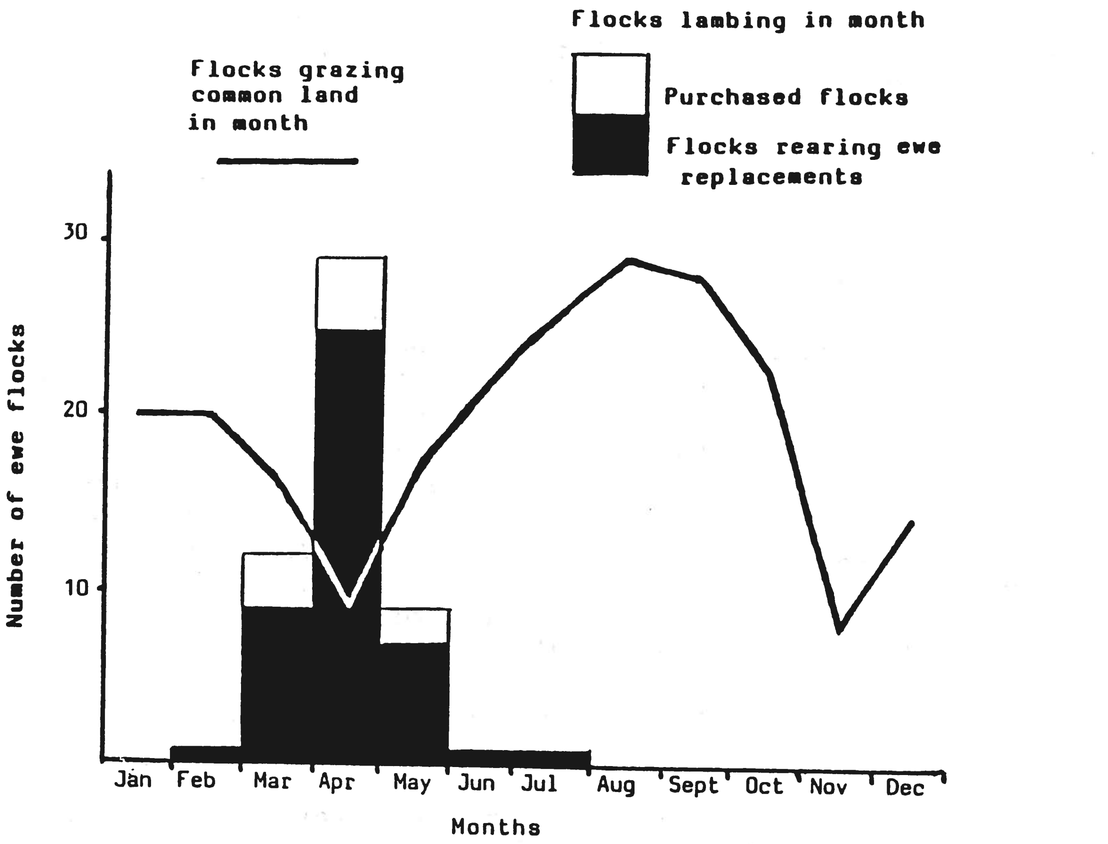

Fig 5. Dartmoor National Park: Season of Lambing and use of Common Grazing by Ewe Flocks

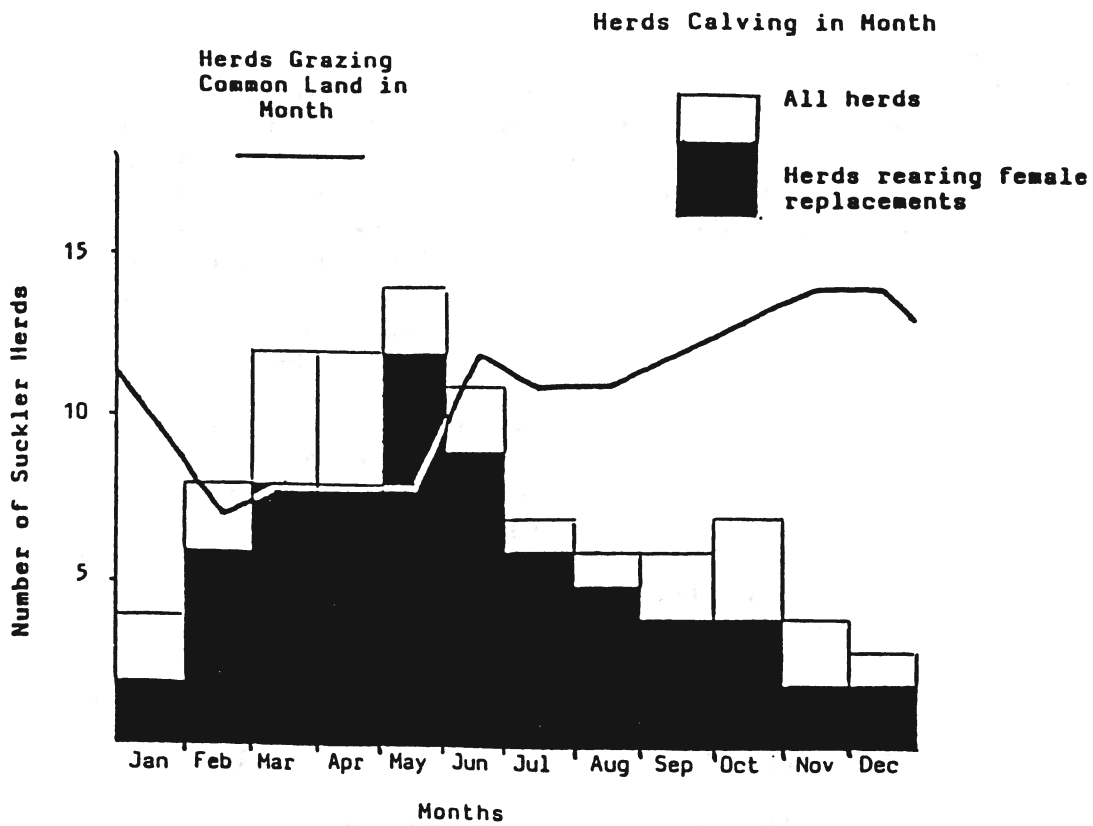

Fig 6. Dartmoor National Park; Season of Calving and use of Common Grazing by Suckler Cow Heds

selection and ear marking of replacement ewe lambs; (iv) preventive anthelmintic treatment, reported to be undertaken by 80% of flocks; (v) treatment for liver fluke and (vi) identification and marking of ewes to be culled.

This gathering of flocks of ewes and lambs off common grazings onto farms in the summer for husbandry purposes is not closely synchronised on different farms. However, recent practice on Dartmoor has been to synchronise the clearance of all sheep from the entire area of the Dartmoor commons onto farms for a minimum period of 2 days in November close to 10 November, the earliest date on which rams can be returned with ewe flocks to the commons (Fig 5). The date of the clearance is agreed 12 months in advance. If a farm has 2 or 3 breeding flocks on the commons, these will be marked with a different colour mark and their separate identify will be rigourously maintained during handling on the farm. This autumn clearance provides the opportunity for preventive dipping of rams and ewes retained in breeding flocks as a preventive measure before they are returned to the commons. Most ewe flocks are gathered into enclosed fields to be put to the ram. Less than 10 per cent of flocks were returned to the commons with a ram for mating.

Replacement ewe lambs are over-wintered on farms and put out onto common grazing in the spring.

By these husbandry practises flocks are leared or hefted on the common grazing, perenially restricting their range to the same defined areas. In this survey the furthest distance from the home farm to the lear or heft of sheep flocks was estimated to vary between 1 and 6 miles, with a mean furthest distance from the home to lear of 3,5 miles.

Cattle

Artificial insemination was used by one herd in the survey; all bulls used for natural service were purchased. Bulls may not be put on common land; consequently spring-calving cows with calves at foot which are put onto common grazing in the summer and autumn must return to enclosed farm land for service. 70% of herds in the survey reared female replacements, and 55% of these herds calved in spring, loosely taken as the months between March and June (Fig 6). May was the month in which the greatest number of herds calved, indicating that the highest rate of reconception of suckler cows was in September, before weaning.

A high reconception rate is important for efficient use of common grazing by cows with calves and this is dependent on supplementary feeding of the in-calf cow after weaning in either October, November or December and before calving. In a proportion of herds, dry in-calf cows are put out to graze the commons during the winter months, often during the day, but at this time the cows will have access to supplementary feeding and daily attention.

Heifers are wintered on farms. It is estimated that heifers of hardy breeds typically calve at 2½ years of age and that their longevity as cows is 10-12 years with a lifetime production of 8-9 calves.

Herds of suckler cows with calves using common grazing in the summer are unattended; these herds are leared or hefted to a traditional range area and retain their herd composition.

DISCUSSION

The Regulations supporting traditional husbandry practises on the Dartmoor commons restrict the movement of mature rams and bulls between farm and common land. This Regulation enables the use of selected sires, gives control over the season of lambing and calving and establishes a routine in the movements of breeding flocks and herds between farm and common for reproductive, nutritional and health management. It is this standard of husbandry which maintains flock and herd structure on the common grazing, supports the rearing of sufficient replacement ewes or cows and enables optimum use to be made of plant growth on the common grazing. In this survey 70% of flocks and herds in the Dartmoor National Park raised female replacements, rising to 87% in the case of hill sheep flocks.

The issue of greatest epidemiological concern in relation to animal husbandry in the Dartmoor National Park is the potential for exchange of disease with livestock on surrounding farms or with introduced breeding stock. The relevant aspects of animal husbandry on Dartmoor are (i) the large overall size and density of the sheep and cattle populations on common grazing and (ii) the frequency of movement of flocks and herds between farms and the commons for management of reproduction and health and the rearing of female replacements.

An example of the benefits to animal health of rearing young stock in the Dartmoor environment, where they are exposed to the tick Ixodes ricinus - a reduction in susceptibility to bovine babesiasis - has been reported by Vaughan 1988.

Large livestock populations have been considered to present a particular risk to the control of notifiable disease because of the difficulty of controlling spread of disease, particularly in intensively managed units, and the consequent cost of disease eradication (Watson 1980). This author cited the need to extend movement controls and acaricide treatment to the whole sheep population on the Dartmoor commons in order to eradicate Sheep Scab (Psoroptes ovis infestation) following the introduction of the disease to Dartmoor in 1976. The ultimate success of Sheep Scab eradication on Dartmoor (Blamire 1986) nevertheless establishes the principle that effective movement controls and preventive medicine can be based upon traditional sheep husbandry on Dartmoor. This conclusion is further supported by developments since 1985. Regular autumn dipping of breeding flocks synchronised with a clearance of all sheep from common land for 2 days in November continues to be supported as a preventive measure by the Dartmoor farming community.

These examples of enzootic and notifiable disease on Dartmoor illustrate (i) the importance of animal movements in the spread and control of disease and (ii) recent improvements in the regulation of animal movements.

Public recreation and enjoyment is one of the purposes of National Parks. Public criticism of animal welfare on Dartmoor since 1985 has been primarily directed at the husbandry of Dartmoor ponies. Reproductive status, nutrition, parasitism and severe weather all contribute to the loss of body condition and mortality of ponies which has attracted public complaint (Lewis 1991). Improvements in pony husbandry have allayed public criticism (Dartmoor Livestock protection Association 1992). This experience has shown that public opinion on animal health and welfare is well informed and that health and welfare on Dartmoor must be based on sound animal husbandry if the National park purpose is to be achieved.

ACKNOWLEDGEMENTS

I am grateful to Andrew Turnbull, Peter Cripps and Paddy Newton for guidance in planning this survey and to my colleagues in the State Veterinary Service, who carried out much of the fieldwork, for their support.

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EPIDEMIOLOGICAL STUDIES WITH MULTIPLE EPISODES AS OUTCOME:
A SUGGESTED ANALYTICAL TECHNIQUE USING A COHORT STUDY OF RESPIRATORY DISEASE IN HORSES

J.L.N. WOOD* AND M.H.BURRELL**

This paper discusses different methods of analysing data from longitudinal studies which incorporate repeated measures from the same subjects as well as covariates that vary with time. Every observation on each subject (including the outcome and covariate measures at that point) is treated as the unit of observation. The effect of using different strategies to account for the lack of independence of observations taken from the same subject are illustrated with the results from a study of respiratory disease in racehorses.

The majority of epidemiological designs, including standard case-control, cohort and cross-sectional studies, allow only for a single outcome in each subject. Moreover, standard analysis of these studies only permits covariates which do not vary with time, although Cox's proportional hazards regression does allow testing for time-dependent covariates and time changes in covariate effect. These limitations restrict the study of diseases that regularly recur in the same subject, especially where covariates often vary with time. However, there is no effect on the analysis of the epidemiology of diseases which are fatal or which have a tendency to either occur or recur only once (e.g. any neoplasia and protectively immunogenic infections such as measles).

An important assumption of cohort studies, cross-sectional studies and unmatched case-control studies is that observations (i.e. outcomes) in different subjects are essentially independent. Where studies are designed so that observations are not independent, as in matched case-control studies, cross-sectional studies with clustered observations and studies which incorporate a 'herd effect', modifications to the standard analysis are required.

Disease endpoints may recur several times in the same subject in respiratory disease epidemiology (e.g. Korn and Whittemore, 1979). Analysis of data with several outcomes in the same subject must account for the lack of independence of sequential observations from each subject. Although it may be possible to censor subjects once they have experienced disease, this would result in a loss of data about effects of prior disease status. Moreover, it may also make the study impossible due to requirements for impracticable numbers of subjects.

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Controlling for lack of independence between observations, or 'group effect'.

Methods of performing statistical studies with repeated measures from the same subject with a continuous serial outcome are flexible and are in general use (Ware, 1985; Ott, 1988; Agresti, 1990). However, adequate methods of analysis of studies with repeated binary or ordered categorical outcomes (see Koch *et al.*, 1977) are not so well established (Stram *et al.*, 1988). Many of the proposed methods perform poorly where there are many covariates, unbalanced data, missing observations and / or large numbers of observations per subject (Stiratelli *et al.*, 1984).

Multiple logistic regression analysis is the appropriate statistical method for studies with dichotomous outcomes (Breslow and Day, 1980). However, treating sequential observations from the same subject as independent violates the assumptions of logistic regression analyses. This lack of independence also occurs in epidemiological studies when the unit of observation (and analysis) is the individual and the observations are grouped (for example by herd, litter or premises).

Different methods have been used in logistic regression models where group effects are present (Curtis *et al.*, 1988). For example, 'herd effects' have been ignored (Curtis *et al.*, 1988), or modelled as fixed effects in standard logistic regression (Waltner-Troewes *et al.*, 1986; Wood, 1991). The disadvantage of modelling groups as fixed effects is that this can result in a large number of dummy variables (one less than the total number of groups).

Two other models have been proposed, which are logistic binomial regression, one of the random effects family of models and conditional logistic regression, stratifying (matching) on group (Curtis *et al.*, 1988; Montgomery *et al*, 1990). The random effect in random effects models corresponds to the presence of extra-binomial variation (EBV); EBV is present when different groups are heterogeneous with respect to disease risk. If EBV is ignored in standard logistic regression analysis, the estimated standard errors of the model coefficients will be too small and conclusions may therefore be affected.

Curtis and others (1988) suggested that the presence of extra binomial variation should be assessed by comparing difference in likelihoods of the LR and LBR models. They concluded that the methods of choice for accounting for group effects were the random effects models; they preferred them to conditional logistic regression due to the loss of data from groups which have non-occurrence of outcome or homogeneous exposure.

Montgomery and others (1990) used conditional logistic regression to examine whether the bacteria carried by children were different when healthy, when suffering from respiratory disease, and when about to suffer from respiratory disease. Sequential samples taken from children were classified by the length of time prior to an episode of respiratory disease and the study was analysed as a case-control comparison, using conditional logistic regression analysis. Each child was treated as a stratum or matched set. The bacterial flora isolated from cases was compared with that isolated from them during periods at least eight weeks prior to an episode of disease. Invasive pneumococci were isolated more frequently from children when they were ill than when healthy and strains of *Haemophilus influenzae* were more frequently isolated in the two weeks prior to an episode of disease than when healthy. This method of analysis was effective even though around 50% of the data were lost due to non-occurrence of disease in this proportion of the children.

This paper compares the results from different logistic regression analyses on a dataset collected during a pilot longitudinal study of respiratory disease in young racehorses.

Materials and Method

Monthly information were recorded over a two year period from a group of young racehorses in training (see Burrell *et al*, 1985). The presence of clinical respiratory disease during the month was recorded, as adjudged by nasal discharge, pyrexia, or coughing. In addition, a monthly tracheal wash was evaluated for the presence of bacteria and airway inflammation (Whitwell and Greet, 1984). Activity of equid herpesvirus (EHV1 and 4) and equine rhinovirus-1 (ERV) were evaluated by serology, again on a monthly basis.

The aim of the study was to examine the relationship between the presence of clinical end-points and lower airway inflammation (only apparent during endoscopic examination) and to examine the association between different microbes and the clinical endpoints and lower airway inflammation.

Data were available from 16 horses, representing a total of 178 horse months and were analysed using the EGRET software package. Other longitudinal data that had been collected from horses that had been selected due to respiratory disease were excluded.

The relationship between lower airway inflammation and clinical disease endpoints, was examined, adjusting for age. Also examined were the relationships between lower airway inflammation and different infections. The following models were used:

1) Conditional logistic regression (CLR), with one stratum per horse.
2) Logistic regression (LR) with no adjustment for horse effect.
3) Logistic binomial random (LBR) effects model, matching on horse.
4) Logistic regression with no adjustment for horse effect, having excluded the sets concordant in 1).
5) Logistic binomial random effects model, matching on horse, having excluded the sets concordant in 1).

Results.

Clinical endpoints: Using conditional logistic regression, there was evidence of an association between lower airway inflammation and the three clinical endpoints. This was stronger for nasal discharge (OR 5.9, $p = 0.002$) and cough (OR 6.7, $p < 0.001$) than for pyrexia (OR 2.7, $p = 0.09$) (see Tables 1 to 3).

Comparing three year old horses with two year old horses showed that there was little evidence of an age effect with pyrexia (OR 1.39, $p = 0.7$) or nasal discharge (OR 1.24, $p = 0.8$), although three year old horses seemed less likely to cough than two year olds (OR 0.30, $p = 0.3$).

These models were extended with a variable denoting the presence of airway inflammation in the previous month, including an interaction term between the two airway inflammation variables. Horses with airway inflammation for the previous two months were more likely to cough (OR 21.0, $p < 0.05$) than those that had only had LRTI that month (OR 2.4, $p = 0.36$). In addition, horses with pyrexia were very likely to have developed airway inflammation during that month (OR 18.8; model with interaction term not maximised). However, the previous month had little modifying effect on the nasal discharge model.

The difference in deviance and likelihoods of the LR and LBR models was compared, but the only difference that was apparent was in the nasal discharge model using the complete dataset. This is despite the differences between the results from CLR and the LR & LBR models.

In the complete dataset, the association between coughing and airway inflammation was weakest when the horse effect was ignored (LR model), intermediate in the random effects model and strongest in the CLR model. This was also the case in the nasal discharge model, although the LR and LBR models were identical in the pyrexia model.

Subsequently, the horses concordant for outcome in the CLR analysis were excluded from the LR and LBR analysis, testing the hypothesis that differences between the models were due to the data lost in the CLR analysis. In the coughing model, the data lost in the CLR analysis did partially but not completely explain the differences between the CLR and the LR and LBR models using the complete data (Table 1). This was also the case in the pyrexia model. However, in the nasal discharge model, differences between the LR and LBR models were more extreme when the concordant sets were excluded (Table 2).

Table 1. Association between the presence of cough and age & airway inflammation using different analyses.

COUGH.	ALL DATA INCLUDED						CONCORDANT SETS EXCLUDED					
	CLR		LBR		LR		CLR		LBR		LR	
	O.R.	*p* value	O.R.	*p* value	O.R.	*p* value	O.R.	*p* value	O.R.	*p* value	O.R.	*p* value
VARIABLE												
%GM	-	-	**0.08**	<0.001	**0.11**	<0.001	-	-	**0.15**	<0.001	**0.15**	<0.001
AGE	**0.30**	0.30	**0.20**	0.14	**0.20**	0.13	**0.30**	0.30	**0.19**	0.12	**0.19**	0.12
LRTI	**6.72**	<0.001	**5.90**	<0.001	**5.27**	<0.001	**6.72**	<0.001	**6.16**	<0.001	**6.16**	<0.001
EBV?	-	-	**NO**		-	-	-	-	**NO**		-	-
%GM	-	-	**0.10**	<0.001	**0.11**	<0.001	-	-	**0.14**	<0.001	**0.14**	<0.001
AGE	**0.29**	0.28	**0.25**	0.19	**0.25**	0.19	**0.29**	0.28	**0.25**	0.20	**0.25**	0.20
LRTI	**2.40**	0.36	**1.81**	0.49	**1.80**	0.49	**2.40**	0.36	**2.12**	0.39	**2.12**	0.39
LRTI last period	**1.74**	0.54	**1.24**	0.80	**1.21**	0.82	**1.74**	0.54	**1.33**	0.74	**1.33**	0.74
LRTI interact.	**5.01**	0.28	**7.57**	0.12	**7.62**	0.12	**5.01**	0.28	**5.81**	0.19	**5.81**	0.19
EBV?	-	-	**NO**		-	-	-	-	**NO**		-	-

OR = odds ratio
LRTI = lower respiratory tract inflammation
EBV? = evidence of extra binomial variation.

Table 2. Association between nasal discharge and age & airway inflammation using different analyses.

NASAL DISCHARGE	ALL DATA INCLUDED						CONCORDANT SETS EXCLUDED					
	CLR		LBR		LR		CLR		LBR		LR	
	O.R.	*p* value	O.R.	*p* value	O.R.	*p* value	O.R.	*p* value	O.R.	*p* value	O.R.	*p* value
VARIABLE												
%GM	-	-	**0.06**	<0.001	**0.09**	<0.001	-	-	**0.15**	<0.001	**0.16**	<0.001
AGE	**1.24**	0.80	**0.71**	0.64	**0.80**	0.74	**1.24**	0.80	**0.72**	0.65	**0.70**	0.60
LRTI	**5.94**	0.002	**5.26**	0.003	**4.43**	0.003	**5.94**	0.002	**4.79**	0.005	**4.61**	0.005
EBV?	-	-	**MARGINAL**	0.076	-	-	-	-	**NO**	-	-	-
%GM	-	-	**0.07**	<0.001	**0.10**	<0.001	-	-	**0.16**	<0.001	**0.16**	<0.001
AGE	**0.95**	0.95	**0.86**	0.84	**0.86**	0.83	**0.95**	0.95	**0.74**	0.67	**0.74**	0.67
LRTI	**3.87**	0.11	**3.35**	0.14	**2.89**	0.15	**3.87**	0.11	**3.35**	0.12	**3.35**	0.12
LRTI last period	**0.69**	0.74	**0.60**	0.65	**0.58**	0.62	**0.69**	0.74	**0.55**	0.58	**0.55**	0.58
LRTI interact.	**1.34**	0.86	**1.95**	0.67	**2.30**	0.56	**1.34**	0.86	**1.72**	0.72	**1.72**	0.72
EBV?	-	-	**NO**	0.28	-	-	-	-	**NO**		-	-

Abbreviations as for Table 1.

Table 3. Association between pyrexia and age & airway inflammation using different analyses.

PYREXIA	ALL DATA INCLUDED						CONCORDANT SETS EXCLUDED					
	CLR		LBR		LR		CLR		LBR		LR	
	O.R.	*p* value	O.R.	*p* value	O.R.	*p* value	O.R.	*p* value	O.R.	*p* value	O.R.	*p* value
VARIABLE												
%GM	-	-	**0.11**	<0.001	**0.11**	<0.001	-	-	**0.13**	<0.001	**0.13**	<0.001
AGE	**1.29**	0.72	**0.98**	0.97	**0.98**	0.97	**1.29**	0.72	**1.09**	0.88	**1.09**	0.88
LRTI	**2.65**	0.09	**2.10**	0.17	**2.10**	0.17	**2.65**	0.09	**2.05**	0.19	**2.05**	0.19
EBV?	-	-	**NO**		-	-	-	-	**NO**		-	-
%GM	-	-	**0.09**	<0.001	**0.09**	<0.001	-	-	**0.11**	<0.001	**0.11**	<0.001
AGE	**2.90**	0.25	**1.24**	0.73	**1.24**	0.73	**2.90**	0.25	**1.33**	0.66	**1.33**	0.66
LRTI	**6.92**	0.01	**3.83**	0.04	**3.83**	0.04	**6.92**	0.014	**4.01**	0.03	**4.01**	0.03
LRTI last period	**0.37**	0.29	**0.40**	0.28	**0.40**	0.28	**0.29**	0.37	**0.36**	0.34	**0.36**	0.23
LRTI interact.	**INTERACTION TERM WOULD NOT FIT,**											
EBV?	-	-	**NO**		-	-	-	-	**NO**		-	-

Abbreviations as for Table 1.

<u>Microbiological associations with lower respiratory tract inflammation (LRTI):</u> As above, the associations between different variables and LRTI were examined using the different analytical strategies. The data are presented as crude univariate odds ratios (Table 4) and modelled with the variables that were more important in the conditional logistic regression model (Table 5).

In the univariate analyses, the results from majority of variables were very similar for the different techniques. The results from the LR and LBR models were identical when the concordant sets had been excluded (not shown). In most cases, the results from the LBR analysis with concordant sets excluded were closest to those from CLR, followed by LBR and then LR on the complete dataset. *S.zooepidemicus*, previous ERV infections and aerobic bacterial colony numbers (>10^4 per ml of tracheal wash) were consistently associated with LRTI.

Table 4. Association between different variables and lower airway inflammation, using different methods of analysis

LRTI	**CLR**		**LBR*****		**LBR**		**LR**	
	OR	*p* value	**OR**	*p* value	**OR**	*p* value	**OR**	*p* value
<u>Variable</u>								
Age (3yo *v* 2 yo)	**0.24**	0.08	**0.22**	0.05	**0.21**	0.04	**0.21**	0.04
Bact count>10^4 /ml	**3.49**	0.003	**4.08**	<10^{-3}	**3.72**	0.001	**3.76**	0.001
EHV s/c	**2.82**	0.09	**2.64**	0.11	**2.07**	0.22	**1.98**	0.23
EHV s/c last mo.	**1.98**	0.34	**1.56**	0.53	**1.37**	0.66	**1.30**	0.70
ERV s/c	**4.77**	0.03	**5.48**	0.02	**5.46**	0.01	**5.46**	0.01
S.zooepidemicus	**3.60**	0.006	**3.53**	0.005	**3.96**	0.002	**3.94**	0.002
S.pneumoniae	**0.31**	0.17	**0.34**	0.16	**0.40**	0.25	**0.41**	0.25
GNR	**2.29**	0.29	**3.05**	0.16	**1.14**	0.85	**1.10**	0.88
B.bronchiseptica	**1.46**	0.68	**1.56**	0.61	**1.95**	0.44	**1.96**	0.43
Staph. spp.	**0.75**	0.69	**1.60**	0.25	**1.62**	0.22	**1.62**	0.22
Peptostrep. sp	**0.95**	0.94	**0.97**	0.96	**1.15**	0.84	**1.16**	0.82
Peptococcus sp.	**3.90**	0.07	**4.39**	0.05	**3.77**	0.06	**3.71**	0.06
Bacteroides sp.	**0.45**	0.25	**0.60**	0.45	**0.63**	0.50	**0.67**	0.55
Fusobacterium sp.	**2.69**	0.30	**2.73**	0.29	**1.50**	0.63	**1.45**	0.65
Environment	-	-	**0.50**	0.09	**0.44**	0.04	**0.44**	0.04

Abbreviations as for Table 1, + Staph = Staphylococcus, GNR = gram negative rods, *Peptostrep.* = Peptostreptococcus ,
***LBR analysis performed on data set with concordant pairs excluded.

The results from some variables were markedly different between the different models. There was a negative association between the presence of LRTI and Staphylococcus spp. in the CLR model which was positive in all the other models. There were marked differences between the CLR model and the LR and LBR models with GNR, *B.bronchiseptica*, and *Fusobacterium* sp. These differences were accounted for, at least in part by excluding the concordant sets from the analysis.

If significance was attached to reaching a $p = 0.05$ level, conclusions would have been different with the different analyses for the effects of age and the presence of *Peptococcus* spp.

All the horses in this study were stabled, but some were kept on straw bedding in a loose boxes and others on shredded paper in an American barn. This management did not change for each horse and so it is not possible to model this effect directly in CLR as it is fixed within horse (and hence within stratum). It is possible to do this as an interaction effect in CLR, but the results from these analyses are not shown. However, environment was modelled in the other analyses, all of which showed that horses housed in barns were around half as likely to experience lower airway inflammation as those in loose boxes.

A multivariate model was built using conditional logistic regression (Table 5). There were positive associations between LRTI and *S.zooepidemicus* ($p = 0.03$) and *Fusobacterium* sp. ($p = 0.08$) and a negative association with *Bacteroides* sp. ($p = 0.04$).

Table 5. Multivariate association between different variables and lower airway inflammation, using different methods of analysis

LRTI	CLR		LBR ***		LBR		LR	
	OR	*p* value	**OR**	*p* value	**OR**	*p* value	**OR**	*p* value
Variable								
Age (3yo *v* 2 yo)	**0.25**	0.14	**0.21**	0.07	**0.27**	0.11	**0.27**	0.11
EHV s/c last mo.	**1.88**	0.50	**0.84**	0.86	**0.52**	0.52	**0.52**	0.52
ERV s/c	**2.26**	0.53	**5.19**	0.30	**2.51**	0.05	**2.51**	0.05
S.zooepidemicus	**4.38**	0.026	**4.56**	0.01	**4.60**	0.006	**4.60**	0.006
GNR	**4.79**	0.12	**4.19**	0.12	**1.37**	0.69	**1.37**	0.69
Peptococcus sp.	**5.08**	0.13	**4.98**	0.09	**4.19**	0.08	**4.19**	0.08
Bacteroides sp.	**0.14**	0.04	**0.21**	0.09	**0.19**	0.07	**0.19**	0.07
Fusobacterium sp.	**11.7**	0.08	**8.37**	0.07	**2.24**	0.41	**2.24**	0.41
Deviance, *DF*	**63.3**		**97.4,**	***116***	**110,**	***141***	**110,**	***141***

As above, there were substantial differences between the results from the CLR model and the LR and LBR models using the complete dataset. Again, some of the differences were due to the data lost due to concordant sets in CLR. However, there were also marked difference between the CLR model and the LBR model on the restricted dataset. These were particularly marked for the effects of equid herpesvirus and equine rhinovirus.

Discussion.

The data were already available on file, having been collected several years ago. For the majority of variables, the study did not have adequate power, and so the actual results should be interpreted with some caution. As a result, the models presented have not all been optimised and only a few interaction effects were tested; rather, this intentions of this paper are to examine the different options for analysing this type of data.

It has been proposed that this type of data should be modelled with a factored variable to account for the effects of period (LogXact, 1992). However, given the size of this dataset and the fact that it was collected over 23 months, the addition of 22 extra variables (equivalent to N-1 periods) prevented most models from fitting. Adjustment for the effects of period are made in the clinical outcome models (Tables 1 to 3) by including a variable in the model corresponding to the influence of that variable in the previous month. This method has been used elsewhere to account for time dependence (Kane, 1984); the results there were found to be qualitatively similar to those from models based on quasi-likelihood theorem (Zeger & Liang, 1986).

In matched case-control studies, the results of the matching are assessed by comparing matched and unmatched analyses. When this comparison is made on this dataset, clear differences become apparent between the matched and unmatched analyses, whether adjusting for horse with random effects or not.

If the fit of the LBR random effects models is identical to that of similar LR models, then it is said that there is little or no evidence of extra-binomial variation. This is taken to indicate that any group effect is not significant (Curtis *et al.*, 1988). Using this criterion, it would appear from these results that there is little or no horse effect. However, comparing the CLR results in this study shows that there are marked horse effects, apparent by comparing CLR results to those from the other modelling techniques. It is clear that some of the differences between the CLR and other models relate to data not being analysed in CLR, as it is lost in CLR if in sets (horses) with no outcome. However, this effect did not account for all of the differences between the CLR and other models.

When conditional logistic regression is performed on very large groups or strata, there is be a tendency for the results to approach those of unconditional logistic regression. The mean size of sets in this dataset was around 11, although there was considerable variation. If the sets had been much larger, then differences between the results obtained from the CLR and LR analyses would be expected to decrease.

A conclusion that might be made from these analyses is that not all group effects are adequately corrected for by incorporating the group as a random effect. This may be analogous to situations where incorporation of a covariate measurement in a multiple logistic regression model does not completely adjust for the effect of that factor, leaving some 'residual confounding' (Davey-Smith and Phillips, 1992).

In analyses with group effects, stratifying by group and performing conditional logistic regression analysis may be the most appropriate technique, rather than using random effects models, particularly for this type of data where the 'group' is an individual subject.

There is a need to investigate the epidemiology of respiratory disease in horses using a study similar to this pilot, but with an appropriate sample size. This study found that, on average, horses spent marginally less than a third of their period in training with LRTI. One or two months missing data per year were common. It is therefore assumed that the ratio of 'case' to 'control' units will be two and that each horse will contribute three 'case' periods per year of observation.

Necessary sample sizes have been estimated using the tables in Breslow and Day (1980) for matched case control studies so that there is adequate power (β = 0.8) to detect a significant (α = 0.95) effect of infections with an incidence of 10% and a relative risk of 1.5. 560 units of observation where disease occurs (i.e. cases) are required to give the study an 80% chance of detecting a significant effect of such an infection. Given that each horse is expected to contribute three case periods per year, 190 horse years of observation would be required. It is hoped to perform such a study in the near future.

Maximising some of the models in the random effects analyses, even on this small dataset required over 100 iterations and took a considerable amount of computer time. These calculations were mostly performed on a 486 33MHz computer, although some were done on a 386 26MHz (without coprocessor) which often took several minutes per iteration.

ACKNOWLEDGEMENTS

JLNW is supported by the veterinary advisory committee of the Horserace Betting Levy Board. The study was supported by the Animal Health Trust and MHB was in receipt of a HBLB research scholarship. The study would not have been possible without the help and co-operation of Mr L.M.Cumani who kindly allowed access to horses.

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USE OF KNOWLEDGE REPRESENTATION METHODOLOGIES TO DIAGNOSE MASTITIS

H. HOGEVEEN*, E.N. NOORDHUIZEN-STASSEN*, M. NIELEN* and A. BRAND*

Farm management is a complex system of decision making on strategic, tactical and operational level (Huirne, 1990). Problem diagnosis is therefore necessary at various levels, for which much expertise is needed. In the last decade, much effort has been put in developing computer programs that support farm management and decision making. These systems are generally known as management information systems (Huirne, 1990). Davis and Olson (1985) defined a management information system as an "integrated, user-machine system for providing information to support operations, management and decision-making functions in an organization".

The management information systems developed so far are merely concerned with data processing and analysis, and provide a decision maker with information. In order to make a decision the information needs to be interpreted. A knowledge-based system is able to interpret information and data from various sources in order to solve a problem at the same level as a human expert would do. Therefore, knowledge-based systems offer good possibilities for application to dairy farming (Schreinemakers et al., 1988; Spahr et al., 1988; Evans et al., 1989; Smith, 1989; Hogeveen et al., 1991).

Many knowledge-based systems built, use production rules as knowledge base. However, rule-based systems have some restrictions (Hogeveen et al., 1991). In artificial intelligence, research is focussing on the development of causal models as knowledge representation scheme. Different causal model types have been developed, mainly in the domains of physics and medicine (Horn, 1989). These causal modeling methodologies are often restricted to narrow domains. When developing a knowledge-based system for dairy farm management support, knowledge from various sources and of different structure must be represented in the knowledge-base. In order to efficiently model these various types of knowledge, different knowledge representation schemes can be used.

In the Netherlands, several universities and institutes are cooperating to develop an integrated knowledge-based system for management of dairy farms (Hogeveen et al, 1992a), known as the Milk Production Project (MPP). The approach of the MPP is based on the Animal Farm proposal (Brée et al, 1992) and is focused on the health care of the herd, productivity of the herd and the profitability of the farm. Part of this project is concerned with automated mastitis detection and diagnosis.

This paper describes the characteristics of the knowledge, necessary to perform automated mastitis detection and diagnosis, together with the methodologies used to model the knowledge.

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DIFFERENT STAGES IN MASTITIS PROBLEM SOLVING

On a dairy farm mastitis problems can occur at a cow level and at a herd level. A mastitis problem at cow level is a cow with clinical or subclinical mastitis. A decision must then be made about treatment of the cow. When the incidence of mastitis on a farm is high, there is a herd level mastitis problem. In the case of a herd-level mastitis a diagnosis has to be performed, concerning the possible causes of the mastitis problem..

In general, decision making in problems involves three stages: 1) problem detection, 2) problem diagnosis and 3) decision generation. Applied to a system for automated mastitis detection and diagnosis, the system contains five subsystems (Fig. 1), which can be described as follows:

<u>Mastitis detection</u>

Mastitis detection on cow level is normally performed by the milker during the udder preparation before milking. Abnormal milk is an indication of clinical mastitis. Diagnosis of subclinical mastitis is harder to perform. Even the definition of subclinical mastitis is not clear (Nielen et al, 1992a). Cow somatic cell counts are commonly being used for detection of subclinical mastitis but also as indication for clinical mastitis (Dohoo & Leslie, 1991). There is an association between electrical conductivity and mastitis (Nielen et al, 1992a). Electrical conductivity can be measured in the milking cluster and is therefore suitable for on line mastitis detection (Maatje et al., 1992). The data collected by an on-line mastitis detection

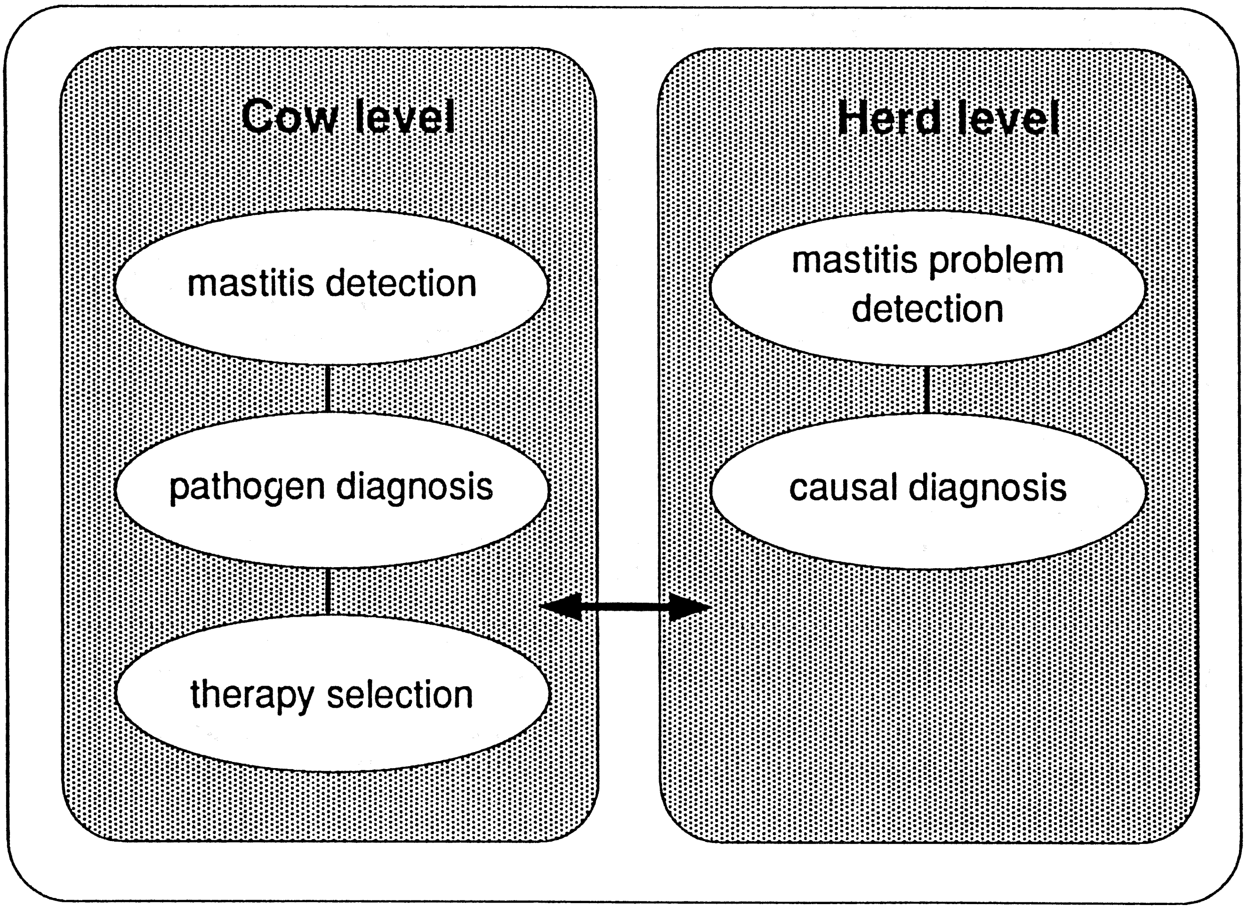

Fig. 1 Subsystems in automated mastitis problem solving

system are characterized by the following features: many measurements during the milking process, freak low and/or high values, repeated measurements, collinearity between subsequent measurements, missing data and external influences on the value of the data (Nielen et al., 1991).

Pathogen diagnosis

In order to treat mastitis properly, a diagnosis on the pathogen causing the mastitis is very helpful. In the Netherlands, a farmer routinely treats a clinical mastitis case with a broad spectrum antibiotic. A veterinarian is in normally only consulted to decide on diagnosis and treatment of severe mastitis cases. Based on clinical examination of the cow, cow history and herd history, the veterinarian makes a probability diagnosis. The diagnostic reasoning process involves uncertain knowledge (Chamberlain, 1992). A diagnosis is stated in terms of a likelihood (i.e. "the most likely cause of this mastitis case is E Coli").

Therapy selection

Once a veterinarian has made a most likely pathogen diagnosis, a decision will be made concerning proper treatment. Treatment in a broad sense can be an advice for antibiotic therapy but can also be an advice to cull the cow. The reasoning process for a therapy advice is relatively straightforward. In case of a certain pathogen, a standard antibiotic for that particular pathogen will be advised. Only when there is reason to believe that a pathogen is resistant against a certain antibiotic, another choice will be made. The type of knowledge used in the therapy advice process is so called heuristic knowledge.

Mastitis problem detection

At the herd level, mastitis problem detection is normally performed by the farmer or when the farm is in a veterinary herd health program, by the veterinarian. When there is a good database concerning herd health on a farm, it is possible to perform automated problem diagnosis (Dohoo & Leslie, 1991). It is hard to give exact guidelines for mastitis problem detection. The mastitis incidence rate or a change in incidence rate can serve as an indicator for a mastitis problem. However, when taking subclinical mastitis into account, somatic cell count can be used to detect a mastitis problem (Dohoo & Leslie, 1991) and electrical conductivity might also be a good tool for screening udder health (Nielen et al., 1992a).

Causal diagnosis

To diagnose causes for a mastitis problem in a herd, specialistic knowledge from various domains is necessary. The causes of a mastitis problem can , for instance be found in a malfunctioning milking machine, a wrong milking technique, suboptimal zootechnical circumstances, a deficient udder defence or more. The knowledge involved in the herd level mastitis diagnosis can be described as text book knowledge and is as such opposed to the earlier described heuristic knowledge (Hogeveen et al., 1991).

METHODOLOGIES TO MODEL MASTITIS DOMAIN KNOWLEDGE

In this section, methodologies which can be used to model the knowledge needed in the mastitis detection and treatment system, as described above, will be presented and illustrated.

Neural network

A neural network is a model consisting of layers of highly interconnected processing units. The subsymbolic knowledge of a trained model is implicitly stored in the weights of the connections (Rumelhart et al., 1986). A neural network can be trained to perform classification tasks. During training, input/output patterns are presented to the model. There are various methods to train a neural network. The most used training algorithm is back propagation with the generalized delta rule (Rumelhart et al., 1986). With back propagation, the model will generate a first output, based on random weights of the connections. This output is compared with the given output (gold standard), and the difference between model prediction and given output is calculated. The total squared sum of the calculated differences is sent back into the model and the weights of the connections are changed to minimize the error. This is repeated many times for all input/output combinations. The ultimate goal for the model is to find and generalize into a single set of weights that will satisfy all the input/output pairs presented to it, i.e. to classify new data correctly.

Advantages of neural networks over parametric statistical methods are: (1) neural networks are good pattern recognizers,(2) they need no assumptions on data frequency distribution and (3) after training, neural networks can perform classification tasks with missing data (Nielen et al, 1991). Chamberlain (1992) showed that a neural network was a good prediction model compared to logistic regression. A neural network therefore promises to be a good method for the on-line mastitis detection task (Nielen et al., 1991).

An initial neural network for on-line mastitis detection has been built (Nielen et al, 1992b). The network consists of 24 input nodes, containing electrical conductivity data from the milking parlor. The hidden layer contains 5 nodes and it has one binary output node. Figure 2 is a graphical representation of this neural network before training started. During training, connections (arrows in Fig. 2) with

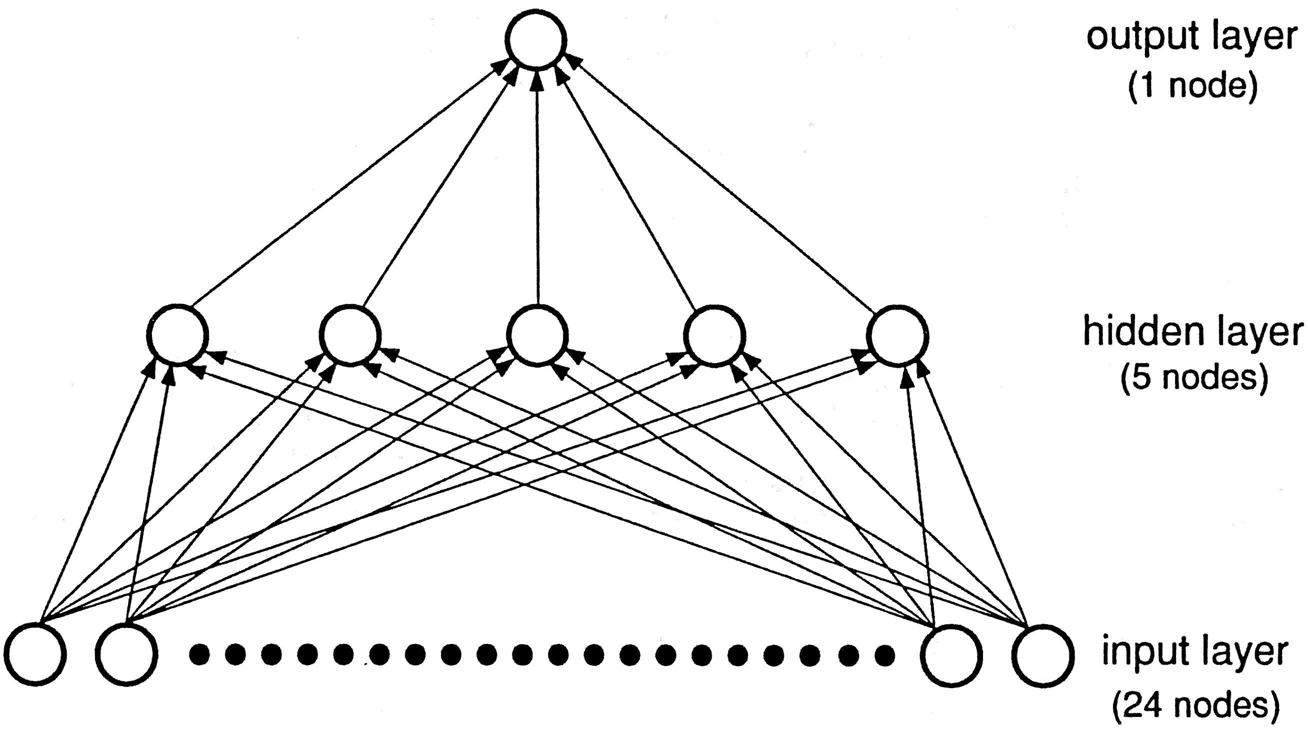

Figure 2. Architecture of the neural network for on-line mastitis diagnosis. Not all connections are shown

Table 1. Classification of healthy and mastitic quarters by the neural network on training set and test set.

		Output defenition (golden standard)			
		Training set		Test set	
		Healthy (17)	Mastitis (13)	Healthy (13)	Mastitis (13)
Network output	Healthy	17	1	13	6
	Mastitis	0	12	0	7

low weights were pruned and the final model consisted of 76 connections. The classification results of this initial neural network are summarized in Table 1. The training set was created from morning milkings. The test set consisted of data from the previous evening milkings. The results indicate that a neural network was able to differentiate between healthy and mastitic quarters (Nielen et al., 1992b).

Causal probabilistic network

The theory of causal probabilistic networks (CPN) is based on Bayesian conditionalization. A CPN is, at a qualitative level, a graph where the nodes represent domain objects and the links between nodes represent relations between these objects. The knowledge is stated in a causal direction (disease causing symptoms). Each node in a CPN has a number of states, describing the possible values of the node. At a quantitative level, the relations expressed by the links are represented by conditional probabilities (Andersen et al., 1989). If A is a top node (parent) and B is influenced by A (child), then the relation between A and B can be described by Eq. 1 (Olson et al., 1990; Charniak, 1991).

$$P(A|B) = \frac{P(B|A)\,P(A)}{P(B)} \qquad (1)$$

In a CPN, the conditional probabilities for each node on its parents (in this case $P(B|A)$) are put in a probability table. When the state of node B has been observed, the conditional probability $P(A|B)$ can be calculated using the probability table and Eq. 1. CPN's can be created with the shell HUGIN (Andersen et al, 1989).

Because CPN's can reason with probabilities, they are very applicable in the domain of pathogen diagnosis. To illustrate the concept of CPN's Fig. 3 shows the nodes and connections in a CPN describing the effects of clinical mastitis. Given a known state of the node "mastitis", probabilities can be given on the state of the nodes "systemic signs", "milk col-

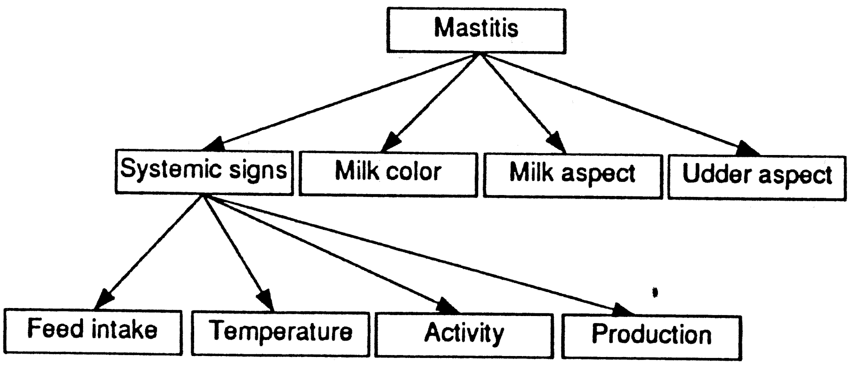

Figure 3. CPN for symptoms of clinical mastitis

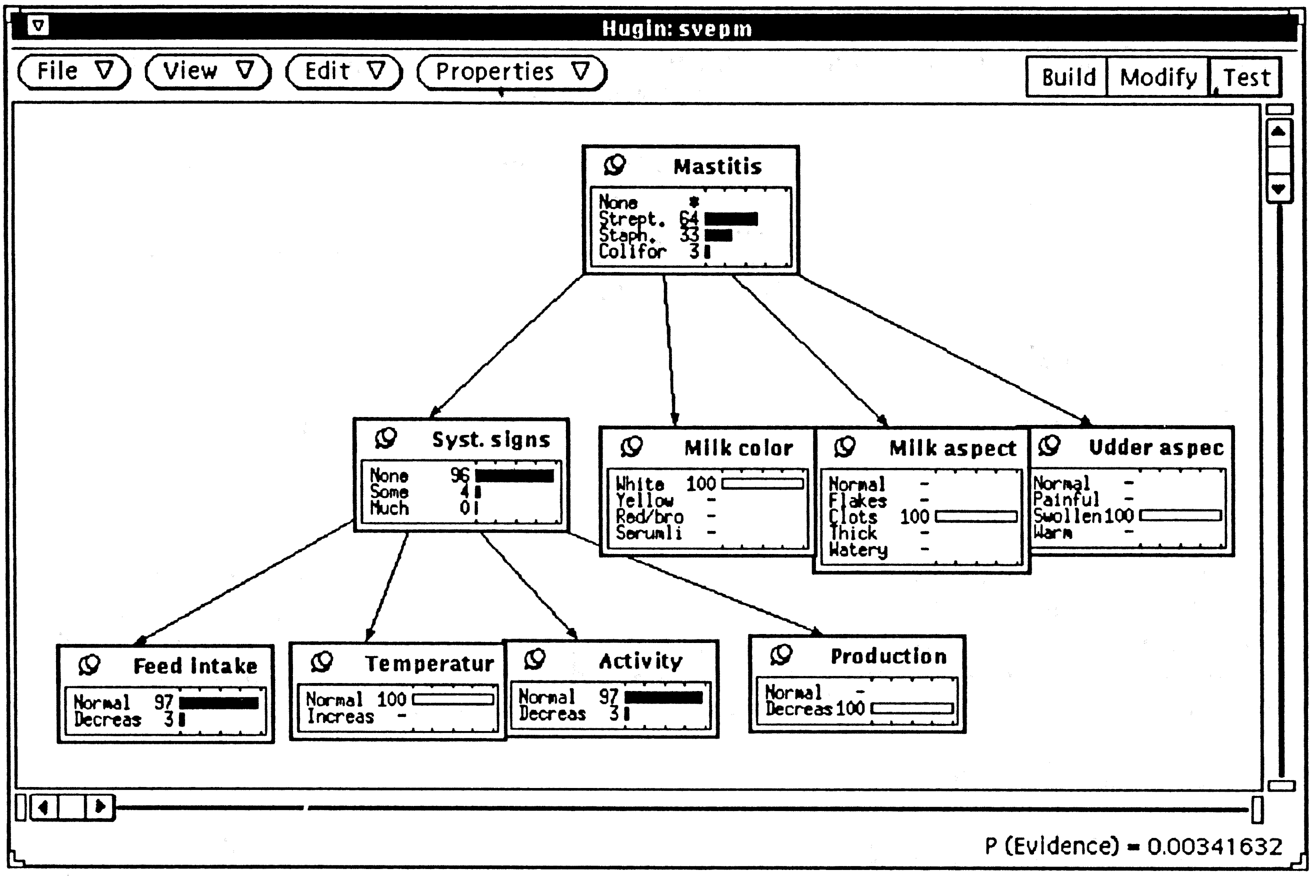

Figure 4. HUGIN screendump of CPN for symptoms of clinical mastitis

or", "milk aspect" and "udder aspect". The state of the node "systemic signs" has effect on the probabilities for the states of the nodes "feed intake", "temperature", "activity" and "production". When we make observations on some of the nodes in the model, the CPN propagates this knowledge to the other nodes, and probabilities on the states of the other nodes will be given. For example: we have the following observations in a mastitis case: the milk color is white, the milk contains clots, the udder is swollen, the body temperature is normal and the production is decreased (white bars in Fig. 4). When these observations are entered, the model propagates this information and gives probabilities for the states of the nodes of which no observations are made (black bars in Fig. 4). In this case the probability of a mastitis caused by streptococci is 64 per cent, the probability of staphylococcus mastitis is 33 per cent and of coliform mastitis is 3 per cent.

For a good pathogen diagnosis, the CPN must be extended with specific risk factors, like teat injury, lactation stage, cow history and herd history. When there is a good data base available on a farm, it is possible to automatically enter risk factors in the pathogen diagnosis subsystem. Technically it is also possible to automatically measure the concentrate feed intake, milk temperature, activity and milk production of a cow, so these factors can also automatically be entered in the CPN for pathogen diagnosis. Clinical signs as milk color, milk aspect and udder aspect must be entered by hand.

Rule-based system

The knowledge in a rule-based system is represented in a set of production rules. The production rules (IF-THEN rules) represent condition-action pairs. The antecedent of a rule (the IF portion) is corresponding to the condition and the consequent of a rule (the THEN portion) is corresponding to the action (Luger & Stubblefield, 1989). Forward and backward reasoning are the most common inference mechanisms. Forward reasoning starts from observations and scans the production rules for antecedents that match the observation. When an antecedent of a production rule matches, the consequent of that production rule will be added to the database. Now the rules will be scanned again. This process continues until no rule matches and a conclusion is found. Backward reasoning is the same process but with consequent matching instead of antecedent matching (Luger & Stubblefield, 1989). A typical rule for diagnosing car starting problems has the following format:

IF	the engine does not turn over and the lights do not work
THEN	the problem is battery or cables.

Production rules are very suitable to represent heuristic knowledge. This is knowledge based on experience, the so called rules of thumb. In the mastitis module, the therapy selection task can well be represented with such rules. No work has been carried out on this part yet. Another area in which a rule based system can be used, is mastitis problem diagnosis. Specialists evaluate herd data on mastitis incidence and somatic cell count to detect a mastitis problem. Heuristics used to perform this evaluation can be represented in production rules. A similar task, the evaluation of lactation curves in conjunction with milk components, can already be performed by a rule-based system (Fourdraine et al., 1992).

Conditional causal model

The concept of conditional causality is introduced by Schreinemakers (1991). A conditional causal model (CCM) consists of a set of nodes, describing a domain. The nodes are connected by a set of (unidirectional) links, representing a causal dependency of a node on another node. The magnitude of the dependency may be influenced by one or more conditions (Hogeveen et al, 1992a). The relations in a conditional causal model may be qualitative as well as quantitative. The basic elements of a CCM are graphical represented in Fig. 5. Node B is causally dependent on node A, a relation represented by an arrow. Node C is a condition, represented by a circle on an arrow. Forward reasoning (simulation) and backward reasoning (diagnosis) is possible with a CCM. CCM's can be developed using CAMEL (CAusal Modeling Environment and Laboratory). CAMEL is a highly visualized software development tool (Tepp and Schreinemakers 1991). Using this tool, a graphical representation of a domain can be made The relations between the nodes can then be quantified with underlying functions, written in the programming language LISP.

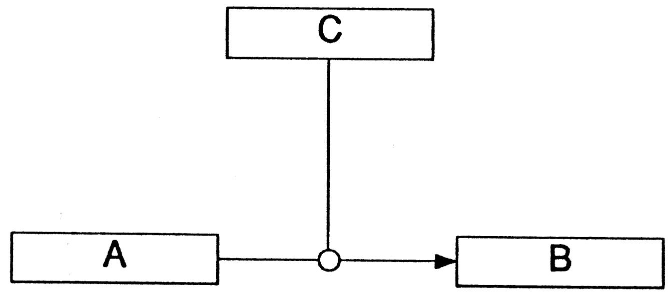

Figure 5. Basic features of a CCM

CAMEL is sufficiently flexible to allow the representation of complex biological domains. The graphical representation of a domain gives the user a good overview and allows the user to follow the reasoning process. These features make a CCM a suitable method to model the textbook knowledge necessary for a causal diagnosis of a mastitis problem on a farm.

To illustrate the use of CCM's for mastitis diagnosis, Fig. 6 contains a CCM of the first line of udder defence. The task of the first line of udder defence is to prevent

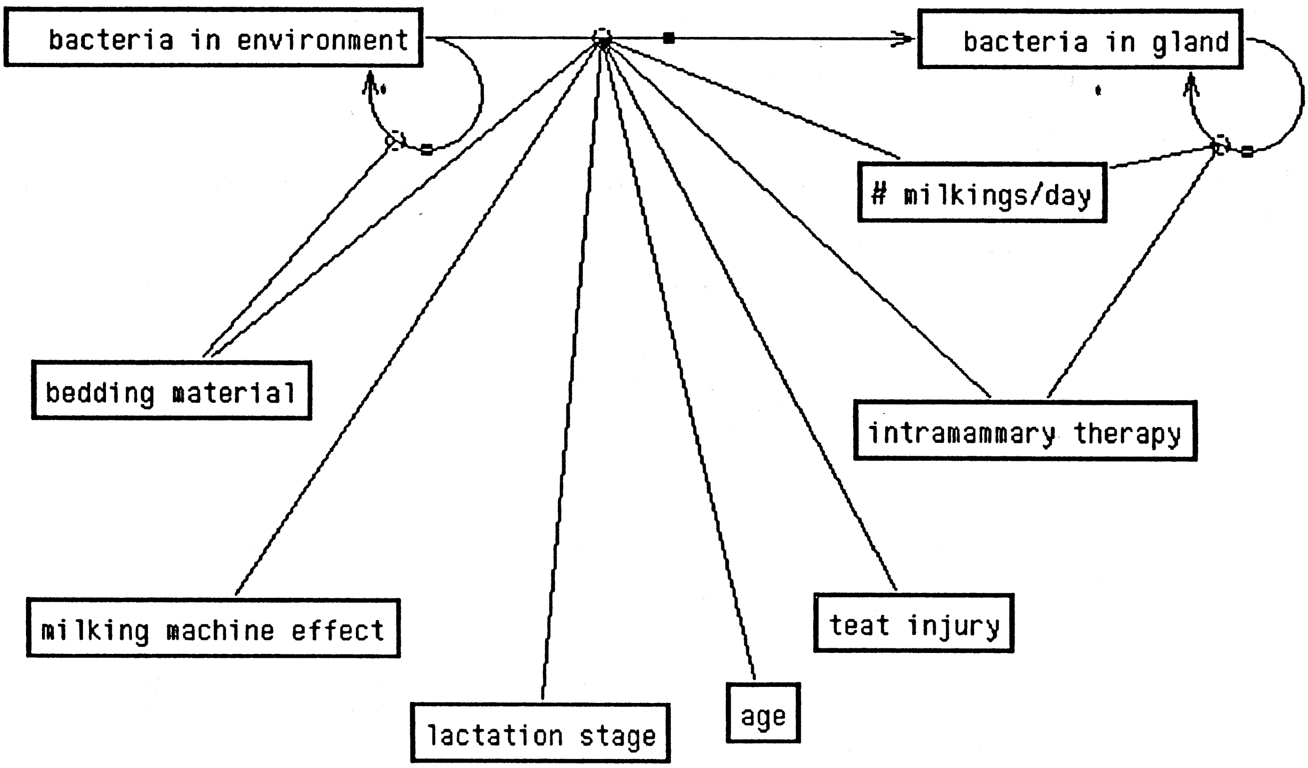

Figure 6. CAMEL screendump for first line of udder defence

bacteria from entering the udder. Therefore the first line of udder defence can be considered as a condition on the basic causal pathway from the node "bacteria in environment" to the node "bacteria in gland" (Hogeveen et al, 1992b). The variables: type of bedding material, milking machine effect, lactation stage, age, teat injury, intramammary therapy and number of milkings per day have a direct effect on the magnitude of the relation between the number of bacteria in the environment and in the udder.

DISCUSSION

The goal of the mastitis module in the Milk Production Project, is to develop a computerized tool for mastitis detection and diagnosis and use the appropriate knowledge representation schemes to perform this task. Artificial intelligence research has resulted in numerous knowledge representation schemes, some of which were developed for a very restricted domain and others are for use in more broad domains. For efficient reasoning it is important that the proper knowledge representation scheme is used for the problem solving task. We therefore propose to use the four different knowledge representation schemes as described in this paper in our research. At the cow level, the mastitis detection can be performed by a neural network, the pathogen diagnosis can be carried out by a causal probabilistic network and a proper therapy can be selected by a rule-based system. At the herd level, mastitis problem detection can be performed by a rule-based system, while a causal diagnosis can be carried out using a conditional causal model.

From an epidemiological point of view it is interesting to model the various aspects of mastitis in order to get a better understanding of the disease, to predict the effects of managerial measures on the mastitis status of a herd and to predict the outcome of the disease. Various methodologies to perform these tasks have been developed in the field of epidemiology. i.e. regression techniques, state transition models, path analysis etc.. Some of these tasks can better be performed by methodologies developed in the field of artificial intelligence. Chamberlain (1992) describes the use of neural networks and rule-based systems to predict the outcome of a disease. Although neural networks and a rule-based system can perform well on the task of prediction, they do not give any insight in the underlying causal mechanisms (Chamberlain, 1992). CPN's and CCM's reason on causal models. They therefore give better insight in the etiology or pathofysiology of a disease and give therefore a good explanation of found results. They cannot only be used for problem solving tasks, but also for simulation.

In conclusion, we feel that the separation of mastitis diagnosis and treatment into different steps with different types of knowledge has enabled us to model the domain approriately. We have tried to choose the most valid knowledge representation methodology for each different step in order to create an efficient system. At the same time the methodologies show to be a good simulation tool from an epidemiological point of view. The research field of artificial intelligence can in such way be a good help in epidemiological studies.

ACKNOWLEDGEMENTS

This research has been made possible by the Foundation Knowledge-Based Systems (SKBS), a Dutch foundation that stimulates research in the field of KBS and technology transfer between universities and industry in the devlopment of KBS.

The authors further wish to thank Iver Thysen and Lene K. Rasmussen of the Danish Informatics Network in Agricultural Sciences (Dina), Tjele, Denmark, for their help in the usage of Causal Probabilistic Networks. Tine van Werven and Wim Kremer of the Department of Herd Health and Reproduction, Utrecht University, are gratefully thanked for serving as domain experts.

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SOCIETY FOR VETERINARY EPIDEMIOLOGY AND PREVENTIVE MEDICINE

APPLICATION FOR MEMBERSHIP

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I wish to be elected to membership of the Society for Veterinary Epidemiology and Preventive Medicine.

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Please tick the appropriate boxes to indicate your interests:

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The annual subscription is £10.

SOCIETY FOR VETERINARY EPIDEMIOLOGY AND PREVENTIVE MEDICINE

CONSTITUTION AND RULES

NAME

1. The society will be named the Society for Veterinary Epidemiology and Preventive Medicine.

OBJECTS

2. The objects of the Society will be to promote veterinary epidemiology and preventive medicine.

MEMBERSHIP

3. Membership will be open to persons either actively engaged or interested in veterinary epidemiology and preventive medicine.

4. Candidates for election must return a completed application form. The Secretary will then circulate the names of candidates on the agenda for the next general meeting. Election of candidates will be by a simple majority vote of members present at the general meeting.

5. Non-payment of subscription for six months will be interpreted as resignation from the Society.

OFFICERS OF THE SOCIETY

6. The Officers of the Society will be President, Senior Vice-President, Junior Vice-President, Honorary Secretary and Honorary Treasurer. Officers will be elected annually at the Annual General Meeting, with the exception of the President and Senior Vice-President who will assume office. No officer can continue in the same office for longer than six years.

COMMITTEE

7. The Executive Committee of the Society normally will comprise the officers of the Society and not more than four ordinary elected members. However, the Committee will have powers of co-option.

ELECTION

8. The election of office bearers and ordinary committee members will take place at the Annual General Meeting. Ordinary members of the Executive Committee will be elected for a period of three years. Retiring members of the Executive Committee will be eligible for re-election. Members will receive nomination forms with notification of the Annual General Meeting. Completed nomination forms, including the signatures of a proposer, seconder, and the nominee, will be returned to the Secretary at least 21 days before the date of the Annual General Meeting. Unless a nomination is unopposed, election will be by secret ballot at the Annual General Meeting. Only in the event of there being no nomination for any vacant post will the Chairman take nominations at the Annual General Meeting. Election will be by simple majority of members voting at the Annual General Meeting. Tellers will be appointed by unanimous agreement of the Annual General Meeting.

FINANCE

9. An annual subscription will be paid by each member in advance on the first day of May each year. The amount will be decided at the annual general meeting and will be decided by a simple majority vote of members present at the annual general meeting.

10. The Honorary Treasurer will receive, for the use of the Society, all monies payable to it and from such monies will pay all sums payable by the Society. He will keep account of all such receipts and payments in a manner directed by the Executive Committee. All monies received

by the Society will be paid into such a bank as may be decided by the Executive Committee of the Society and in the name of the Society. All cheques will be signed by either the Honorary Treasurer or the Honorary Secretary.

11. Two auditors will be appointed annually by members at the annual general meeting. The audited accounts and balance sheet will be circulated to members with the notice concerning the annual general meeting and will be presented to the meeting.

MEETINGS

12. Ordinary general meetings of the Society will be held at such a time as the Executive Committee may decide on the recommendation of members. The annual general meeting will be held in conjunction with an ordinary general meeting.

GUESTS

13. Members may invite non-members to ordinary general meetings.

PUBLICATION

14. The proceedings of the meetings of the Society will not be reported either in part or in whole without the written permission of the Executive Committee.

15. The Society may produce publications at the discretion of the Executive Committee.

GENERAL

16. All meetings will be convened by notice at least 21 days before the meeting.

17. The President will preside at all general and executive meetings or, in his absence, the Senior Vice-President or, in his absence, the Junior Vice-President or, in his absence, the Honorary Secretary or, in his absence, the Honorary Treasurer. Failing any of these, the members present will elect one of their number to preside as Chairman.

18. The conduct of all business transacted will be under the control of the Chairman, to whom all remarks must be addressed and whose ruling on a point of order, or on the admissibility of an explanation, will be final and will not be open to discussion at the meeting at which it is delivered. However, this rule will not preclude any member from raising any question upon the ruling of the chair by notice of motion.

19. In case of an equal division of votes, the Chairman of the meeting will have a second or casting vote.

20. All members on election will be supplied with a copy of this constitution.

21. No alteration will be made to these rules except by a two-thirds majority of those members voting at an annual general meeting of the Society, and then only if notice of intention to alter the constitution concerned will have appeared in the notice convening the meeting. A quorum will constitute twenty per cent of members.

22. Any matter not provided for in this constitution will be dealt with at the discretion of the Executive Committee.

April, 1982
Revised March, 1985; April, 1988