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CONTENTS

	Page
Acknowledgements	v
PUBLIC HEALTH, QUALITY ASSURANCE AND FOOD SAFETY	
Monitoring Health and Production in Finishing Swine Populations - P. Davies	1
Causes of Variation in the Use of Anticicrobials in Meat Pig Husbandry: A Preliminary Study - J.P.T.M. Noordhuizen, A.M. Henken, K. Frankena, W. Mocking and C.T.W. Vrolijk	11
Rabies Elimination in Belgium - P.P. Pastoret and B. Brockier	18
Persistence of bovine shedding of Escherichia coli, Serotype O157: H7 PFGE strains - T.E. Besser, D.D. Hancock, L. Pritchett, E. McRae, M. Sanderson and D. Rice	27
ANIMAL MOVEMENTS	
GATT and the Principles of Risk Assessment as they Relate to Trade - J.M. Scudamore	34
Animo Risk Management System (ARMS) - A computerised system of identifying and managing risks associated with importing livestock into Great Britain - D.G. Pritchard, J.A. Blake and A. Valente	40
Free Trade has come - Are Diseases Coming or Going? - R.M. McCracken	57
OPEN SESSION	
Statistical Evaluation of Impacts of Animal Health Interventions on Livestock Productivity - G.J. Rowlands	64
Appropriate Methods for the Investigation of Animal Health Problems in Backyard (Traspatio) Systems in Yucatan, Mexico - A.J.C. Cook	74
Integrating Epidemiologic Research and Veterinary Practice: Ideas and Experiences - M.R. Slater and D.M. Boothe	84
Effect of Reproductive Disorders and Performance on Length of Productive Life of Holstein Dairy Cows Assessed by Survival Analysis - F. Beaudeau, F. Ducrocq, V. Fourichon, K. Frankena and H. Seegers	91

Modelling Listerial Activity within a Silage Bale - L.A. Kelly, W. Donachie, G. Gettinby, G. Gibson and J.C. Low 101

Classical Swine Fever in Germany - Some Epidemiological Aspects - M. Kramer, R. Ahl, J. Teuffert, K. Kroschewski, H. Schlüter and J. Otte 110

Evaluation of optimal size of restriction zones in disease control with particular reference to classical swine fever - M. Roberts 119

Temporo-spatial Evaluation of mortality events in a 20,000 cage-layer operation - N. Tablante, J.P. Vaillancourt, S.W. Martin and M. Shoukri 131

ECONOMICS AND WELFARE

Estimating the Perceived Benefits of Measures to Improve Animal Welfare - R. Bennett 140

The Cost of Welfare - The Food Consumer's Viewpoint - J.P. McInerney 147

TOOLS AND TECHNIQUES

Methods for the Assessment of Disease on Livestock Productivity - A. James 156

Problems Encountered in the Practical Implementation of Geographical Information Systems (GIS) in Veterinary Epidemiology - A. Paterson 162

Disease and Production Modelling: Developing Accessibility and Usefulness - S.K. Sivam 172

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Constitution of the Society

PUBLIC HEALTH, QUALITY ASSURANCE AND FOOD SAFETY

MONITORING HEALTH AND PRODUCTION IN FINISHING SWINE POPULATIONS

PETER DAVIES*

Over the last 25 years, intensification of swine production systems in many countries has been associated with a decline in the number of producers and an increase in average herd size. Production of large numbers of animals in confinement has brought new challenges in the maintenance of animal health, welfare issues, and the need for greater management expertise. Over the last 10 years, the development of computer software programs, such as PigCHAMP® (University of Minnesota, St. Paul, MN) and PigTALES® (Pig Improvement Company) to facilitate management of large populations of animals has been a major technological advance. In the rapidly expanding swine industry of the southern United States, breeding herds of over 2000 females, and commonly 3,500 females, are the norm for new facilities on a single site. Several companies in the US now control herds of the order of 100,000 sows. In concert with the increase in breeding herd size, there has been a shift to "multiple-site" production systems where different phases of production (breeding, weaned pigs, finishing) are operated on separate locations. These systems usually incorporate all-in/all-out management principles to reduce the probability of pathogen transmission among different age-groups of pigs (Dial et al., 1992). "State of the art" systems have 3-site production with all-in/all-out management of growing pigs by site (that is, an entire site will be depopulated between successive groups, rather than one room of a building or one of several buildings at a site). There are various ownership structures for these facilities, including total corporate ownership, contract agreements between independent farmers and corporates, and cooperatives of independent producers.

Use of computers, either on farm or via bureaux, to manage data is essential for efficient operation of these large breeding herds. While primarily used for day to day management applications, such as generating action lists and monitoring of herd performance (farrowing rate, litter size, pre-weaning mortality rates), some programs have powerful "diagnostic" capabilities which allow detailed definition of the nature of production problems. For example, PigCHAMP® 3.05 has some 31 "reports" that document different aspects of breeding herd performance, and can be customized in many ways to characterize potential problems. To keep pace with the increasingly sophisticated methods of their clients (or employers), swine veterinarians must be "computer literate" and capable of harnessing the increasing quantity, and hopefully quality, of data to make cost-effective recommendations on production and health management.

The rapid adoption of software for managing swine breeding herds reflects a need for better "management information systems" as herd sizes increase. However, record keeping and data management systems for growing pig populations are much less advanced. PigCHAMP® 3.05

* Department of Food Animal and Equine Medicine, College of Veterinary Medicine, North Carolina State University, 4700 Hillsborough St., Raleigh, NC 27606, USA

includes data entry and report options for growing pigs, but these are used regularly by a minority of producers who purchase the program. There are several reasons why sophistication of record keeping systems for grow-finish populations has lagged behind those used for breeding herds. Compared with breeding herds, management of growing swine is a relatively simple task requiring much less day to day management and labor input. Individual identification of breeding females is essential because many routine procedures (estrus detection, mating, pregnancy detection, culling decisions) pertain to individuals and are facilitated by information about individuals (day of weaning or previous oestrus, previous reproductive performance). In contrast, growing pigs are generally handled as groups, and group level information (mortality rate, average daily weight gain, efficiency of feed conversion) is of greatest interest. Traditionally, even these basic measures have not been routinely monitored on many farms. However, changing circumstances such as the shift to all-in/all-out management, greater penalties from packing plants for pigs that are outside specifications (carcass weight and fat), and declining margins make it timely to reassess the potential information sources for managing growing pigs.

MONITORING HEALTH IN GROW-FINISH POPULATIONS

Inspections of slaughtered pigs

Several important diseases of growing swine cause macroscopic lesions that can persist until market age (Pointon et al., 1992). Inspection of gross lesions in slaughtered pigs may be used to diagnose disease problems in herds and estimate rates of disease; for surveillance of herds of high health status; in decision support models and quality assurance programs; and to help communicate with and motivate producers. The data must facilitate cost-effective decision making with respect to herd health management, and be obtained at acceptable cost. Since originating in Scandinavia in the 1960's, slaughter monitoring has been adopted with varying enthusiasm in different countries. Some countries, such as Denmark, instituted comprehensive programs in which most slaughtered pigs are inspected (Willeberg et al., 1984/85). The limitations of slaughter data and the need to integrate them with production data have been recognized, and there have been some initiatives in this direction (Doohoo, 1988; Ellegard, et al., 1992; Lloyd et al., 1993). In the USA, until recently there was no coordinated program for collecting and compiling data of lesions occurring in swine, apart from condemnation data from the Food Safety Inspection Service of the USDA. In 1990, the University of Minnesota, in cooperation with the USDA National Animal Health Monitoring System, adapted an Australian system, named PigMON, to compile data of lesion prevalence in the US swine industry (Pointon et al., 1992).

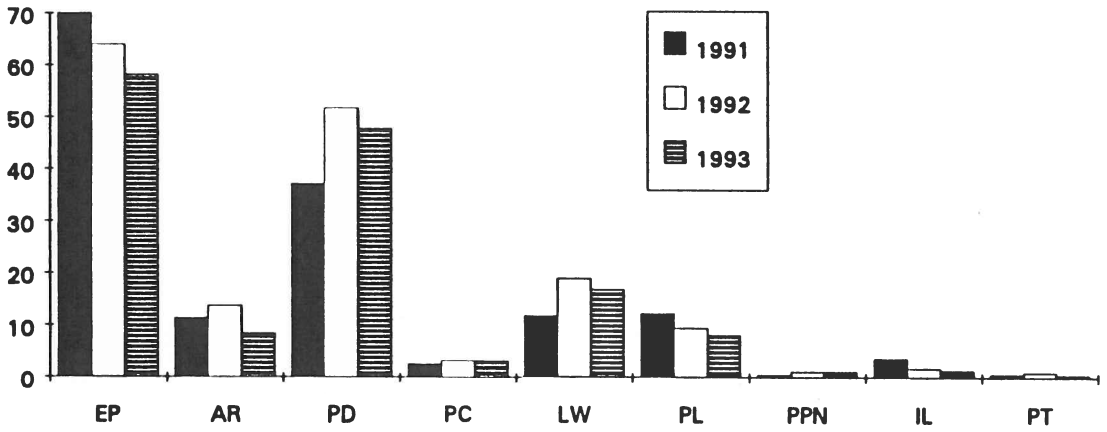
The value of monitoring of lesions in slaughtered pigs to obtain information that helps to improve health in swine herds is difficult to assess. Some advantages and limitations of slaughter inspections are listed in Table 1. If slaughter inspections are to be useful, it is necessary to minimize the impact of these limitations on the reliability of the data. The procedures adopted in the PigMON program were designed to maximize the reliability of data obtained by slaughter inspections. Key features of the program include training and quality control of inspectors to use standardized methods to describe and record lesions (described in a detailed procedures manual); inspection of a wide range of lesions (the marginal cost of inspecting for additional lesions is negligible); and statistically based sampling to improve accuracy of prevalence estimates and ability to detect disease (Pointon et al., 1992). Lesions routinely recorded by PigMON inspectors include cranio-ventral lung consolidation (enzootic pneumonia), atrophy of nasal turbinates (atrophic rhinitis), liver white spots (ascariasis), papular

dermatitis (sarcoptic mange), pleuropneumonia-like lesions (*A. pleuropneumoniae*), ileitis (proliferative enteritis), pleuritis, pericarditis and peritonitis. In Australia, kidneys are also examined for the presence of white spots (leptospirosis).

Table 1: Advantages and limitations of inspections of slaughtered pigs

Advantages	Limitations
Actual lesions observed (vs. antibody/clinical signs)	Biased sample of finishing population
Low cost (several lesions evaluated)	Dead and cull pigs not included
Best for high incidence/long duration diseases (related to economic impact?)	Only for lesions persisting to slaughter
	Specificity/sensitivity - ??
Convenient sample collection	Observer variability and bias
	Retrospective (all-in/all-out)

The PigMON program in Minnesota is named after a computer software program developed by the Department of Agriculture, Western Australia, specifically to compile the data and generate reports for producers. This enables summary data to be described and used as a frame of reference by veterinarians (Fig. 1). Frequency distributions of lesion prevalence among groups of pigs inspected enables ready comparison with other herds in the region. (Fig. 2).



EP = enzootic pneumonia
AR = snout score of 3-5
PD = papular dermatitis
PC = pericarditis
LW = liver white spots
PL = pleuritis
PPN = pleuropneumonia
IL = ileitis
PT = peritonitis

Fig. 1 Prevalence of lesions in slaughtered pigs over consecutive 12 month periods (May to April) from 1990 to 1993 (PigMON, University of Minnesota).

For swine practitioners, one source of disappointment with slaughter data is the inability to confidently infer the biological or financial impact of diseases. In addition to market factors (price of feed, price of pigs), common sense suggests that the financial costs of a disease to a producer depend on its incidence (proportion of animals affected), severity (how much the disease affects them) and the duration of the effect. The probability that a pig will have lesions at slaughter is determined by disease incidence in the herd, duration (and probably severity) of lesions, age at infection, age at slaughter, and the sensitivity and specificity of the inspection procedures. Prevalence of lesions in a group of slaughtered pigs is the net result of these factors, which are likely to vary among farms and among pigs within groups. In the case of enzootic pneumonia, there have been numerous conflicting and

inconclusive studies attempting to link slaughter lesions with biological performance (Morrison et al., 1986; Pointon et al., 1992), despite early warnings of the likely futility of such endeavours (Betts et al., 1955). All-in/all-out management of finishing population magnifies the limitation of the retrospective nature of slaughter data. In continuous flow populations, a group of slaughtered pigs represents a biased sample from an existing "steady state" and previously contiguous population, to which the information can be extended. With AIAO systems, sheds are depopulated between consecutive groups, and these are often restocked from different locations (i.e. there is no ongoing population). The data thus represent a sample in time of the output of a facility, and have limited value unless health status of the overall enterprise is being evaluated.

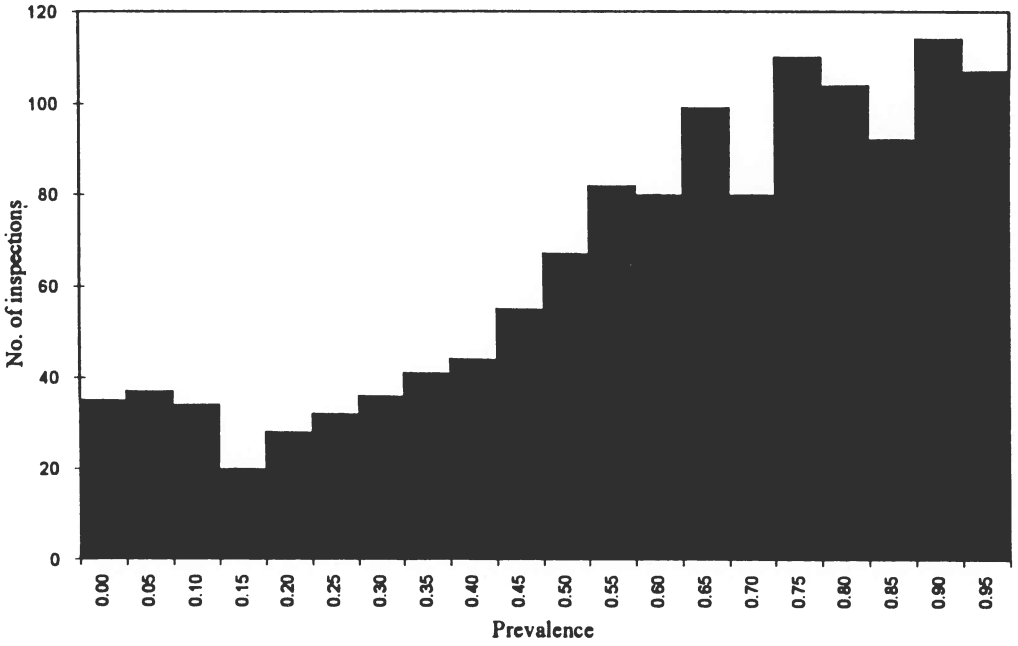


Fig. 2 Frequency distribution of prevalence of cranio-ventral lung consolidation (typical of enzootic pneumonia) among 1297 groups of pigs (PigMON)

Despite these limitations, slaughter data are an unparalleled source of information about sub-clinical disease in finishing populations. At an industry level, we see that many lesions are very common in ostensibly "healthy" pigs at slaughter (Fig. 1). The prevalence of lesions of parasitic diseases (liver white spots, papular dermatitis), for which control can be achieved relatively simply, remains surprisingly high and suggests either a general lack of awareness or an acceptance of these infections in the industry. Another message from the PigMON data is that great variability exists among herds with respect to the prevalence of lesions at slaughter (Fig. 2), which implies that progress is achievable for many producers.

Apart from surveillance of minimal disease herds, perhaps the least debatable application of slaughter inspections is with less efficient producers. Slaughter data serve to demonstrate the extent of endemic disease problems in herds, and hopefully serve to motivate producers to improve management practices. Data from Australia showed considerable reduction in the prevalence of papular dermatitis lesions in a population of herds that regularly used slaughter monitoring over 4 years (Davies et al., 1991a), and suggest progress can be achieved, at least for diseases that are relatively easy to control. Straw and Dewey (1994) concluded that periodic slaughter inspections can provide useful feedback on the progress of ascarid control programs, but saw little value in repeated assessment of respiratory lesions. These authors stated that unless new control measures are being introduced, it is difficult to justify frequent slaughter inspections for most commercial

producers. In contrast, Lloyd et al (1993) concluded that four inspections per year of at least 50 pigs is required to obtain adequate data to apply in decision support systems. Hurnik (1991) described the APHIN system, in which lesion data and other farm specific data (pigs shipped per month, weight, lean yield) are routinely collected, and indicated that new technology broadens the opportunity for veterinarians to incorporate slaughter lesion data in swine "herd health" consultancy programs in which profit maximization of the client is the goal. Certainly, traditional slaughter inspections are of limited value to progressive producers, and the future value of slaughter data will depend on our ability to integrate slaughter data with comprehensive data of other components and outputs of finishing operations.

Recording of mortality and culls

Disease outbreaks causing increased mortality often lead to veterinary involvement. However, systematic recording by producers of sporadic occurrences of mortality and calculation of endemic mortality rates is variable. Owing to resource limitations, necropsy of dead pigs is not usually routine on farms. AIAO systems facilitate record keeping as all animals in a barn are of comparable age when placed. Deaths can be charted by time since placement, and further information such as body weight of dead pigs, location, and probable cause may be useful. Although there is a problem of validity with producer diagnosed causes of mortality (Vaillancourt et al., 1990), with minimal training by veterinarians, producers can recognize lesions of some important causes of mortality of growing pigs, such as ulceration of the pars oesophagea and proliferative enteritis. In large corporate enterprises, in which numerous barns of similar design are stocked from the same sources and use the same feed, surveys of age, weight, and causes of mortality across barns may be useful to document endemic problems in the "system" and assist recognition of problem barns/producers. Good documentation of usual mortality patterns should also facilitate early detection and investigation of abnormal patterns of mortality. Culling of underweight pigs or pigs with health problems (arthritis, lameness, hernias) is an important source of financial loss, and a similar argument can be made for recording culls. Although the timing of culling decisions is often determined by staff, documentation of cull rates and reasons across barns will assist in identifying problem farms. Again the evolution of large and relatively uniform production systems makes documentation and understanding of the production process more feasible and more viable.

Recording clinical disease and treatments

Recording of morbidity is inherently subjective, and is not practiced widely in swine. Non-specific signs of respiratory and enteric disease are routinely recorded in some larger poultry enterprises. In swine, recording of pruritus and coughing events has been used experimentally to evaluate the onset and severity of sarcoptic mite hypersensitivity (Davies et al., 1991b) and enzootic pneumonia (Gardner & Hird, 1990; Bahnson et al., 1992) respectively in commercial herds. In addition, numerous authors have used systems to describe the duration and severity of scouring due to a range of enteric diseases. An added limitation to recording morbidity in the facilities now popular in North Carolina is the high level of automation of feed and water delivery systems. The associated decrease in frequency and intensity of observation of stock must generally lower the sensitivity of recording morbidity. If clinical signs are to be useful for monitoring health, systematic regimens for observing animals must be devised. Bahnson et al., (1992) recorded coughing events twice weekly for 3 minutes in two pens located centrally in barns and found significant associations between the time of onset and frequency of coughing episodes in barns and the prevalence of lung consolidation at slaughter. This suggests that relatively simple and low-cost observation regimes might be practical for defining the onset of clinical

disease and optimising medication strategies, as well as complementing slaughter data to help understand the epidemiology of endemic diseases.

Recording treatments of sick animals provides another crude index of general health, and related measures such as total drug cost per pig marketed may be calculated. One advantage of good documentation of treatments is to avoid marketing pigs at risk for residues. The Pork Quality Assurance program of the National Pork Producers Council (USA) applies principles of HACCP (Hazard Analysis Critical Control Point) to reducing the risk of antimicrobial residues in pork, and includes regular recording of treatments.

Serological monitoring

Serological testing has numerous applications in swine medicine including investigation of disease outbreaks, eradication programs, surveillance of minimal disease herds, and screening of purchased stock prior to introduction into a herd. With respect to routine monitoring of health, serology has some disadvantages including cost of sample collection and testing, imperfect and often unknown sensitivity and specificity, the desirability of sequential sampling for interpretation, and interference from maternal and vaccination titres. Serological monitoring of several diseases has been used when samples are collected routinely for pseudorabies (Aujesky's disease) testing (Chase & Hurley, 1994). With AIAO systems, we again have the problem that the population sampled is depopulated, and any value of the information is more transient than for a continuous flow population. Excluding investigation of disease outbreaks, current applications of serology for monitoring finishing populations are limited to obtaining "baseline" information on the disease status of a production system (i.e. pathogen present or not) or opportunistic testing of samples collected for other reasons. In the future, better and cheaper tests should increase the utility of serology for health monitoring. Collection of serum samples at slaughter is relatively convenient and could have an application in "quality control" programs for monitoring food borne pathogens such as *Trichinella spiralis* and *Toxoplasma gondii* within production systems.

Carcass Quality and Condemnations

Much data characterizing the quality of pigs submitted for slaughter is routinely provided by packing plants in the USA, but often in a form that is not user friendly. As technology improves, availability of electronic retrieval of carcass and condemnation data for groups of pigs will facilitate the integration of this information with other production data (Hurnik, 1991), particularly for larger producers with close ties to packing plants.

MONITORING PERFORMANCE OF GROW-FINISH PIGS

To assess and understand efficiency of production in a herd, it is essential to measure some basic parameters of the biological performance of growing pigs. Such measures can provide yardsticks of overall performance, and alert attention to sub-standard performance due to health, nutrition, management or other causes.

Average daily gain (ADG)

Superficially, measurement of ADG seems a very simple concept. However, as usual under conditions of commercial production we find a range of methods can be applied, each with inherent

limitations (Leman & Fitzsimmons, 1992). A compromise exists between the cost of obtaining more precise data of ADG and its utility. Ear notching to record age is the simplest way to determine days to slaughter for pigs that survive until slaughter weight. An estimate of days to slaughter can be calculated from average inventories and pig movements through a barn, without weighing pigs on the farm (Wilson et al., 1986). It is important to understand how calculations are done, particularly with respect to how dead and cull pigs are treated (i.e., is weight gain of non-survivors included in calculations). In PigCHAMP® 3.05, ADG is calculated for groups from total gain (total weight sold - total weight placed) over total pig days, and does not include weight gain of dead and culled pigs. If ages and weights of dead and cull pigs are recorded, more accurate estimates of performance can be made.

While ADG is the traditional focus of growth performance, in AIAO systems variability of weight is also an important consideration. As penalties for underweight pigs tend to be severe in the USA, producers face the decision of selling pigs underweight or keeping tail-end pigs longer and delaying repopulation of the barn. The importance of marketing strategies based on payment grids of packers, pig weights and feed and facility costs to optimise revenue by meeting the specifications of packers is recognized, and is facilitated by information on growth performance and variation. In larger companies, scheduling of transport of pigs to slaughter is one facet of these strategies. Drs. John Deen and John Roberts at North Carolina State University are adapting methods of Statistical Process Control to optimise marketing of finished pigs (Roberts, 1994). In contrast to conventional retrospective calculation of ADG after sheds are depopulated, this approach involves repeated weighing of random samples of pigs to obtain real time graphs of mean ADG and coefficient of variation which can be incorporated in spreadsheets to project optimal marketing times for the group.

Feed intake and Efficiency of Feed Conversion

As feed accounts for approximately 70% of the cost of production of pigs, monitoring of feed intake and feed conversion efficiency have obvious applications in evaluating overall herd performance. As with ADG, the common approach has been retrospective calculation following depopulation of the barn. In addition to the retrospective nature of the data, inherent measurement problems include feed wastage and accounting for consumption by dead and cull pigs. The use of load cells under feed bins to monitor daily feed disappearance is likely to increase. This technology is common in the poultry industry, and software to integrate this data into computerized record systems is available for poultry. Another system that measures feed flow from bins is now available to continually monitor daily feed movement into a barn, and provides 3 day and 7 day averages of feed "entry" (Easy Systems inc., Trimont, MN). This technology is yet to be proven in the field, but should enable easy "real time" monitoring and charting of feed usage at barn level, and may assist in early detection of inappetance due to disease and sub-optimal performance due to depressed feed intake.

Modeling of swine growth

Although somewhat beyond the scope of this paper, some reference needs to be made to developments in modeling of swine growth. Several "models" have been developed by swine nutritionists from various countries with the objective of optimising nutrition of the growing pig (National Pork Producers Council, 1992). A decision support system for health management of growing swine has been described but not yet validated under commercial conditions (Lloyd et al., 1994). Rather than basing nutritional programs on generic values such as ARC requirements, the evolution of larger herds of uniform genotype has increased the potential for customising nutritional

programs according to the specific biological requirements of animals. Practical application of such models requires information such as initial and final body weights, diet composition, number of diets that can be fed, size of operation, environmental conditions, payment systems and prices, feed intake at various stages of production and protein deposition potential (de Lange, 1992). One comprehensive model (Auspig) is being used routinely as a management tool and for research purposes by the largest swine producer (approximately 40,000 sows) in Australia (Campbell & Peake, 1992). These authors state "The biological system, although reasonably well understood, is far too complex for any individual to accurately predict the effects of a change in one or more factors on animal performance, and virtually impossible to determine the economic implications of the change(s). On the other hand, Auspig does both in a matter of minutes and its output and 'recommendations' are not biased by previous experience, training, published recommendations, gut feel or other factors currently used daily as decision making tools by piggery managers." While they caution that validation trials are necessary to check the accuracy of simulation outputs and of the need to update genotype description, the authors consider that in the long term such tools will be necessary for producers to remain competitive.

SUMMARY

Many swine producers have been relatively slow to adopt systems for monitoring the health and production of finishing pigs. While conventional veterinary approaches, such as slaughter inspections, provide considerable information about endemic diseases in finisher populations, such information needs to be integrated with comprehensive production information. As competition increases in the industry, cost-effective systems for obtaining and managing production and health information will be integral to the viability of producers. Swine veterinarians have a big challenge to obtain skills appropriate for the future in this rapidly changing industry, and to provide leadership in the implementation of appropriate technology. Profound understanding of the biology and economics of pig production, computer literacy and familiarity with relevant software for pig management are obligatory.

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CAUSES OF VARIATION IN THE USE OF ANTIMICROBIALS IN MEAT PIG HUSBANDRY: A PRELIMINARY STUDY

J.P.T.M. NOORDHUIZEN, A.M. HENKEN, K. FRANKENA, W. MOCKING, C.T.H. VROLIJK
Dept. of Animal Husbandry, Epidemiology division, Agricultural University, P.O.Box 338, 6700 AH Wageningen, The Netherlands.

SUMMARY

Technological and economic development in meat pig husbandry has stimulated reliance on antimicrobial products. This reliance on antimicrobials, or medicines in general, is now increasingly criticized. To attain reduction of application of microbials, one should know how much actually is applied per farm and whether variation in application exists between farms. The latter may be due to variation in farm characteristics, management practices and/or veterinary attitude. To obtain data on use of antimicrobials at farm level a protocol was designed to electronically transfer client data from veterinary practices to a central data processing unit. Subsequently, a method to standardize the different medicinal products with regard to active substance and volume was developed. Data on farm characteristics, management practices and veterinary attitude were obtained through a questionnaire. Complete information from 70 farms, each serviced by one of 5 group veterinary practices, became available. The following dependent variables were used: 1. the summarized total of all antimicrobial products used per pig place per year per farm (TOTMED); 2. the summation of the five most important products that accounted for 98% of TOTMED (MED98); and 3. the single most important category of products that accounted for 71% of TOTMED (MED71). The final multivariate models explained 85, 82, and 91% of the variation in, respectively, TOTMED, MED98, and MED71 (all, $p < .01$). The results, their consequences and further perspectives of this type of approach are discussed.

INTRODUCTION

The health status of pigs determines economic farm result to a large extent. Consequently, application of antimicrobials (antibiotics and chemotherapeutics) is common practice under intensive husbandry conditions. Examples of the most predominant diseases in pigs are: Aujeszky's disease, atrophic rhinitis, Actinobacillus pleuropneumoniae and E. coli. Infectious agents play a substantial role because the technological developments at pig house level (e.g., housing design, climate control, automatic feeding) of the last decades and the necessary infrastructure have produced high densities of animals at farm and at regional level. Once infectious agents are introduced on a farm in a high density area, they easily spread within and between farms. Intensive traffic between farms at various layers in the production pyramid facilitates this spread. In order to control disease occurrence under these conditions, availability and application of medicinal products have become of substantial importance. At the same time vaccines were developed to prevent pigs from contracting certain important infections. However, variation exists between farms in disease prevalences which are related to differences in, e.g., microclimate, pig density and housing design (Elbers et al., 1990).

Currently, the call for a reduction of the use of vaccines and for a more justified and

limited application of antibiotics is increasing. This call for less reliance on application of antimicrobials is based on critical consumer attitudes towards the use of medicinal products in the animal production sector in general (Reinders, 1989; Boogaard et al., 1994), and on the demands that certain memberstates of the European Union (EU) can put forward with regard to health status of animals, especially if these are meant for exportation (Bosch et al., 1993). The Netherlands exports about 5.5 million live pigs per year (Anonymous, 1993).

In the Netherlands, the annual turn-over of medicinal products in the total animal production sector has been estimated at about 220 (Van Eijk, 1994) to 650 million Dutch guilders (De Wit, 1992). The difference in estimates is caused, among others, by inclusion of feed additives by the latter author. The total amount of active substance of antibiotics used in the Dutch pig production sector is estimated at 130 metric tonnes (Vulto, personal communication; Boogaard et al., 1994). Data available only allow for estimates at production sector level. Per slaughtered meat pig the average costs for curative and preventive health care have been estimated at 10 Dutch guilders (Van Eijk, 1994). To attain reduction of application of microbials, one should know how much actually is applied per farm and whether variation in application exists between farms. This variation may be attributable to certain factors, e.g., management, social or veterinary practice strategy. If so, it might provide a means to realize reduction of antimicrobial usage.

The objectives of this preliminary study were, therefore, (1) to design a methodology to make different dosages of different antibiotics meant for different administration routes comparable for uniform data collection and analysis, and (2) to design and test a methodology to collect and analyze data on the use of these antibiotics on pig farms and in veterinary practices.

MATERIALS AND METHODS

* Pig farms and veterinary practices

Based on estimates of the total amount of antimicrobials used by Dutch pig farms (130 metric tons active substance), the total number of pig farms present (27000) and the standard deviation of the estimate at farm level (25% of usage per farm), it was deduced that 20 to 100 farms, depending on the adopted error (10 or 5%, respectively), were needed for our purposes. Our intention was to use data from at least 20 farms per practice accepting a somewhat higher error at the veterinary practice level (n=20). To arrive at a more accurate estimate at the overall level (n=100) it was decided to use 5 practices. The practices were all clients of Mumps Business and Veterinary Systems (MBVS, Houten, The Netherlands) and, thus, used their Veterinary Information Package. This package is an automated client recording software program for services rendered. It contains data on delivery of antimicrobials at a specific farm. Selection of veterinary practices was based on the number of estimated meat pig farms among their clients and expected willingness to standardize codes used in their administration. The information from the practices was electronically transferred to a central processing unit of MBVS and prepared for analysis. The data file covered the year from August 1, 1992 to July 31, 1993. After screening of files 70 farms remained. Number of farms per veterinary practice varied between 9 and 19. The participating veterinary practices were known to the researchers; the farms remained anonymous to them.

* Standardization of antimicrobial products

Uniformation, categorization, and standardization of the antimicrobial products used took place at the central processing unit with the MUMPS programming language (Noordhuizen & Buurman, 1984). Each practice used its own medicine coding. Therefore, all antimicrobial products in the study were uniformally coded for all practices. Then, the products were categorized according to the method presented by the FIDIN, the Dutch association of manufacturers and importers of medicinal products (Anonymous, 1989). The categories used are shown in Table 1.

Table 1. Categories of antimicrobials used and their contribution to the total amount used.

Category	% of total
small spectrum penicillines	.05
broad spectrum penicillines	5.76
penicilline combinations	.07
cefalosporines	.01
tetracyclines	71.86
chloramphenicol, thianphenicol, florphenicol	.39
aminoglycosides	.10
macrolides	.14
other antibiotics	3.37
sulphonamides, trimethoprim (and combinations)	8.50
nitrofuranes, chinolones, chinolinolderivates	.94
combination products	8.83

For each product the "kg Pig-Day-Dosage" (kgPDD) per standard quantity of active substance of the product was used as a standardization technique (Boogaard et al., 1992 and 1994). The kgPDD is defined as the quantity of medicinal product that is needed to treat 1 kg of pig for 1 day. It is determined by the application of conversion factors for the active substances. Subsequently, for all products in each category, the total amount of kilograms of pig which could be treated for one day was determined. The results were summarized within and over categories.

* Questionnaire

A questionnaire was developed to obtain information from the farm on factors or conditions potentially related to the use of antibiotics. The major categories of this questionnaire are shown in Table 2.

Table 2. Major categories on farm questionnaire.

Category of questions	number of questions in category
Management	2
Farm size	6
Labour	2
Feed and water	8
Hygiene	17
Housing	5
Use of medicines	3
Production results	3
Personal questions	2

As the researchers did not know which farms participated, the questionnaire was conducted by the veterinarians. The resulting data file contained 70 variables per farm.

* Analysis procedures

The two data files were merged. The following dependent outcome variables were used: 1. the summarized total of all antimicrobial products used per pig place per year per farm (TOTMED); 2. the summation of the five most important products which accounted for 98% of TOTMED (MED98); and 3. the single most important category of products which accounted for 71% of TOTMED (MED71). Following a univariate analysis to determine the effect of each factor on the outcome separately, factors potentially relevant ($p \leq .25$) for the multivariate model were selected. In the multivariate analyses, forward inclusion and backward deletion ($p > .25$) after inclusion of each next variable were used. In the resulting model the threshold value for deletion of variables was set at $p \leq .05$. Deletion was performed using a stepwise procedure. No interactions were tested because of the small number of farms relative to the number of variables. The General Linear Models (GLM) procedure of SAS® (SAS Institute, 1990) was used for the statistical analyses.

RESULTS

The relative contribution of each category of antimicrobials is shown in Table 1. The five categories, broad spectrum penicillines, tetracyclines, other antibiotics, sulphonamides + trimethoprim (+ combinations), and combination products, accounted for 98% of usage (MED98). The category tetracyclines accounted for 71% of usage (MED71). The means of kgPDD for TOTMED, MED98 and MED71 were, respectively, 2598, 2554, and 1867 per pig place per year with standard errors of about 84% of these means. The models explained about 85, 82 and 91% of the variation in, respectively, TOTMED, MED98 and MED71. The results of the statistical analyses are summarized in Table 3.

Table 3. Results of the statistical analyses (mean squares) of TOTMED (total amount of antimicrobials used), MED98 (total amount of the five most important antimicrobials which accounted for 98% of TOTMED) and MED71 (the single most important category of antimicrobials used which accounted for 71% of TOTMED).

Source of variation[1)]	df	TOTMED	MED98	MED71
FreqVet	5	46839057**		
AgricOther	1	67518866**		
#Sub	6	26559500**		
Mort%	2	28153520**		
Dist	5	22625419**		
SepDis	1	44543242**	49781659**	42713979**
TreatEct	3	16943825*		
PenSize	5	38090476**	17480760*	26085539**
VetPrac	4		25173465**	20034647**
FarmSizeExact	1		67464211**	42513689**
Disease%	3		31270345**	11041177**
SubSize	5		24788192**	
	4			18925228**
All-inAll-out	1		53179805**	51746957**
Fence	2		23835943*	
BootBrush	2			15199901**
FarmSizeCat	7			9815753**
error TOTMED	41	4955665		
error MED98	47		5145652	
error MED71	40			2154403

* $p \leq .05$, ** $p \leq .01$

[1)] FreqVet = frequency of farm visits of veterinarian, AgricOther = whether the farmer had other agricultural activities at his farm, #Sub = number of compartments with pig pens at the farm, Mort% = average pig mortality at the farm, Dist = distance to closest pig farm in (south-)western direction, SepDis = whether diseased pigs were separated from the others, TreatEct = frequency of treatment against ectoparasites, PenSize = size of the pen, VetParc = veterinary practice, FarmSizeExact = exact size of the farm (continuous variable), Disease% = average percentage of diseased pigs at the farm, Subsize = size of compartments, All-inAll-out = whether all-in all-out is applied, Fence = relates to presence and use of fence around farm, BootBrush = relates to presence and use of brush for boots, FarmSizeCat = division of farms in size categories.

The main effects model for TOTMED expressed in kgPDD per pig place per year showed that eight factors were significantly associated with TOTMED. For MED98 and MED71 these numbers of significant factors were, respectively, eight and nine. Between the latter two consistency of the factors significantly associated with the outcome variables existed.

DISCUSSION

The procedure developed in this study reflects a new, more direct, approach towards attaining reduction of antimicrobial application. The direct usage of antimicrobial application as the variable to explain in the models instead of some kind of health parameter, such as number of diseased pigs or number of days with diseased pigs, constitutes the basic difference. If the objective is the reduction of use of antimicrobial products, variables related to the health status of the pig may only be indirect tools as judgement of health status is a subjective process. A more refined study should comprise aspects such as use of antimicrobials in relation to infection category or disease period. Also, the attitude of veterinarians with respect to prescription of products may vary as is indicated in our study. The major setback encountered was the lack of uniformity in the coding of antimicrobial products used. This makes exchange of information between electronic data sets very difficult. A laborious process of uniformation was necessary. This was foreseen and, therefore, selection of veterinary practices had not been at random. The veterinarians had to be willing to explain to the researchers every abbreviation used in their files. As the main objective was to develop a procedure, the nonrandom selection of practices was not considered to be a major constraint. However, the result of this study will therefore not be representative of the dutch meat pig industry. Also, about 80% of the feedstuffs for pigs contain an antimicrobial additive (Boogaard et al., 1994). These additives are not present in the recording system of the veterinary practices. It is estimated that via the veterinary practices only about 50% of the antimicrobial products is registered. Moreover, if a farmer buys antimicrobials from other sources, these will not be included in our study. If anything can be concluded on antimicrobial application based on this study, it could at most be an indication of a lower border of amounts used. Also, to cover a larger percentage of the antimicrobial products used at a farm, the data from the veterinary practices can be extended with data from the feed industry and/or with data from the recently obligatory logbooks for recording the use of antimicrobial products at farms.

Although MED98 accounted for 98% of the TOTMED, the factors which were significant were different from those associated with TOTMED. This could be caused by the variation in the use of the antimicrobials from the other categories. Some categories were used at a few farms and/or practices only. An indication for this phenomenon might be the fact that the explanatory factors for MED71 were largely equal to those for MED98, showing consistency among the most important categories. However, the procedure followed in the necessary selection of factors during univariate analysis may have skipped factors which may be of interest after all. With larger data sets more combinations of factors can be tested in the multivariate analysis procedures. Maybe the small scale of the present research is a reason that some factors reported in the literature to have an impact on the use of antimicrobials, such as microclimate (Elbers et al., 1990), were not detected. Other findings were in accordance with reported results, such as the frequency of farm visits by the veterinarian, the size of the herd, aspects of housing and hygiene, and disease prevalence (Elbers et al.,

1990; Schoorlemmer & Snoeyen, 1992).

It can be concluded that the methods developed in this study to investigate causes for variation in the use of antimicrobials in meat pigs are appropriate. It appears that factors related to both the pig farm, farmer and his veterinarian can be studied. Several factors named here could in principle be used for advisory purposes to reduce the occurrence of disease and the use of antimicrobial products. The latter is of importance to reduce the chances of developing resistance and of detrimental effects on the environment, and at the same time improve aspects of quality of food products of animal origin (Tielen, 1988; De Wit, 1992; Bos et al., 1993; Boogaard et al., 1994).

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RABIES ELIMINATION IN BELGIUM

P.P Pastoret*, B. Brochier*

INTRODUCTION

Whereas rabies among domestic animals can be controlled by appropriate prophylactic measures, it poses a bigger problem in wildlife, and until recently the only possible means available were considered to be the reduction of vector populations. These control measures were only temporarily effective and did not stop the spread of the disease (Aubert, 1994a). For this reason, other methods such as oral immunisation of wild rabies vectors needed to be assessed. The principle of this control method consists of the immunisation of that fraction of the target species population which is sufficient to reduce the efficacy of rabies transmission, thus disrupting the viral infection chain (Anderson *et al.*, 1981). This fraction depends on the mean density of target animals and for foxes can be estimated to be roughly 0.75. Research focused on oral vaccination, the only procedure appropriate for the immunisation of wildlife in the field (distribution of vaccine baits). There have been numerous experiments in which procedures varied according to the type of vaccine, the type of bait used as vaccine vehicle and the baiting methodology. The method of vaccinating wild animals against rabies was developed first in the USA (Baer, 1975), then in Europe (Steck *et al.*, 1982), and used for the first time in the field in October 1978 in Switzerland. Since 1978, several European countries have conducted at different times, large scale field trials of oral vaccination of foxes using the SAD, standard or B19 modified (Schneider and Cox, 1982), attenuated strain of rabies virus. The remarkably promising results obtained with these vaccination campaigns attest to the feasibility and efficacy of the method. However, the use of attenuated rabies virus still remains controversial as far as innocuity and stability are concerned, since these virus strains retain pathogenicity for some non target species (Artois *et al.*, 1992; Bingham *et al.*, 1992) and are heat-sensitive. Moreover attenuated strains of rabies virus may still be pathogenic for man; therefore humans exposed to those strains must be protected using standard procedures. Therefore, recent work has focused on technical adjustments, particularly the type of vaccine. In order to improve both the safety and the stability of the vaccine used, a recombinant vaccinia virus which expresses the immunising glycoprotein of rabies virus has been developed and extensively tested in the laboratory as well as in the field. Field trials using this vaccine are currently carried out on a large-scale level in several European and North American countries.

DEVELOPMENT OF A VACCINIA-RABIES VECTOR VACCINE

The glycoprotein (G) of rabies virus is the sole viral protein present on the external surface of the viral membrane. Several studies have established that the isolated G is capable of protecting animals against rabies (for review, see: Wunner *et al.*, 1988). Thus, the rabies virus glycoprotein is an ideal candidate for the construction of a subunit marked vaccine.

The rabies virus glycoprotein gene (ERA strain) has been inserted into the thymidinekinase (TK) gene of vaccinia virus (Copenhagen strain), generating a selectable TK-virus (Kiény *et al.*, 1984; Wiktor *et al.*, 1984) known as VRG, which is safer than the parental strain (Buller *et al.*, 1985).

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* Immunology-Vaccinology, Faculty of Veterinary Medicine, B 43 bis, University of Liège, Sart-Tilman, B-4000 LIEGE, BELGIUM.

EFFICACY

VRG efficacy, notably when administered by oral route, has been attested to the main target species in Western Europe and North America: red fox (*Vulpes vulpes*) and racoon (*Procyon lotor*) (Blancou *et al.*, 1986; Rupprecht *et al.*, 1986; Tolson *et al.*, 1988; Blancou *et al.*, 1989; for review see: Pastoret *et al.*, 1986). Duration of protection conferred by VRG (a minimum of 18 months in adult red foxes) corresponds to the length required for fox vaccination in the field due to the high turnover of the fox population.

SAFETY

Many experiments carried out by several laboratories do demonstrate that VRG is completely apathogenic for target species, whatever the route and dose of administration. Furthermore, numerous wild, domestic and laboratory non target species were chosen for safety testing, both because of their opportunistic feeding behaviour, and because of their presence in vaccination areas. In every case, the recombinant virus was always safe (Wiktor *et al.*, 1984; Wiktor *et al.*, 1985; Soria-Baltazar *et al.*, 1987; Koprowski, 1988; Brochier *et al.*, 1988b; Rupprecht and Kiény, 1988; Rupprecht *et al.*, 1988; Blancour *et al.*, 1990; Chappuis and Kovavlev, 1991; Artois *et al.*, 1992). Recent experiments have notably shown that the recombinant virus, administered either by scarification or by oral route, is safe for non-human primates: squirrel monkeys (*Saimiri sciureus*) and for chimpanzees (*Pan troglodytes*) (Rupprecht *et al.*, 1992).

Epizootiological risks, such as the emergence of asymptomatic carriers of wild rabies virus after vaccination can also be discarded (Brochier *et al.*, 1989a). It is also preferable that a vaccine virus used for oral vaccination of wildlife should not be horizontally transmitted to unvaccinated animals. Accordingly, no transmission of immunising amounts of VRG was found to occur in target and non target species. Changes in tissue tropism were also not observed (Thomas *et al.*, 1990).

The genetic stability of VRG has been verified after passages *in vitro* in cell lines, as well as *in vivo* in the laboratory mouse and the red fox (Desmettre *et al.*, 1990). The only remaining perceived risk to be investigated was the eventual recombination of the recombinant virus with a wild orghopox virus. For such an event to occur, both parental viruses would need to multiply during the same period of time in the same cells of the same animal. As no serological evidence for orthopox virus infection in the fox population has been found, however, the risk may be discarded in the main target species. Moreover, experimental inoculation of cowpox virus into foxes via the oral route results in viral multiplication only at a low level and for a short duration in the mouth cavity (Boulanger *et al.*, 1994).

All these results obtained in laboratory conditions have been confirmed by field trials carried out in Belgium, France and the USA. They confirmed that the VRG was efficient and safe in respect of target and non target species (Pastoret *et al.*, 1988; Brochier *et al.*, 1990b; Brochier *et al.*, 1991a; Rupprecht *et al.*, 1993; Aubert *et al.*, 1993, 1994b; Masson *et al.*, 1993a).

HEAT STABILITY

Heat stability is an important attribute of a vaccine for use in field conditions. VRG heat-stability was tested in the laboratory (Languet *et al.*, 1991) as well as in the field (Brochier *et al.*,

1990b). Results showed that VRG can resist environmental conditions, especially climatic factors such as heat, temperature fluctuations and UV light. VRG has been shown to retain its capacity to immunise for one month in field conditions, a period which corresponds to the delay of uptake that many baits may undergo in the field. This point is the more important since foxes are likely to hide their food for storage before eating it. In addition, a stable vaccine allows the planning of a better temporal strategy of bait dispersal. Comparison of the efficacy of VRG with rabies attenuated strains used over large areas in France showed that the thermostability of the former could explain that good results were more regularly observed with this vaccine (Aubert *et al.*, 1994b).

DEVELOPMENT OF A VACCINE-BAIT SYSTEM

The development of an efficient baiting system is important since an attractive bait permits the self-vaccination of the target species.

The VRG vaccine suspension consists of the supernatant of a Baby Hamster Kidney (BHK) cell culture infected with VRG. The viral suspension medium is a saline solution supplemented with gentamycine (125 µg/dose). The baiting-system is formed from an appetising mixture of fish meal and fish oil aggregated by use of hydrophobic synthetic polymer. A sealed polyethylene sachet containing 2.5 ml liquid vaccine (titrating 10^8 to 10^9 CCID50) is fixed into the bait with a binding agent.

Tetracycline hydrochloride, introduced into the appetising bait mixture (150 mg/bait), serves as a biomarker of bait uptake.

This machine-made vaccine-bait system (RABORAL®) forms a rigid 5 x 3 x 2 cm parallelipiped weighing from 34 to 40 gr.

The RABORAL® vaccine-bait offers facilities of easy storage and transport (without freezing). In addition, it can be dropped by air because of its mechanical resistance. The efficacy and especially the attracting power of this baiting system to the red fox was established in experimental station (Brochier *et al.*, 1990a; Artois *et al.*, 1993) and in the field (Brochier *et al.*, 1990b; Masson *et al.*, 1993b).

VACCINATION STRATEGIES

For the vaccination of foxes in Europe, several strategies have been defined:

1. **Large scale vaccination** is the initial procedure to attack the rabies endemic and usually requires 2-4 campaigns over a 2 year period.
2. **Cordon vaccinations** creating an immune barrier become increasingly important during the second phase of rabies elimination, because it is necessary to prevent reinfection of areas previously freed from rabies. Usually an area 20-30 km is vaccinated.
3. **Special strategies**:
   - immediate spot vaccinations in residual rabies foci or reinfected areas;
   - a single vaccination per year, justifiable only under special conditions (low population densities with low rabies incidence.

The bait dispersal strategy needs to be planned at spatial, temporal and methodological levels by considering epidemiological, geographical, climatic, biological and economic factors.

The uniform distribution of baits, carried out twice a year and according to a grid pattern resulting in a given mean density of baits per km^2, is the only part of the method commonly applied by all European countries. The other strategic factors (bait density, time of vaccination, number of campaigns, method of distribution, ...) often differ slightly depending on the experience of the national teams and local conditions.

POST-VACCINATION EPIDEMIO-SURVEILLANCE

Post-vaccination epidemio-surveillance is the correct basis of any programme for sylvatic rabies control.

The efficiency of vaccination campaigns is generally evaluated by using three methods:

- the detection of a biomarker, usually tetracycline, which is incorporated into the bait (target species);
- the serological analysis (target species);
- the assessment of rabies incidence (target and non target species).

The WHO (1992) has established that an area is declared rabies-free if no case of indigenously acquired rabies has been detected in humans or any animal at any time during a two year period. The achievement of the latter status requires the following procedures:

1. Intensive sampling and analysis of rabies vector species:
   In Europe, a minimum sample of 8 foxes per 100 km^2/year must be shown to be rabies negative.
2. The area should be approximately 5,000 km^2 in size and the nearest existing rabies case at the end of the two-year observation period should be at least 50 km away from the borders of the rabies-free area.

A long term surveillance is required for the detection of either residual foci or reinfections in areas previously freed from rabies. In these case, the molecular analysis of isolated rabies strains, used as a complement to usual techniques of rabies diagnosis (WHO, 1992) is helpful for determining the isolate origin (Brochier *et al.*, 1994c).

FIELD USE IN BELGIUM

Belgium was heavily infected before fox vaccination campaigns began. The rabies infected area covered 10,000 km^2 in the southern part of the country.

Five vaccination campaigns, covering the totality of the infected area, were carried out from autumn 1989 until 1991 (Brochier *et al.*, 1991b; Coppens *et al.*, 1992). The first two campaigns (autumn 1989, spring 1990) were carried out using both attenuated rabies virus strain (SAD B19) and VRG as vaccines. Since autumn 1990, the VRG was used exclusively.

These campaigns induced a drastic decrease in the incidence of rabies and the elimination of the disease from 80% of the initial infected area. Regarding the geographical evolution of rabies in Belgium and in adjacent regions in neighbouring countries, new spatial strategies for bait dispersal were planned for 1992, 1993 and 1994: successive restricted campaigns were carried out along political borders only (Brochier *et al.*, 1993; Brochier *et al.*, 1994a and b). These campaigns induced a new decrease of incidence; no rabid foxes could be detected in 1993 in spite of an

improved epidemiological surveillance. In 1994, rabies was again confirmed in 29 foxes and 7 domestic animals collected in a region situated close to the French border. These cases demonstrate either a reinfection or the persistence of a residual rabies focus in a border region and justify further restricted campaigns of vaccination.

CONCLUSIONS

Due to its efficacy, innocuity and heat-stability, the VRG vaccine offers an excellent alternative to attenuated strains of rabies virus. The bait used is attractive and efficient. In addition to the efficiency of this vaccine-bait association, the temporal and spatial strategy of bait delivery is of major importance for achieving the immunisation of the required fraction of fox population for rabies virus elimination. In this respect, the heat-stability of the VRG-bait system is an important advantage since it provides much greater flexibility in planning a campaign. For instance, for the vaccination of foxes in Europe, the latter vaccine can be distributed during the cold season when the population density is at its lowest of the year. At this time, a baiting campaign can readily ensure the protection of the required fraction of fox population.

In Western Europe, the use of VRG has led to the elimination of sylvatic rabies from large areas in several countries, which have consequently been freed from vaccination. The ongoing absence of rabies in these areas provides the evidence that rabies virus has been eliminated from the fox population.

Nevertheless, vaccination campaigns should not be interrupted for several months when no rabies cases are found any more (one year and a half at least) and when neighbouring countries are still infected. These rules come from major setbacks observed after the excellent results obtained in Western Europe (the current epidemiological situation is characterised by the persistence of border rabies foci or by the reinfection of countries previously freed of rabies). Despite very good examples of cross-border co-operation, some reinfections were due to the difficulty to co-ordinate vaccination plans between neighbouring countries, others were due to a too strong confidence in the positive results obtained at the beginning.

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PERSISTENCE OF BOVINE SHEDDING OF *ESCHERICHIA COLI*, SEROTYPE O157:H7 PFGE STRAINS

THOMAS E. BESSER, DALE D. HANCOCK, LORI PRITCHETT, ELLA McRAE, MICHAEL SANDERSON, AND DANIEL RICE*

The bacterium *Escherichia coli* O157:H7 is associated with diarrhea, hemorrhagic colitis, and hemolytic uremic syndrome in humans (Griffin & Tauxe, 1993). Cattle are suspected to be a major source of this agent, through direct or indirect contamination of foods by fecal material containing the agent. *E. coli* O157:H7 has been isolated from fecal material of clinically normal cattle (Wells et al., 1987, Hancock et al., 1994), and in some outbreaks *E. coli* O157:H7 isolates with identical molecular fingerprints have been obtained from both the affected humans and from cattle in the herd of origin of the incriminated food vehicle (Martin et al., 1986, Griffin & Tauxe, 1993). In general, the strains isolated from diseased humans and normal cattle share toxin types, plasmid profiles, phage types and DNA restriction patterns (Paros et al., 1993, Chapman & Siddons, 1994).

It may eventually prove possible to intervene to reduce the incidence of human *E. coli* O157:H7 disease by on-farm management strategies that reduce the numbers of cattle shedding the agent. An important question which must be answered is the duration of shedding by individual cows, that is, whether individual cattle can be a long term reservoir of this bacterium. The data reported here is a preliminary attempt to determine the duration of *E. coli* O157:H7 shedding by individual cattle, including both inoculated isolated calves and naturally shedding dairy cattle on farms in Washington state.

MATERIALS AND METHODS

Herds and animals sampled

Ten Washington state dairies on which access to at least some individually restrained heifers was possible were selected for this study. Twelve sequential sampling visits at approximately monthly intervals were made over a one year period. At each visit, attempts were made to re-sample the same group of animals using the same methods.

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*Washington State University College of Veterinary Medicine, Department of Veterinary Microbiology and Pathology and Field Disease Investigative Unit, Pullman, WA 99164-7040, USA.

Cultural methods

E. coli O157:H7 was detected in fecal samples by modifications of previously reported methods. Briefly, rectal swab samples were placed in 3 ml tryptic soy broth (Difco, Inc., Detroit MI) containing vancomycin(40 μg/ml, Lyphomed, Deerfield IL) and cefixime(50 ng/ml, Lederly Labs, Inc., Pearl River NY). After 18 hr incubation at 35 C the broths were diluted to 1:1000 and 1: 10,000 and 0.3 ml of each dilution was plated onto 150 mm diameter plates containing MacConkey's agar(Difco) in which sorbitol replaced lactose, and to which was added cefixime and potassium tellurite(Sigma Chemical Corp., St. Louis MO) (Chapman et al. 1992, Zadic et al. 1993). After overnight incubation, sorbitol non-fermenting colonies were selected and further screened to select isolates which fermented lactose, did not produce β- glucuronidase (Thompson et al., 1990), reacted with O157 antiserum (Oxoid Ltd, Basingstoke, UK), and whose DNA hybridized with labelled DNA probes to verotoxin gene sequences (Paros et al., 1993).

Immunomagnetic separations

Immunomagnetic beads coated with antibody to O157 (Dynabeads, Dynal Inc. Lake Success NY) were used according to manufacturers directions to detect *E. coli* O157:H7 present in enrichment broths that had previously been screened using the cultural methods described before, and which had been preserved with buffered glycerine and stored at -70C.

Experimental inoculations

Eight calves were inoculated with *E. coli* O157:H7 strain 86-24, a strain initially obtained from a human with HUS and subsequently subjected to selection for a nalidixic acid resistance (courtesy of Phillip Tarr, Seattle WA). Detection of shedding of this agent was facilitated by the use of nalidixic acid containing media.

Pulsed field gel electrophoresis

PFGE was applied to multiple isolates of *E. coli* O157:H7 obtained from individual animals using methods described by Barrett et al. (1994). This procedure involves lysing bacterial cells and digesting with restriction endonucleases while the cells are immobilized in agar plugs.

RESULTS

Repeated rectal swab samples were obtained from 1091 identified cattle in 10 herds at approximately monthly intervals over a one year period. The number of samples obtained from individual animals ranged from 2 to 12. *E. coli* O157:H7

was isolated from 69 of 4031 samples, for an overall sample prevalence of 1.69% (Table 1). Cumulative individual cow prevalence was 56 of 1091, or 4.94%.

Table 1. Prevalence of *E. coli* O157:H7 shedding by herd

Herd	Number of Samples	Number of Animals	Positive Samples	Positive Animals
A	743	269	15	15
B	90	85	0	0
C	591	90	19	15
D	111	82	0	0
E	740	186	19	16
F	588	116	16	10
G	819	191	0	0
H	231	61	0	0
I	51	43	0	0
J	67	50	0	0

Duration of shedding

A total of 377 samples were obtained at approximately monthly intervals from the 54 cattle which were detected shedding *E. coli* O157:H7 on one or more occasions (mean, 6.98 samples per animal, range 2-12 samples per animal). In 45 cattle, only a single sample yielded *E. coli* O157:H7. In six other cattle, two samples yielded the agent, either in sequential samples (six cattle), or separated by 1, 6, and 7 negative samples (one cow each). Finally, in two cattle, three sequential samples yielded *E. coli* O157:H7.

Immunomagnetic separation

Immunomagnetic separation (IS) using beads coated with antibody to the O157 antigen was used to isolate *E. coli* O157:H7 from broth enrichment cultures which had previously been tested by conventional isolation techniques. Multiple serial samples from individual cows which had been detected shedding *E. coli* O157:H7 on one or more occasions were re-tested using IS, including samples which had been positive and samples which had been negative by previous conventional culture. IS resulted in additional isolates, and the likelihood of isolation varied by the date of the sample compared to the date of the positive culture: *E. coli* O157:H7 was isolated from 8 of 21 samples obtained within 30 days of the date

of sampling on which the agent had previously been isolated (1, 9, and 11 samples respectively from one month prior, one month after, or on the date of samples from which *E. coli* O157:H7 had been isolated). Of 31 samples obtained more than 30 days after the sample date on which *E. coli* O157:H7 had been isolated, no additional isolates were obtained.

PFGE strain types shed by individual calves

PFGE was used to identify strains of *E. coli* O157:H7 within isolates obtained from individual animals and herds. In one herd, two PFGE types were identified among isolates obtained over a nine month period. Three of four calves detected shedding on two or three sequential monthly samples shed only a single strain type. However, the fourth calf shed one PFGE type on the first positive sample, and the second type in the two subsequent monthly samples. In a third herd in which 7 PFGE types have been isolated over a three year period, each animal yielded only a single isolate. However, additional isolates obtained by IS from the stored enrichment broths are currently being tested to determine their PFGE type. In the fourth herd, only a single PFGE type has been identified among isolates tested to date (18 isolates from 14 animals).

Experimentally inoculated calves

Eight calves inoculated with 1.0-5.0 x 10^8 cfu of *E. coli* O157:H7 strain 86-24, NalR, shed the agent for periods ranging up to 49 days (mean 26 days, range 5 - 49 days). Repeated sampling of these calves for up to 2 months after the shedding period, including bulk broth enrichment cultures in media containing vancomycin and nalidixic acid, failed to demonstrate persistent carriage.

DISCUSSION

There is a high degree of variability in the shedding patterns of *E. coli* O157:H7 by cattle. For example, some herds shed the organism at relatively high prevalence, while in other herds it was difficult to recover the organism at all. The large number of negative samples obtained from herds such as herd G in this study, show that the prevalence of *E. coli* O157:H7 may be low for extended periods of time within a herd. Our observations have shown that these 'negative herds' can change status suddenly and dramatically (data not shown). In addition, seasonal variation in *E. coli* O157:H7 shedding prevalence has been observed in some Washington state herds, with Summer and Fall peaks in prevalence separated by periods of extremely low shedding prevalence during the Winter and Spring (Hancock et al., 1994). This variability in prevalence raises important questions about the nature of the bovine reservoir of *E. coli* O157:H7. An understanding of the biological basis for this variability may be critical to the development of on-farm control of this important food borne zoonotic agent.

This study requires an interpretation of the significance of negative culture results. It is nearly certain that some test-negative samples in this study contained undetected *E. coli* O 157:H7 due to the limitations of sensitivity of the culture methods. However, the consistent patterns of shedding within these conventional culture results, and their agreement with the more sensitive results provided by immunomagnetic separation and with antibiotic aided culture of the NalR strain 86-24 in experimentally inoculated calves, suggest that the patterns of shedding demonstrated here are accurate.

Our interpretation of these results is that shedding of *E. coli* O157:H7 by cattle is typically short, that is, generally less than two months. This conclusion is supported by both observations of naturally shedding cattle, and by limited numbers of experimentally inoculated calves.

If the shedding of *E. coli* O157:H7 by individual cattle is typically short, recurrent episodes of high prevalence shedding on farms must represent recurrent exposure of animals to some source of this agent. Several sources of *E. coli* O157:H7 are obvious possibilities, including individual persistently shedding cattle, other persistent animal reservoirs, and possible environmental and food-borne sources. However, it remains to be determined whether rare periodic exposure of cattle to the agent is sufficient to cause episodes of high shedding prevalence, or whether such episodes also require (dietary or environmental) factors that lower the resistance of cattle to transient *E. coli* O157:H7 colonization. The latter possibility is supported by the demonstration that some episodes of high herd prevalence shedding are characterized by the simultaneous appearance of multiple PFGE types.

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ANIMAL MOVEMENTS

GATT AND THE PRINCIPLES OF RISK ASSESSMENT AS THEY RELATE TO TRADE

J M SCUDAMORE[1]

The Final Act embodying the results of the Uruguay round of multilateral trade negotiations was signed in April 1994 and resulted in the establishment of the World Trade Organisation (WTO) on 1 January 1995. Under the Final Act, there were a number of Agreements which impact on animal health, the most important being the Agreement on Sanitary and Phytosanitary (SPS) measures. As part of this Agreement, a Committee on SPS measures will be established. The Committee will rely on the specialist international bodies such as the Office International des Epizooties (OIE) to provide advice, information and international standards in animal health to ensure the increasing use of international standards, guidelines and recommendations and to ensure that animal health measures do not become a discriminatory and arbitrary barrier to trade. In taking on this role the OIE has expanded the International Animal Health Code to include sections on risk analysis. This aims to provide importing countries with a scientific and defensible method for assessing risks associated with the importation of animals and animal products. This demonstrates the way in which basic epidemiology, along with the science of risk analysis, has an impact on the complex area of trade by contributing to the development of international standards. It is important for countries to have demonstrable risk analysis procedures as they may be called upon at some stage to defend their import policies.

GENERAL AGREEMENT ON TARIFF AND TRADE

The General Agreement on Tariff and Trade (GATT) was established in 1947. Over the years, there have been a number of multilateral trade negotiation rounds within the framework of GATT with the Uruguay round being the eighth. It was agreed from the outset of the Uruguay round of negotiations that agriculture would be brought fully within the GATT multilateral trade rules. The Uruguay round was launched in September 1986 in Punta del Este in Uruguay. Throughout the long negotiations, the two main protagonists were the United States (US) and the European Community (EC). The Cairns Group of Agricultural Exporters comprising, as its main players, New Zealand, Australia, Canada and Brazil was formed in late 1986 to maintain pressure for greater liberalisation of agricultural trade. With the exception of Canada, the Cairns Group, both developed and developing countries, only offered limited support to their domestic agriculture with a significant proportion of foreign earnings coming from agricultural exports and had as an important sub-theme the opening up of certain protected markets in the Far East.

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[1]Scottish Office Agriculture and Fisheries Department, Pentland House, 47 Robb's Loan, Edinburgh. EH14 1TW.

The inclusion of agriculture in the Uruguay round was contentious from the beginning with early negotiations making little headway. The agricultural negotiations fell into stagnation although progress in other areas meant that the momentum was not completely lost. Negotiations on agriculture were relaunched in 1991 and a framework of commitments on agriculture was outlined for implementation over six years. With some modification, this framework formed the basis of the eventual Agreement on Agriculture. Changes in the CAP as a result of the MacSharry Reforms put in place in 1992 opened the way for EC participation in this Agreement. On 15 December 1993 in Geneva, 114 participants approved the Final Act embodying the results of the multilateral trade negotiations. This was signed in Marrakesh in April 1994 and came into force on 1 January 1995.

The Final Act covers a wide range of issues: trade in goods and services, patent protection, Technical Barriers to Trade, Trade and the Environment, as well as Agriculture and the Sanitary and Phytosanitary area. It also sets up the WTO which now provides the institutional framework for the conduct of trade members in relation to the various Uruguay Round agreements. They are binding on all members. The most important in the animal health field is the Agreement on Sanitary and Phytosanitary (SPS) measures.

AGREEMENT ON SANITARY AND PHYTOSANITARY MEASURES

Prior to the Agreements in 1993, a country's food safety and animal and plant health regulations were already covered by GATT Rules which had always required non-discriminatory treatment of imported products from different foreign suppliers. Equally governments, for the purposes of protecting human, animal or plant health, were allowed to impose more stringent requirements on imported products than they required for domestic goods. Because it was recognised that SPS measures could effectively restrict trade, there was a desire during the negotiations to have clearer rules regarding the use of SPS measures including rules on the circumstances in which member countries could apply stricter standards than those agreed in international conventions. This was important as concern had been expressed that liberalisation of trade under GATT might, in practice, stimulate a return of disguised protectionism in the form of spurious safeguards to animal, plant and human health.

As a result of these concerns, an Agreement on the application of sanitary and phytosanitary measures was negotiated as part of the Uruguay round. The SPS negotiations were open to all governments participating in the Uruguay round and many were represented by their food safety or animal and plant health protection officials. Negotiators also draw on the expertise of technical international organisations, such as the Food and Agricultural Organisation (FAO), the FAO/WHO Codex Alimentarius Commission and the OIE.

The text of the Agreement is fairly straightforward and incorporates a number of important rules relating to the fundamental principles of non-discrimination, harmonisation, equivalence and transparency. The main principle underlying the whole basis of the trade agreements is non-discrimination. It is clearly stated both in the Preamble and in the body of the Agreement that member countries must ensure that their SPS measures do not arbitrarily or unjustifiably discriminate between members where identical or similar provisions prevail. Equally these measures must not be applied in a manner which would constitute a disguised

restriction on international trade. In adopting a principle of non-discrimination, the presumption of sovereignty is not called into question. Members still have the right to take the measures necessary for the protection of human, animal or plant life and health. Also, the Agreement attempts to define and clarify the circumstances in which members can apply more demanding standards and tests which other countries will need to meet.

Historically many measures have been applied as a result of bilateral agreements between countries. There is a desire in the Agreement to establish a multilateral framework of rules and to further the use of harmonised measures. The Agreement itself indicates that the aim is to harmonise sanitary and phytosanitary measures on as wide a basis as possible and that these should be based on international standards, guidelines or recommendations. Where member countries adopt measures which conform to the international standards, these will automatically be recognised as consistent with the provisions of the SPS Agreement. However, it is equally clear that members may introduce measures which result in a higher level of sanitary or phytosanitary protection than would be achieved by measures based on the relevant international standards.

When a country chooses to set more demanding standards than, for example, those laid down in internationally recognised bodies, such as the OIE, then this can be challenged. When this happens, the measures will need to be justified on the basis of available science. They must not be excessive relative to the specified risk against which protection is needed.

As its name implies, equivalence is a facility for member countries to accept the measures taken by other members as equivalent provided the outcome is the same even if the actual measures themselves are different.

In order to ensure there is transparency between countries, members are required to notify their sanitary and phytosanitary measures in a specified form to the WTO. These measures have to be published promptly to enable other interested members to become acquainted with them with a suitable interval before they come into force to allow exporting members to adapt their arrangements to the requirements of the importing member.

In addition to the above, the Agreement aims to provide special treatment for developing countries. Recognition of preferential trading conditions has been progressively given to developing countries and is achieved in one of two ways. Firstly by the provision of technical assistance to developing countries to improve infrastructure and encourage research, and processing technologies by means of advice, credits, donations and grants to achieve the appropriate level of sanitary protection in their export markets. Secondly in recognition of the special needs of developing countries they are given a longer time frame for compliance when new sanitary measures are being introduced.

RISK ANALYSIS

Three different types of precaution relevant to SPS measures are provided for in the SPS Agreement. The first is a detailed article dealing with the assessment of risk and determination of the appropriate level of protection. It is important that any measures are based on an assessment of the risks to human, animal or plant health life taking into account risk

assessment techniques developed by the relevant international organisations which, in the case of animal health, is the OIE. In assessing the risks, the available scientific evidence must be taken into account and should cover also a wide range of factors such as processing and production methods; inspection, sampling, and testing methods; prevalence of specific diseases; existence of disease-free areas; the relevant ecological and environmental conditions along with the possibility of using quarantine or treatment. In assessing the risks and in determining the measures to be applied for achieving the appropriate protection from the risks, member countries must take into account the relevant economic factors as well as the potential damage in terms of loss of production or sales in the event of entry, establishment or spread of the pest or disease. The costs of control or eradication in a territory can also be taken into account. The cost effectiveness of alternative approaches to limit risk must be considered.

As each country determines its own level of acceptable risk, they can respond to social and cultural concerns regarding what are necessary precautions. It is important to recognise that the perception of acceptable risk will vary from one country to another for many reasons. For example, one country may have a vast number of a susceptible species, as is the case in the UK with over thirty million sheep. Consequently the risk associated with the importation of live animals, semen or blood from bluetongue infected countries assumes a far greater importance than for countries with small numbers of sheep. Again, using bluetongue as an example, the acceptable risk associated with this disease will vary between countries depending on the presence or absence of the vector capable of spreading the disease.

The SPS Agreement clearly permits the provisional adoption of measures as a precaution when a member country considers that there is insufficient scientific evidence on which to base an assessment on the safety of a product or process. This also allows immediate measures to be taken in emergency situations. There are many examples of bans on production, sale and import of products based on scientific evidence that they pose an unacceptable risk to human, animal or plant health. The SPS Agreement will not affect the government's ability to ban products under these conditions.

The crucial argument, however, is that the SPS Agreement allows countries to give food safety, animal and plant health priority over trade provided there is a demonstrable scientific basis for their requirements. Each country can determine the level of risk it considers appropriate provided this is based on proper assessments. Once a member has determined the acceptable level of risk, a number of alternative measures may be available to achieve satisfactory protection. In choosing from alternative methods, the member country must adopt those measures which are no more trade restrictive than required to achieve its objectives provided they are technically and economically feasible.

A further article in the SPS Agreement allows the adaptation of the measures to regional conditions including the recognition of disease-free zones and areas of low disease prevalence. The determination of these areas is based on factors such as geography, ecosystems, epidemiological surveillance and the effectiveness of controls. If a member wishes to claim areas of their territory as free of disease, they are required to provide evidence to demonstrate objectively that the areas are in fact free and will remain so in future. Reasonable access must be given to the importing member for inspection, testing and other relevant procedures.

OFFICE INTERNATIONAL DES EPIZOOTIES

GATT is not in itself a body which draws up or agrees standards on animal health requirements. Its focus is on free and fair trade and the procedures for dealing with disputed cases. That is why in technical areas, like animal health, it relies on the standards developed in other international bodies, such as OIE. There are a number of references throughout the Agreement to the OIE by name. For the purposes of animals and animal products, the OIE is considered to be the relevant international organisation as its members play a full part within the limit of their resources to promote the development and periodic review of standards, guidelines and recommendations with respect to all aspects of sanitary measures. The Committee on SPS measures to be established within the WTO has a number of important responsibilities, one of which is to maintain close contact with the relevant international organisations in the field of SPS protection.

OIE has a long-standing relationship with GATT which was emphasised at the conclusion of the Uruguay round with the agreement on SPS measures where the OIE is mentioned on a number of occasions. In accepting responsibility for international standards, guidelines and recommendations on animal health, the OIE has recognised that it must be involved in the work on risk assessment and risk analysis. Papers on risk assessment have been included for debate by the OIE General Meetings since 1990 and, following the meeting in May 1993, the Scientific and Technical Review of the OIE published in December (OIE, 1993) contained a series of articles on risk analysis and risk assessment.

The Guidelines on risk analysis and importation are contained in the International Animal Health Code produced by the OIE. This now has sections specifically dealing with import risk analysis, guidelines for risk assessment, evaluation of veterinary services, zoning and regionalisation and the surveillance and monitoring of animal health. These guidelines have been developed in order to assist both importing and exporting countries. It is important that all importing countries develop a methodology of assessing risk which they can defend should an exporting country lodge a complaint with the WTO or wish to have a clear indication as to why their goods are not acceptable.

DISCUSSION

The world trade in animals and animal products continues to increase and with it are problems for veterinary authorities. The tendency to relax international barriers for livestock and their products is likely to grow especially with the initiatives from the WTO and the Agreement on SPS. The object of harmonisation of international health regulations is to reach agreement on the level of restrictions to be applied to international trade without jeopardising agricultural production. The evaluation of risk has always been a feature of national decision-making as it relates to the importation of animals and animal products. In the past, many assessments have been based on qualitative analysis of the means by which a disease could enter the country and the potential risk it would pose should it become established. The trend now is towards more quantitative assessments with the development of more complex statistical analysis. This can be helpful as it provides regulatory authorities a more defensible and transparent basis on which to make decisions.

The impact of international trade agreements and the formation of the WTO with the SPS Committee means that member countries will have to consider very carefully the scientific basis of the measures which they have in place or propose to introduce to safeguard animal health. The impact of these agreements will stimulate the need for more methodical risk analysis by member countries and demonstrate the importance of basing import and other control measures on scientific requirements. These in turn must be based on good epidemiology and economic analysis. It should be remembered, however, that risk analysis is a technique which is an aid in formal decision making and that the limitations associated with quantitative risk assessments must not be underestimated. Where relevant scientific evidence is insufficient for a member country to establish an appropriate level of protection for a specified problem, then all the available information should be used to carry out a provisional assessment of risks which should be periodically reviewed in the light of fresh scientific evidence.

There is no doubt that the impact of international trade agreements will stimulate the need for methodical risk analysis by member countries. It demonstrates the importance of basing any import rules on scientific requirements which, in turn, will be based on good epidemiological and economic analysis.

REFERENCE

Office International des Epizooties (OIE) (1993). Revue Scientifique et Technique - Risk analysis, animal health and trade. Vol. 12, No. 4.

ANIMO RISK MANAGEMENT SYSTEM (ARMS)

A computerised system of identifying and managing risks associated with importing livestock into Great Britain.

D G PRITCHARD * J A CLARKE + A VALENTE*

The introduction of harmonised rules for the movement of livestock in the European Community led to the replacement of import permits and systematic checks at frontier posts with random checks at places of destination, and where necessary safeguard action by Member States. The ANIMO computerised messaging system provides all Member States with coded details of each consignment, its place of origin and destination. The ANIMO Risk Management System (ARMS) is a separate computer system developed for use in Great Britain. It utilises the ANIMO data files of codes of all animals, their products and geographical areas and has reference files for diseases and associated carrier animals, products and incubation period. All international disease reports are assessed if they pose a risk to Great Britain. Each risk is defined by a geographical area (county, region or local veterinary unit), commodities, date of onset, level of importance and checking instructions. All ANIMO messages concerning consignments sent to Great Britain are entered into ARMS which automatically identifies and sends via a fax gate details of "risky" consignments and checking instructions to the local veterinary unit responsible for the place of destination. Each local veterinary unit enters results of random checks and checks on "risky" consignments into ARMS to enable assessment of the effectiveness of the risk management strategy and to communicate results to decision makers and the public.

THE INTRODUCTION OF THE SINGLE MARKET

The move to complete the internal market of the European Communities required the dismantling of veterinary and zoo technical barriers to intra Community trade in animals and animal products. Free movement of animals is a fundamental aim for the common organisation of markets and should facilitate the rational development of agricultural production and the optimum use of the factors of production.

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*Animal Health (International Trade) Division, Ministry of Agriculture, Fisheries and Food, Hook Rise South, Tolworth, Surbiton, Surrey KT6 7NF

+ Information Technology Division, Ministry of Agriculture, Fisheries and Food, Guildford, Surrey

In preparation for the single market a variety of rules were put in place to harmonise the notification of diseases , disease control measures , requirements for trade, animal identification, and to protect animal welfare. Checks at internal frontiers between Member States had been used to safeguard public and animal health. In drawing up the Veterinary Checks Directive 90/425/EEC which lays down rules to control the movement of animals and germplasm the Council of Agriculture Ministers expressed the view that the ultimate aim was to ensure that checks are conducted only at the place of dispatch. The consignment would be accompanied by a harmonised health certificate or an identification document stating its conformity with Community rules. Importing States would have confidence in the veterinary checks carried out by the State of dispatch and in the industries to abide by the rules. To check compliance with the rules States can carry out non discriminatory checks at places of destination and if a serious irregularity was suspected then checks could also be carried out in transit. Where a Member State has controlled a serious disease which is not subject to harmonised measures throughout the community then in order to protect its health status additional trade guarantees can be agreed by the Commission using Standing Veterinary Committee (SVC) procedure; for example Great Britain has eradicated Aujeszky's disease and benefits from additional health guarantees for pigs imported from areas of the community not recognised as free of this disease. Provision was also made for a Member State of destination to take , on serious public or animal health grounds, interim protective measures with regard to holdings etc. in the case of an epizootic disease. In such an event Member states must notify the State of dispatch as well as the Commission who have powers to investigate the event. The Commission seeks the views of Member States on problems in the implementation of the Directive at the Standing Veterinary Committee and adopts Commission Decisions for further detailed rules.

Measures to reduce the risk of introduction of disease via imports of live animals from third countries are laid down in Council Directive 91/496/EEC which includes arrangements for border controls at border inspection posts. These are to be linked by a computer system called SHIFT (System for Harmonisation of Imports From Third countries).

LIVING WITH RISK

The movement of live animals and germplasm is widely recognised as carrying with it the risk of introduction of agents of disease National decisions have traditionally tended towards zero-risk or risk -averse rather than risk balancing when considering

imports into a disease free area. Recent developments in international trade have required regulatory authorities to conduct import risk analysis to ensure that import policies are objective and defensible The Office International des Epizooties has laid down in the Animal Health code procedures for import risk analysis (Anon 1993). Risk analysis consists of risk identification, risk assessment, risk management, and risk communication. The application of risk analysis to animal health issues has focused on the value of quantitative risk assessment and the standardisation of nomenclature (See for example Hathaway (1991), Ahl et al (1993), MacDiarmid (1993)). Risk identification, management and communication will be briefly considered in the context of trade within the European Union .

RISK IDENTIFICATION AND MANAGEMENT

With respect to intra Community trade the principal interest of competent Authorities is to identify and reduce the risks of introduction of the major epidemic diseases. Within the confines of the European Union all major epizootic diseases are subject to harmonised disease control measures laid down in the disease control Directives. Following the suspicion/confirmation of disease, protection and surveillance areas are established which either prohibit the movement out of these areas or allow movement subject to specific measures. Member states are required by Council Directive 82/894/EEC to inform the Commission and other Member States as soon as these diseases are confirmed. In practice the Commission send a coded telex to each Member state within 24 hours of confirmation of the major diseases. In the UK this is decoded by entering into a computerised international disease data base and the information distributed to decision makers. Where appropriate industry organisations and the press are also informed. Due to the close contact maintained with other veterinary services and the industry, information of the suspicion of notifiable disease frequently precedes the official notification of a disease outbreak. This information requires careful evaluation but, if appropriate, is used to assess the risk of importing commodities from the area under suspicion. The protection and surveillance areas associated with the outbreak are also usually rapidly communicated to other Member States. The affected Member State is required to advise the Standing Veterinary Committee (SVC) of the measures which have been taken to investigate the source of the outbreak and to control the outbreak. If necessary the Commission places additional restrictions on the movement of animals etc. For example, following the outbreak of Foot and Mouth disease in Greece on 1 August 1994 the Commission adopted Decision 94/683/EC of the 8 August which prohibited trade in live susceptible species and certain products from Greece.

For the major notifiable diseases there is available information on the occurrence and distribution of disease which can be used to assess and define the risks of importing specific commodities from any area of the European Union. The affected Member State should prevent the export of commodities from control areas once they have been established. There will be a period of time prior to suspicion of disease when carrier animals may leave the affected area and pose a risk. There is the possibility that consignments may be sent illegally from the affected area. The risk posed by such consignments can be reduced if they can be rapidly traced and checked for signs of disease and either destroyed or their carrier status defined by use of appropriate diagnostic tests whilst the animals are held in isolation. In this way the risk of introduction of disease can then be managed and minimised. The principal purpose of ARMS is to assist in the rapid identification of consignments which pose a risk of introducing serious epidemic diseases.

RISK COMMUNICATION

There has been considerable public interest in the effects of the change from border controls to intensified checks at origin and random checks at destination. The House of Commons Agriculture Committee (1993-94 Session)(HC 347) addressed the issue of health controls for live animal imports and emphasised the need for the two way exchange of information and opinion about the risk of importing disease. The Committee concluded that the disease outbreaks which had occurred in 1993 were not directly attributable to the lifting of internal border controls. They endorsed the steps taken by Agriculture Departments to maintain the United Kingdom's high health status. The Committee's examination emphasised the need for clear and detailed analysis of the risks and need for data on the effectiveness of the current control arrangements.

EVOLUTION OF THE ANIMO SYSTEM

Removal of internal border controls deprived Member States of information on the consignments of animals entering their territory. The ANIMO computer system was developed to provide Member States with this information on the intra Community movement of animals and certain animal products which would enable checks to be conducted at places of destination. Directive 90/425/EEC specifically requires the Member State of origin to send, on the day of issue of the certificate or document which accompanies the animals or products, a message via the ANIMO system to the competent authority of the place of destination and to the central competent authority .

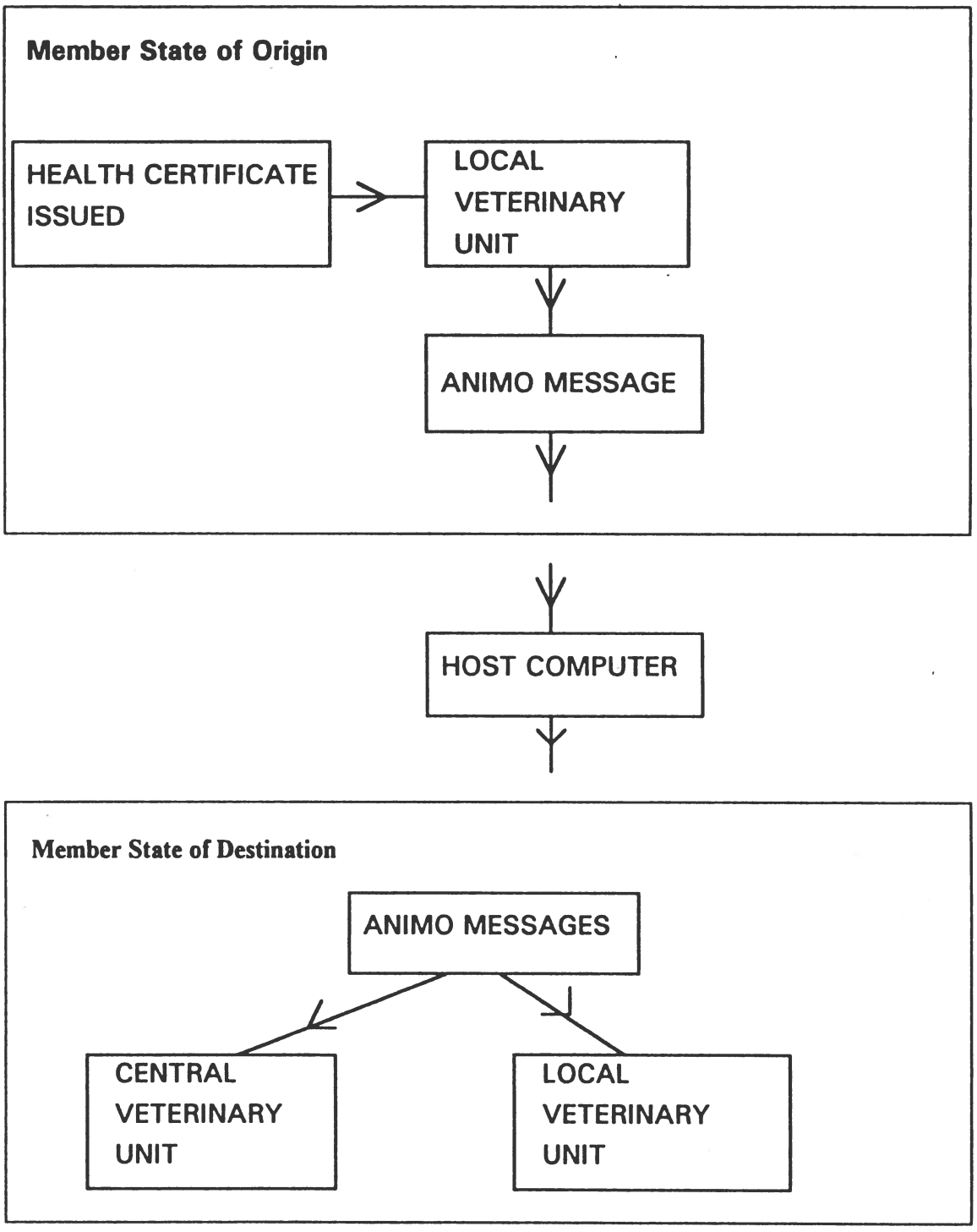
TABLE 1 MODEL FOR THE ANIMO MESSAGE

1. **Date of transmission**
2. **Origin**
   - Country code - unit code
   - Health certificate
   - Number
   - Date
   - Name of veterinarian signing the certificate
3. **Destination**
   - Country code - unit code
   - Receiver and address of place of destination
   - Post Town - Post Code
4. **Merchandise**
   - Type - code
   - Number/quantity
5. **Means of transport**
   - Type of transport (lorry, train, plane, ship, etc)
   - Identification of means of transport (registration of lorry, wagon, number, flight number, name of vessel, container number, etc)
6. **Observations**
   (In particular, for frontier inspection posts: origin of animals and Products).

In addition importers may be required to notify the competent authorities in advance of the proposed import of live animals. Directive 90/425 /EEC also made provision for the setting up of the ANIMO system by SVC procedure and for funding from the Veterinary Fund of the Community (Decision 90/424/EEC).

The legal framework of the ANIMO system was laid down prior to the design of the system. The development of a resilient computer system to run in 2.500 offices in 12 Member States with translation into nine languages posed a major challenge to the Commission. The approach adopted by the Commission was to progress the project by the introduction of Commission Decisions. Firstly, as funds were required to install hardware, Decisions 91/398/EEC and 91/585/EEC laid down the definition of Central Veterinary Units (CVUs), Local Veterinary Units (LVUs) and Border Inspection Posts (BIPs). Each unit was required to have a microcomputer, a modem, a printer and identical software to enable connection to a computerised veterinary network. There was considerable debate as to whether an electronic mail system based on international standards such as X400 or a central host computer using a mailbox file

FIGURE 1 OVERVIEW OF EUROPEAN COMMUNITY ANIMO SYSTEM



transfer system should be used. As the infrastructure to support an X400 system was not available in several member states a mailbox system was agreed (see figure 1).

Next came agreement for details of the message (91/637/EEC) which provided for numerical codes for countries, regions, local veterinary units and goods (commodity) codes (See Table 1).

Agreement of the identification numbers of CVUs, LVUs, and BIPs was difficult as the administrative structure of Member States varies considerably. There was a need to carefully consider the structure of Veterinary Administrations and the relationship between central competent authorities and autonomous regions. Decision 92/175/EEC laid down the Unit codes in the format country/name of unit/region. Thus 07.001.01 is the code for U K /Bedford/England. Decision 92/176/EEC required Member States to submit maps to geographically define the area served by each CVU and LVU and to record the location of BIPs. The areas served by each LVU were in general identical to the areas of the community laid down for disease reporting purposes in Council Directive 82/894/EEC.

POSTAL DESTINATIONS

A major reason why a computer system is required for notification of consignments rather than say a facsimile system is to solve the problem of each sender knowing the correct LVU and CVU to which the message is to be sent. Although postal addresses vary between Member States each has a "postal destination" which can be linked to an LVU and a CVU. All Member States except the Republic of Ireland also have post codes. Decision 92/341/EEC required Member States to forward a computer file to the Commission containing a list of postal destinations linked to the LVUs and CVUs. Postal destinations were defined as "Commune" for Belgium and Italy, "By" for Denmark, "Gemeinde" for Germany, "Nomos" for Greece, "Municipio" for Spain, "Department" for France, "County" for Republic of Ireland, "Pays" for Luxembourg, "Gemeenten" for Netherlands, "Freguesia" for Portugal and "Post town" for United Kingdom. This file forms an essential element of the system. Given a correct address it enables a reliable means of ensuring that the ANIMO message reaches the veterinary authority responsible for the place of destination. Under 90/425/EEC importers are required to take the animals to the place of destination listed on the health certificate, which is repeated on the ANIMO message. The local veterinary authorities have two working days following notification in which to check the consignment and take samples. Three types of checks are conducted ,documentary, identification and

physical examination which may include sampling. Member States have a need to collate and analyse the results of these checks, but this requirement is outwith the scope of the ANIMO system.

GOODS CODES

Another important function of the ANIMO system is to translate the nature of the consignment between the nine languages of the European Community. An internationally agreed code (known as custom code (CN) or Taric code) exists for the classification of animals , plants and their products for customs, statistical and taxation purposes. These codes were found unsuitable for use in relaying information in the message as to the precise nature of a consignment from an animal health point of view. A new set of codes was agreed which reflects the subdivisions of animals used to produce health certificates under the trade Directives (Commission Decision 93/70/EEC). Where possible the customs code was incorporated into the ANIMO goods code and also account was taken of existing coding systems in use in Member States. For example: the custom code for equidae is 0101 ; the rules for trade in Equidae are laid down in Council Directive 90/426/EEC and different certificates exist depending on the purpose of the movement; the codes for equidae are as follows:-

Commodity	Goods code
- registered horses	210101090000
-horses for breeding and production	210101010000
-horses for slaughter	210101020000
-horses in temporary admission	210101100000
-other equidae	210109000000

In addition to the goods code the ANIMO computer system has a high level class code such a EQU for all equidae .This is useful for searching, statistical purposes and also for defining risks which apply to all members of the class. In the preparation of the software, codes for quantity of goods and units of measurement were produced to facilitate the translation of the message. A set of codes for animal products other than germplasm were also agreed (Commission Decision 94/34/EEC). ANIMO messages for such products are only sent in few defined situations when goods at BIPs are subject to channelling procedures to processing plants.

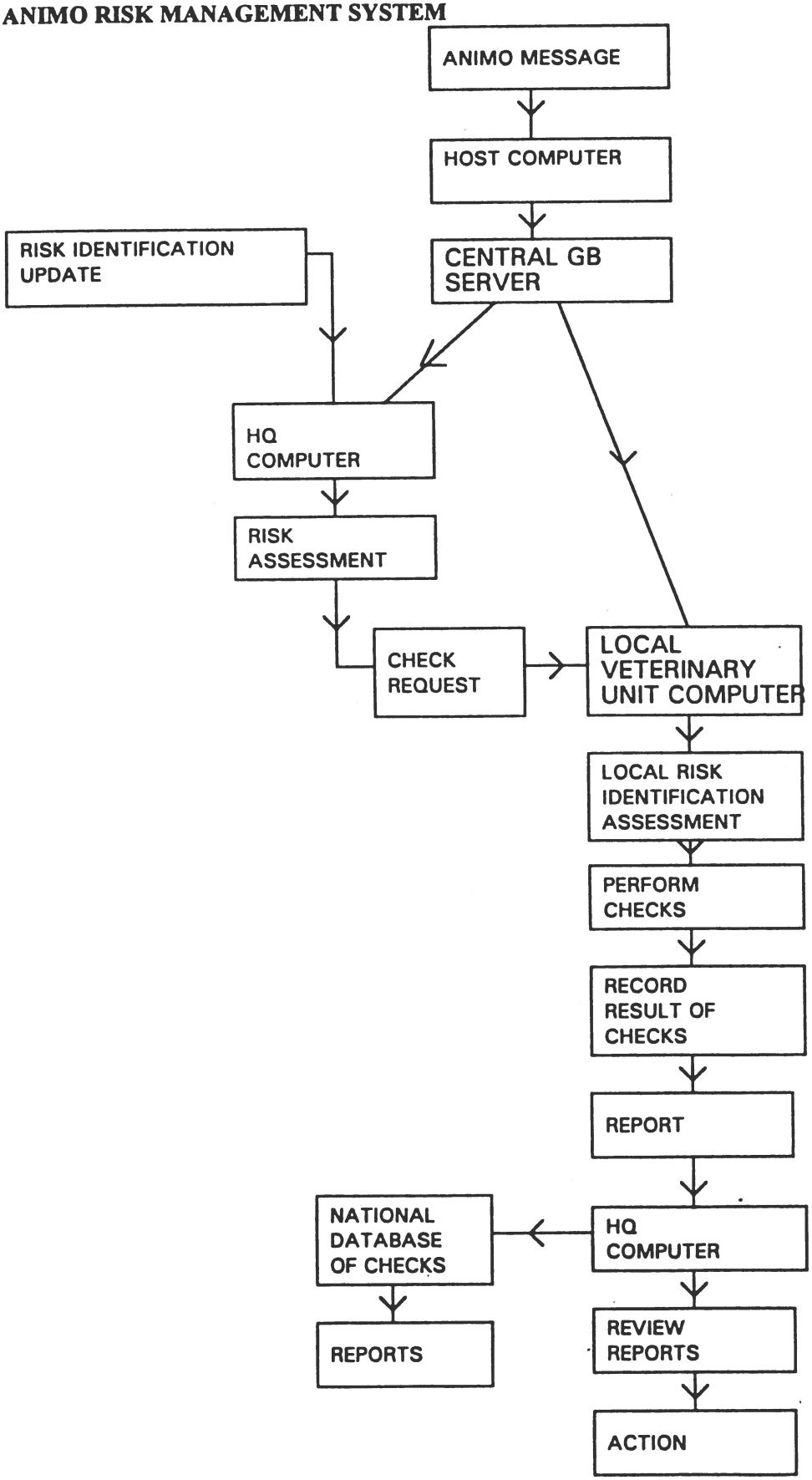
IMPLEMENTATION OF THE ANIMO SYSTEM

The ANIMO system was due to be implemented on the 1st July 1992 but was delayed because of lack of agreement of the codes and the host computer, and the absence of software and an agreed plan of implementation. An interim system was adopted using facsimile transmission of ANIMO messages between the LVUs and CVUs . The Commission software was designed to communicate directly via with the host computer of Eurocom Ltd., in Dublin. The roll out of the software in Great Britain was greatly facilitated by Animal Health offices communicating to the host computer via a central server (see figure 2). A usable version of the software became available in September 1993 and was installed in all animal health offices in the United Kingdom and went operational on 15 November 1993. A training programme began in 1992 with senior field staff. Installation and training of users of the system was effected by a training cascade by the Veterinary Service's Regional Computer Trainers.

DEVELOPMENT OF ANIMO RISK MANAGEMENT SYSTEM (ARMS)

The removal of import licences and internal border controls necessitated new procedures for the risk management of imports. A large increase in imports of cattle and sheep followed the removal of post import quarantine for Foot and Mouth Disease (FMD) susceptible stock prior to the introduction of the Single Market. The ANIMO Risk Management System was developed to identify those consignments which may pose a risk of introducing disease to Great Britain following an outbreak in another Member State. A computer system was necessary as a large number of consignments need to be checked rapidly. The change of checks from frontier posts to places of destination also required a system of collecting data on checks conducted at places of destination. There was also a need to monitor the compliance of importers with their obligation to send advanced notification of consignments to the local Divisional Veterinary Officer. The ARMS system was developed as described in figure 2. ANIMO messages are sent from the host computer to the central server in Great Britain. This sorts the messages and sends them to the appropriate Animal Health Office and the Central Veterinary Units at Tolworth, Cardiff and Edinburgh. The Tolworth Headquarters unit maintains a database of all ANIMO messages received in Great Britain. On collection of messages at Headquarters, they are entered into the ANIMO Risk Management System to be checked against a file of risks. If the ANIMO message contains animals/products which may pose a risk, the system prepares a check request which is sent via a computer fax gate to the Divisional Veterinary Officer responsible for the place of destination. The check request

FIGURE 2 OVERVIEW OF ANIMO SYSTEM IN GREAT BRITAIN AND ANIMO RISK MANAGEMENT SYSTEM



reproduces the ANIMO message and adds a risk message which includes details of the disease outbreak reference to the appropriate Commission Decision, the checks required and resulting action with reference to standing instructions.

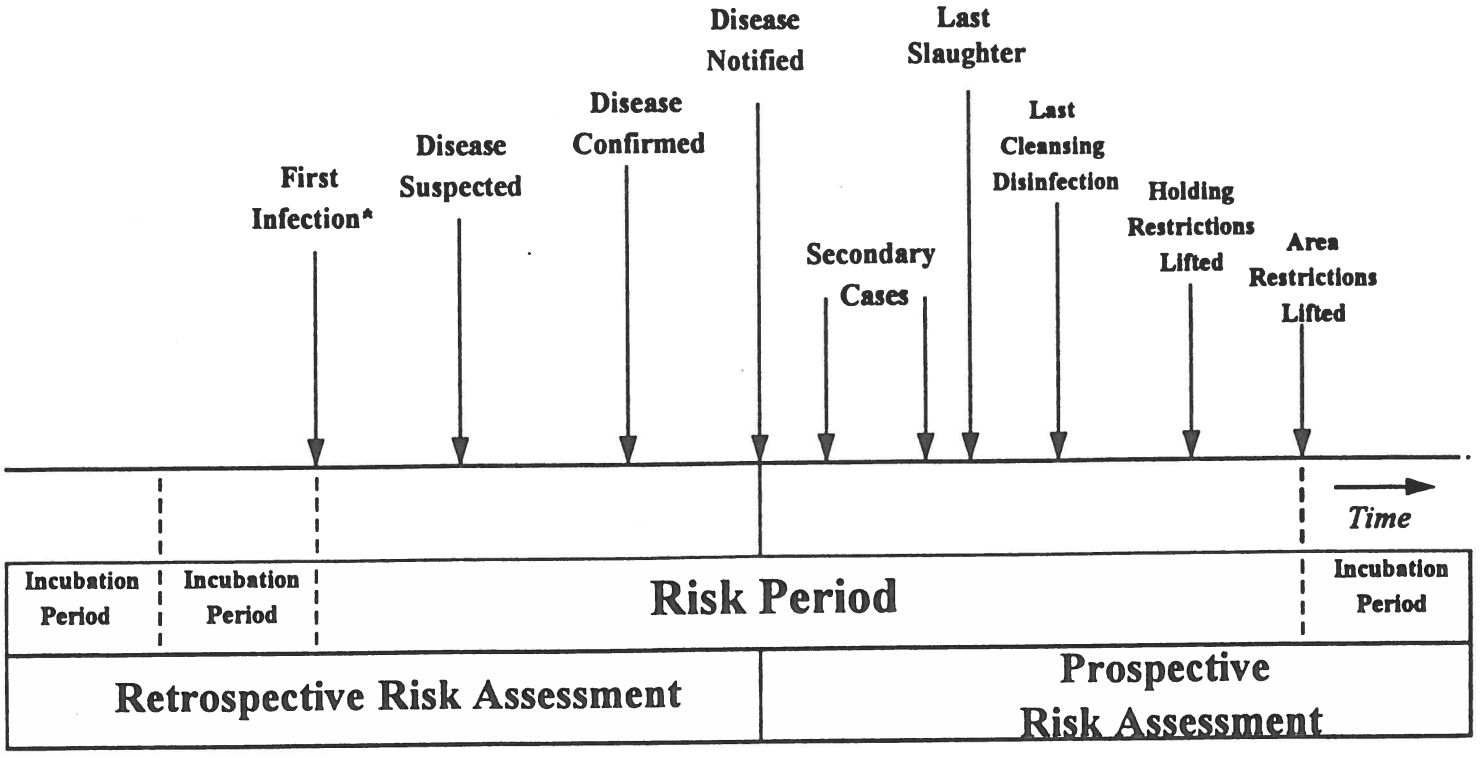
RISK DETAILS

Risk details are produced using files containing reference information on diseases and associated incubation periods and susceptible animals and products. Table 2 lists the fields required to define a risk in the ARMS system.

TABLE 2 DEFINITION OF A RISK IN THE ANIMO RISK MANAGEMENT SYSTEM (ARMS)

AREA	County
	Region
	Local Veterinary Unit
DISEASE	Name
	Code
	Incubation period
	Carrier animals and products
GOODS	Goods class eg Semen
	Goods code eg Porcine Semen
OUTBREAK DETAILS	Date notified
	Outbreak date
PRIORITY	Immediate
	Urgent
	Normal
MESSAGE	Disease outbreak
	Commission Decision
	Checks required
	Action required

Figure 3: Theoretical definition of risk period of an outbreak of a disease during which risk assessment is conducted

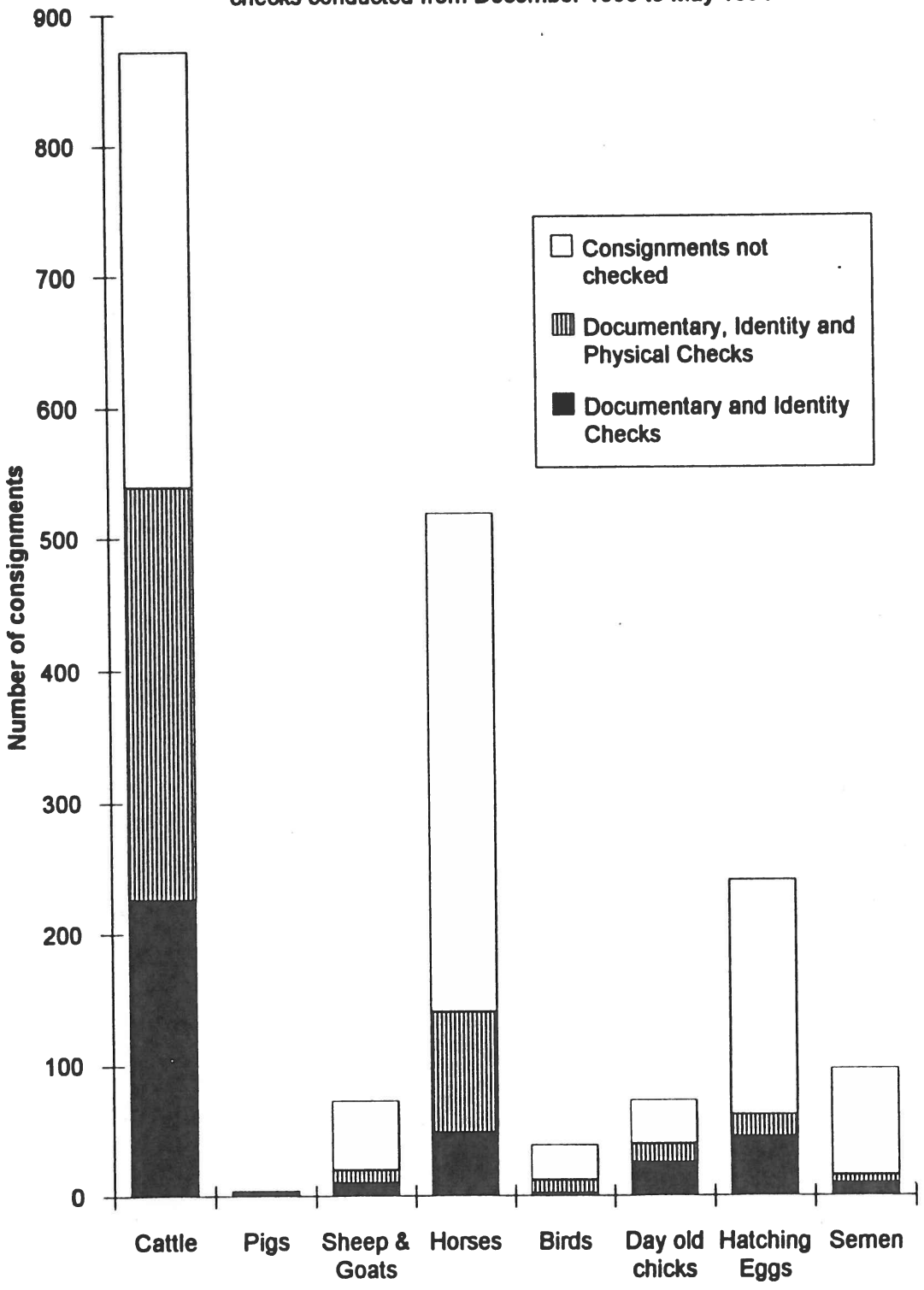


* Estimated

The area of the risk can be defined by county, region or local veterinary unit. The animals/products posing a risk can be defined using a list of animals or products which is fixed for each disease, for example, all the animals and products which may introduce Foot and Mouth Disease. Alternatively, a risk may be set for a single product, eg porcine semen. The risk is usually initiated by official notification of an outbreak from either the Commission or another Member State under Directive 82/894/EEC. Official notification of an outbreak includes whether the outbreak is primary or secondary, date of suspicion, date of confirmation, date of first infection, date of slaughter, date of destruction, details of animals at risk, animal affected, numbers died, numbers slaughtered for human consumption and numbers destroyed. Information is also provided with respect to the origin of the outbreak and the control methods used. Figure 3 summarises the theoretical factors involved in assessing the risk period. As a minimum, the risk period would start on the estimated date of first infection (which is called the outbreak date in the ARMS system) and ends when the area restrictions are removed. As a maximum, the period could start from twice the incubation period before the date of first infection. Traditionally, quarantine for a group of people/animals has been set at twice the incubation period of the disease. Quarantine is derived from the Italian word meaning forty which is about twice the incubation period of major epidemic diseases such as smallpox which has an incubation period of 7 to 17 days. The maximum likely incubation period of epidemic diseases of animals can be difficult to estimate. The use of twice the recorded incubation period is used when maximum assurance is required. When disease control procedures have been correctly and thoroughly implemented by a Member State, it may be satisfactory to stop the risk period when the Member State, or the Commission via Standing Veterinary Committee procedure lifts the restrictions. In certain cases, due to extraneous factors, the Member State may not have effectively implemented the disease control measures and it may be prudent to extend the risk period by one incubation period. In practice each case must be judged on the epidemiology of the disease and the circumstances of the outbreak. When a new risk is entered on the system then the system makes a retrospective check of the ANIMO messages and lists those consignments which 'match' the risk. An assessment is then made of the need to trace those consignments. Consideration is given to the resources required to conduct the checks at places of destination relative to the epidemiology of the disease.

On arrival at each Animal Health Office, the ANIMO messages are placed in the ARMS system which sets up a record file in which details of receipt of importer notification and results of checks are placed. These check results are in due course forwarded to Headquarters for collation. Figure 4 shows the checks done from

Figure 4 Summary of number of consignments of live animals imported and veterinary checks conducted from December 1993 to May 1994



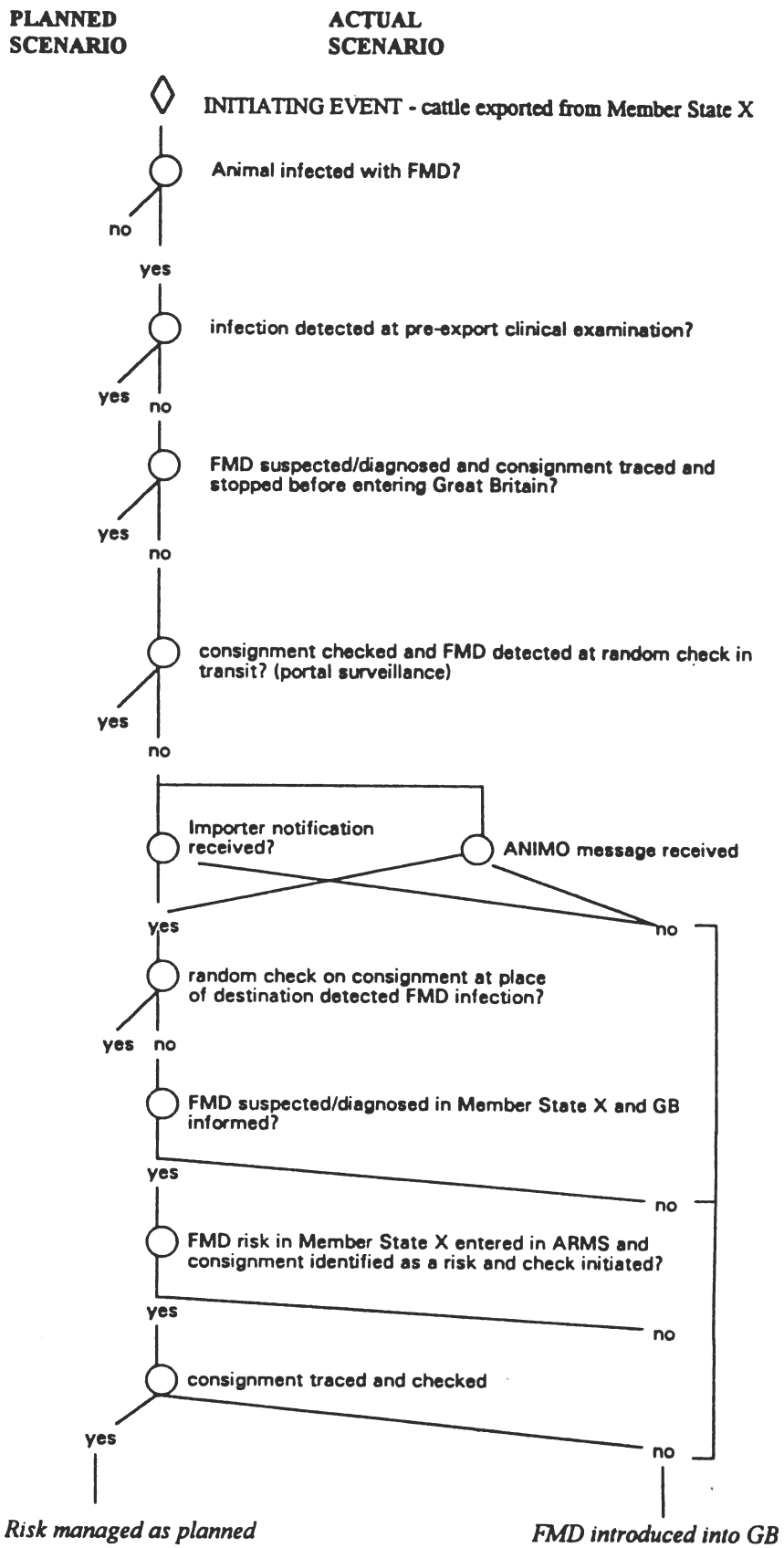
December 1993 to May 1994. Overall, some 50% of consignments are checked. Where checks reveal a serious disease risk such as the Warble Fly infestation found in consignments of French cattle during 1993 and 1994, then the level of checking is increased to safeguard the health status of Great Britain. With respect to Warble Fly all cattle in Great Britain must be treated with a warblecide or subject to movement restriction until treatment. In 1994, 45 cattle (from 13 consignments) were found on import to have clinical evidence of warble infestation and affected animals were returned to France.

BENEFITS OF ARMS

As would be expected, to date the ARMS system has shown that no ANIMO messages have been received for consignments from areas under restriction in other Member States. The system has evolved during the year of its use and has proven a useful method of ensuring that field staff are alerted to potentially risky consignments. The provision of information pertinent to each consignment such as the nature of the disease risk, the areas under restriction and any additional certification requirements allows effective distribution of information. The certification requirements for intra Community trade are subjected to frequent changes as outbreaks develop and Commission Decisions are taken to place restrictions on trade. The ARMS system is a useful method of ensuring that these decisions have been implemented by other Member States and that consignments entering Britain fully meet the requirements of Community Rules.

Potentially the system can rapidly initiate tracing of consignments which may contain infected carriers of diffusive disease before they infect animals in Britain. Fortunately due to the import policies adopted by the European Union and effective border controls the likelihood of the introduction of diffusive diseases, such as Foot and Mouth Disease (FMD), to the European Union is small (see Davies 1993). Should the disease be introduced into another Member State, there are many measures which prevent its spread to the United Kingdom. Figure 5 uses the scenario tree method (Miller et al, 1993) to analyse the risk of introducing FMD into Great Britain with a consignment of infected cattle and shows the roles of ANIMO and ARMS. Community Rules require all FMD susceptible species come from "epizootic disease free areas". There is a small but significant risk when disease is first introduced to an area that animals which are latently infected with FMD in a herd in an area without any evidence of FMD, may be correctly certified for intra Community trade. Following confirmation of the disease in the Member State, the ARMS should rapidly identify

FIGURE 5 SCENARIO TREE FOR THE RISK OF INTRODUCING FOOT AND MOUTH DISEASE (FMD) INTO GREAT BRITAIN (GB) IN A CONSIGNMENT OF IMPORTED CATTLE FROM MEMBER STATE X UTILISING VETERINARY CHECKS DIRECTIVES 90/425/EEC AND TRANSPORT OF ANIMALS DIRECTIVE 92/628/EEC, THE ANIMO COMPUTER SYSTEM AND ANIMO RISK ASSESSMENT SYSTEM (ARMS)



such consignments. Animals legally traded are unlikely to pose a major risk, however animals illegally traded which are not subjected to certification would escape these risk reduction measures. For this reason portal surveillance is carried out. A major benefit of the ANIMO system is that it provides an inventory of legally traded consignments which with other measures required by the Veterinary checks Directive facilitates the recognition of illegal consignments. The ARMS system is also of use to collate information on live animal imports and the risks of introduction of disease.

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FREE TRADE HAS COME - ARE DISEASES COMING OR GOING?

R M McCRACKEN

DEPUTY CHIEF VETERINARY OFFICER

VETERINARY SERVICE

DEPARTMENT OF AGRICULTURE FOR NORTHERN IRELAND

January 1, 1993 saw the implementation of the Single European Market (SEM) and the associated free movement of animals amongst Member States and from approved Third Countries. Whilst Member State Governments will continue to have a responsibility to ensure that animals and/or their products are certified as coming from a Member State or Region free from epizootic diseases such as Foot and Mouth Disease (FMD), Classical Swine Fever (CSF), African Swine Fever (ASF) and Swine Vesicular Disease (SVD) they have no authority to prevent the export or import of pigs infected with non-epizootic diseases such as Porcine Reproductive and Respiratory Syndrome (PRRS) or Transmissible Gastroenteritis (TGE).

In the absence of Industry-led control measures it is inevitable that the Northern Ireland pig population will be pervaded with imports of pigs from other Member States and approved Third Countries and with the exotic diseases (ie currently absent from Northern Ireland) already present in such countries. In recognising the need for free movement from and to Northern Ireland it is incumbent upon DANI and the Northern Ireland Pig Industry to ensure that adequate measures are in place to prevent the introduction of epizootic and other exotic, economically important diseases. How can we, together, achieve this?

Within the European Union (EU) diseases have been grouped into five Groups:-

Group 1	Where such a disease occurs there will be mandatory action and area restrictions eg FMD, ASF, SVD.
Group 2	Where such a disease occurs there will be mandatory action and farm restrictions eg Tuberculosis, Brucellosis.
Group 3	Where such a disease occurs voluntary action may be introduced. Animal Health Schemes are included in this Group. "Additional" diseases are also included in this Group.

Group 4	Includes Zoonotic diseases not covered by Groups 1 and 2 diseases. eg Rabies
Group 5	Includes diseases of fish.

It would be appropriate to consider the first three Groups and in the context of todays topic, these can be summarised as follows:-

Group 1 - epizootic diseases - FMD, CSF, ASF, SVD, Teschen Disease.

Group 2 - Brucellosis, Aujeszky's Disease

Group 3 - (i) Endemic Disease

- Atrophic Rhinitis, Enzootic Pneumonia, Swine Dysentery, "Haemophilus" pleuropneumonia, Streptococcal meningitis.

(ii) Other Exotic Diseases

- PRRS, TGE, Respiratory Coronavirus Infection, Epidemic Diarrhoea, Encephalomyocarditis.

(iii) "Additional" Diseases

Group 1: Epizootic Diseases

An exporting Member State must provide certification that the pigs being exported have not been obtained from a holding or an area which, for health reasons, is subject to prohibition, in accordance with Community or National Legislation. This infers that pigs being imported into Northern Ireland are certified by the exporting Member State in relation to freedom from FMD, CSF, ASF, SVD and Teschen Disease. In theory this appears to give us the protection which we need, in relation to these specific diseases but in practice may not necessarily do so.

(i) An outbreak of SVD in Northern Italy occurred in pigs imported from the Netherlands with appropriate certification; source of infection was not established.

(ii) An outbreak of CSF in Belgium occurred in pigs imported from Germany with appropriate certification; source of infection was not established.

Both lots of pigs could equally have been imported into the UK, we would have accepted them on the basis of the certification and we could now be dealing with outbreaks of CSF and SVD. It is to be hoped that such events will be extremely rare in the future but it is essential that we are able to cope quickly and effectively if such diseases were to be introduced. The

registration and identification of pigs are primarily in place to help deal with such an emergency - to permit rapid tracing of all imported pigs and pigs in which they have come in contact (through farm and market movements). We have only to recall the 1967 outbreak of FMD in Great Britain to realise the implications of FMDV infected animals passing through a market.

In addition to import certification, we continually monitor pigs at our slaughterhouses for evidence of these diseases and all pigs submitted to our VSD laboratories are checked for CSF.

In summary, we in DANI must strive to prevent the introduction of an epizootic pig disease but in the event of it being introduced the continued viability of our Industry is dependent upon early recognition of the disease, slaughter of all infected herds, and rapid tracing of all in-contact animals so that the disease can be eliminated before it becomes widespread within the Northern Ireland pig population.

Group 2 Diseases

For diseases such as Brucellosis and Aujeszky's Disease we also will require certification as indicated above. Brucellosis has not been recorded in pigs in Northern Ireland and it is to be hoped that our high animal health status can be maintained. However, Great Britain, Denmark, Luxembourg and Regions of France and Germany are free of Aujeszky's Disease whereas we know only too well that many of our farms are infected. Whilst only 10 clinical cases may be recorded in Northern Ireland in a year, surveys indicate that 20-40% of our breeding herds may be infected.

Following considerable discussion with the Northern Ireland Pig Industry we have agreed and embarked on an eradication programme for Aujeszky's Disease using deletion vaccines. I look forward to a successful eradication programme which is feasible only if the Industry and DANI work together to this end. We must continue to remind our Industry of one aspect of this unique eradication programme.

Effective vaccination will stop pigs excreting Aujeszky's Disease virus but it will not prevent pigs becoming infected.

In practice, in a 100 sow herd, this means that one infected, non-vaccinated pig on a farm could readily result in the other 99 vaccinated pigs becoming infected. The 99 will not subsequently shed the virus but they would be infected. Recognising this scenario it is essential to ensure that all appropriate pigs are regularly vaccinated; failure to vaccinate one sow could result in three years hard work being neutralised overnight.

Group 3 - Endemic Diseases

It is pleasing to note that Northern Ireland pig meat is of excellent quality and undoubtedly reflects the care and attention which have been given to breeding programmes by our Industry. Whilst we rightly claim to have a high animal health status we must also accept that some diseases do exist amongst our pigs. Such diseases include Atrophic Rhinitis, Enzootic Pneumonia, "Haemophilus" (Actinobacillus) Pleuropneumonia, Streptoccoccal

Meningitis and Swine Dysentery. Some of these are present only in a few herds and since they are all essentially spread from farm to farm by the movement of pigs it is possible to eliminate them all from a farm and to remain free. The most effective way to do so is to depopulate totally and restock with pigs from a herd free from these diseases (minimal disease herds). Such action is costly, and it is essential that everyone who sees a justification for doing so ensure that the new herd are genuinely free of pig-to-pig transmitted diseases. The control and eradication of these diseases are a responsibility, obviously, of the Industry (with Private Veterinary Practitioners) but DANI help and advice are available for anyone contemplating such a move.

Antibacterial residues (especially antibiotics and sulphonamides) are an issue over which we must all continue to be vigilant. Whilst the effective use of licensed drugs will continue to be part of a farmer's armour against infectious diseases it is essential that every consumer is protected against any harmful residue in pig products. With the Industry, we have made great strides in this area but we cannot afford to be complacent. In dealing with this issue we all recognise that potential problems can occur throughout the chain of events leading to pigs receiving such medicaments and this chain involves both farmers and millers. In Northern Ireland it has always been my experience that all sectors work together for the benefit of each other and of our customers and I would pay tribute to the responsible attitude taken by millers in overcoming the problem of sulphonamide contamination. I firmly believe however that the use of licensed drugs could be reduced in some instances and at times, much more thought should be given to a disease control programme before drug administration is implemented. In the longer term, there is a necessity to move more and more towards an all-in, all-out policy on a farm or house/common air space basis. The use of licensed drugs is merely one tool available in disease control and often they should only be used in conjunction with other tools such as management practice and hygiene. The tendency to treat with drugs and implement no other changes is not only ineffective but does not optimise the economics of pig production.

I am convinced that this issue will become more pertinent in the near future and in many ways, links in with the whole concept of Farm Quality Assured pig production. Given the nature of our Industry - relatively small farms compared to many other Member States - I am confident that we are in a unique position to take advantage of promoting our pigs and pig products on a high animal health and animal welfare ticket. Our immediate customers and consumers are looking for such a ticket and I am confident that we can provide it.

Group 3 - Other Exotic Diseases

For consideration within the Group are those diseases for which there is no Community legislation and which are absent from Northern Ireland; PRRS, TGE, Respiratory Coronavirus Infection, Epidemic Diarrhoea, Encephalomyocarditis, Swine Pox, Influenza H1NI-92, "Haemophilus" Pleuropneumonia seroptype 6 and Post-Weaning Respiratory Syndrome are examples.

Whilst DANI has no authority to insist that exporting Member States must provide certification of freedom from any of these diseases, the individual pig farmer has every right to demand that herds (and the pigs being exported) are tested free of all these diseases prior to importation. Certification of clinical freedom is totally inadequate.

To protect our Pig Industry it would be considerably more effective if all pigs farmers were to speak with one voice on this issue. Such a task is difficult but I am convinced that the only practical way forward is through general adherence to an agreed Code of Practice. I commend the Industries, both in Northern Ireland and in the Republic of Ireland, for having taken the initiative with the practising veterinary profession to formulate and implement such a Code. If our Industry is to prevent the introduction of such exotic, economically important diseases it is essential that every importer of pigs adheres to the Code of Practice. In reality, there is the danger that the importer of pigs may be an "international dealer" who has no long term commitment to our Pig Industry but such a dealer cannot exist if he has no market for his imported pigs - the power lies with the pig farmer, whose survival and livelihood depend upon an economic return from pig production. For the past two years the economics of pig production have been depressing but this only serves to underline the importance and relevance of preventing the introduction of such exotic diseases if the Industry is to survive and fluorish.

Group 3 - "Additional" Diseases

There is a potential for DANI to play a more direct role in preventing the introduction of some of these exotic diseases; thus if we can demonstrate our freedom from one or more of these economically important diseases to the satisfaction of the Commission and the Standing Veterinary Committee then we have a right to seek and obtain additional guarantees in relation to the disease status of exporting herds and/or pigs.

With this in mind we have collected and examined 7,000 sera for TGE, Respiratory Coronavirus Infection and PRRS. We have now completed the tests and all are negative. We now believe that we can convince the Commission and the Standing Veterinary Committee of our freedom from these three diseases and must now also convince them that all exporting herds and pigs must be tested and demonstrated to be free also. This will be difficult as the Commission and Standing Veterinary Committee may interpret such moves as a deliberate barrier to trade but these diseases are too important in economic terms for the Industry to willingly allow into Northern Ireland. Whilst I recognise that there is a delicate balance between maintaining a high health status yet ensuring free trade, it is nevertheless disappointing to our Industry to note that current Commission proposals are aimed at restricting additional pig diseases to Aujeszky's Disease only.

Free trade is now with us and it is incumbent upon all of us involved in the Industry to play our relevant roles and ensure a viable and visionary Industry in the future; the Industry now has to reorganise, accept and elaborate the major role and responsibility which it has now inherited from Government.

OPEN SESSION

STATISTICAL EVALUATION OF IMPACTS OF ANIMAL HEALTH INTERVENTIONS ON LIVESTOCK PRODUCTIVITY

G.J. ROWLANDS*

It is sometimes impossible, on a controlled experimental basis, to statistically evaluate interventions such as new methods of disease control. In other words, it is impossible to either sub-divide herds and allocate animals at random to treated and control groups or to even assign herds at random to control and treated groups. In Africa, for example, the evaluation of tsetse control techniques in the field to reduce trypanosome prevalence, which in turn may be limiting animal productivity, comes into this category of interventions. Tsetse control is usually applied to an area which includes several herds.

Four possible solutions come to mind. One (method 1) is to compare animal productivity before and after an intervention has been applied, but this is expensive and requires several years of data to be collected in order to overcome other confounding factors which may affect year-to-year variations in productivity. A second solution (method 2) is to carry out a trial using herds in both controlled and uncontrolled areas but this is difficult because of the virtual impossibility of finding two areas identical in every respect. A third solution (method 3) is not to apply a health intervention at all but to predict the potential outcome from the association between productivity of diseased and non-diseased animals in a situation where no intervention is being applied. This method, however, ignores other possible factors limiting production and may not achieve correct predictions if trypanosomiasis and other limiting factors are not additive. A fourth solution (method 4) is to utilise herd-to-herd variations in the primary impact of the intervention, in this case reduction in trypanosome prevalence, to investigate the secondary impacts on productivity. This approach uses regression analysis with herd as the experimental unit, increase in animal productivity resulting from the intervention as the dependent variable and decrease in disease prevalence as the independent variable. The problem is that, because the analysis is conducted among than within herds, the method relies both on a wide range of values in the primary variable and a large number of herds to be monitored in order to achieve precise estimates of biological impact.

Precise and unbiased estimates of impacts of animal health interventions on productivity are essential for valid assessments of economic loss due to disease. This paper illustrates the inherent difficulties (also considered by Rowlands (1994)) in obtaining such estimates.

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*International Livestock Research Institute, P.O. Box 30709, Nairobi, Kenya.

SOURCES OF DATA

Two tsetse control campaigns are used for illustrative purposes. The first, in a region around the town of Boundiali in northern Côte d'Ivoire, used biconical traps (Challier and Laveissiere, 1973) impregnated with alpha-cypermethrin insecticide (Fendon®, Shell) to combat *Glossina palpalis gambiensis* and *G. tachnoides* species of tsetse. These were placed at 300 metre intervals along the River Bagoué flowing north of Boundiali as described by Coulibaly *et al.* (1995). The second campaign was near Ghibe in southwest Ethiopia. A synthetic pyrethroid cypermethrin 'pour-on' (ECTOPOR®, Ciba Geigy, Switzerland) was applied monthly to cattle as described by Leak *et al.* (1995). *Glossina pallidipes* and *G. morsitans submorsitans* were the main vectors of trypanosomiasis in this location.

At Boundiali, nineteen herds of cattle were monitored from 1987 to 1989. Tsetse control was initiated in 1988. Average herd size was about 90, ranging from 40 to 270.

At Ghibe, where results have previously been described in earlier proceedings of this society (Rowlands *et al.*, 1990), one herd of 90 cattle was monitored from 1987 to 1994. The tsetse control campaign started in 1991. Over the same period 650 cattle from eight herds were monitored in a valley approximately 25 km downstream. These herds were subjected to tsetse control in 1990 using insecticide-impregnated targets, but this method proved to be unsustainable and was abandoned in 1992. These herds were assumed not to have been affected by the pour-on trial and they were therefore used as 'statistical controls'.

All animals were eartagged and weighed monthly, and calvings, deaths, slaughters, etc. recorded. All animals at Ghibe were also blood sampled for the determination of packed cell volume and the detection of trypanosomes (using the phase-contrast, buffy-coat parasitological technique described by Murray *et al.* (1977)). At Boundiali, one third of cattle were selected for blood sampling and the same animals were monitored each month.

Data on growth rates, mortality, abortion rates, calving intervals, etc. were derived. Calf growth rate is used in this paper in order to illustrate the four analytical methods.

STATISTICAL METHODS

An analysis of growth rate over each year showed that growth was approximately linear during wet seasons from March to October at Boundiali and from March to September at Ghibe. Growth rates were calculated over these periods by linear regression for animals less than 24 months of age on 1st March of each year.

Boundiali

Method 1: Analyses of variance, including parameters for age and sex in the linear model, were carried out for 1987, 1988 and 1989 separately to estimate mean growth rates between March and October for each of the 19 herds. Least squares estimates for

growth rate in 1988 and 1989 were then averaged for each herd and compared with corresponding 1987 growth rates by a paired t test.

Method 2: Data were not collected on control herds and so analysis by this method was not possible.

Method 3: Using the 1987 data only for individual calf growth rates, a linear model was fitted by least-squares analysis of variance with terms for herd, sex, age and for the frequency with which an animal was detected parasitaemic during the season (on no occasion, ≤ 0.25 and > 0.25 of occasions). The estimated difference in growth rate between infected and non-infected animals was then used to predict the overall increase in growth rate that would have occurred had none of the animals been found to be parasitaemic.

Method 4: Mean trypanosome prevalences in the same calves from March to October each year were also calculated. The mean trypanosome prevalences in 1988 and 1989 were then averaged and subtracted from the 1987 trypanosome prevalence to give decreases in trypanosome prevalence for each herd. Linear regression analyses were then undertaken to compare increases in growth rate from 1987 to 1988/1989 against decreases in trypanosome prevalence.

Ghibe

Method 1: As for Boundiali, analyses of variance were carried out to estimate mean growth rates between March and September, separately for each year from 1987 to 1994, for the herd monitored in the tsetse control area. Leak *et al.* (1995) showed that it took 12 months (namely the whole of 1991) for the pour-on to have a significant effect. The effect of tsetse control on liveweight gain was therefore determined by comparing, by a t test, the mean value between 1992 and 1994 (the next three years of control) with that between 1987 and 1991.

Method 2: Mean growth rates were similarly calculated by analysis of variance for each year for the 'control' group of herds. These mean values were used as a covariate in an analysis of covariance of mean values for the test herd.

Method 3: A similar linear model was fitted, as for Boundiali, to the growth rates calculated for calves born from 1987 to 1994 for the eight control herds with parameters for year, herd, sex and age and frequency of detected parasitaemia. Because of higher average trypanosome prevalences in these calves than in those at Boundiali, four categories were defined (parasitaemic on no occasion ≤ 0.25, ≤ 0.50 and > 0.50 of occasions). The same method was used for predicting the increase in growth rate that would have occurred had none of the calves been found to be parasitaemic.

Method 4: Data were collected on only one herd, and so analysis by this method was not possible.

RESULTS

Annual mean growth rates and trypanosome prevalences in calves in 1987, 1988 and 1989 for the herds at Boundiali were 246, 283 and 266 g/d and 19.7, 4.7 and 3.0% respectively. Ranges in herd trypanosome prevalences are illustrated in Fig.1. The figure shows how some herds had higher trypanosome prevalences in 1987 than others; reductions in trypanosome prevalence in 1988 and 1989 were also greater in some herds than others. *Trypanosoma vivax* was the most frequently detected species in calves. The proportions of *T. congolense*, *T. vivax* and *T. brucei* detected before tsetse control were 0.14, 0.59 and 0.27 respectively. The mean reduction in trypanosome prevalence associated with tsetse control was 15.8% units.

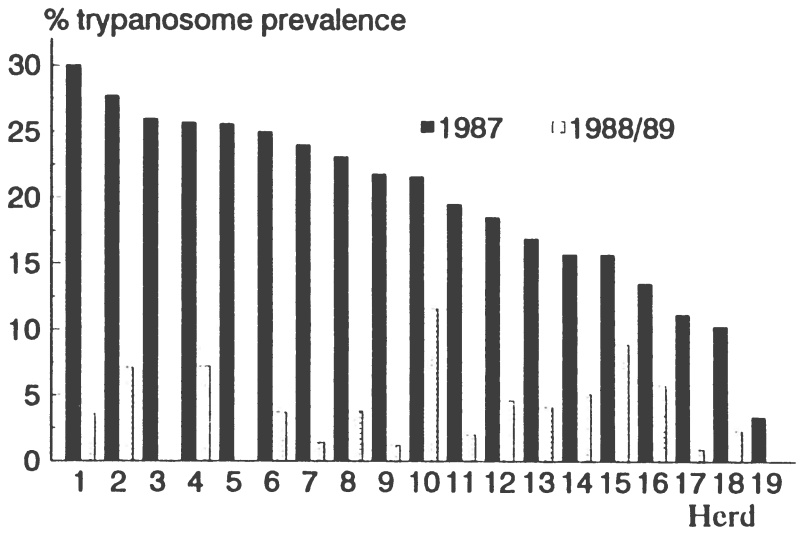

Fig.1 Mean trypanosome prevalences in young cattle less than 24 months of age in 1987 and 1988/89.

Results for Ghibe are shown in Table 1. The proportions of *T. congolense*, *T. vivax* and *T. brucei* detected in calves in the years before tsetse control were 0.71, 0.26 and 0.03 respectively. The reduction in overall mean trypanosome prevalence from 1987-1991 to 1992-1994 associated with tsetse control was 17.6% units. This was despite high levels of drug resistance (see Rowlands *et al.*, 1991; Codjia *et al.*, 1993).

Table 1. Mean trypanosome prevalences and growth rates of calves less than 24 months of age, corrected for sex and age, over wet seasons March-September at Ghibe, southwest Ethiopia in one 'test' herd in a tsetse control area and eight herds in a non-tsetse control area.

	'Test' herd			'Control' herds		
Year	No calves	Mean trypanosome prevalence (%)	Mean growth rate (g/d)	No calves	Mean trypanosome prevalence (%)	Mean growth rate (g/d)
Before tsetse control						
1987	12	15.6	236	193	5.1	303
1988	16	15.6	157	281	5.8	128
1989	17	24.3	256	192	25.0	272
1990	21	25.1	196	169	8.1	246
During tsetse control						
1991	23	34.9	233	280	8.4	224
1992	23	9.6	280	354	21.4	223
1993	33	2.4	248	299	26.8	214
1994	47	4.6	250	191	16.8	249
means ± SE						
1987-1991[a]		23.1 ± 3.6	216 ± 18		10.5 ± 3.7	235 ± 30
1992-1994		5.5 ± 2.1	259 ± 10		21.7 ± 2.9	229 ± 10

[a]1991is included with 1987-1990 since control of tsetse using 'pour-on' took one year to reduce tsetse density (Leak *et al.*, 1995).

Boundiali

Method 1: A one-tailed paired t test applied to the difference in growth rates between 1987 and 1988/1989 showed the increase of 28 g/d to be significant ($P < 0.01$). Expressed in terms of liveweight gain over the 7-month period from March to October, this represented an increase of 6.1 ± 2.4 (SE) kg.

Method 3: Mean growth rates in 1987 were 266 ± 8.9 (SE) g/d for 139 animals not detected parasitaemic with trypanosome infection, and 248 ± 9.6 g/d and 227 ± 9.1 g/d for 100 and 112 calves respectively detected parasitaemic on ≤ 0.25 and > 0.25 occasions

(P < 0.001). Using these results, it was estimated that the predicted increase in liveweight gain over the 7-month period, had no parasitaemia been detected, would have been 3.8 ± 0.9 (SE) kg.

Method 4: When regression analysis was used to compare increases in growth rate with decreases in trypanosome prevalence in the calves a significant relationship was found (P < 0.01) (Fig.2). The regression coefficient was 3.91 ± 1.45 g/d/1/unit % prevalence. This represented an average increase in liveweight gain of 13.4 ± 5.0 (SE) kg from March to October post intervention due to the average decrease in trypanosome prevalence of 15.8% units.

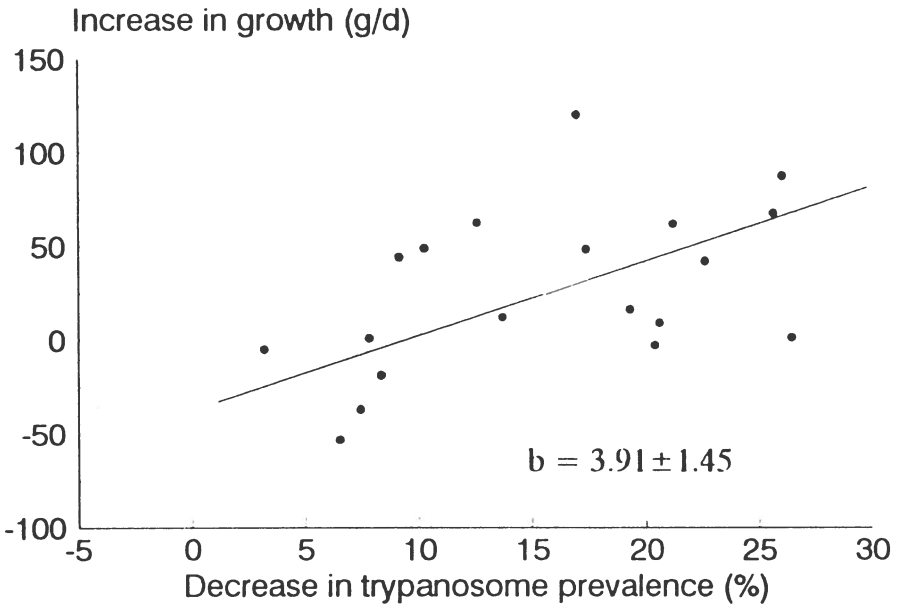

Fig. 2. Increases in growth rate of calves in 19 herds plotted against decreases in monthly trypanosome prevalences.

Ghibe

Method 1: A one-tailed t test applied to the difference in growth rates between 1987-1991 and 1992-1994 showed that the difference in growth rate of 43 g/d calculated from Table 1 was not significant (P = 0.06).

Method 2: When mean annual growth rates for control herds were included as a covariate the increase in growth rate of 47 g/d (adjusted for differences among 'control' years) was significant (P = 0.02) by a one-tailed t test.

Method 3: Mean growth rates for calves between 1987 and 1994 in the eight control herds were 261 ± 2.9 (SE) g/d in 1145 calves not detected parasitaemic and 245 ± 4.0,

221 ± 5.4 and 193 ± 5.6 g/d in 406, 207 and 201 calves respectively detected parasitaemic on ≤ 0.25, ≤ 0.50 and > 0.50 occasions. The predicted increase in liveweight gain over the 6-month period, had there been no parasitaemia detected, was estimated to be 2.6 ± 0.3 kg.

The estimated increases in liveweight gain by the four methods are summarised in Table 2.

Table 2. Estimated increases in liveweight gain (kg) ± standard error over wet seasons (7 months at Boundiali, northern Côte d'Ivoire, and 6 months at Ghibe, southwest Ethiopia) for calves less than 24 months of age.

	Boundiali	Ghibe
Method 1[a] (t test comparing data before and during tsetse control)	6.1 ± 2.4	8.0 ± 4.5
Method 2 (analysis of covariance using data on 'control' herds)	—	8.5 ± 3.1
Method 3 (prediction from regression of growth on parasitaemia)	3.8 ± 0.9	2.6 ± 0.3
Method 4 (regression of increase in herd growth rate on decrease in trypanosome prevalence)	13.4 ± 5.0	—

[a]See text for fuller descriptions of methods.

DISCUSSION

The variations in estimates of increases in liveweight gain given in Table 2 demonstrate the inherent difficulties of obtaining reliable measures of the effects of tsetse control on livestock productivity. Reliable estimates of impacts of animal health interventions on productivity are essential for valid assessments of the economic benefits of such interventions.

Methods 1 and 2

Methods 1 and 2 are statistically flawed. Method 1 is difficult to justify for it ignores other confounding factors, e.g. weather, nutrition, associated with years. Only three years were used at Boundiali. At Ghibe, however, eight years were included in the statistical analysis so that the confounding issues may be of less significance. Still, in 1988, average growth rate was particularly low during the wet season (Table 1). This was due to the failure of early rains in that year, and it lowered the mean annual growth rate during pre-tsetse control years. Analysis of covariance (method 2), using corresponding annual mean values for the control herds, helped to reduce any bias associated with these year-to-year variations, but the method nevertheless assumed that the two areas were similar in every respect. Although only 25 km apart, the two areas have very different geographical characteristics - one area is in a valley, the other on a plateau. There were also differences in the densities of the populations of tsetse in the two areas. Furthermore, a tsetse control campaign, although unsuccessful in the long-term, was attempted between 1990 and 1992 and this may have had a slight increase on calf growth rate in these herds. From 1992 to 1994 the mean trypanosome prevalence in calves in the control herds was particularly high (Table 1). A straight comparison of growth rates between calves in control herds and calves in the test herd in these years would tend to overestimate the effect of tsetse control. All these confounding factors affect interpretation of the results of analysis of covariance.

Method 3

There are dangers too using method 3, for predictions made in the presence of other possible factors limiting production may be biased, especially if the effects of trypanosomiasis and these other factors are non-additive. There is the additional problem too that, because the technique used to detect parasitaemia has low sensitivity, trypanosomiasis may also have limited growth rate in those calves not detected as parasitaemic. If so, this method may provide an underestimate of the increase in liveweight gain that can be achieved by tsetse control. Use of the pour-on at Ghibe also significantly reduced the numbers of nuisance, biting flies (Leak *et al.*, 1995), and this may also have been an additional factor, not considered in method 3, in the apparent increased liveweight gains brought about by the application of the pour-on.

Method 4.

This method circumvents the problems of dealing with confounding factors. The higher standard error, which is due to the analysis being conducted among rather than within herds, however, makes for wider 95% confidence limits, which overlap those for the other estimates for the Boundiali calves. This method also relies on a suitable range of values among herd for the primary variable, in this case changes in trypanosome prevalence. In an earlier analysis of these data, Rowlands (1994) distinguished between *T. vivax* and *T. congolense* infections. *Trypanosoma vivax* was more prevalent than *T. congolense* and, within the ranges of reduction in trypanosome prevalence among herds, it was only possible to demonstrate a significant effect for *T. vivax*, not *T. congolense*.

Other productivity variables

'Wet season' growth rate is not a commonly used 'productivity variable'. It was useful here because values for this variable could be determined within a relatively short time span contained within one year. Variables that are commonly used are, for example, 12-month calf body weight, mortality to 12 months and calving interval. The former two require up to years and the latter one up to three years of record keeping in order to calculate complete data from an annual batch of births. The study at Boundiali was not long enough to calculate these variables. Instead of calving interval an alternative variable has been defined as the number of cows calving within the first six months of a year and found, from the subsequent date of calving, to have conceived within six months of calving. In this way it was possible to calculate separate 'conception rates' for 1987 (pre-control) and 1988 (first year of tsetse control) without any overlap between years. These data are not shown, but when method 4 was used, a 19.1 ± 7.3 unit percentage increase in the number of cows conceiving during the first six months after calving was demonstrated. The data for Ghibe are still being analysed, comparing pre-control and control years by methods 1 and 2, but preliminary results indicate major difficulties in determining any effect of tsetse control in improving reproduction. Trypanosomiasis, however, has been shown to be significantly associated with reproduction in these cows (Rowlands *et al.*, 1994), and so the difficulties in detecting significant results with respect to conception rate may be due to the year-to-year variations in conception rate unrelated to the introduction of tsetse control.

CONCLUSIONS

In conclusion, this study has demonstrated the difficulties in estimating effects of animal health interventions on productivity. Such studies should not be taken lightly, and their design carefully planned, if precise estimates of biological impact are to be achieved. To compare animal productivity before and after an intervention has been applied (method 1) is dangerous and requires several years of data, both before and after, to minimise effects of other confounding factors. The use of control herds (method 2) is not really practicable and adds to the expense. Method 4 requires a large number of herds to be followed, but biologically significant results can be achieved over a period of time shorter than that required by methods 1 or 2. This method, which utilises herd-to-herd variations in the primary impact of tsetse control on disease prevalence to investigate secondary impacts on production, is the only one that is statistically valid. The size of such a study in terms of sample size, however, may be prohibitive. There may thus be scope for novel approaches in the development of statistical models that can be utilised in conjunction with results from field study research.

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APPROPRIATE METHODS FOR THE INVESTIGATION OF ANIMAL HEALTH PROBLEMS IN BACKYARD (TRASPATIO) SYSTEMS IN YUCATAN, MEXICO

A J C COOK*

The skills which veterinary scientists acquire through training and experience are used by them to solve disease problems. Ultimately, whether we are practising vets or researchers, the value of our endeavour may be judged by the impact of our work upon the welfare of animals and their ability to satisfy the expectations of the people who own them, care for them or simply eat them. Although a glittering array of technical methods are available to us, their applicability is constrained by circumstances - eg. some pet owners cannot afford vaccination, some countries cannot afford eradication of bovine brucellosis. The selection of appropriate methods is a challenge faced by field investigators throughout the world. The objective of this presentation is to discuss possible methodological approaches to the investigation of animal health problems within the backyard (traspatio) system in Yucatan, with the hope that the arguments will be relevant to colleagues elsewhere.

1.BACKGROUND

The majority of the human population of Yucatan still live in rural communities. Their agricultural system may be classified as complex, diverse and risk-prone (Chambers 1992). The staple crop is maize, which is cultivated using a slash and burn rotation (*milpa*) established long before the Spanish conquest and is one of the few ways of utilising the scant and fragile soils of the Yucatan. A major deity, Hun Hunahpu, was the maize god, indicating the

*Facultad de Medicina Veterinaria y Zootecnica, Universidad Autonoma de Yucatan, AP 4/116, 15.5 km Carreterra Merida - Xmatkuil, MERIDA CP97100, Yucatan, Mexico.

profound cultural importance to the Mayan people of this crop (Coe, 1993).In the more recent past, many families relied upon the subsidised henequen (sisal) industry for an income and other agricultural activity was largely for home consumption. The decline of this industry has had a major impact on many villages and played a part in a movement of people to larger urban centres in search of work. Rural people practising subsistence agriculture (campesinos) essentially utilise an enclosed garden around the home *(traspatio)* for growing fruit and other trees and communal land around the village for crop production. Livestock are generally kept in the traspatios. Care of livestock is predominantly the responsibility of the women in the family. The roles of the animals include home consumption, sale, savings, rearing of replacements and ceremonial purposes (Avila et al, 1993). These authors and others (Barredo Pool et al, 1991; Berdugo Rejon & Franco 1990; Wassink et al 1992) note that the majority of families (60% - 80% approx.) keep some livestock. Numerically, poultry - including chickens, turkeys, ducks and geese - are the most important. Criollo breeds are favoured and are used mainly for home consumption. Some households construct pens for their birds; others allow them to roost in the trees. Feed is generally home produced. Although fewer pigs are kept, these may have a greater role in sale and for ceremonial purposes. Pig keeping has been characterised as traditional weaner production, traditional fattening and fattening of improved breeds of weaners, usually purchased from commercial units (Richards & Morales, 1983). In the former two systems, criollo pigs are kept and raised with household waste. They may be allowed to forage outside the traspatio. In the latter system, which is increasing in popularity, a special pen is built and commercial concentrate rations are purchased. Very few campesinos keep small ruminants or cattle. The foregoing description is focused on livestock; it is important, however, to recognise that livestock exist as an integral part of the agricultural system and the total means used by a family to maintain their livelihood.

The Faculty of Veterinary Medicine of the Autonomous University of Yucatan (FMVZ-UADY) has had support from the British Overseas Development Administration (ODA) for several years. As a final phase of this involvement, ODA is currently funding a link between the University of London and FMVZ-UADY. One stated aim of this project is to undertake relevant research to increase sustainable livestock productivity in the poorer farming sectors of Yucatan. Three full time University of London staff have been seconded to FMVZ-UADY to facilitate this work - a farming systems specialist, an environmental economist and a veterinary epidemiologist (the author).

2. IDENTIFICATION OF PROBLEMS

Research resources are limited, in terms of available finance, time, equipment etc. Therefore, researchers have a responsibility to try to use these resources wisely, to investigate problems that are important. This requires that some criteria are used to define importance. There are two models for defining these criteria - a "traditional" approach and a "farmer first" approach.

2.1 The traditional model

Disease represents a constraint on livestock production through mortality, reduced production, lost market opportunities, inability to effectively use available resources or introduce more productive genotypes and costs of treatment or control (Putt & Hanks,1993). To determine the importance of a disease requires that, firstly it is identified and secondly, its impact is measured. In practice, the following steps may be followed:

1) Review secondary data sources to obtain data on the livestock population and diseases known to be present;
2) Design and undertake descriptive studies (surveys) to determine the distribution and frequency of those diseases;
3) Use observational studies (case control or cohort) to test hypotheses generated from the above;
4) Design and test appropriate interventions (field trials);
5) Encourage the adoption of proven interventions through extension.

The repetition of parts of such work, with each turn of the iterative wheel bringing the solution closer, has been recommended (Martin et al, 1987). The aim of the process is to produce results from a representative sample which can be extrapolated to the population of interest. This requires prior definition of the outcome and explanatory variables of interest. Implicitly, these may include economic measures as well as biological measures. It is clearly impossible to study all diseases that are present to the depth indicated above, so at each step, a judgement must be made, based on the available information from the previous stage in the process, about which diseases and which variables to discard. Ideally, the final distillate will be a detailed knowledge of the epidemiology of a specific disease within a defined population leading to the widespread adoption of an effective remedy so that its impact is negated.

It is recognised by many authors that implementing this process is, in practice, often difficult. In the specific context of the State of Yucatan, the following difficulties have been noted:-

1) Secondary data: information on the distribution of livestock within different systems (eg. commercial, semi-commercial or subsistence) is scanty. Veterinary laboratories deal almost exclusively with material derived from commercial livestock producers. Veterinary clinicians likewise have little or no contact with campesino farmers. In consequence, secondary data has proved of little or no value in determining priorities for research in the traspatio system.

2) Descriptive studies: in response to the paucity of information, specific descriptive studies have been undertaken. These have generally been cross-sectional and have typically provided a snapshot of the animal population of a particular community at a point in time. Useful information from such studies was used in the background section above. In addition to data on the number of households owning animals, data can be collected on productivity, mortality and morbidity and samples may be taken eg. for serology or parasitology. However, none of these studies purports to be representative of a greater population. Different criteria have been used by different authors and studies have been carried out at different times, so a quantitative summary is not valid.

3) Observational and intervention studies: The author of this paper has not yet identified any formal studies of this type undertaken in the traspatio system in Yucatan.

4) Practical problems: No sampling frame exists, beyond a list of village names. For this reason alone, cluster sampling would be the most appropriate means of obtaining representative results. The problem with cluster sampling is that, within each village, households are much more homologous than between villages. This can be seen as differences in reported studies in such factors as, for example, the number of households that own animals, the median number of animals per household, levels of mortality, type of animals kept, environmental conditions and socio-economic factors. This will increase the standard error of the measured variables when an approximation of population values is calculated. This can only be overcome by increasing the sample size and consequently, the cost of a study.

In villages, each household owns a small number of animals. Therefore, several households must be visited to obtain a representative sample of the animal population. If eg. blood samples are to be taken, it will take much longer to do so than in a commercial farm. For example, in Yucatan, the author conducted an interview with the veterinarian of a commercial pig unit and took samples from 30 pigs chosen at random in the space of three hours. In an adjacent village, random selection of households owning pigs, obtaining samples from twenty pigs and interviewing their owners was a process that required three visits to the village, with two extra assistants and took a total of 12 hours.

Thus, each sample was perhaps three times more expensive to obtain.

In any study, the informed consent of the participant is crucial. In the case of the commercial farm mentioned above, it was relatively easy to explain the purposes of the study and the unit owner could judge whether or not the disruption that participation would cause was a cost he was prepared to meet. Before visiting individual households in the village, we presented our credentials to the local council and obtained their permission. In addition, we tried to carefully explain our activities to householders. However, many viewed us with suspicion and did not agree to participate. Some householders denied having pigs, even though they were clearly visible over the garden wall (in some cases, of course, these may have been the property of someone else). Since perhaps only half of those households that we identified as keeping pigs participated, there may have been bias introduced.

In the same study, our purpose was to obtain a random sample of households that kept pigs by visiting every "Xth" house along a transect chosen at random. This process mystified some people, who wondered why we didn't simply go to pig keeping households that they could identify for us.

In work on commercial farms, knowledge of the system is shared by the farm manager and the researcher. Production parameters are or can be established, inputs and outputs measured and the impact of a disease upon profitability can be assessed. The researcher and the participant speak the same language. By contrast, understanding of the complex inter-relations within a backyard system is incomplete. Not only do we not share a technical language with campesinos, but for some, Mayan rather than Spanish is their first tongue. As well as implications for communication, this fact may make it difficult for a campesino to understand what our objectives are - and for us to understand our participants. This gulf may be a particularly important source of interviewer bias.

Since most animals are not clinically ill most of the time, one seldom has the opportunity to obtain samples from sick animals. Animals that die are frequently eaten, so post-mortem material is also difficult to obtain. Thus, a disease is most likely to be reported in interview or detected in laboratory tests, for example, screening sera for antibodies. This makes assessment of impact difficult, especially when the interviewees' definition of disease may be at variance with that of a vet.

5) Problems of interpretation: As discussed above, practical problems make extrapolation to a greater population difficult. Even within a single community, bias in participation may preclude a valid description being derived from a

survey.

A survey is by nature static. The animal population of a village fluctuates according, for example, to fiestas or feast days, when many may be slaughtered. Disease may also show seasonality, so the timing of a survey may influence the results obtained. However, beyond these more or less predictable temporal effects, there are also dynamic changes within villages in relatively short periods. For example, in one village, the number of households keeping poultry and the median number of birds per household fell by nearly a half in less than three years. In this situation, the results from an earlier survey may rapidly become obsolescent. One possible solution to this problem is to repeat surveys regularly or to develop monitoring exercises. Unfortunately, if these are to be representative, the time and cost involved may be prohibitive.

Since the objective of the exercise was to acquire information that could be used to generate hypotheses for testing in observational studies which would lead in turn to design of appropriate interventions against important diseases, it is pertinent to consider what conclusions can be drawn from earlier studies. From reading such reports, a general picture can be gained. Levels of production are low, nutrition is poor, parasitism in all its varied forms is rampant, hygiene is frequently less than deemed desirable by UK standards and many pathogens (eg viruses in poultry include: fowl pox, Newcastle Disease, infectious bronchitis) are endemic. Unsurprisingly, mortality is often high. It might be suggested that an educated observer could have reached similar conclusions from a walk around a village. Results are usually given as summaries for the entire group studied - little attention is given to the investigation of whether there are differences between households with results at the extreme of the ranges detected. Given this plethora of problems, possible actions which might suggest themselves include use of anthelminthics, vaccines, improved diets etc., although there is often stated to be a need for further research to confirm the findings and identify the impact of the detected diseases. The author has not yet learned of any disease control measures being implemented as a result of these studies. It can be argued that this simply reflects the fact that we do not have sufficient data and must patiently await the methodical grinding of the scientific mill. However, the circumstances affecting the livelihoods of campesino farmers are changing rapidly and their responses to altering circumstances will surely have effects on their livestock. It is unlikely that sufficient resources will become available to allow rapid completion of the traditional research cycle as outlined above and we may always be trailing behind present reality. In these circumstances, other methods must be considered.

2.2. THE FARMER FIRST APPROACH

As described previously, traspatio farmers manage complex agricultural systems which integrate livestock of different breeds and species with crop production and use of trees. The systems have a diversity not only of components but also of outputs, which include food production for home use and sale. The overall aim may be stated as the maintenance of the well-being of the family, rather than the maximum production of any one part of the system. The entire system is risk prone and any change in one part will have consequences elsewhere. Thus, rather than a separation of components into areas of particular expertise (eg crops, forestry, livestock), there are advantages in considering and characterising the farming system as a whole.In the farmer first approach (Chambers et al 1989), there is recognition that the people living in and managing these systems are more likely to be able to understand their systems and identify their problems than people from outside. Farmers are seen as equal partners in the process and their own knowledge is accepted and drawn upon. A panoply of techniques which come under the broad heading of Participatory Rural Appraisal (PRA) have been developed to encourage the direct involvement of farmers in the process of problem identification and resolution (Chambers, 1992). These include mapping, semi-structured interviews, construction of seasonal calendars, preference ranking and diagrams (Kirsopp-Reed, 1992). For researchers, this leads to new challenges, since a campesinos definition of a problem may be very different to a researchers. To give an example, a problem might be described as a lack of sufficient food for the family. Identification and the search for solutions to these problems are greatly helped by a multidisciplinary approach.

Within Yucatan, various groups have been using participatory techniques over recent years to address problems faced by campesino farmers. Important factors in determining the success of the projects include the development of confidence between farmers and researchers, continuity of commitment by everyone involved in the process and the achievement of progress from the farmers perspective. The implication of this is that the group is more important than its individual members, who will inevitably change with time.

One of the drawbacks of a farmer first approach in practice may be that it does not produce results that can be generalised to a greater population. It might be compared to a case study where the participating group are the corollary of the farm manager or pet owner and the outside research group is "the vet". A diagnosis is reached and hopefully, an effective treatment is given, acceptable to all. To extend the analogy further, the "vet" and the "owner" both learn from the experience. However, the next problem faced by either may be very

different. Therefore, whilst the specific diagnosis and treatment might not be generalisable, perhaps the process by which they were reached will have wider applicability.

2.3. Complementarity of traditional and participatory techniques: No methodology offers a universal panacea and solving problems is more important than dogmatic puritanism over the "right" technique. The greatest strengths of the farmer first approach are that it helps to direct research to themes that matter to people, it embraces local knowledge and experience, encourages a holistic and multidisciplinary consideration of the system rather than seeking to address one part in isolation and leads to realistic and sustainable solutions. Perhaps the greatest weakness lies in the difficulty of producing generalisable results. In contrast, the traditional methodologies offer the prospect of generalisation. Thus it might be argued that the latter is a more appropriate approach to problems that can be simply defined, which are widely distributed and are not sensitive to sudden change. These might include diseases which have a public health importance, such as TB or brucellosis. Traditional methods can produce quantifiable results and so can be used within the farmer first scenario to measure the impact of changes or interventions. One role of an outsider in such a scenario is to identify which outside technologies may be of value - in veterinary terms, what samples to take and which tests to request. The routine contact with families and mutual confidence that results aids the collection of data for monitoring purposes. In the investigation of diseases of multifactorial aetiology, observational epidemiology has a role to play in analysing important risk factors that can then form a basis for control - however, it may well be that only by learning from local people will some of these risk factors be identified.

3. CONCLUSIONS

The aim of this paper was to identify methods that will be appropriate for the investigation of animal health problems in the traspatio system in Yucatan. Traditional, formal epidemiological techniques suffer from practical difficulties which can result in bias and available resources may not permit sufficiently large studies to be carried out. Additionally, they may fail to incorporate local knowledge and may not be sufficiently dynamic to take account of changing circumstances. As a result, although they have generated useful descriptive data, they have not yet led to action at a field level. A farmer first, participatory approach offers the prospect of identifying problems which truly concern the people who depend upon the traspatio system for their livelihoods. Use of PRA should involve researchers and farmers in an equal partnership, within which

formal techniques may play a role in quantifying identified problems or effectiveness of interventions. The author is currently working within a multidisciplinary team and community participation in Yucatan, where problems under investigation include mortality in backyard poultry. The validity of the approach will be determined in the future, when the success or otherwise of the project will be judged by everyone - farmers and researchers alike.

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INTEGRATING EPIDEMIOLOGIC RESEARCH AND VETERINARY PRACTICE: IDEAS AND EXPERIENCES

M R SLATER*, D M BOOTHE**

In veterinary medicine in the United States, most of the epidemiologic research has been designed and conducted by faculty at veterinary teaching hospitals. Recently, there has been an increased interest in developing research linkages with veterinarians in private practices. For the purposes of this paper, we will be using the term practice-linked research (PLR) to refer to epidemiological research projects which involve both faculty at a veterinary teaching hospital and one or more veterinarians in private practice (referral or general practices). These projects may also involve individuals from industry or government. Research networks are groups of established collaborators including at least one faculty member and practitioners in two or more practices. While usual routes of referral of patients to a VTH or submission of tissues to laboratories is important for ongoing research, this will not be included as PLR unless practitioners are aware that the patients or tissues submitted are to be used as part of a specific research protocol.

Our perspectives are that of a companion animal epidemiologist and clinical pharmacologist in the United States. Therefore, we are most familiar with this type of research done in dogs, cats and horses. The importance and logistics of conducting these types of projects is likely to be different in other countries and potentially in food animal species. Indeed, food animal researchers have been using some type of collaborative networks for many years. We believe that most of the proposed infrastructure and methodologic issues are likely to be similar across many different situations.

The purposes of this paper are to: 1) present the rationale for practice-linked research; 2) discuss the current status of this type of project; 3) suggest methods to facilitate such projects and future directions and 4) serve as a source of discussion for individuals who are involved in practice-linked research.

WHY DO PRACTICE-LINKED RESEARCH

There are three major rationales for conducting practice-linked research. The first is a

* Department of Veterinary Epidemiology and Public Health, ** Department of Veterinary Physiology and Pharmacology, College of Veterinary Medicine, Texas A&M University, College Station, TX 77843-4458, USA.

scientific one: the patient population seen at a veterinary teaching hospital is not representative of patients seen by veterinarians in general. This referral bias has two main areas of impact. The first is our ability to correctly estimate baseline information on the prevalence and incidence of disease in animal populations. If our target population is animals that receive veterinary care, the external validity of our research projects will be much better if the data come from private practice. Certainly, there are regional differences, differences between specialty and general practices, and between city and rural practices. However, there is a better chance of our sample population being representative of our target population in a practice setting than at a VTH. The second problem with data only from VTHs is our inability to evaluate health problems which would not typically be referred to a VTH. Studies of less complex problems such as cat bite abscesses, complications of spay or castration surgery or similar primary care health problems are very difficult if data are collected only from VTHs. Information about un-complicated skin disease or best approaches to the initial treatment of vomiting can rarely be evaluated by studies at a VTH. Information about prognosis is also more likely to be available in a private practice setting.

The second rationale for PLR is that it can be more practical and economical since larger numbers of patients (or owners) can potentially be accessed in a short time period. The most obvious potential advantage is increased sample size. This advantage is especially helpful in companion animals where there are not many herds or flocks to study and there are rarely any sampling frames available. In addition, once a network of collaborators has been established, it is very efficient to conduct multiple studies simultaneously or sequentially. Another practical consideration is the transfer of knowledge of the study conclusions to the individuals who will be applying the new knowledge. This transfer of useful and applicable new information is greatly facilitated by the practitioners' participation in the collection of the information. Collecting data and studying subjects with special application to private practice can also have ramifications for continuing education. Understanding the common problems and questions in private practice can focus continuing education programs and make them more relevant. Therefore, private practitioners are perhaps more apt to apply new knowledge and skills learning during continuing education courses.

The third rationale for PLR is more philosophical: one of our main purposes is to help our clients and patients. In many situations, we can best help them by doing science on the front lines of veterinary practice (Green et al., 1994). Collaborations between practitioners and academicians can also improve communications (Moreau, 1994). This may result in practitioners becoming more comfortable in making referrals and continuing after-care for referred cases, both of which will improve patient care and client satisfaction. In human medicine, participants in practice networks report that their patients feel that this type of research increases the status of the practitioners (Niebauer & Nutting, 1994). Network research also answers some of the really important questions that are particular to private practice; in contrast, questions of importance in academic settings may not always apply to private practice (Green et al., 1994).

WHERE ARE WE NOW?

Much of our current information comes from studies in human medicine. In human medicine, PLR in established networks began in the 1970's in North America (Nutting & Green, 1994). Currently, there are 27 practitioner networks involving over 6,000 clinicians. About 80% of the practices involved are general medicine practices (Nutting & Green, 1994). There have been a

number of research project from these networks which have been published. There have also been some papers published about the strengths, weaknesses and methods used in this approach (Green et al., 1994; Senturia et al., 1994) and the rewards and motivation of involved practitioners (Niebauer & Nutting, 1994). Recommendations on developing and maintaining networks have been suggested (Green et al., 1994; Neaton, 1992; Yarbro, 1984). Data completeness and accuracy have been explicitly assessed in a few papers (Green et al., 1994; Yarbro, 1984).

In veterinary medicine, there have been studies in the United States and other countries that are examples of PLR (Jones et al., 1994; Wilson et al., 1994). We believe that two particular studies are worth mentioning because they illustrate two points. The first is one of the earliest examples of PLR in veterinary medicine and was conducted in 1971-73 (Reif et al., 1979). This was a prospective cohort study of cryptorchidism and testicular neoplasia in dogs. One of the two specific goals accomplished was demonstrating that epidemiological research could be done in private practice. In spite of the demonstrated practicality and utility of this high quality PLR cohort study, little additional PLR has been done in veterinary medicine until fairly recently. The second study is a very recent one which documented the prevalence and risk factors for obesity in cats (Scarlett et al., 1994). The study was based at Cornell University and initially included a random sample of 38 feline practitioners. Thirty six (95%) agreed to participate. Data forms were completed on over 2000 cats. Practitioners were asked to enroll 100-120 cats sequentially entering their practices. Participation and enthusiasm were very high. However, a follow-up study on these cats has begun and owner response rates have been lower than anticipated despite a limited time and effort commitment on their parts. To date, one additional veterinarian has refused to participate in the follow-up study.

There are several past projects involving PLR at the College of Veterinary Medicine at Texas A&M University. Two projects involved practitioners using a specific drug for a particular disease. A recent publication on foal morbidity and mortality relied on data collected by private practitioners (Cohen, 1994). Two common problems were demonstrated by these studies. One was lack of compliance by the practitioners (and owners). A second problems was response rates. The author of the foal study reported his participation rates (Cohen, 1994). In a systematic random sample of 106 equine veterinarians, 67% initially expressed a willingness to participate. After 12 months of data collection, 55% of the initial 106 veterinarians completed the study. Nine of the 13 who initially responded said that lack of time was the reason for dropping from the study. The reasons that 33% of contacted veterinarians were not interested initially was unknown.

Current projects involving private practitioners range from telephone interviews of owners to randomized clinical trials. Similar problems with response rates continue to occur. A telephone interview of owners of cats with cancer was conducted with assistance from specialty practices in the area. One of the practitioners provided only two cases. Our impression was that he was busy and unable to remember to ask owners if they were interested in participating. A case-control study of laminitis in horses included seven practices. Nine originally agreed to participate. It is unknown why two individuals never provided data in spite of personal visits, repeated telephone calls and commitment at the beginning of the study. A study involving referral of canine patients with renal disease has also been ongoing. Difficulties with this project involved finding enough animals that met the entry criteria for moderate but not severe renal disfunction.

In contrast, a randomized clinical trial of treatment for dogs with refractory epilepsy involves careful data collection by the owner and practitioner according to protocol. Owners of a few eligible animals are seen at our VTH but the majority of cases are handled entirely through the practitioner by means of telephone calls and letters. Practitioners were made aware of the study through a variety of publicity and continuing education opportunities. Interest has been strong and compliance has been surprisingly good given the detailed data collection requirements.

It is very likely that the level of enthusiasm for the objectives of a PLR project by the practitioners and their staff and the time and effort required to participate are critical for good response rates and compliance. In the clinical trial of refractory epilepsy, many veterinarians telephoned for information on the treatment of this often frustrating disease. The strong interest by the veterinarians and the commitment to the dogs by their owners may be key in the success of this project. There is also a variety of time and effort required by practitioners depending on the type of epidemiological study. However, there does not appear to be a clear pattern for predicting which studies will be successful in achieving high response rates. Nor are there data on the level of response rate to expect for certain types of studies or which incentives might work in a given situation. More research in this area would prove invaluable for future PLR projects.

In general, the time and effort commitment required of participants in PLR falls into four categories. The first is referral of cases or submission of tissues in response to a specific call for a particular project. This often does not require much more time or effort on the part of the practitioner than a usual referral or submission. Cognizance of the project and willingness to send clients to a VTH are all that is needed. The second type of participation is an observational study in which practitioners carry out some or all of the data collection. Data collection may be simply noting that an animal with a particular health problem was seen or may be more complicated and involve a form of several pages. Data unloaded from a computer data base would also be considered this type of study. Practitioners must be willing to identify eligible owners and patients, complete the form and mail, FAX or telephone results to the investigator. The third type of project involves the application of a specific therapeutic or diagnostic protocol to patients in the practice. Typically, this will be a clinical trial. This type of project requires not only time and commitment, but also a willingness to follow the protocol and often randomly assign treatments. Since the protocol is likely to differ from the standard treatment or diagnostic protocols in the practice, participants must be open-minded and highly committed to the project and to the philosophy underlying clinical trials. The fourth type of project is one in which a private practitioner generates the project and serves as the primary investigator. This is still considered PLR if the practitioner includes a faculty member at a VTH as part of the project (probably for their expertise in the disease process or in study design and statistics). This often requires the most time, energy and creativity on the part of the private practitioner of all types of PLR. We are not aware of any projects of this type at Texas A&M University and it is often difficult to identify this type of study from published papers. However, one paper presented at the International Symposium for Veterinary Epidemiology and Economics was initiated by a practitioner with interest in the question (Willeberg et al., 1994). We expect that some of the projects developed for the networks in human medicine have arisen from interests expressed by practitioners in the networks. This type of project is likely to become more common as private practitioners become more interested in answering questions that are relevant to their practice, as computerized medical records become more common in practice and as veterinarians in private practice have more interaction with faculty (especially epidemiologists) at Colleges and Schools of Veterinary Medicine.

HOW DO WE IMPROVE?

Based on conversations and the limited veterinary literature on PLR, there are several important areas in which we can improve and facilitate this type of research. A critical need is the education of private practitioners and academicians about the importance of this type of clinical, epidemiologic research. These individuals must understand the necessity of scientific studies instead of anecdotal reports. In addition, we must make them aware of the potential of PLR for addressing the types of questions and problems found in private practice. We can accomplish this in several ways: 1) by the publication of articles which demonstrate the utility of PLR; 2) by the publication of newsletters and 3) through continuing education seminars and workshops. Another vital area of education concerns the need for funding this type of research. Epidemiological studies are not well understood by many outside the field and we are hampered in our understanding of health and disease by a lack of financial support. These issues must be addressed in order to improve and expand PLR.

When beginning to implement PLR, an important early step is to become more organized in our approach. This would eliminate starting from the very beginning to identify participants for each new research project. Databases containing information on veterinarians who are interested in participating in certain types of projects and information on their practices (including size, species, location, etc) would allow for selection of motivated and representative practices. For random samples, sampling frames from special interest groups or geographical regions with similar practice data would facilitate the sampling process. Information on practitioners who have already participated in projects would also help improve data quality and decrease losses in future studies.

We need to better understand ways of motivating potential participants. Little has been published on the rewards needed to maintain a veterinary practitioner's interest in a project. How long is a reasonable time for a practitioner to collect data? How much data is reasonable to expect? In human medicine, there has been some suggestion that for very simple data collection, no tangible reward is needed (Senturia et al., 1994). Participants find satisfaction in being part of a larger whole, in combining an interest in research with practice and in gaining useful information upon completion of the study (Niebauer & Nutting, 1994). For more complicated data collection, providing additional staff members may be necessary since the main constraint appears to be time (Senturia et al. 1994). Response rates are likely limited by the number of eligible participants who are approached; therefore, explaining complicated studies may require more time than is possible in a busy practice. Incentives for owners (in veterinary medicine) are also an important issue. In some situations, access to an experimental drug or treatment which would otherwise not be available is enough. Sometimes, free laboratory work or medication is adequate. In other cases, money or coupons may be more appropriate. We need to determine which situations are likely to require which incentives.

Which types of studies are likely to be successful? One set of suggestions for selecting topics for clinical trials in human medicine was presented in 1992 (Neaton, 1992). Based on his own experiences, the author proposed the following guidelines: 1) choose a common disease with serious consequences; 2) select a project that is applicable to a large number of patients; 3) design the study such that the endpoints are clinical events and 4) select projects that have widespread interest to clinicians and patients. He further recommended that the protocols should be straightforward, timely and relevant and that data collection must be very focused (Neaton, 1992). If we accept these guidelines, then we must conduct research in veterinary medicine to

determine just what diseases are common and of interest to veterinarians and owners. Very little has been done in collecting this type of basic information.

Two additional related and vital areas are data quality measurements and methodologic questions. How good are the data we have collected? This is an important question in any study, but we have yet to address it in an organized fashion for PLR. In human medicine, PLR data accuracy and completeness are at least as good as in research institutions (Yarbro, 1984) and have error rates of less than 5% (Green et al., 1994). We know that there are biases inherent in studying populations seen at VTHs and we have some idea of the types of biases present. What are the biases in PLR? How large are they? Can we control them using the same types of variables that we know are important in studies in referral institutions? What exactly is our target population? If we are interested in animals who receive some veterinary care then PLR is likely to be a relatively valid approach. If, however, we are interested in the prevalence of a particular disease in a particular species, then we are missing a lot of animals that never or only irregularly visit a veterinarian. How many horses are there out there anyway? Issues about basic information on numbers of animals arise when trying to understand the various target populations. The design of the best survey instrument for a particular type of data collection is a familiar problem and needs to be addressed for PLR.

Why is PLR successful in human medicine? What can we learn from existing networks? One very successful practitioner network in human medicine is the Ambulatory Sentinel Practice Network of North America (ASPN) (Green et al., 1994). It was created in 1978 and in 1993 consisted of 72 practices in 32 states and four Canadian provinces. Twenty nine studies have been conducted (Green et al., 1994). This network maintains its cohesion through an annual meeting, newsletters and informal interactions at a variety of additional meetings. Routine data from participating practices are: 1) an annual report of the active patient population (everyone seen in the past two years); 2) a quarterly update on the practice and clinicians; 3) a general survey which provides demographic data in order to better evaluate comparability to the general population of the United States and 4) a weekly card which is completed by each practice which includes information on the number of hours the practice was open that week, the number of encounters and the data for two or more specific ongoing studies. ASPN achieves 90% to 100% participation from the eligible practices (Green et al., 1994).

As researchers, we believe that PLR is a very useful approach for certain types of research questions. It can also provide us with baseline data on the frequency of disease problems and the relative importance of these problems in practice. Some types of information simply cannot be collected using VTH patient populations. To improve the quality and ease of PLR, we need to teach researchers and private practitioners more about epidemiologic research. Often, these individuals are unfamiliar with study designs and do not realize that, for example, the addition of a carefully chosen control group can turn a case series into a case-control study. In addition, we need to be more organized and avoid reinventing the wheel. We need to explicitly address data quality issues. And finally, we need to improve communication with veterinarians in private practice and enlist them as potential collaborators for the benefit of our patients and clients.

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EFFECT OF REPRODUCTIVE DISORDERS AND PERFORMANCE ON LENGTH OF PRODUCTIVE LIFE OF HOLSTEIN DAIRY COWS ASSESSED BY SURVIVAL ANALYSIS

BEAUDEAU, F.[a,b], DUCROCQ, V.[c], FOURICHON, C.[a], FRANKENA K.[b], SEEGERS, H.[a]

In dairy farms, losses due to health disorders are minimized by paying attention to health management. Length of productive life (LPL), defined as the number of days between date of first calving and date of exit from the herd, influences the replacement cost and is therefore related to farm profitability. Studying the ability to delay involuntary culling due to health disorders is worthwhile for health management and decision support. Reproductive disorders are frequent in dairy herds. Whatever the production systems, infertility is the most frequent culling reason, as declared by farmers. The objective of the present work was to assess the effect of reproductive disorders and performance on LPL of dairy cows, using a proportional hazard model (Cox's regression), with time-dependent covariates.

MATERIALS AND METHODS

A prospective longitudinal survey was conducted in 47 commercial Holstein herds located in western France. Data were collected between February 1, 1986 and June 30, 1990. Data collection, storage and validation were described previously (Beaudeau et al., 1994).

Definition of variables

The observations analysed were LPLs. If the cow was alive at the end of the study period, the record was considered as censored at this date.

[a]Unit of Animal Health Management, INRA - Veterinary School, C.P. 3013, 44087 Nantes cedex 03, France; [b]Department of Animal Husbandry, Division of Animal Health and Epidemiology, Agricultural University, P.O. Box 338, 6700 AH Wageningen, The Netherlands; [c]INRA - Station de Génétique Quantitative et Appliquée, 78352 Jouy-en-Josas, France.

Five reproductive disorders were considered: retained placenta (> 12 hours), early metritis (including vulvitis, vulvovaginitis, endometritis, vaginal discharge, metritis and pyometritis) diagnosed from 22 to 49 days postpartum, late metritis diagnosed after 49 days postpartum, cystic ovaries diagnosed after 45 days postpartum, and early abortion (from 100 to 180 days of gestation). Clinical diseases were defined as time-dependent variables, and their effect on the hazard was assumed to be piecewise constant within lactation, with changes at date of first occurrence. The absence of disease was assumed at each date of calving, and diseases were assumed to influence hazard from the date of their first occurrence onwards in the current lactation. Effects were assumed to have a different impact depending on lactation number, except when the incidence of each possible association was too low (>9 cases). The effect of early and late metritis, retained placenta and cystic ovaries were assumed to be different in lactations 1, 2, >2. Therefore, they were considered as separate effects in the models. The effect of early abortion was assessed regardless of the lactation number.

Reproductive status was defined in four ordinal classes of values of days open. When the status changed from one class to the next one, the cow was supposed to be affected by more severe fertility problems. This variable was a time-dependent variable, and its effect was piecewise constant; changes occurred at date of calving and at the first date of any recorded AI occurring within the intervals 90 to 149, 150 to 209, >209 days postpartum of each lactation. Lactations 1, 2, and >2 were considered separately when defining this variable. Hence, 12 classes of reproductive status x lactation number were evaluated.

Incidence rates of reproductive disorders and of reproductive status were assessed.

Model building

The model used was based on the concept of hazard function $\lambda(t)$, where $\lambda(t)$ is the probability for a cow of being culled at t, given the cow is still alive just prior to t. This hazard characterizes the relative risk of being culled. A proportional hazard model, also known as a Cox regression model (Cox, 1972), was used. The model considered can be written as:

$$\lambda(t) = \lambda(t,z_1(t),z_2(t)) = \lambda_0(t) \exp \{ \Sigma z_1(t) + \Sigma z_2(t) \}$$

where $\lambda(t)$ is the hazard function at time t; $\lambda_0(t)$ is the unspecified baseline hazard function; $z_1(t)$ describes the effect of reproductive disorders possibly influencing length of productive life of cows; $z_2(t)$ describes the effect of covariates other than reproductive disorders possibly influencing culling risk. The effects of these variables were estimated independently from the baseline hazard function with a semi-parametric estimation procedure (Cox, 1972; Kalbfleisch and Prentice, 1980) involving the maximization of a partial likelihood.

Because the occurrence of reproductive disorders is known to be significantly related to poorer reproductive performance, the relationships between the five reproductive disorders and the number of days open in the current lactation were assessed, using χ^2 tests (Table 1). All reproductive disorders were found to be significantly related to reproductive status, since the percentage of affected lactations increased with increased number of days open.

Table 1. Relationships between reproductive disorders and reproductive status (3589 cows; 7703 lactations)

Health disorder		Postpartum days open <90 d (n=3579)	90 to 149 d (n=2278)	150 to 209 d (n=1018)	>209 d (n=828)	Signi-ficance[c]
Retained placenta	Yes[a]	8.7	10.1	14	15.3	0.01
	No[b]	91.3	89.9	86	84.7	
Early metritis	Yes	5.2	6.9	7.8	8.1	0.1
	No	94.8	93.1	92.2	91.9	
Late metritis	Yes	1.4	5.8	12.6	14.1	0.01
	No	98.6	94.2	87.4	85.9	
Early abortion[d]	Yes	not possible	not possible	1	4.7	0.01
	No	100	100	99	95.3	
Cystic ovaries	Yes	1.6	4.2	6.8	7.7	0.01
	No	98.4	95.8	93.2	92.3	

[a]proportion of lactation with occurrence of the corresponding reproductive disorder;
[b]proportion of lactation with no occurrence of the corresponding reproductive disorder;
[c]the test statistics of the hypothesis of association follows a chi-squared distribution with 3 df under the null hypothesis.
[d]postpartum days open is the interval between the last normal calving and the last AI known before the next normal calving.

Owing to these relationships, and in order to avoid overadjustments in models, two separate models were used. The impact of reproductive performance on LPL was assessed using a model including reproductive status, herd-year-season, stage of lactation, lactation number, month of calving, milk production, fat and protein contents and 11 other health disorders (late abortion, calving ease, milk fever, ketosis, mastitis, teat injury, non traumatic udder disorders, high milk somatic cell counts, foot, digestive and respiratory disorders). The impact of reproductive disorders on LPL was assessed using a model excluding the reproductive status as covariable, and including the reproductive disorders, herd-year-season, stage of lactation, lactation number, month of calving, milk production, fat and protein contents and 11 other health disorders (late abortion, calving ease, milk fever, ketosis, mastitis, teat injury, non traumatic udder disorders, high milk somatic cell counts, foot, digestive and respiratory disorders).

Estimates of effects were obtained by maximizing the logarithm of the partial likelihood, using a FORTRAN program developed by Ducrocq and Sölkner (1994). For the analyses, a 3-stage procedure was used for estimating the parameters.

In the first stage, effects of covariates not related to health were introduced in a forward procedure to assess their impact on LPL. In the second stage, each health disorder was added separately to the previous model and only those significantly related to LPL were retained ($P < .20$). In the third stage, a backward procedure was run with all disorders kept after stage 2 and all other covariates forced into the model, until all health disorders were significantly related to LPL ($P < .10$).

A relative hazard ratio was calculated as the instantaneous risk of being culled when exposed to disease relative to the instantaneous risk of being culled when not exposed to disease. It was estimated for each covariate from the hazard function by taking the exponent of the estimates of effects. Additionally, the effect of covariates on LPL was measured by computing several expected survivor curves, for instance, given the occurrence of a particular reproductive disorder or of a combination of reproductive disorders. The computation of these curves requires one to assume a priori values of all covariates over time. Reproductive health disorders were assumed to occur at median times of occurrence within lactation. Criteria were computed from the expected survivor curves. The decrease in median LPL, compared with a reference cow (with no health disorder, average milk production, average fat and protein contents, days open below 90 days postpartum), and the fraction still alive at the end of a given lactation showed differences in expected survivor curves.

RESULTS

The incidence rate and median time of occurrence of reproductive disorders, and of reproductive status, depending on lactation number of occurrence are shown in Table 2.

Table 2. Incidence Rates in % (IR) and Median Time of Occurrence in days postpartum (MTO) of reproductive disorders and reproductive status

Variable	Cows in					
	lactation 1 (n=2259)		lactation 2 (n=1796)		lactation 3 or over (n=3648)	
	IR	MTO	IR	MTO	IR	MTO
Disease						
Retained placenta	8.0	0	10.0	0	12.3	0
Early metritis	6.9	30	5.5	32	6.4	31
Late metritis	6.2	107	5.8	107	5.1	96
Early abortion	0.8	170	0.3	168	0.7	157
Cystic ovaries	3.3	89	2.6	99	4.6	74
Class of reproductive status (in days open)						
Class 1 (<90 d.)	49.8	0	47.8	0	43.7	0
Class 2 (90 to 149 d.)	27.4	90	30.9	90	30.3	90
Class 3 (150 to 209 d.)	13.0	150	12.0	150	14.0	150
Class 4 (>209 d.)	9.8	210	9.3	210	12.0	210

Table 3 shows the effects of reproductive disorders on LPL.

Table 3. Effect of reproductive disorders on length of productive life (3589 cows; 7703 lactations). Only effects significantly related to length of productive life are reported ($P < .10$)

Effects	Relative hazard ratio	90% CI	Decrease in median longevity[a]	Fraction still alive at the end of the second lactation[b]
Late metritis				
in lactation 1	1.5	1.1-2.0	182	0.70
in lactation 2	1.4	1.0-2.0	239	0.69
Early abortion	2.7	1.9-3.8	693[c]	0.51[c]
Retained placenta in lactation 1	0.7	0.6-1.0	-36	0.78

[a]in days, in comparison to cows with no health disorder, average milk production, average fat and protein contents, days open below 90 days postpartum;
[b]reference for a cow with no health disorder: .82;
[c]throughout lactation 1

Of the 5 five reproductive disorders investigated, only 3 were found to be significantly related to decreased longevity. Early metritis and cystic ovaries had no impact on longevity, whereas the occurrence of late metritis in lactation 1 or 2, and of an early abortion, regardless of the lactation number, were associated with higher risk of being culled. For instance, the occurrence of a metritis after 49 days postpartum in lactation 1 reduced the median LPL of the corresponding cow by about one half of a standard lactation duration.

The effect of reproductive status is shown in Figure 1. Reproductive status had a high impact on LPL, regardless of the lactation number. Within lactation, the relative hazard ratio increased when days open increased. For instance, the risk of being culled in first lactation was five times higher for a cow not pregnant at day 210 postpartum compared with a cow with days open < 90 days.

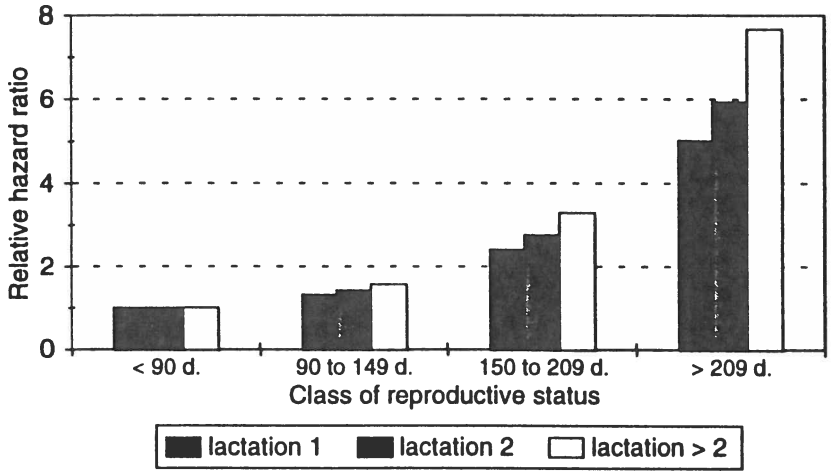

Figure 1. Estimates of effect of reproductive status on risk of being culled

Figures 2 and 3 present examples of expected survivor curves for cows with different reproductive status in lactations 1 and 2. The survivor rate was lowered at the end of lactation 1

or 2 with increased number of days open in the current lactations. Moreover, the recurrence of reproductive failure in lactations 1 and 2 induced a further decrease in the fraction of cows still alive at the end of the second lactation (Figure 4).

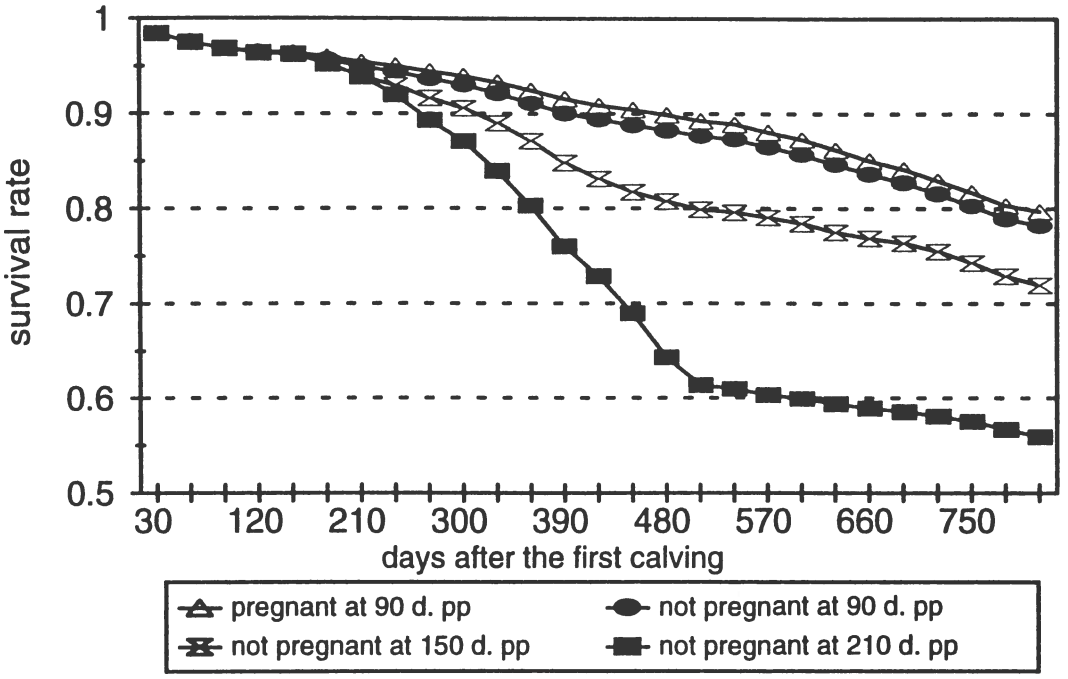

Figure 2. Survivor curves of cows with different reproductive status in lactation 1

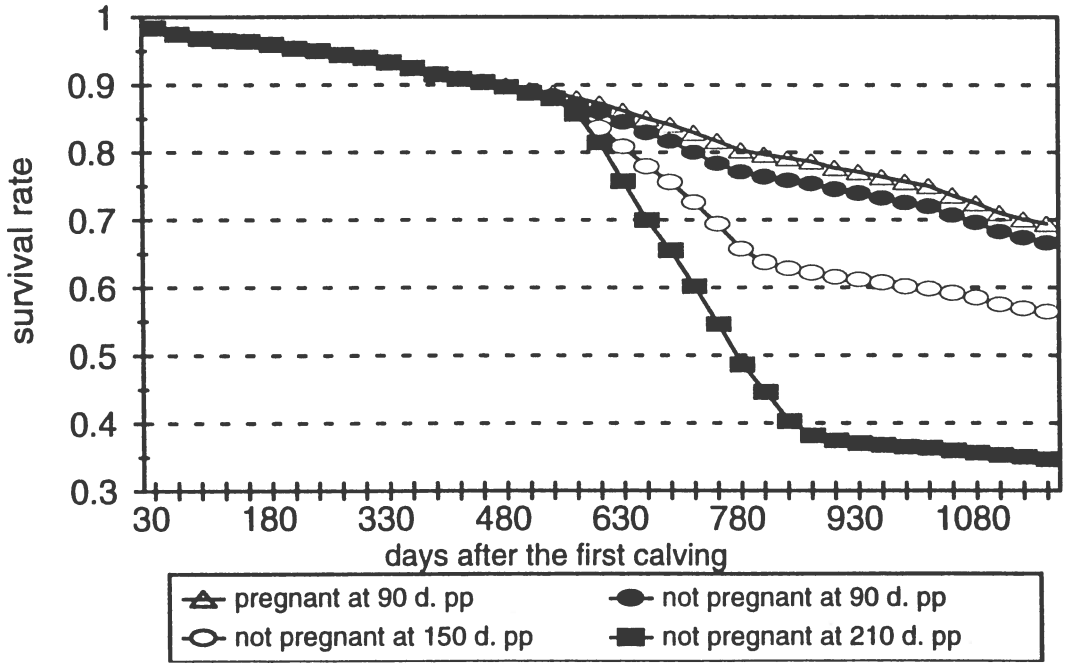

Figure 3. Survivor curves of cows pregnant at 90 d. pp in lactation 1, with different reproductive status in lactation 2

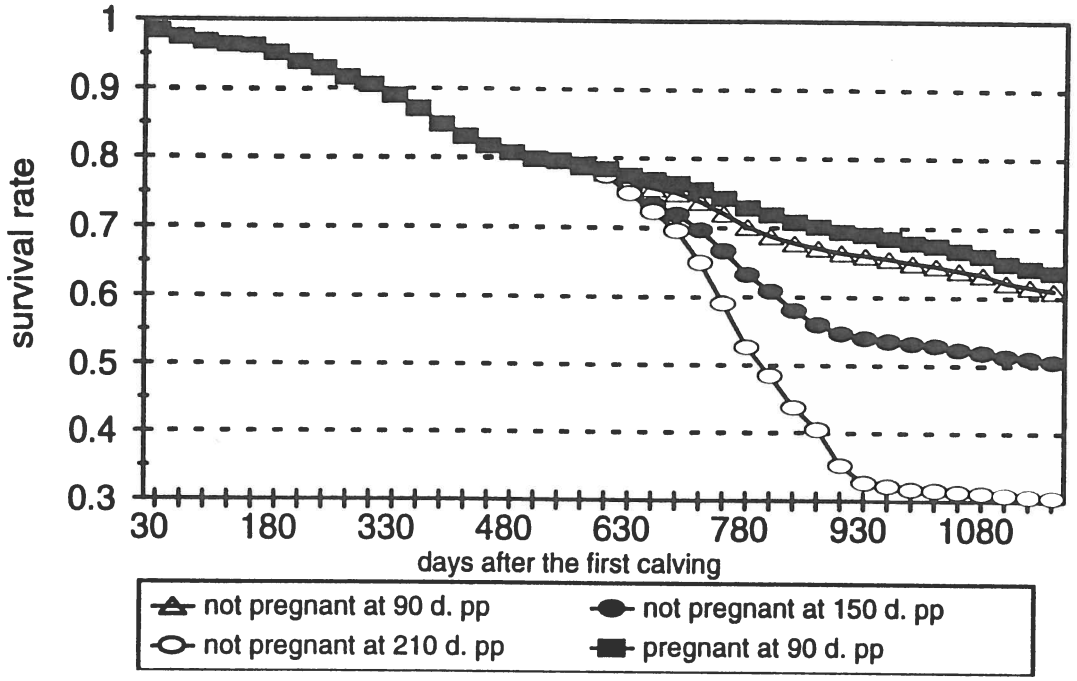

Figure 4. Survivor curves of cows not pregnant at 150 d. pp in lactation 1, with different reproductive status in lactation 2

DISCUSSION

Reproductive status was intended in this study to describe the reproductive performance of the cows. Similarly to previous studies (Sandals et al., 1979; Shanks et al., 1979; Oltenacu et al., 1983; Lee et al., 1989), the occurrence of reproductive disorders was associated with increased days open in the present data set. This led us to use two separate models: one including the reproductive status but not the related diseases, and another one including the reproductive diseases but not the related status. The inclusion of all variables in one model would have resulted in overadjustments. Consequently, the true effect of each variable related to reproduction would have not been assessed.

A drawback of such a procedure was that it did not completely 'mimic' the reality. When computing expected survivor curves of cows, with for instance a late culling or an early abortion resulting in non pregnancy at 210 days postpartum (class 4 of the reproductive status), the outputs from models were either (i) the survivor curve of a cow having the corresponding health disorder, without any reference to the possible consequences on reproductive performance, or (ii) the survivor curve based on reproductive performance without accounting for its possible cause, i.e. the reproductive disorder. From a managerial viewpoint, it was deemed preferable to assess the true impact of reproductive status, because farmers are used to making reproduction related culling decisions on the basis of days open.

Another strategy could have consisted in building a synthetic variable which would have accounted for both the occurrence of a reproductive disorder and its possible consequences on reproductive performance. However, to define such a variable as time-dependent would have

induced a methodological problem. If the effect on longevity of this variable was assumed to start at the date of occurrence of the reproductive health disorder, this would have resulted in assuming that farmers already knew at this date the consequences of that disease. Therefore, this strategy was not retained.

The effect of reproductive disorders and performance on the LPL of Holstein cows was assessed using survival analysis. The proportional hazard model used is now recognized as a powerful method to analyse measures of longevity (Ducrocq, 1987; Ducrocq, 1994). Information from censored observations can be used, contrary to standard regression techniques which require that cows are classified as culled or nonculled in each lactation. Furthermore, consideration of variables possibly influencing LPL as time-dependent allows a more accurate description of the exact follow-up of cows' life. In addition, survival techniques provide information through several criteria. The probability of being culled within a given time interval (for instance the lactation) is described by the hazard ratio, which is the most comparable parameter to outputs from logistic regression analysis, such as odds ratio. Moreover, dynamic parameters, such as fractions still alive at a given t of the LPL, and expected survivor curves are provided as well and illustrate the dynamic effect of covariates through time.

This study showed how farmers accounted on average for reproductive disorders and performance in their culling decisions.

The risk of being culled increased when days open increased, regardless of the lactation number, in agreement with Erb et al. (1985) and Milian-Suazo et al. (1989), who investigated days to first AI and number of AI before conception as risk factors for culling respectively. The high risk of being culled with large days open (>209 days postpartum) stresses that farmers probably take into account losses due to high calving interval, when making culling decisions.

Among the 5 five reproductive disorders investigated, only the ones occurring after the peak of lactation (late metritis, early abortion) had a significant impact on longevity. Reproductive performance appears to be a key criterion for making culling decisions. Therefore, the reproductive diseases, among all health disorders, appeared to have an impact on longevity through poor reproductive performance. In some cases, the occurrence of a health disorder must be considered as a strengthening factor among all cows potentially candidate for culling.

Several factors may explain the absence of negative impact on LPL of early metritis by itself. This could be due to its very early stage of occurrence within lactation, usually associated with any impact on reproductive performance. Furthermore, the definition of early metritis may be questionable. The differentiation between normal postpartum vaginal discharge and actual endometritis was probably not always made at this stage of lactation. That could explain why early metritis was not accounted for on average by farmers when making culling decisions. In addition, the actual impact of cystic ovaries on longevity was not clearly explicited. They were found to increase the risk of culling by Erb et al. (1985) and Oltenacu et al. (1990), whereas Cobo-Abreu et al. (1979), in agreement with the present study, found a non-significant effect on culling. In addition Dohoo and Martin (1984) reported a protective effect on culling.

The economic impact of reproductive disorders through anticipated cullings at the herd level must be assessed by accounting for both their impact on LPL at the individual level and their incidence rate. Major attention must be given to late metritis, which, in addition to a high incidence (Table 2), generates an average loss of median LPL over 180 days. Despite their high impact on LPL, the economic impact of early abortions may be low, owing to their low incidence in herds.

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MODELLING LISTERIAL ACTIVITY WITHIN A SILAGE BALE

L. A. KELLY[1], W. DONACHIE[2], G. GETTINBY[1],
G. GIBSON[3] and J. C. LOW[4]

Mathematical modelling is one aspect of epidemiology which has recently received considerable attention in the veterinary field. The availability of powerful computers has led to an increase in the use of statistical and mathematical techniques in the analysis and interpretation of biological data. In this paper these skills have been applied to a bacterial disease which presents particular challenges to the mathematician. This disease is listeriosis.

Listeria monocytogenes is the pathogenic species of the genus *Listeria*. Pathogenesis extends to both humans and animals causing the often fatal disease listeriosis. In animals listeriosis is most common in ruminants and in particular sheep. Encephalitis is the dominant form of the disease although septicaemia and abortion also occur.

An increasing incidence of ovine listeriosis was observed during the late 1970s and throughout the 1980s. During this period, peak incidence was in late winter and early spring. Both the increase in incidence and seasonality of the disease have been attributed to big-bale silage feeding. This type of fodder is fed to housed animals and grazing animals when grass is limited and became popular during the 1980s for economic reasons. An understanding as to how this fodder is implicated in listerial infection can be obtained by considering the silage making process.

SILAGE AND THE SILAGE MAKING PROCESS

Silage is produced by the controlled anaerobic fermentation of high moisture content crops. In this oxygen free environment the growth of anaerobic bacteria reduces the pH of the material which leads to preservation. Problems occur when oxygen enters into the process. This is a particular problem with big-bale silage. The plastic covering, with which the bale is wrapped, may not be properly sealed during production and is easily damaged in the farm environment.

[1]Department of Statistics and Modelling Science, University of Strathclyde, Richmond Street, Glasgow G1 1XW
[2]Moredun Research Institute, 408 Gilmerton Road, Edinburgh EH17 7JH
[3]Scottish Agricultural Statistics Service, University of Edinburgh, James Clerk Maxwell Building, The Kings Buildings, Edinburgh EH9 3JZ
[4]Scottish Agricultural Colleges, Veterinary Services, Edinburgh Centre, Bush Estate, Penicuik, Midlothian EH26 0QE

When oxygen enters the bale the growth of aerobic organisms such as yeasts and moulds is initiated. The growth of these organisms increases the pH of the silage which in turn provides a favourable environment for the growth of *L. monocytogenes*. If this organism was present on the grass and small numbers survived during fermentation, then when oxygen enters the dormant cells will rapidly begin to grow, multiply and spread through the bale. As a result of this activity, the listerial composition of the bale will vary throughout the storage period and hence may present a danger to animals at the time of feeding.

At present, mathematical modelling applied to bacterial diseases has focused on the growth of organisms under different environmental conditions and in particular temperature. This paper takes a novel approach. A mathematical model that can be used to describe the variation in the listerial composition of the silage when oxygen enters the bale is examined. The model is a mass-action differential equation model which relies on the following biological hypothesis.

BIOLOGICAL HYPOTHESIS

Consider a silage bale that has just been made. Simplification of the biochemical activities that go on within such a bale allows the following description of listerial activity to be put forward.

Assume that the bale can be represented as n distinct volumes, each of which is either populated or unpopulated with *L. monocytogenes*. The notion of volume is a complicated one. The silage bale is cylindrical in shape but, for modelling purposes, it is assumed to be cuboid. Each volume can then be thought of as a smaller cuboid.

Initially, when the bale has just been made, organisms in a populated volume are dormant. At some point in the future, whether it be due to inadequate sealing or damage, oxygen may enter the bale and dormant organisms may become active, i.e. grow and multiply, as a result. Whether they become active or not will depend on how far away the volume is from the site of damage, as the oxygen will be used up as it moves through the bale. Whether a particular volume is suitable for growth has been discussed in detail by Ruxton and Gibson (in press). Active organisms can spread from one volume into a neighbouring volume, and hence populate that volume with active organisms. Activity within a volume will continue until the full bacterial growth cycle has been completed. The duration of activity will depend on the conditions within the bale as the normal growth cycle is completed. Following activity, the organisms will then either return to a dormant state or die, resulting in either a volume populated with dormant organisms or an unpopulated volume. Volumes that return to a dormant state may become active again in the future, though this is perhaps unlikely. Dormant organisms may die at any time and the volume they occupy will become unpopulated.

This process may continue throughout storage of the bale, with organisms in populated vol-

umes moving between active and dormant states and ultimately dying, resulting in an unpopulated volume. Thus when the silage is opened for feeding, a proportion of the bale will be populated with *L. monocytogenes.*

An example of such activity is described diagrammatically in Fig. 1.1. Here the bale is split into 20 individual volumes and initially 6 of these are populated with dormant organisms. When oxygen enters the bale those organisms in volumes closest to the point of oxygen entry become active. These organisms then spread into neighbouring unpopulated areas and at the same time other dormant organisms become active or die. By day $T = 20$ after the entry of oxygen, 5 volumes are populated with listeria, of which 2 are dormant and 3 are active.

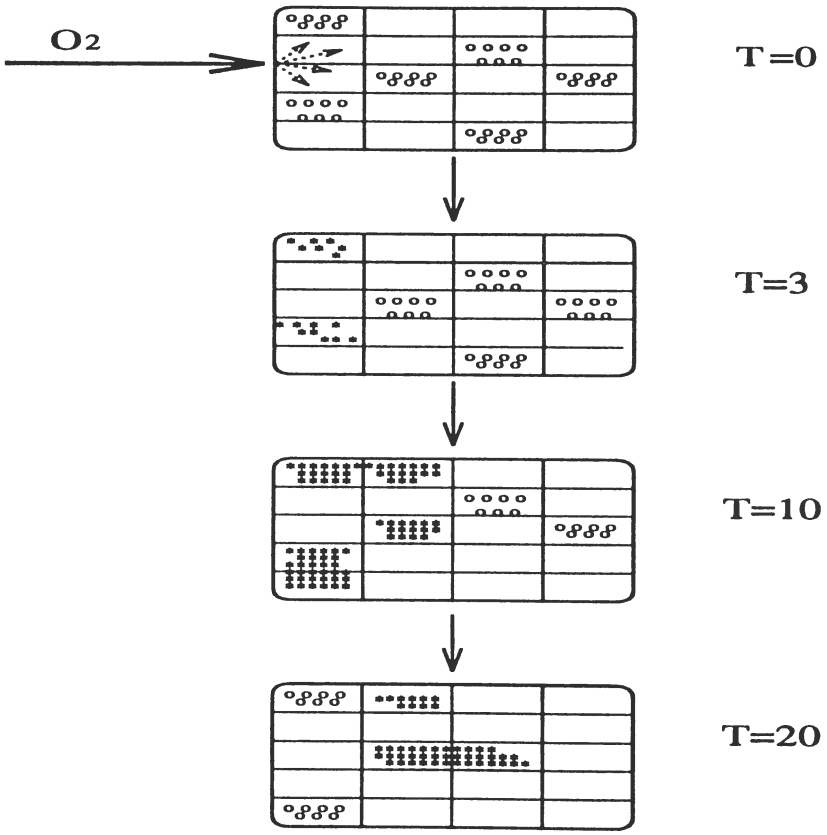

Figure 1.1: Illustration of listerial activity following entry of oxygen into a bale: o -dormant organisms; * - active organisms

DIFFERENTIAL EQUATION MODEL

Mass action differential equation models are widely applied to describe changes within populations. Applications extend to human and animal populations and often classes of population

such as in susceptible-infective-recovered (SIR) models are studied in this way. These types of model are discussed by authors such as Bailey (1975).

In a listerial activity model, three populations are considered - dormant, active and unpopulated volumes within the silage bale. The following assumptions as to how these populations change over time are made

- whether or not a dormant volume becomes active at a certain time is a random event and does not depend on distance from the damage site
- when a dormant volume becomes active, all the organisms in that volume become active
- whether or not an active volume becomes dormant at a certain time is a random event and does not depend on the bacterial growth cycle
- when an active volume becomes dormant, all the organisms in that volume become dormant
- whether or not dormant or active volumes become unpopulated at a certain time are random events and do not depend on the bacterial growth cycle.
- when active or dormant volumes become unpopulated, all the organisms in those volumes die
- active organisms can spread into any unpopulated volume, hence resulting in an unpopulated volume becoming active

Defining the three populations as

$X_1(t)$ - number of dormant volumes at time t,
$X_2(t)$ - number of active volumes at time t,
$X_3(t)$ - number of unpopulated volumes at time t.

the system can be represented by the compartmental diagram shown in Fig. 1.2

Nodes represent the three populations and arcs from these nodes represent transitions of volumes from one population to another. In essence, such a transition represents a change of state for a particular volume. Transitions happen at the rates $\alpha, \beta, \gamma, \delta$ and ϵ which will depend on the size of the volumes, and hence on the value of n. The transitions and their corresponding rates lead to the following system of differential equations for the rate of change in the number of volumes in each population (or state) over time.

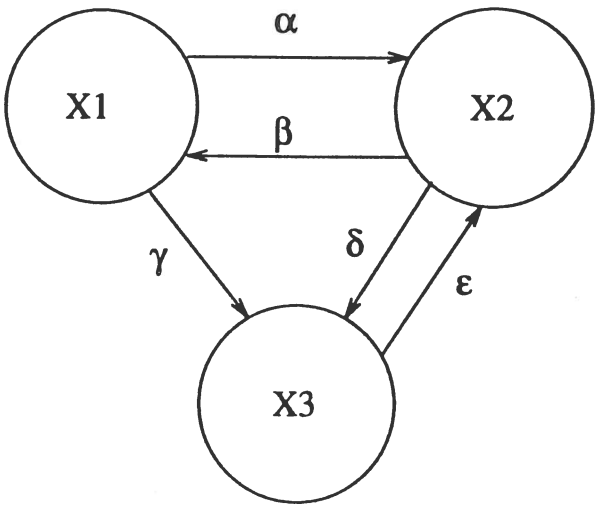

Figure 1.2: Compartmental representation of the silage model:$X_1(t)$-dormant volumes, $X_2(t)$-active volumes, $X_3(t)$-unpopulated volumes

$$\begin{aligned}
\frac{dX_1(t)}{dt} &= -(\alpha+\gamma)X_1(t) + \beta X_2(t) \\
\frac{dX_2(t)}{dt} &= -(\beta+\delta)X_2(t) + \alpha X_1(t) + \epsilon X_2(t)X_3(t) \\
\frac{dX_3(t)}{dt} &= \gamma X_1(t) + \delta X_2(t) - \epsilon X_2(t)X_3(t)
\end{aligned} \tag{1.1}$$

Because of the nonlinear nature of these differential equations, analytical solutions for $X_1(t)$, $X_2(t)$ and $X_3(t)$ cannot be found. Nevertheless, an expression for the equilibrium values, i.e. the values as $t \to \infty$, can be found analytically. When the system is in equilibrium, the rate of change in the numbers in each state is zero, hence the flows into and out of each state are equal. The equilibrium values will depend on both the values of the transition rates and the value of n.

Determination of equilibrium values does not provide any information on how quickly equilibrium is reached or how it is reached. To obtain this information the system of differential equations can be solved numerically and the values of $X_1(t)$, $X_2(t)$ and $X_3(t)$ plotted against time. Such solutions were obtained using the numerical integration package SOLVER, developed at the University of Strathclyde. Time varying stochastic solutions were also obtained using a Pascal program.

RESULTS

Numerical solutions for $X_1(t)$, $X_2(t)$ and $X_3(t)$ are shown by the dashed lines in Fig. 1.3a-c. These are for the transition rates α,β,γ,$\delta = 0.1$, $\epsilon = 0.001$ and a silage bale divided into $n = 1000$ volumes. These values have been chosen for illustration purposes and they indicate that the rates of flow between populations are the same and that the chance of a $X_3(t)$ to $X_2(t)$ conversion is exceptionally small.

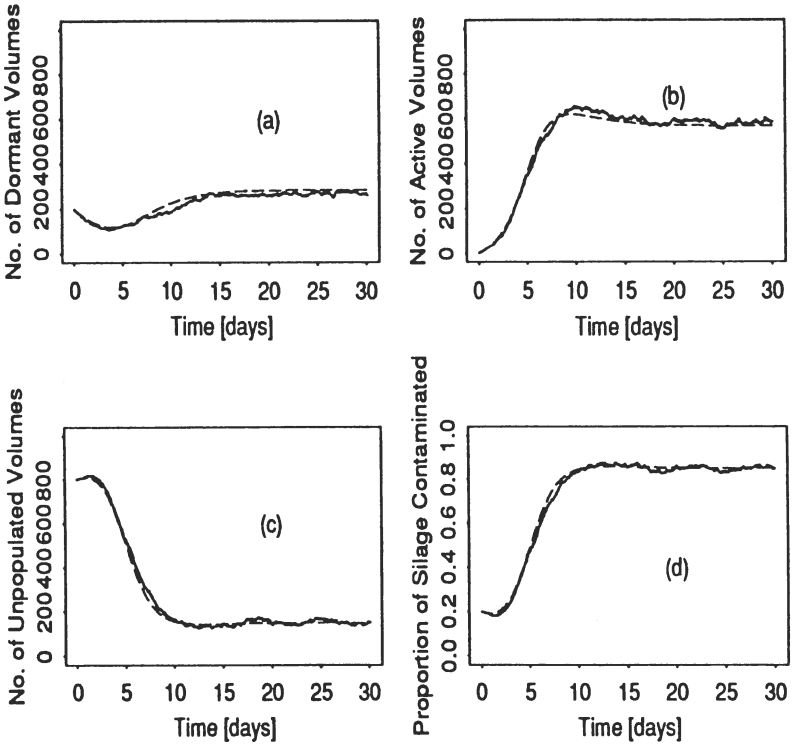

Figure 1.3: (a)-(c): Deterministic numerical solutions (---) and one stochastic realization (—) for $X_1(t)$, $X_2(t)$ and $X_3(t)$; (d): deterministic numerical proportion (---) and stochastic proportion (—) of silage contaminated. In all cases $\alpha, \beta, \gamma, \delta = 0.1$, $\epsilon = 0.001$, $n = 1000$

The derived numerical solutions are deterministic in nature. This means that they represent the exact numbers in each state at any time, hence they do not take into account random fluctuations. The randomness which will undoubtably be present in reality can be examined by considering the stochastic counterpart of the deterministic model. Here the probabilities of particular transitions occurring are considered and the resulting solutions for $X_1(t)$, $X_2(t)$ and $X_3(t)$ are random variables with a probability distribution characterized by a mean and variance.

Considering probabilistic transitions results in a stochastic process which can be simulated on a computer. By repeating such a simulation many times, estimates of the mean and variance of the random variables $X_1(t)$, $X_2(t)$ and $X_3(t)$ can be generated. Often the mean of the stochastic realizations will be close to the deterministic solution.

One particular stochastic realization is shown along side each of the deterministic numerical solutions in Fig. 1.3a-c. For each population, the deterministic and stochastic solutions follow the same behavioural pattern, with the stochastic values fluctuating around the deterministic values.

The equilibrium corresponding to this parameter set is $X_1^* = 283$, $X_2^* = 567$ and $X_3^* = 150$. Here the * notation refers to equilibrium values. From Fig. 1.3a, the number of dormant organisms shows an initial decrease and then from the minimum value the population size increases to reach the equilibrium value. The majority of the early departures from the dormant population will be to the active population as the oxygen initiates activity. Along with the fact that there are initially no active volumes, this means that the number of unpopulated volumes only increases slightly at the start as shown in Fig. 1.3c. The increase in the number of dormant volumes following the initial decrease results from active organisms completing the growth cycle and returning to the dormant state.

From an initial value of zero, the number of active volumes increases sigmoidally to a value which slightly exceeds equilibrium, then falls from this value to the equilibrium. The sigmoidal pattern of slow, followed by exponential, increase results as follows. Initially, the only new active volumes are those which were originally dormant and then activated by the presence of the oxygen. As more volumes become active, the active organisms spread into unpopulated volumes rendering them active. This can also be seen from the corresponding exponential decrease in the number of unpopulated volumes which follows the initial increase. When the population size exceeds the equilibrium value, active organisms return to the dormant state until equilibrium is reached.

The proportion of the bale contaminated, and potentially capable of causing disease, at any time is given by

$$P_c(t) = \frac{X_1(t) + X_2(t)}{n} \tag{1.2}$$

This proportion is shown in Fig. 1.3d and the equilibrium proportion is 0.85. Hence 85% of the bale will ultimately be contaminated. The behaviour of this proportion reflects the combined behaviour of the two dangerous populations, dormant and active, and hence is inversely related to the behaviour of the listeria free population, which has an equilibrium proportion of 0.15. This value can also be thought of as the probability of extinction of the organism within the bale. The equilibrium proportion is reached in around 11 days after damage although transitions between

the two dangerous populations still occur after this time. These transitions correspond to the increase in dormant volumes and decrease in active volumes discussed earlier.

DISCUSSION

The behaviour shown above is for one particular parameter set. As the parameters are changed, the equilibrium values and the transient behaviour will correspondingly change. Also, although not affecting the equilibrium values, the initial population sizes will determine the route to equilibrium. Hence a whole spectrum of possible behavioural patterns could be observed.

The notion of different equilibrium values serves to introduce the importance of time taken to reach equilibrium. A possible equilibrium is a totally listeria free silage bale i.e. $X_1^* = 0$, $X_2^* = 0$ and $X_3^* = n$. However if the time taken to reach this equilibrium exceeds the time from damage to opening, then the bale will still be contaminated at feeding, unless of course it was initially free of listeria. Hence, in this case, although the model predicts that the silage is *eventually* safe, it may still be contaminated when consumed.

CONCLUSIONS AND FUTURE WORK

The model offers a conceptual framework for investigating the dynamics of listeria in silage. It could be used to test the implications of hypotheses or suggest experiments which could be used to test hypotheses. From the results of such tests, suggestions as to the risk of silage feeding could be made.

The model was developed by making many simple assumptions about the dynamics of listeria within a silage bale. One particular assumption was the fact that an active volume ceasing to be active was a totally random event. As mentioned in the biological hypothesis, this event will depend on distance from the damage site as the oxygen is used up as it moves through the bale. There are two possible ways to encapture this distance dependency in the model. One way is to assume that the dependency on distance can be represented by dependency on time since damage. This would introduce a time dependent model. Alternatively each individual volume could be labelled according to its distance from the damage site and its state at any time recorded. Hence as more realism is built into the model, the model itself becomes complicated.

To overcome the problems of analytical intractability, simulation can be used and as with the previous model, this will produce random variables for each population size. The simulation results will demonstrate behaviour patterns and show if any equilibrium is reached. Such simulation models are currently being worked on.

Development of the model has involved interactions between biologists, veterinarians and mathematicians and through these interactions new ideas have been generated and the understanding of those involved has been improved. Similar interactions in the future will lead to new and better models which will ultimately benefit the farmer and his flock.

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CLASSICAL SWINE FEVER IN GERMANY - SOME EPIDEMIOLOGICAL ASPECTS

M KRAMER*, R AHL[2], J TEUFFERT*, K KROSCHEWSKI*, H SCHLÜTER*, J OTTE*

Classical Swine Fever (CSF) also known as hog cholera or European Swine Fever is one of the most dangerous viral diseases of pigs (Harkness 1985, Dahle & Liess 1992). The clinical picture varies from acute forms with predominantly hemorrhagic and septicemic symptoms to subacute and chronic forms accompanied by inflammation of the respiratory as well as the digestive tract. In affected regions, CSF causes severe losses in the pig population and has a strong impact on the trade with pigs and pig products. In recent years (1991 - 1994) CSF occurred worldwide with exception of North America. Most of these outbreaks occurred in Asia, especially in China (456 cases), India (255) and in the southeast Asian countries. Germany (205 cases) is presently the most affected country in Europe, (Data of the OIE Bulletin; January 1991-September 1994)

HISTORY OF CSF EPIDEMICS IN GERMANY

Although in Germany CSF is often called "European" Swine Fever, the disease was first described in North America in 1833 (Beer 1987). CSF occurred in several European countries in the middle of the last century and by the end of the century the disease had spread throughout the whole of Europe. In Germany, the disease was first described in 1894 (Beer 1987).

CSF epidemics have occurred throughout German agriculture history. Several severe epidemics occurred prior to and during the world wars. After World War II, five large epidemics with an average duration of 3.8 years were recorded (Fig. 1). It seems that major epidemics occurred in ten-year intervals. Küttler (1984) mentioned a 10-year cycle of CSF in Germany. Not including the epidemic in the GDR in the fifties because of the singular character of this population, four great epidemics followed by smaller ones three to six years after the peak of the greater epidemics can be observed.

Major epidemics in the past two decades were mainly controlled by vaccination of all types of pig herds. Nonetheless, during the epidemic from 1982 till the end of 1985 1,900 outbreaks were recorded in West Germany.

* Federal Research Centre for Virus Diseases of Animals, Epidemiology Dept., Seestr. 55, 16868 Wusterhausen, Germany
[2] Federal Research Centre for Virus Diseases of Animals, Dept. of Vaccines, Paul Ehrlich Str. 28, 72076 Tübingen, Germany

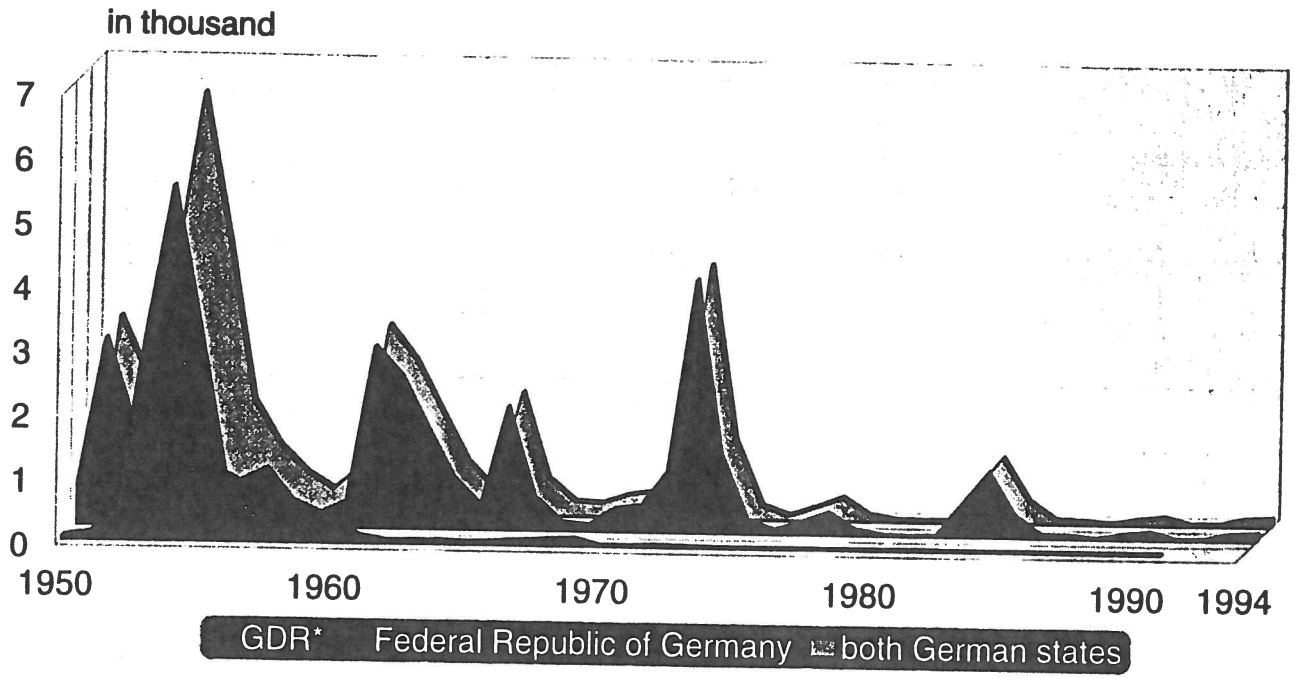

Fig. 1 Number of CSF outbreaks in Germany from 1950 to 1994
(Data source: Disease statistics of the Federal Ministry of Nutrition, Agriculture and Forestry, Bonn, Heckmann 1984)

THE RECENT OCCURRENCE OF CSF IN GERMANY

In 1991 and 1992 only 6 and 13 sporadic cases, respectively were notified in different regions of the country. Antigenic characterization of the virus isolates using a panel of monoclonal antibodies indicated that a proportion of primary cases originated from contact with wild boar where the disease was first observed at the end of 1992, whereas subsequent spread to domestic pig herds was due to trade in piglets among which some might have been virus carriers.

Since the end of 1992, two independent cycles of spread of the disease could be observed. In so-called CSF infected wild boar areas the virus was found to be widely distributed among wild boar. As an example, 11.3 percent of all serological and 15.5 percent of the virological examined wild boar in Mecklenburg Western Pomerania had CSF antibodies and hunters frequently observed severe cases of CSF in wild boar. A number of outbreaks in that region could be attributed to indirect contacts to wild boar e.g. through contaminated feedstuff. Sporadic outbreaks in the south of Rhineland Palatinate and in the eastern part of Lower Saxony were likewise related to CSF in wild boar.

A second cycle of infection developed after introduction of the virus into domestic herds in the northern part of Lower Saxony in January 1993. In this cycle, the virus was mainly carried on through contacts between pig farms. Also the outbreaks in Baden Württemberg all originated from the purchase of sows coming from one farm infected by wild boar in Rhineland Palatinate. The CSF started in October 1993 in the Oldenburg region of Lower Saxony which is the region with the highest pig density in Germany. The disease originated from moving piglets from Baden Württemberg to that area. On that occasion the virus was also transmitted to Belgium.

In Lower Saxony, the CSF epidemic continued in 1994 with a second peak in March and April. The major means of spread were neighbourhood contacts, purchase of infected animals and contaminated vehicles such as that from rendering plants or feedstuff suppliers. In October 1994 a limited series of outbreaks occurred in Bavaria where swill feeding was attributed as the cause of the primary case.

The temporal development of the current CSF outbreaks comprising the affected regions is shown in Fig. 2. The epidemic showed two peaks in both years. But most of the cases were observed in the summer time in 1993 while in 1994 more cases happened in the spring.

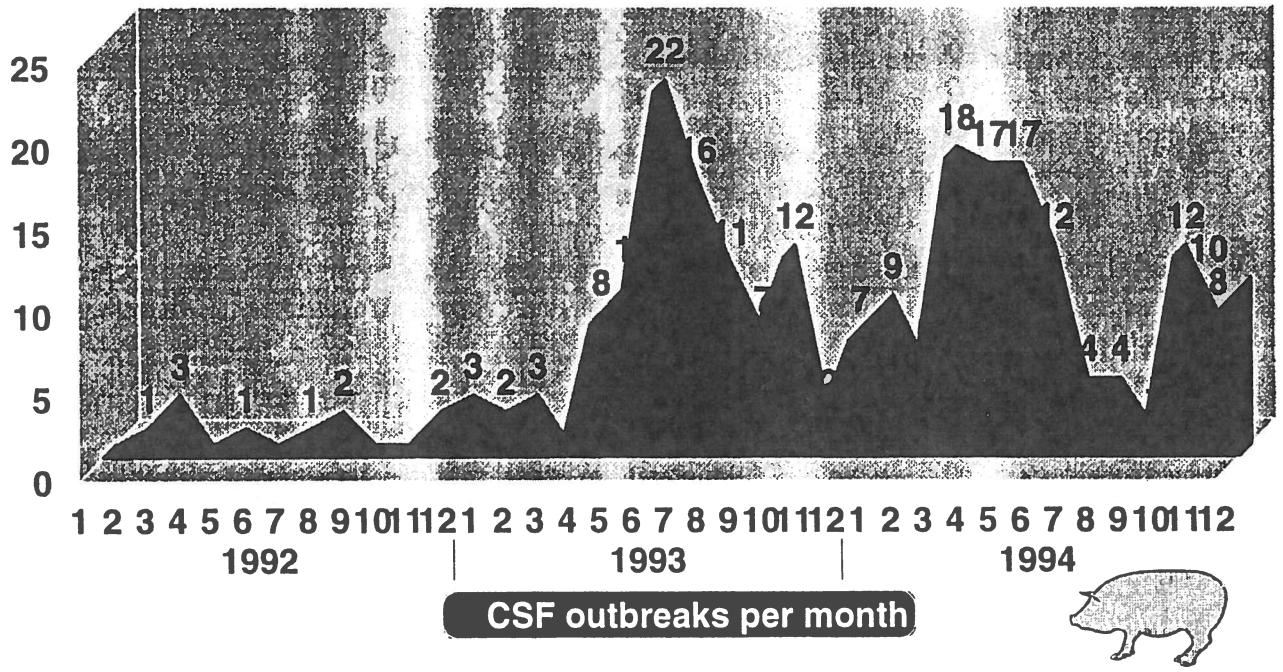

Fig. 2 Temporal distribution of CSF outbreaks in Germany from 1992 to 1994

A map of Germany showing the geographic distribution of CSF outbreaks in 1993 and 1994 is given in Fig. 3. Lower Saxony incorporating 44,700 pig farms had been mainly affected with a total of 127 cases, followed by Mecklenburg Western Pomerania (5,600 pig holdings) with 42 cases. In Bavaria (84,400 holdings) 20 outbreaks were recorded within two years. The percentage rate is 0.28 for Lower Saxony, 0.75 for Mecklenburg Western Pomerania and 0.02 for Bavaria. Other regions had only single cases of CSF.

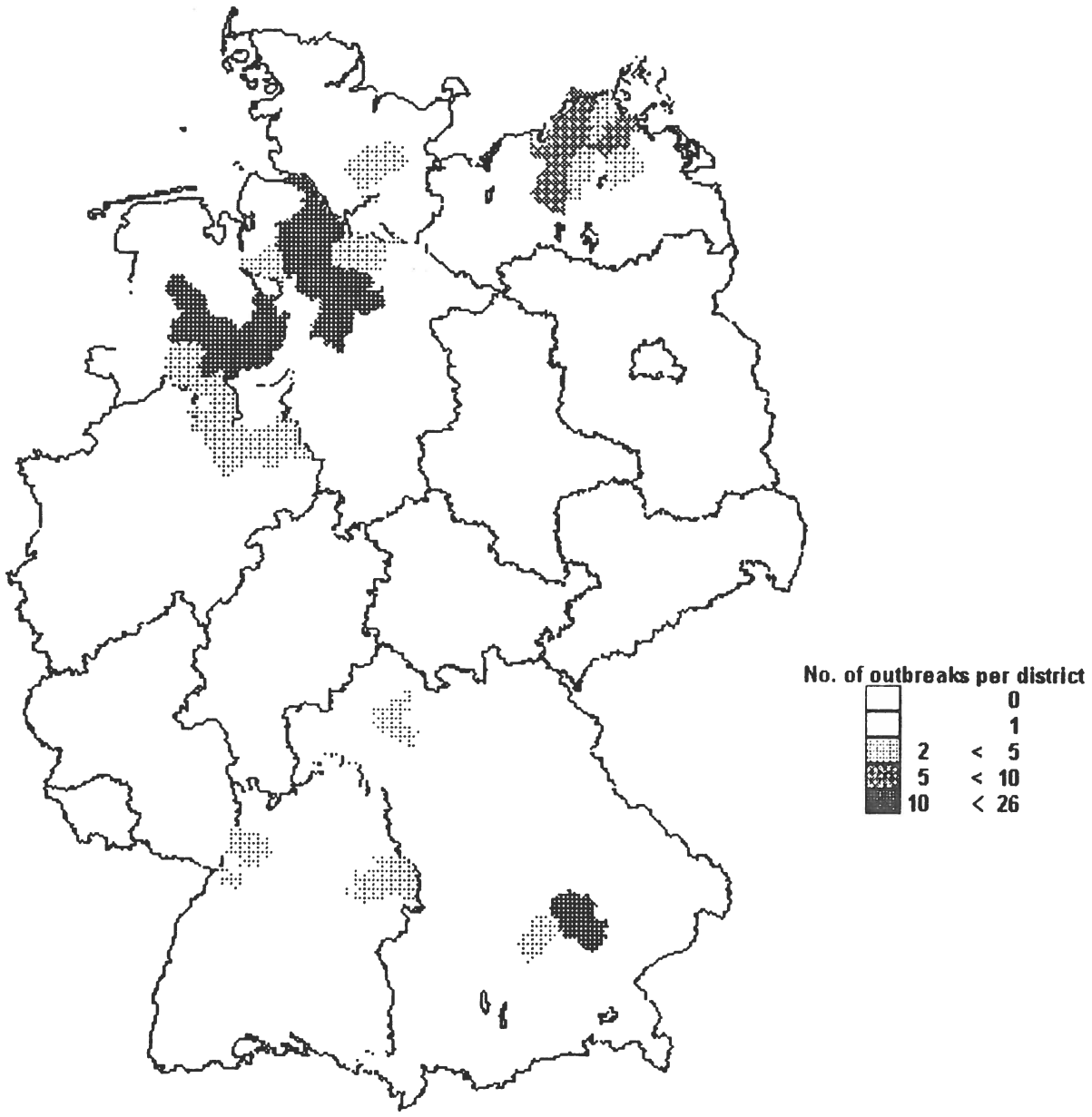

Fig.3 The spatial distribution of CSF outbreaks in Germany from 1993 to 1994

TYPING OF CSF VIRUS ISOLATES USING MONOCLONAL ANTIBODIES

Virus was isolated from almost all outbreaks of CSF in Germany and antigenic typing

was carried out at the Federal Research Centre. Using a panel of 23 monoclonal antibodies (Mabs) directed against epitopes of viral glycoproteins gp44 (E0) and gp55 (E2), respectively, it was found that the outbreaks were caused by three different types of the virus during the last two years. Type "Flanders '90" was first isolated from cases in Belgium in 1990. A second type, called "Lorraine '92" was first isolated in Lorraine, France in 1992 and then in Rhineland Palatinate and independently in Lower Saxony. The third type was detected when a few outbreaks occurred in the district of Schweinfurt, Bavaria and was named "Schweinfurt '93". The origin of this virus strain apparently was wild boar meat imported from Eastern Europe.

Table 1 shows that virus type Lorraine '92 was the most important during the two years and caused, with exception of a few primary cases, two epidemics of CSF in Germany. Typing of virus isolated from wild boar in different regions coincided with that from domestic pigs confirming that CSF in pig herds was related to the infection of wild boar in different areas. Virus type Flanders '90 has been so far only detected in wild boar shot or found dead in Mecklenburg Western Pomerania, whereas type Lorraine was isolated from wild boar in Rhineland Palatinate and Lower Saxony.

Table 1 Results of virus typing in Germany from 1993 to 1994

Type of virus	No. of cases the type identified	Ferderal state affected and number of types ( )	
		1993	1994
Lorraine '92	171	Lower Saxony (59) Northrhine Westphalia (7) Rhineland Palatinate (1) Mecklenburg Western Pomerania (2) Schleswig Holstein (4) Baden Württemberg (8)	Lower Saxony (67) Rhineland Palatinate (2) Bavaria (16) Baden Württemberg (4) Saxony (1)
Flanders '90	40	Lower Saxony (1) Mecklenburg Western Pomerania (13)	Mecklenburg Western Pomerania (26)
Schweinfurt '93	6	Mecklenburg Western Pomerania (1) Bavaria 4	Northrhine Westphalia (1)

EPIDEMIOLOGICAL RISK FACTORS FOR CSF OUTBREAKS

Source of infection

The epidemiological investigations carried out when outbreaks had occurred were frequently unsatisfying because of two recurrent problems:

1. A questionnaire sometimes proved helpful, however the information received from farmers was often insufficient or incomplete;

2. Epidemiological inquiries often yielded hints regarding the infection chains, although verification frequently remained impossible.

Thus, in a large proportion of the outbreaks (29 percent in 1993 and 42.7 percent in 1994) it was impossible to identify the source of the infection within the first few days afterwards. Sometimes, the origin of infection could only be established some weeks after confirmation of the outbreak.

In the past two years about 20 percent of the outbreaks could be attributed to the movement of animals. This route of infection was rather easily determined, especially in cases where an infected breeding herd and fattening herds were connected. The introduction of the disease via humans accounted for 6 and 11 percent of the outbreaks respectively thus representing an important spread factor. This included also some neighbourhood spread.

The proportion of outbreaks attributed to traffic by vehicles which had not been thoroughly cleaned and disinfected was around 5 percent in both years. This source of infection could sometimes only be identified later when other routes of infection could be excluded. Trucks used for the transport of pigs and lorries belonging to rendering plants were possibly carriers of the virus.

Direct but more often indirect contacts with infected wild boars was only the source of 6.8 to 9 percent of the CSF outbreaks. These cases were only observed in so called "wild boar risk areas" in Mecklenburg Western Pomerania, Lower Saxony and Rhineland Palatinate.

Swill feeding was one of the most important origins of primary infections, although only 3 and 1.7 percent of the outbreaks could be attributed to it in total.

Some other epidemiological factors are also influencing the risk of a disease outbreak.

The pig population density

The majority of all CSF cases in the last two years occurred in regions where the pig population density was high (166 cases corresponding to 78 percent). In Fig. 4, the geographical distribution of pig density is shown (data of animal head count 1992). Large farms are mainly situated in the north. As indicated in Fig. 3 and Fig. 4 as well, there seems to be a positive correlation between the number of CSF outbreaks (hatched areas) and the pig population density as soon as the virus has been introduced into a region. The extent of an epidemic increases when the density is high because of the intensity of movements in the pig industry including shipment of live pigs.

The herd size

Veterinary authorities as well as insurance companies are interested in knowing which type and size of pig holding bears a greater risk of introducing CSF. Statistics indicated a difference between affected farms located either in eastern or in western Germany. In western Germany large holdings were significantly more affected than smaller farms. This may in part be due to intensive trade with live pigs. The situation in eastern Germany regarding herd size appears to be quite different from that in western Germany. About 92 percent of pig holdings keep more than 1000 pigs, but only 50 percent of the affected farms belong to this size group. Small herds with up to 40 pigs contributed to CSF cases at a rate of 37 percent. These results indicate that very small farms or non-professional pig owners bear a higher risk of picking up the virus. One explanation is that those people are less aware of the requirements relating to prevention

of CSF especially in regions where wild boar is affected. No such conclusions could be drawn if farm size and number of cases were compared for all of Germany.

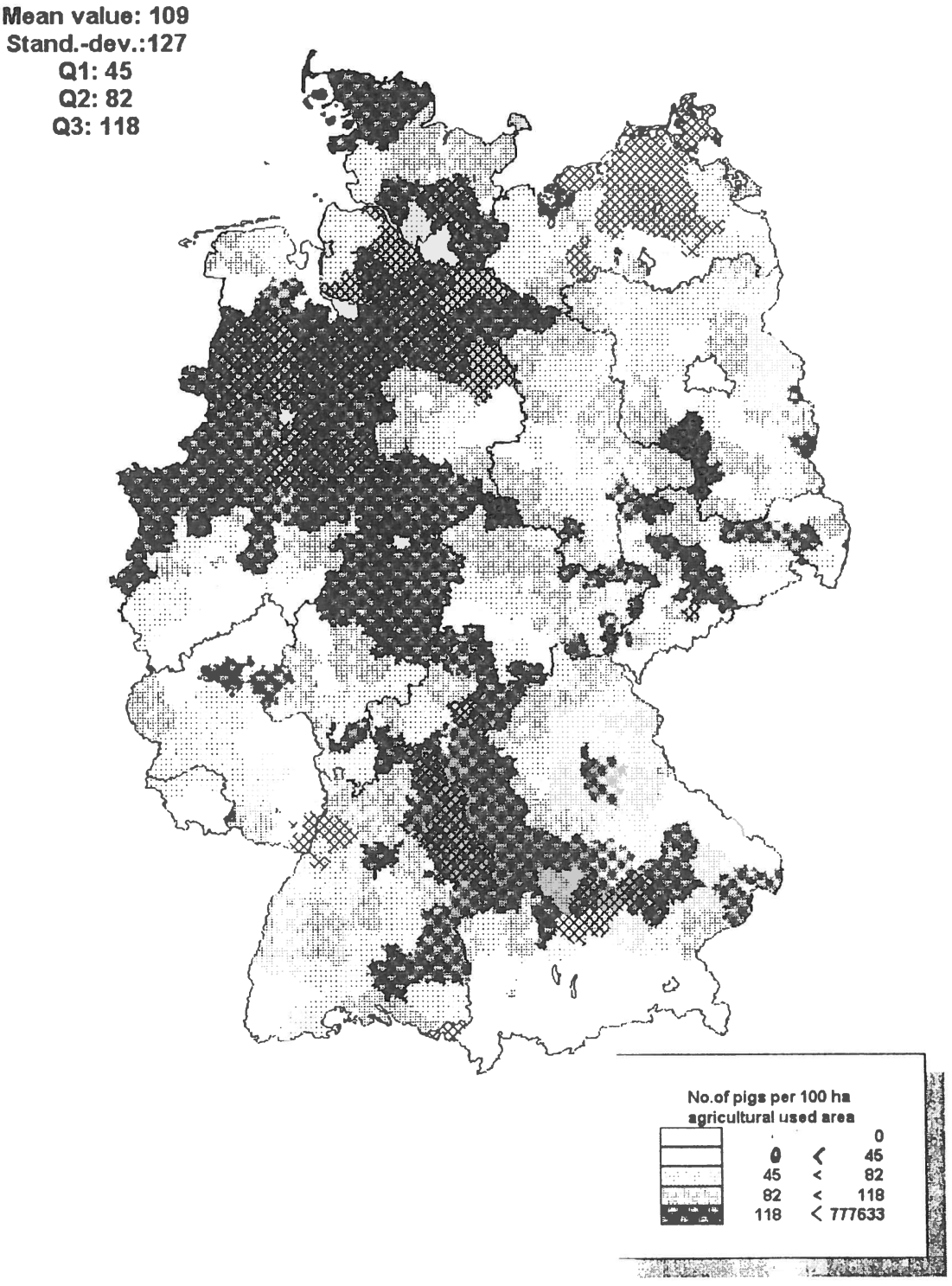

Fig. 4 Pig density and the occurrence of CSF cases in Germany from 1993 to 1994

Looking at herd size with respect to type of farming (breeding vs. fattening farms) we found that fattening farms with more than 200 pigs became more frequently infected than smaller ones. The problem was even greater for holdings with more than 1,000 pigs. This might be explained in part by the fact that these farms have to collect a larger number of piglets for fattening which originate from numerous breeding farms. Clearly, one piglet carrying the virus within a collection of animals would suffice to infect the whole group. We did not find such differences in breeding farms.

OTHER PROBLEMS RELATED TO CSF CONTROL AND PREVENTION OF CSF IN GERMANY

The structure of the pig industry in Germany comprising a large number of small breeding farms and hence an intensive movement of pigs via collecting centres or markets constitutes a problem in the prevention of spread of CSF should a primary infection occur. Furthermore, the spread of the disease due to other factors is supported by the high concentration of pig holdings in certain areas.

Problems also arise when protection and surveillance zones around outbreaks are established (Directive 80/217/EEC). Some zones overlap when a series of outbreaks within an area is observed. This results in a prolonged period of stand still and movement restrictions while pigs are still growing. A stand still period of six weeks is too long for breeders as well as fatteners. In Germany, a program was launched to buy and destroy excess pigs in these zones and to compensate farmers. This program was partly financed by the EU Commission.

Some problems were also encountered with serological screening on a random base in possibly infected herds. In nearly half of the outbreaks, CSF was diagnosed at the time when more than 10 percent of pigs had already developed antibodies while in the other half no or extremely few seroreactors were found (Table 2). This can partly be attributed to the indistinct signs of disease caused by the virus types involved in the current epidemics. Any delay in the diagnosis will increase the risk of further spread via trade of incubating pigs.

Table 2: Antibody prevalences of infected premises inGermany

Antibody prevalence in percent	Germany (73 cases)	
	absolute	in percent
0	28	38.4
0.1-1	0	0
1.1-3	2	2.7
3.1-5	2	2.7
5.1-10	5	6.8
10.1-20	13	17.8
> 20	23	31.5

Difficulties in CSF control arose particularly in regions were the disease occurred for the first time. Control measures differed from those in former epidemics when vaccination was included in the control program. There was limited experience in crisis centres in working with computers. Legislation as well as training has now been improved to ensure proper handling of outbreaks by local authorities.

CSF occurred in Germany in different regions and periods during the last two years. As a political measure, affected regions were excluded from intracommunity trade. As a result, fresh meat and markets were lost. Tests prescribed to check lots of pigs before movement to a slaughterhouse were difficult and time consuming.

Compared with previous epidemics, the current CSF situation in Germany is of minor importance with regard to number of cases. However, the economic impact has drastically increased and has been a disaster for the whole agricultural industry in affected regions.

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EVALUATION OF OPTIMAL SIZE OF RESTRICTION ZONES IN DISEASE CONTROL WITH PARTICULAR REFERENCE TO CLASSICAL SWINE FEVER

M ROBERTS*

Classical swine fever (CSF) has been a cause of severe economic loss to the European pig industry. It has traditionally been controlled by vaccination with and without the slaughter of infected stock. A study of the economic impact of the disease and a cost benefit analysis of various control strategies was carried out in the mid-1970`s on behalf of the Commission. It clearly demonstrated the advantages of eradicating classical swine fever from Europe and advocated a move towards a non-vaccination policy and control through slaughter. Vaccination ceased in 1989. This approach is reflected in the veterinary Directives adopted for the realisation of the internal market. These lay down a common policy for disease control based on identifying infected herds and imposing movement controls and surveillance procedures in protection zones and surveillance zones around the outbreaks.

Directive 80/217 EEC contains the legal basis for action in event of an outbreak of classical swine fever. Its minimum provisions are:-

- slaughter of all stock on an infected holding
- cleansing and disinfection of the infected holding
- establishment of a protection zone of radius of 3km for not less than 15 days
- establishment of a surveillance zone of radius of 10km for not less than 30 days
- prohibition of the movement of pigs within the protection zone for 21 days
- prohibition of the movement of pigs within the surveillance zone for 7 days
- movement of pigs after this time to be
    - directly to slaughter
    - authorised by the competent authority
    - preceded by clinical inspection
- serological and clinical examination of pigs within the restricted zones before the lifting of restrictions
- epidemiological enquiry to be carried out
- prohibition of vaccination except for under exceptional conditions
- meat derived from animals from restricted premises to be processed in accordance with Directive 80/215/EEC

The Directive was adopted in 1980 and the embargo on vaccination apart from emergency vaccination was added in 1989.

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*Veterinary Officer, Department of Agriculture for Northern Ireland, Veterinary Service, Dundonald House, Upper Newtownards Road, Belfast, BT4 3SB

Various problems have become apparent in the restriction zone strategy particularly in areas where there are large numbers of pigs and pig units. In areas where there are many pig units in close proximity it is difficult to prevent the infection spreading from farm to farm. This has led to preventative slaughter of herds at risk from neighbouring infected premises and restrictions being in place for many weeks or months as further infected premises are detected. The maintenance of movement restrictions for any length of time means that breeding units become overstocked and fattening units are unable to dispose of pigs which have reached slaughter weight. This in turn has led to farmers taking matters into their own hands and moving pigs out of the restricted areas illegally.

To deal with overstocking problems and prevent illegal movements the Commission has financed the purchase of surplus pigs under market support measures. The pigs are slaughtered and the carcasses are rendered. Due to the long duration of recent epizootics of CSF in Belgium and Germany the cost of continuing to implement Directive 80/217/EEC and market support measures has become prohibitive. The estimated costs of recent epidemics in Belgium and Lower Saxony are 74.9 million ECU and 750 million DM respectively. It has become a matter of considerable importance to improve the efficiency and reduce the cost of the present disease control strategy.

Without doubt the restriction zones are among the most costly and unpopular aspects of the present strategy. There are two possible approaches to reducing the costs incurred in restriction zones:-

- Reduce the DURATION of a restriction zone by improving the detection of infected herds
  and in particular reducing the time period from initial herd infection to detection by laboratory
  tests or clinical surveillance. Early detection helps to prevent further spread
- Reduce the AREA under restriction.

This paper discusses the duration and area of restriction zones using data which has been obtained from three major epizootics of CSF which have occurred in Europe in the last four years.

Belgium 1990

An epizootic which began near Wingene in West Flanders. 113 outbreaks occurred between
January and October. Data from 105 outbreaks is included in the following graphs.

Belgium 1994

A total of 45 outbreaks occurring in East Flanders between January and July. The primary outbreak in this area resulted from contact with an outbreak located in West Flanders. Data from 44 outbreaks is included in the following graphs.

Lower Saxony 1993/94

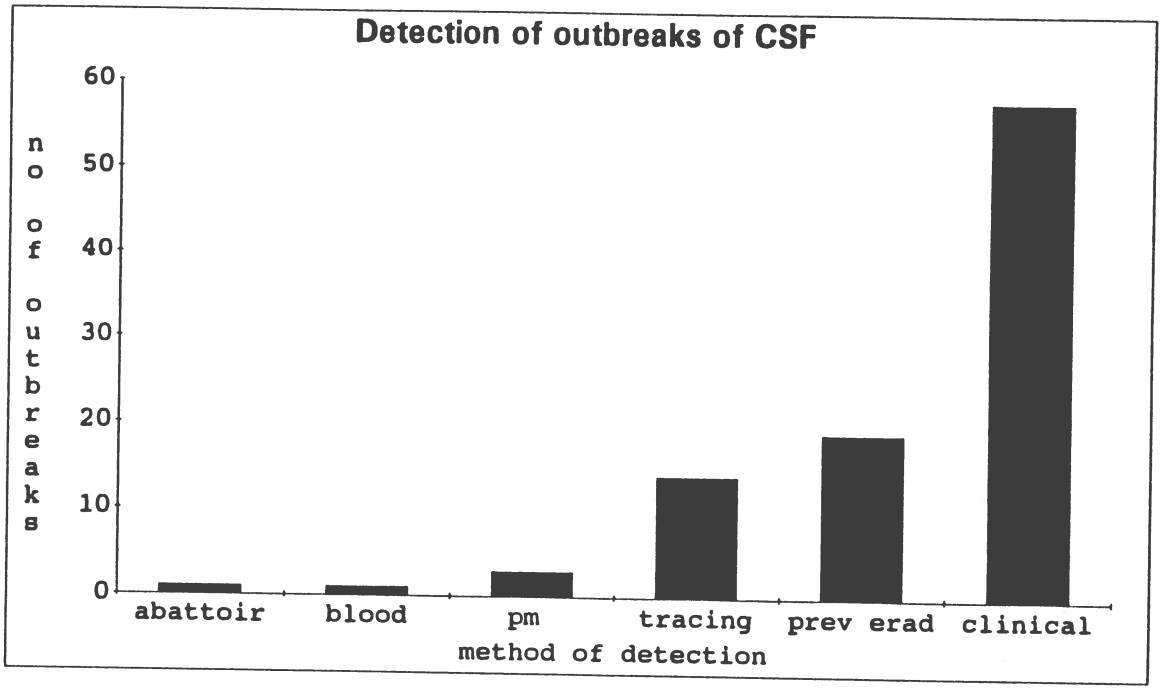
Approximately 60 outbreaks between October 1993 and July 1994. The epizootic began in the Damme area when 6 different farms received infected pigs from another part of Germany. Data is incomplete.

DATA

Duration of a restriction zone

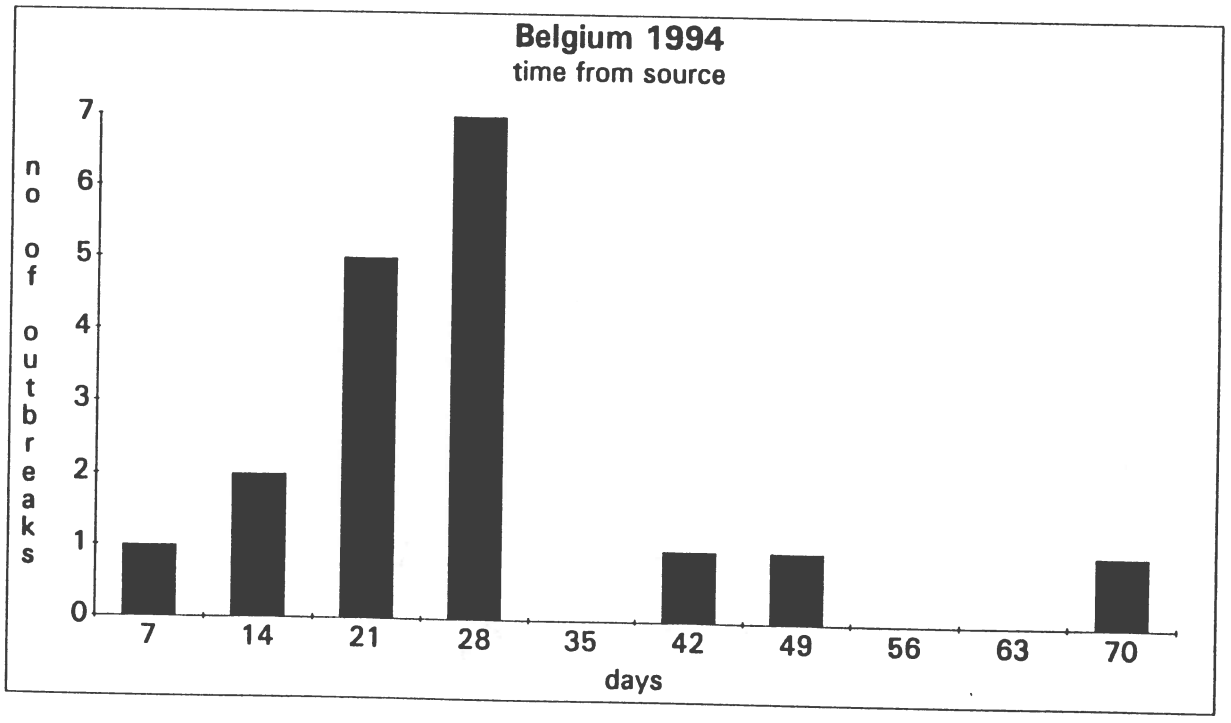
Graph 1 Clinical Detection of CSF

Observation of clinical signs of CSF is the most common method of detection of CSF.



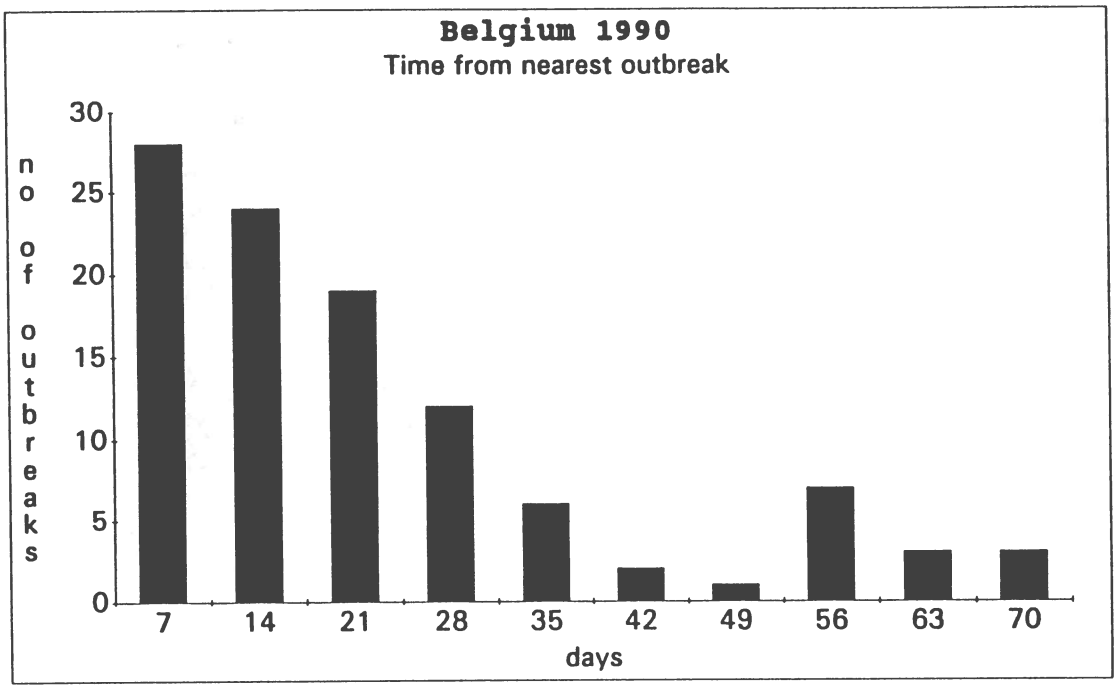
Graph 2 The time elapsed between confirmation of an outbreak and confirmation of the suspected source -Belgium 1994

Data includes outbreaks detected by clinical observation but not those detected through preventative eradication.(18/44 outbreaks)

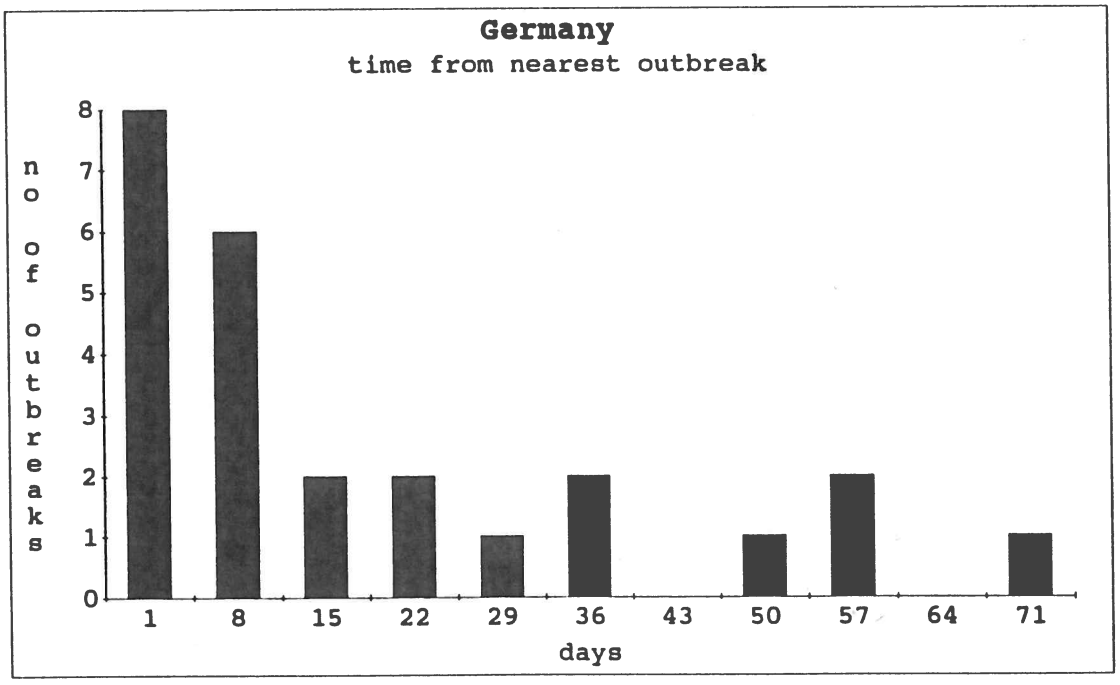


Graph 3 The time elapsed between confirmation of an outbreak and confirmation of the nearest outbreak-Belgium 1990

No data is available regarding the suspected source of an outbreak or which outbreaks were detected through preventative eradication. The graph assumes that the most likely source of infection is the nearest outbreak. In areas of high pig density with clusters of infection this is highly probable and while it may not be as accurate as measuring the time from the source outbreak it is still possible to state that 84 % of outbreaks occur within 35 days of the nearest outbreak.



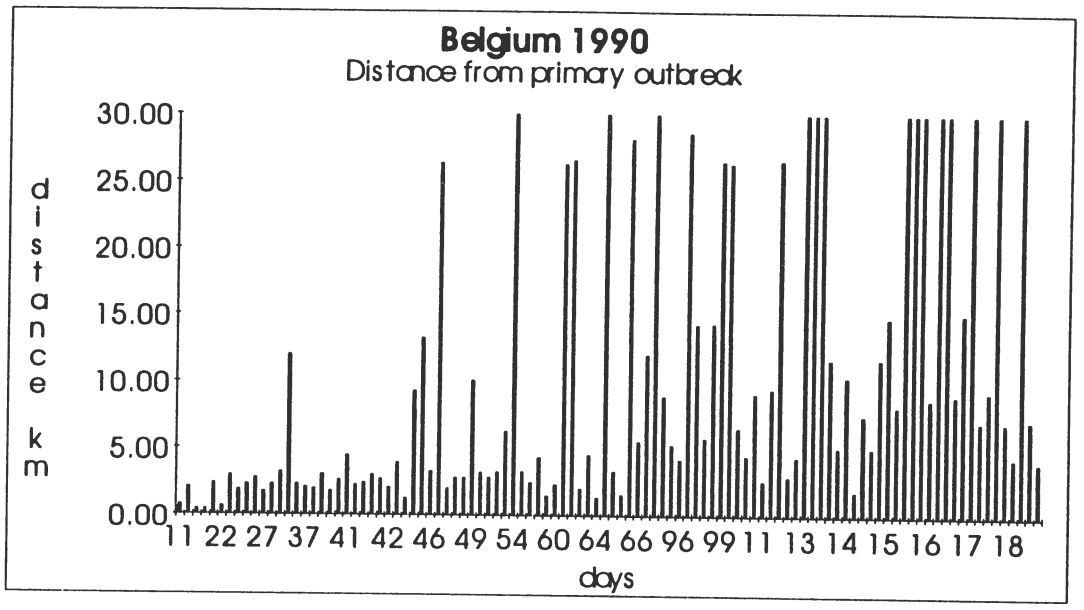
Graph 4 Time between an outbreak and the nearest outbreak Lower Saxony 1993/94
Data from 25/60 outbreaks.



Area of a restriction zone

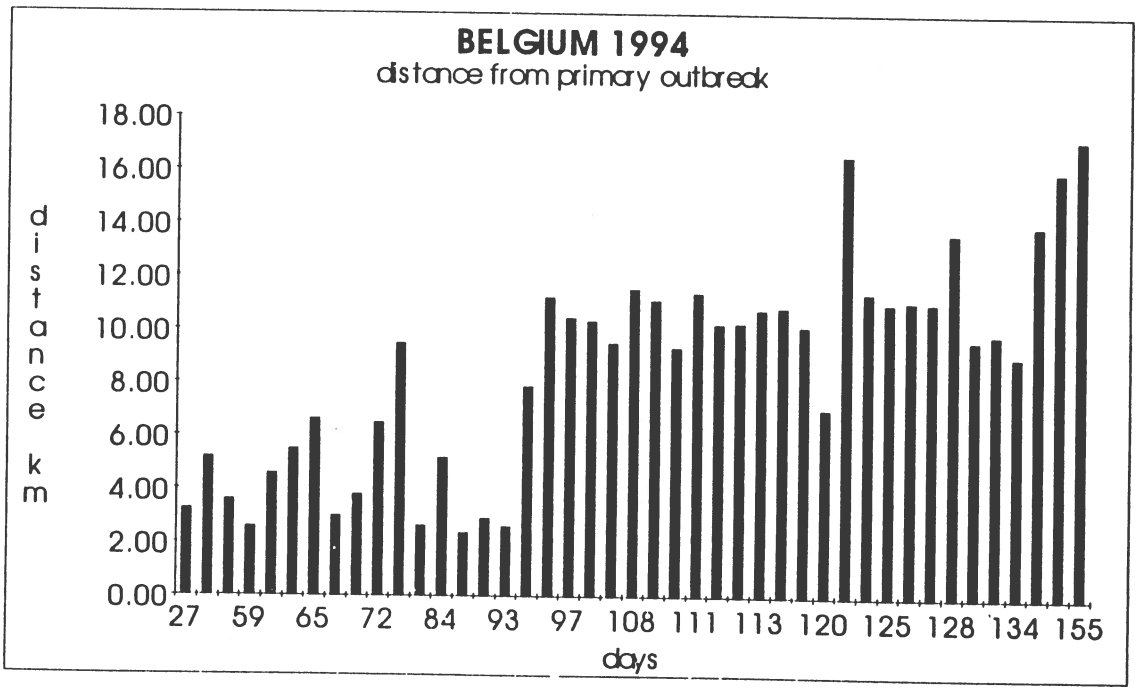
Graph 5 Belgium 1990 Distance from the primary outbreak.

In the first 6 weeks of the epizootic all outbreaks occur within 4km of the primary outbreak except for one outbreak which occurs at a distance greater than 10km (ie outside the restriction zone.) After this secondary clusters appear at varying distances from the primary outbreak. All outbreaks occur within 15km or greater than 25km from the primary outbreak.



Graph 6 Belgium 1994 Distance from primary outbreak

There are a smaller number of outbreaks in this epizootic All outbreaks occur within 4km of the primary during the first two months of the epizootic. This is followed by the formation of secondary clusters. One particularly large cluster occurs at a distance of about 10-11km from the primary. All outbreaks occur within 18km of the primary outbreak.



Lower Saxony

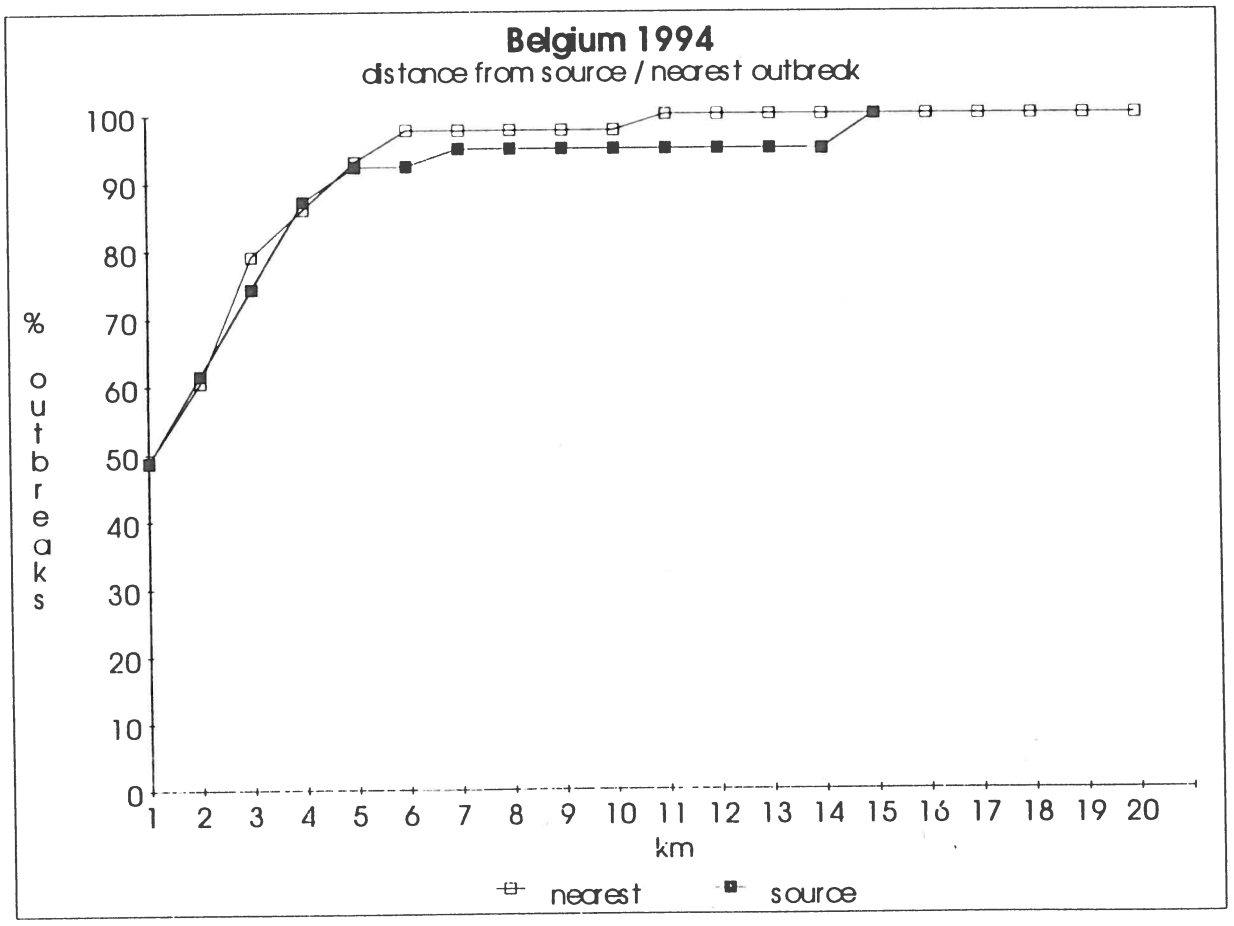
In Lower Saxony there were six primary outbreaks resulting from the movement of a batch of infected pigs from Baden-Wurttemberg. It is not possible to produce a graph but secondary outbreaks initially occurred within approximately 4km of a primary outbreak. Subsequent outbreaks appeared at distances up to 60km from the primaries.

As the epizootic progresses secondary clusters of outbreaks appear. In order to establish the optimal size of restriction zones to be placed around these outbreaks it becomes necessary to look at the distances between outbreaks within these clusters .
The optimal size of restriction zone will depend upon
- the distance of an outbreak from the suspected source of infection
- or the distance from the nearest outbreak since this will determine whether or not the holding will be contained within a restriction zone.
In areas of high pig density the nearest outbreak and the source are likely to be one and the same.

Graph 7 Belgium 1994 Distance of an outbreak from its suspected source or from the nearest outbreak

Data from 39/44 outbreaks

Because the nearest outbreak and the suspected source are the same outbreak in nearly all cases there is very little difference between the two plots on the graph.
The graph shows that 50% of outbreaks occur within 1km of the suspected source and that all the outbreaks occur within 6km of the suspected source.

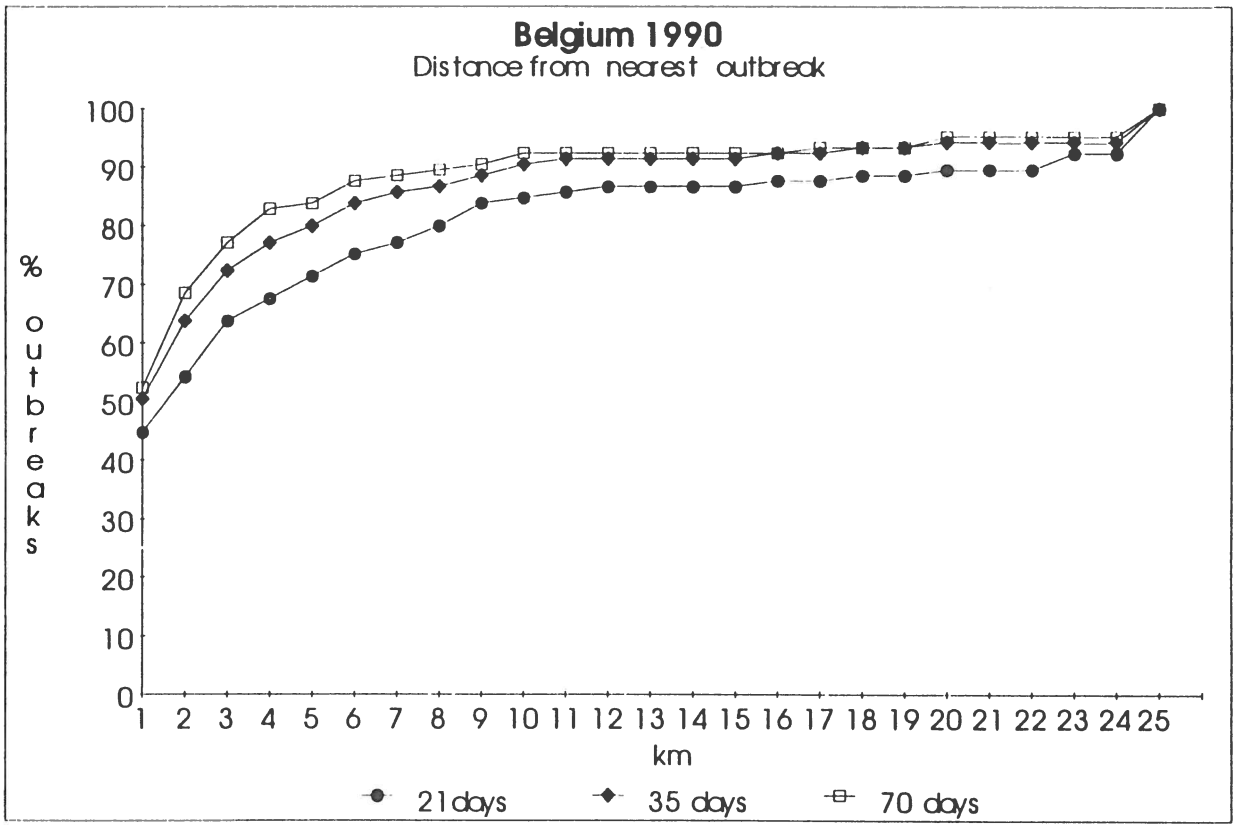


Graph 8 Belgium 1990 Distance of an outbreak from the nearest outbreak.

No information is available regarding the source of infection in this epizootic. Due to the very long duration of this epizootic and the very high density of outbreaks it became necessary to introduce a time limit when selecting the nearest outbreak. (A nearby outbreak cannot be considered to be a possible source of infection for a holding if it occurred over five months ago). The nearest outbreak is defined as the nearest outbreak which occurred within the previous 21,35 or 70 days.

- 21 days is the minimum duration of a surveillance zone.(14 days + 7 for clinical inspections and sampling)
- 35 days is the minimum duration of a protection zone (30 days +5 days for clinical inspections and sampling)
- 70 (67) days is the longest recorded elapsed time between an outbreak and its source. (Belgium 1994)

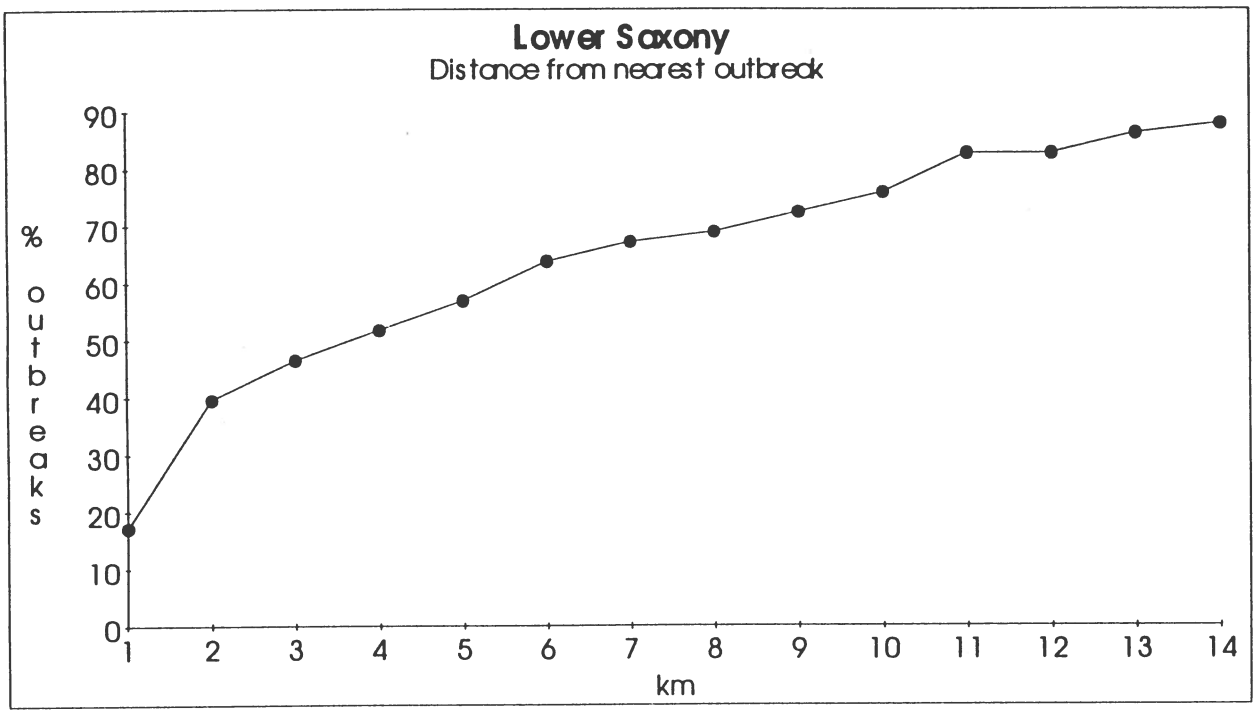
The graph is similar to the one for Belgium 1994. 50% of outbreaks occur within 1km of the nearest outbreak. Of outbreaks occurring within a 10km restriction zone, 94% occur would occur within a 6km restriction zone. Nearly all outbreaks occurring within 70 days occur within 35 days of the nearest outbreak regardless of the distance between outbreaks.



Graph 9 Distance of an outbreak from the nearest preceding outbreak. Lower Saxony

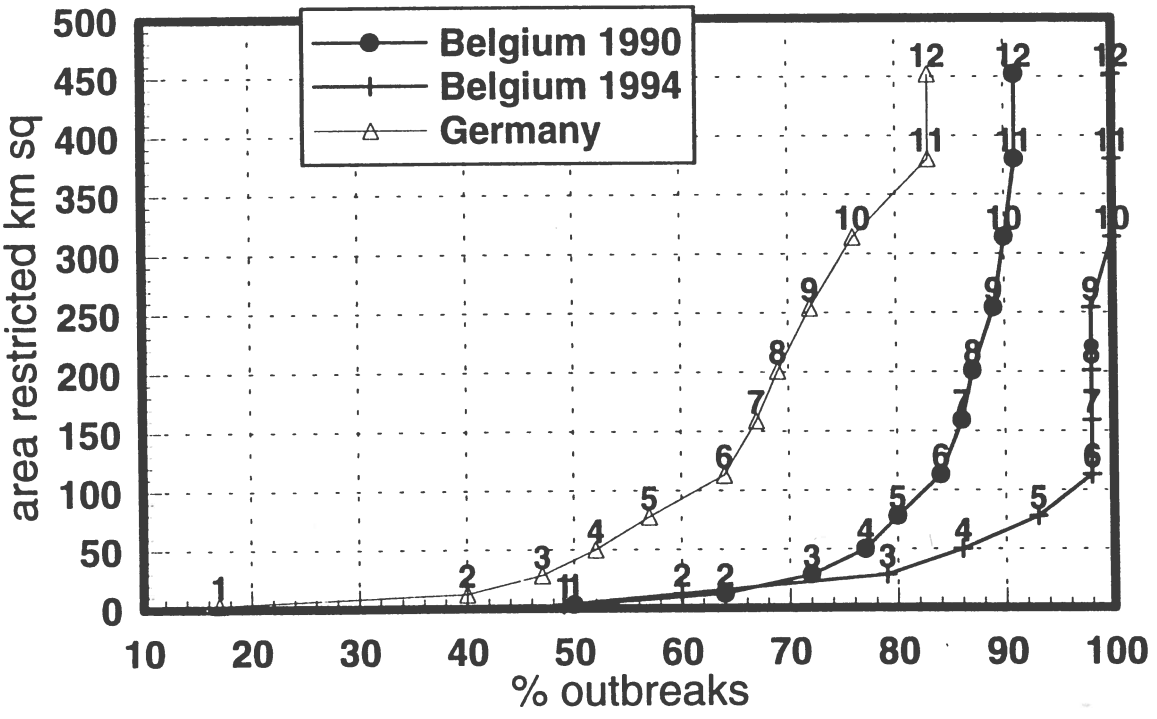
Data from 58 outbreaks

While the graphs for Belgium 1990 and Belgium 1994 are similar the equivalent graph for Lower Saxony shows that a much smaller % of outbreaks occurs within 1km of the nearest outbreak. and a larger % of outbreaks occur at distances greater than 10km from the nearest outbreak. While there is a marked reduction in the number of outbreaks occurring at distances greater than 6km in Belgium this does not occur in Lower Saxony



Graph 10

Graphs 7,8 and 9 show the % of outbreaks which fall within a certain distance of another outbreak. This distance is equivalent to the radius of the zone which would be required to be drawn around each outbreak in order to contain that % of all of the outbreaks.
Graph 10 contains essentially the same information but instead of the radius of the zone the area of the zone required to contain a certain % of outbreaks is shown on the graph.
As the area of a restriction zone increases there is a diminished return in terms of the increase in the % of outbreaks contained.



DISCUSSION

At the beginning of this paper the question was raised, Is it possible to reduce the costs of disease control by reducing either the duration of restrictions or the area under restriction ?

Duration

The duration of a restriction zones should be at least equal to the time taken for the development of observable clinical signs on an infected farm or the time taken to develop a detectable serological response in the herd.
The data given in this paper indicates that in the on farm situation:-

- detection of CSF relies heavily upon clinical observation(graph 1)
- outbreaks are not likely to be detected until 3-4 weeks after confirmation of the source outbreak (graph 2)
- most outbreaks could reasonably be expected to occur within 35 days of an earlier outbreak although a small number of outbreaks will occur up to 70 days later (graphs 2,3&4)

While detection of CSF relies upon the observation of clinical signs the possibilities for reducing the duration of the restriction zone are limited. Indeed the above data would suggest an increase in the duration of the zone to at least 35 days.

Laboratory testing could be expected to improve the detection of infected herds and so reduce the duration of a restriction zone, but recent work at the Community Reference Laboratory for CSF has shown that a serological response will only become detectable shortly before the onset of clinical signs.(Depner 1994). Furthermore it is the opinion of the scientific veterinary committee that a period of at least 35 days should elapse after the last possible date of contamination of an infected holding before serological sampling is carried out in order to ensure that a detectable serological response has developed.

While an increase in the duration of the restriction zone to at least 35 days is indicated for both clinical and serological detection of disease, in practice the occurrence of secondary outbreaks results in an area being under restriction for many months regardless of the duration of a zone around a particular outbreak. Increasing or decreasing the duration of restrictions by a few days is unlikely to have a significant effect on the costs involved.

Area

If the duration of a zone cannot be decreased, consideration must then be given to reducing costs by reducing the size of the restriction zone. However the question may not be what is the optimal size of restriction zones but should restriction zones be used at all?

Restriction zones are used to prevent spread of infection out of an area by containing farms which may be infected but undetected and to concentrate resources in an area where these undetected but infected premises may be located. The major methods of spread of disease in these particular epizootics are the movement of animals, equipment or staff (contact spread) and possibly by airborne spread. Spread of CSF by wildlife or swill-feeding is not thought to be significant in these particular epizootics. Although airborne spread is assumed to be possible over very short distances (between adjacent pig houses) it is not held to be of importance over any great distance. If the major movement of this disease is through direct and indirect contacts,

tracing of these contacts through epidemiological enquiry and restriction of high risk contacts would appear to be a more appropriate method of disease control than use of restriction zones. However field experience has shown that in areas of high pig density the use of restriction zones is extremely important.

High density areas

In areas of high pig density such as Damme and Wingene the disease would appear to spread uncontrollably in clusters around primary outbreaks. In both Belgian epizootics approximately half the outbreaks occur within 1km of an earlier outbreak with the 96-100% of outbreaks occurring within 6km of an earlier outbreak. (graphs 7&8). It would seem reasonable to assume that this type of spread is due either to short distance airborne spread or to local contacts which are unavoidable and untraceable and that consequently restriction zones are appropriate to deal with this situation. Since very few outbreaks occur outside an existing restriction zone(ie at distances greater than 10km from another outbreak) in the Belgian epizootics, the zones could be considered to be reasonably effective at containing spread of the disease to within that area and eradication of CSF in a high density area would appear to be possible within the framework of Directive 80/217 (Vanthemsche 1994). Outbreaks occurring outside restricted areas (as happened in Belgium in 1990) tend to occur after restrictions have been in place for many months and are probably due to illegal activity by disgruntled farmers.

At present a restriction zone of a minimum radius of 10km is used but the data presented in graphs 5, 6,7and 8 would suggest that a reduction from 10km to 6km could be considered. Graph 7 indicates that virtually all outbreaks occur within 5km of the suspected source of infection. Graph 5 shows that for 42 days following the primary outbreak in Belgium 1990 all secondary outbreaks occur within 4km of the primary outbreak. Graph 6 shows that for the 60 days following the primary outbreak in Belgium 1994 all secondary outbreaks occur within 6km of the primary outbreak. Graphs 7& 8 indicate that this reduction would not significantly increase the number of outbreaks which would lie outside an existing restriction zone at the time of detection.

Low density areas

Graph 7 shows the distances between outbreaks in Lower Saxony. It can be seen that this graph shows certain differences from the equivalent graphs for the Belgian epizootics. These differences are possibly the result of the movement of the disease from a region of high pig density(Damme) to one of lower pig density(North Lower Saxony) . It is reasonable to suppose that the17% of outbreaks occurring within 1km of another outbreak lie within the high density area of Damme and that the 24% of outbreaks occurring at least 10km from another outbreak are situated in the area of lower pig density to the north. The division of outbreaks into local or long distance implies a different method of spread in the different areas. While local spread could be expected in areas of high pig density due to unavoidable contacts and possibly airborne spread, the spread of the disease over longer distances is more likely to be due to movements of personnel, equipment and animals. This could be expected to affect the choice or effectiveness of a disease control strategy.

The use of a 10km restriction zone may be appropriate in the high density area of Damme but this is not an effective method of dealing with the 24% of outbreaks which lie at a distance greater than 10km from another outbreak. An initial response might be to use larger restriction zones but even if these could be enforced they would be prohibitively expensive.

Instead an argument for a decrease in the size of the zones can be made for the following reasons. Reduction of the zone size may allow more effective implementation of controls within that area and so prevent or reduce the number of outbreaks occurring outside the area. Spread of disease over distances greater than 6km is more likely to be of the contact type due mostly to the movement of pigs or dealers and other indirect contacts which could be traced. Epidemiological tracing in combination with restriction of "high risk" contacts may make more efficient use of resources than in applying restriction zones. Graph 9 would go some way towards showing that once the radius of a zone is increased over 6km the resulting increase in area of the zone makes this an extremely expensive method of dealing with a relatively small number of outbreaks. At what point does the cost of the area under restriction outweigh the benefits in terms of the number of outbreaks contained ?

Epidemiological factors

Disease which appears in holdings which were placed under restriction before or shortly after becoming infected is unlikely to have spread out of the immediate area and a six km zone should be more than sufficient to deal with local spread. However in the case of a primary outbreak where no information is available as to how long the disease has been present in an area it may be advisable to use a larger zone since the disease may have spread from secondary to tertiary outbreaks. Conflicting evidence for the use of larger zones in the case of a primary outbreak is given in graphs 5&6. These show that subsequent outbreaks in the epizootic appear up to 15km (Belgium 1990)or 18km (Belgium 1994) from the primary outbreak which might suggest the use of a larger primary zone. However the graphs also show that all outbreaks (except for one outbreak at a distance of greater than 10km) which occur in the 60 days following the primary outbreak occur within 6km of the primary outbreak which may suggest that a 6km zone is adequate.

Direction

It should be noted that in Lower Saxony, in Belgium 1994 and in the first few months of the Belgium 1990 epizootics there is a pronounced movement of the disease in a northerly and east erly direction which would initially suggest airborne spread. Alternatively movement of disease could be explained by factors unique to each epizootic, such as topography, trading practices, fluctuations in pig density, or the application of control measures.

In Lower Saxony certain topographical features such as a range of hills, a lake, major roads and a large city in combination with the movements of particular dealers and a marked drop in pig density could provide an apparent explanation for the north and easterly movement of the disease but may not provide an adequate explanation for the absence of disease to the south.
The situation in Belgium is less clear. Without further information it is impossible to do more than speculate as to whether the direction of spread is significant and if so what the cause may be.

CONCLUSION

While restriction zones as applied at present may be effective in regions of high pig density their use may be questionable in regions of low pig density where due to the increasing distance between outbreaks epidemiological tracing becomes comparatively more important as a method of disease control. An argument can be made for a reduction in the radius of restriction zones from 10km to 6km in regions of both high and low pig density.

With regard to the duration of the zone, while detection of outbreaks depends upon the observation of clinical signs a restriction zone of at least 35 days would be desirable.

The direction of spread of disease may or may not be significant but requires further investigation as does the potential for airborne spread.

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TEMPORO-SPATIAL EVALUATION OF MORTALITY EVENTS IN A 20,000 CAGE-LAYER OPERATION

N TABLANTE[1], J-P VAILLANCOURT[1], S W MARTIN[1] AND M SHOUKRI[1]

The vast majority of today's egg production comes from cage-layer operations. These cages have increased productivity and the benefit-cost ratio (North and Bell, 1991). However, it is usually difficult, if not impossible, to observe birds kept in these conditions. Hence, health status is normally evaluated based on egg production and mortality figures.

Mortality in egg-layers varies considerably from one flock to another. Producers usually set a "target" or "standard limit" on the mortality rate (0.1 to 0.2% per week or 0.5 to 1% per month on average). However, for the same mortality rate, the causes and distribution of mortality may vary considerably depending on the flock.

The objective of the study was to determine whether clustering of mortality events occurs in cage-layers. The temporal and spatial distributions of mortality events were recorded to provide a better understanding of different conditions as they occurred during the different stages in the life of a commercial layer flock. The purpose of this proceeding article is to present the approach used for this study. Cage layer fatigue, mainly associated with hypocalcemia, is one of the most prevalent problems in cage layers and is the condition used to illustrate the analytical approach.

MATERIALS AND METHODS

Description of Facility

The subject of this study was a leghorn flock which was part of a 5-barn multi-age/multi-breed commercial layer operation in Ontario. The flock was housed in a single-floor barn consisting of four banks of two-deck stair-step cages. There were 4944 wire-mesh cages, each holding 4 hens. The feed was mechanically distributed by drag-chains while water was provided through cup drinkers that were placed two cages apart (i.e. 8 birds per drinker). Overhead incandescent bulbs were used for lighting which was controlled by an automatic timer. The barn utilized negative pressure ventilation. Eggs were mechanically gathered by canvas egg belts.

Protocol

In order to trace each dead hen to its cage of origin, each cage was assigned a number (from 1 to 4944). At the start of the study, two tags were placed on the upper right-hand side of each cage using ordinary 3/4 inch paper clips which had been numbered with permanent ink.

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[1] Department of Population Medicine, Ontario Veterinary College, University of Guelph, Ontario, Canada N1G 2W1

Farm personnel were asked to attach a tag (clip) to the dead hen's comb corresponding to the cage where this hen was found. Because maintaining 4 hens per cage was a standard practice on the farm, a live hen was immediately transferred from one cage located on the farthest end of a row of cages to a cage where a mortality had occurred. In order to keep track of the transfer of hens from one cage to another, a corresponding tag was moved from a live hen's cage of origin to a cage where it was transferred. This tag was placed on the left-hand side of the receiving cage. This study was initiated at 21 weeks of age, one week after the hens were transferred from a growing facility to the egg-laying operation, and ended when birds where 54 weeks old. Mortalities collected by farm personnel on a particular day were placed in a plastic bag with a corresponding day/date label and kept in a freezer until they were picked up during the weekly visit to the farm. At the time of the farm visit, bird transfers were also recorded and used or missing tags were replaced.

Aside from the collection of weekly mortalities, the farm visits also involved the monitoring of temperature, humidity, and ammonia levels. These environmental parameters were measured weekly in the middle of the barn between 9:00 and 10:00 AM at bird level using a "fast response digital hygrometer/thermometer" (Fischer Scientific, 1200 Denison Street, Unionville, Ontario L3R 8G6, Canada) (Temperature and Humidity) and a Gastec gas gauge with an ammonia low range (0-30 ppm) detector tube (Gastec Corporation, 6431 Fukaya, Ayase-City, 252, Japan).

Post-mortem examination

Each dead hen was subjected to a detailed post-mortem examination at the Ontario Veterinary College (OVC). A diagnosis was made on the basis of gross lesions whenever possible. Cases that required confirmatory diagnosis were evaluated histologically. The presence of a depleted bone cortex resulting in a weak skeleton without any other lesions was the basis for the diagnosis of cage layer fatigue.

Data Analysis

Diagnoses were recorded on a customized necropsy report form. Each disease or condition was assigned a numbered code which was then entered into a computer for statistical analysis (Statistix, Version 4.0, Analytical Software, P.O. Box 12185, Tallahassee, FL 32317-2185). Temperature, humidity and ammonia readings were also entered into a computer using the same statistical software program and analyzed to determine whether they were associated with mortality. Time series analyses (time series plots, auto-correlations and cross-correlations) were used to assess the relationship between total mortality and ammonia level, temperature, and humidity. Rates for specific categories of mortality were not considered for this paper. The mortality rates in the upper and lower deck cages were calculated and analyzed statistically using the chi-square test. A statistical evaluation of clustering was performed for all categories of mortality. The analysis for the cage layer fatigue category (subsequently referred to as "layer fatigue") is presented in this paper.

Cage numbers were entered on a spreadsheet file (Lotus 123, Lotus Development Corporation, Cambridge, Massachusetts, USA) in a pattern similar to the arrangement of cages in the barn. Each of the four banks of cages (each bank consisting of four rows of 309 cages), was set up vertically under a specific variable pertaining to cage location (i.e. bottom left, top

left, top right, bottom right). The number of deaths attributed to layer fatigue in a cage was entered as "0" if no death occurred, "1" if 1 death occurred, or "2" if 2 deaths occurred). No more than two cases of layer fatigue were recorded within the same cage in this study. Formulas were created to assess whether, for a given cage with a death due to layer fatigue, a similar death occurred in an adjacent cage or multiple deaths within it. If a cage on either side (horizontally or diagonally for either top or bottom cages) had a death due to layer fatigue or if the same cage had more than one such case, that cage number was given a "1". A cage with no death within or adjacent to it was given a "0". The total number of cages with deaths due to layer fatigue and the total number of cages without such deaths were also calculated for each bank of cages. Likewise, the total number of cages adjacent to a cage with death due to layer fatigue and the total number of cages adjacent to a cage without layer fatigue death were calculated (Fig. 1). Testing for clustering was done using a two by two table for each bank of cages with the total number of cages with and without deaths due to layer fatigue against the total number of cages with and without deaths due to layer fatigue in adjacent cages. A chi-square statistic and an odds ratio were calculated for each bank.

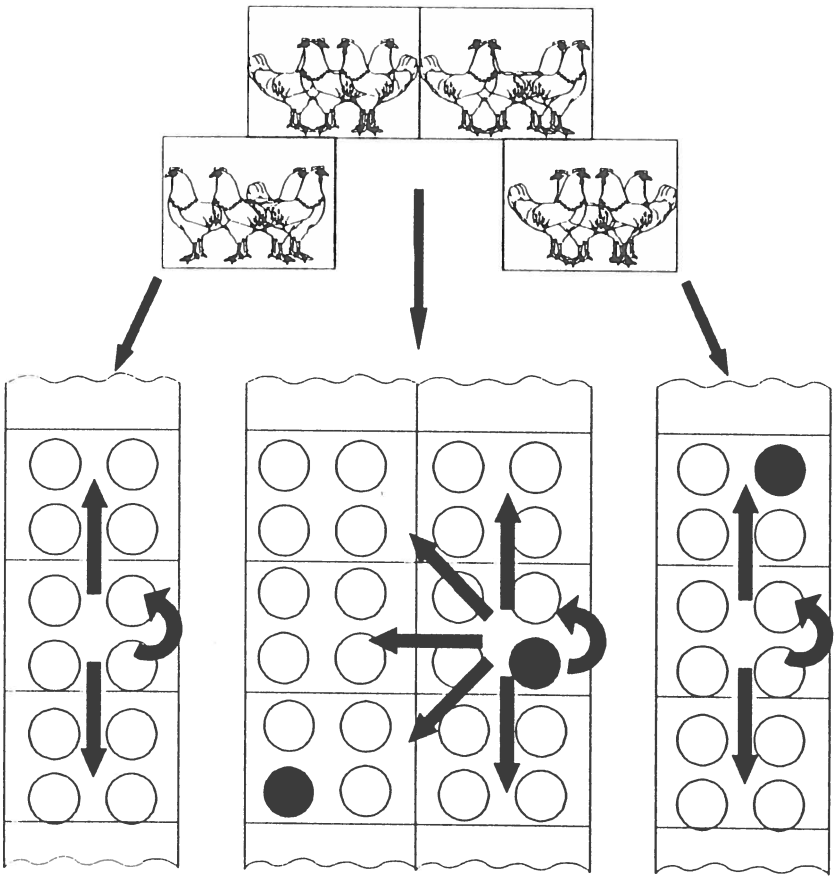

Figure 1: One bank of two-deck stair step cages. Clustering present if a case of a specific mortality (●) is adjacent or within the same cage as a similar case.○ represents a live bird or a bird that died from a different category of mortality.

RESULTS

The overall mortality rate was 6.28% during the study period (20 to 54 weeks of age) (Fig. 2).

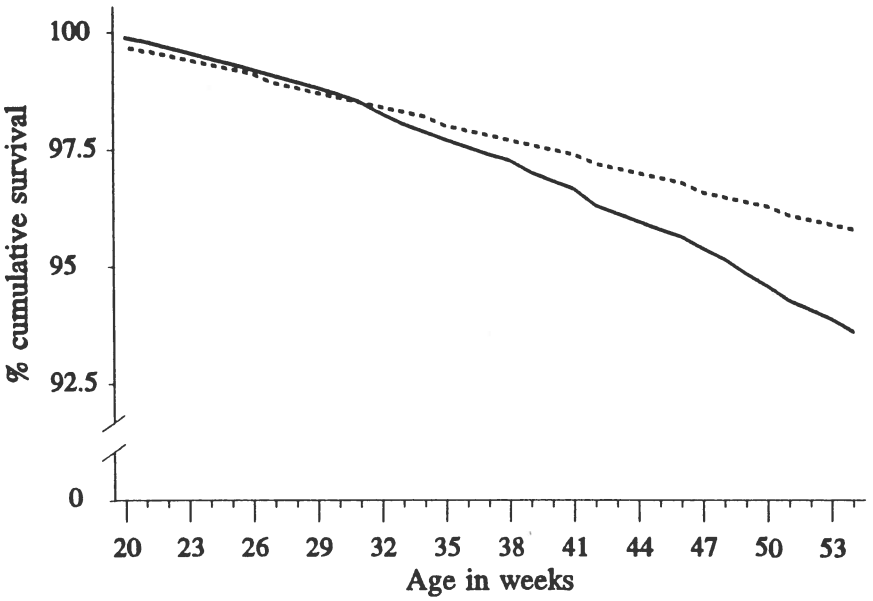

Figure 2: Cumulative survival (%) for a standard Babcock flock (expected results: ·····) and the investigated flock (——)

Egg peritonitis accounted for the highest percentage of total mortalities from 21 to 54 weeks (21.4%) followed by hypocalcemia (15.5%), neoplastic disease (13.9%), traumatic injury (10.0%), prolapse (7.8%), emaciation (6.6%), cannibalism (6.6%), impacted oviduct (5.1%), and egg bound (4.3%). Miscellaneous conditions such as fatty liver hemorrhagic syndrome, cystic oviduct, internal laying, and cloacal impaction comprised the remaining mortalities.

The proportional mortality ratio for most categories of death varied over time. For example, layer fatigue represented only 5.6% of all deaths during the early stage of production (20-29 weeks). However, 15.3% and 18.4% of mortality events were classified as layer fatigue between 30 and 39 weeks and between 40 and 54 weeks of age, respectively.

Autocorrelation values for temperature, relative humidity and ammonia levels indicated that the lag periods, each about 3.5 weeks long, were independent of each other (Table 1). Autocorrelation results for total mortality percentage indicated a certain dependency of the data over time. However, the results depend, to a certain extend, on the lag period considered.

Humidity and ammonia levels did not seem to be related with total mortality. However, temperature appeared to be related with mortality (Fig. 3). The cross-correlation evaluations tend to support this assessment. The cross-correlation values for total mortality versus temperature show a fair correlation for the first four lag periods (Table 2).

It was also found that the mortality rate was higher in the upper deck cages (57.6%) compared to that in the lower deck cages (42.4%); this difference was statistically significant ($p < 0.0001$; OR = 1.39).

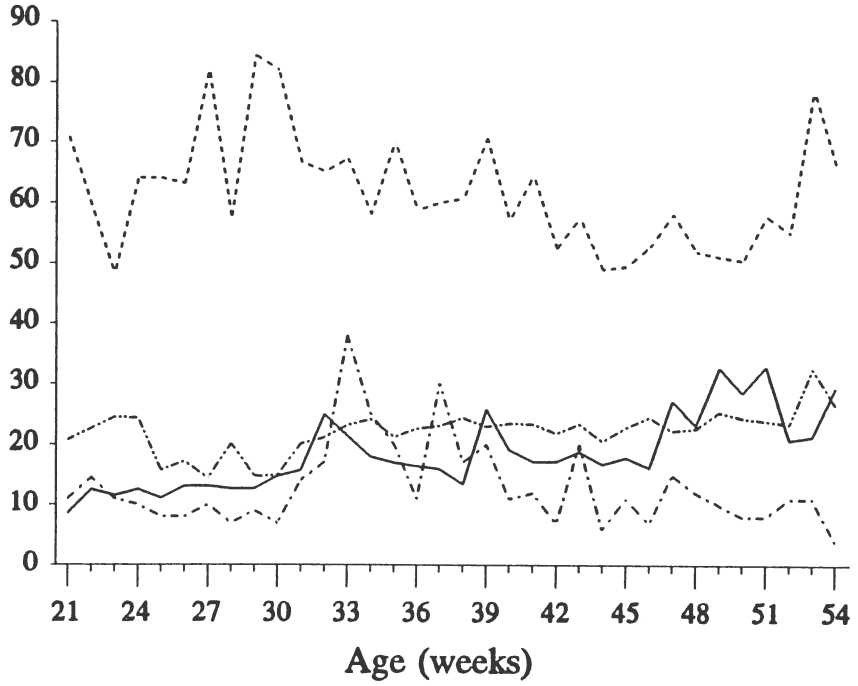

Figure 3: Time series plot of Temperature (°C) (·····), Relative humidity (%) (·····), Ammonia (ppm) (·····) and Deaths/10,000 birds (———)

Table 1. Auto-correlation evaluation for temperature, relative humidity, ammonia levels, total mortality proportion and mortality proportion due to cannibalism between 21 and 54 weeks of age.

Lag period[a]	Correlation value			
	Temperature	Humidity	Ammonia	Total mortality
1	0.56	0.31	0.38	0.63
2	0.38	0.41	0.39	0.56
3	0.30	0.28	0.04	0.43
4	0.27	0.11	0.33	0.35
5	0.14	0.11	0.00	0.21
6	-0.04	0.11	0.09	0.15
7	-0.04	-0.16	-0.32	0.18
8	-0.04	0.04	-0.18	0.10
9	-0.09	-0.10	-0.28	0.01
10	-0.01	-0.05	-0.03	0.03

[a] One lag period = 3.5 weeks

Table 2. Cross-correlation values for total mortality proportion versus temperature, relative humidity and ammonia level for the period between 21 and 54 weeks of age.

Lag period[a]	Cross-Correlation value		
	Temperature	Humidity	Ammonia
1	0.48	-0.42	0.05
2	0.67	-0.20	-0.01
3	0.52	-0.18	-0.13
4	0.52	-0.11	-0.05
5	0.29	-0.14	-0.11
6	0.31	-0.07	-0.11
7	0.10	-0.04	-0.17
8	-0.07	0.00	-0.20
9	-0.11	-0.03	-0.25
10	-0.08	-0.05	-0.31

[a] One lag period = 3.5 weeks.

A significant association between death due to layer fatigue in one cage and death due to the same problem within the same cage and in adjacent cages was found in all banks (Table 3).

Table 3 Two-by-two tables for chi-square analysis of layer fatigue cases

Bank 1

		Layer Fatigue	
		Yes	No
Death Nearby (Layer Fatigue)	Yes	13	147
	No	36	1040
	Total	49	1187

OR = 2.55, X^2 = 8.36
p = 0.0038

Bank 2

		Layer Fatigue	
		Yes	No
Death Nearby (Layer Fatigue)	Yes	8	109
	No	28	1091
	Total	36	1200

OR = 2.86, X^2 = 7.04
p = 0.0159

Bank 3

		Layer Fatigue	
		Yes	No
Death Nearby (Layer Fatigue)	Yes	23	144
	No	26	1043
	Total	49	1187

OR = 6.41, X^2 = 48.8
p < 0.0001

Bank 4

		Layer Fatigue	
		Yes	No
Death Nearby (Layer Fatigue)	Yes	25	131
	No	23	1057
	Total	48	1188

OR = 8.77, X^2 = 70.52
p < 0.0001

DISCUSSION

The investigation of all mortalities occurring in a 20,000 layer operation was a time consuming effort. Although very little can be done to change this, the approach used for this investigation had two major advantages: (1) The producer did not have to write anything down. Since dead birds must be removed from cages under normal conditions, the protocol was, therefore, not disruptive for the producer; (2) Freezing the birds allowed us to minimize the number of farm visits, which are both time consuming and expensive. A similar approach was used by Vaillancourt et al (1990) in swine. The impact of the freezing and thawing process on gross lesions proved to be negligible (Vaillancourt and Martineau, 1988). Of course, freezing and thawing do limit the extent of histopathological investigations. However, it has no negative consequences on microbiologic evaluation of tissues.

The definition of "adjacent cage" was fairly restrictive. Of course, different definitions are possible. The spreadsheet formulae can easily be altered and copied throughout the spreadsheet.

Because weekly information was collected on temperature, ammonia and relative humidity, the shortest lag period possible for time series analysis was 1 week. However, the software used for this analysis imposed a maximum of 10 lag periods which, in this case, met that each period was the equivalent of about 3.5 weeks. This may be too long for the assessment of the relationship between environmental conditions and mortality.

The increase in total mortality starting at 30 weeks of age could have been triggered by stress due to egg production and by the aging process itself. The apparent relationship between temperature and mortality could be only statistical in nature and may not be biologically valid. Although one could argue that a condition such as cage layer fatigue could be more prevalent if high temperature reduces feed consumption and, hence, calcium intake. The increasing temperature inside the barn despite the low outside temperature could have been due to the reduction in the use of ventilating fans as is normally done during winter. With reduced ventilation, one would expect a corresponding increase in the level of ammonia inside the barn. However, this was not observed, perhaps due to the more frequent removal of manure that was initiated by farm personnel during this time period, resulting in lower levels of ammonia.

The high incidence of layer fatigue coincided with the peak of egg production. This is not surprising considering the high demand for calcium (for egg shell formation) during this period. In addition, hypocalcemia and subsequent osteoporosis are common in caged layers because of the inability of the birds to recycle phosphorus from their own feces (Whiteman and Bickford, 1989). Caged layers are therefore routinely given a supplementary source of calcium in the form of coarse-particle oystershell or limestone. These particles leave the gizzard more slowly and become available during dark hours when the egg shell is formed (North and Bell, 1990). However, some hens may be unable to eat enough oystershell or the oystershell may be too fine that they leave the gizzard too rapidly thereby becoming unavailable at the time of egg shell formation. Water restriction may also reduce feed consumption, resulting in lower calcium intake. Other circumstances, such as diseases affecting feed consumption or the relative inaccessibility of feed due to a dominant hen or due to poor cage design should also be considered. Several of these possibilities could explain the clustering observed for cage layer fatigue for this flock. For instance, since cup drinkers were placed two cages apart (i.e. 8 birds per drinker), a malfunctioning cup could result in layer fatigue cases in two adjacent cages.

The clustering analysis was performed without considering the number of birds in each cage since it was kept constant for all cages, except for a few at the extremities of each bank.

The statistically significant association between mortality rate and cage deck location (i.e. hens located on the upper deck cages were at 1.39 times greater risk of dying than those on the lower deck cages) provided further evidence that because of traditional overhead lighting, upper deck cages are always subjected to a higher light intensity resulting in increased problems such as picking, cannibalism, prolapse, and nervousness (North and Bell, 1990).

Although it was beyond the scope of this paper, we must emphasize that the analysis of the distribution of all categories of mortality over space and time in this commercial layer flock had considerable value in pinpointing certain management errors. The cases diagnosed pointed to a variety of management problems related to feeding, lighting, and probably genetics. Identification of such problem areas and prompt corrective action are crucial to any egg producer whose main objective is to achieve optimum production at the least possible cost.

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ECONOMICS AND WELFARE

ESTIMATING THE PERCEIVED BENEFITS OF MEASURES TO IMPROVE ANIMAL WELFARE

RICHARD BENNETT*

The benefits to society of various measures to improve animal welfare, such as government legislation, are usually estimated largely in terms of subjective judgment on the part of animal welfare experts (such as the Farm Animal Welfare Council in the UK) and by policy makers who may also be influenced by public opinion and pressure groups.

However, the opinions and specific concerns about animal welfare that the vast majority of citizens may have are not necessarily represented in this way. In a democratic society, policy makers need to be able to gauge public opinion and to take account of the expressed desires of its citizens.

Of course, there are a number of ways in which society does this, including representation by elected representatives (local councillors, Members of Parliament, etc.), various surveys and opinion polls and, when issues warrant it, referenda.

This paper describes the application of a technique, contingent valuation (CV), to the measurement of people's concerns about animal welfare and their desire to see specific legislation to protect it. CV is a relatively sophisticated means for measuring people's expressed wants in money values (see Mitchell & Carson, 1989 for a very readable text on CV). The technique has been extensively applied to estimate the value that people place on environmental and other public goods (see Carson et al, 1993) and has been widely recognised by policy makers as a valid approach (e.g. DoE, 1991) for measuring the value that people place on non-market goods (i.e. those that have no explicit market price attached

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* Department of Agricultural Economics and Management, The University of Reading, 4 Earley Gate, PO Box 237, Reading RG6 2AR, UK.

to them - such as animal welfare).

The paper outlines the method, analysis and results of an exploratory survey intended to test the application of the CV methodology to animal welfare issues. The survey was carried out at the University of California, Davis during 1994.

METHOD

Sample classes containing some 140 students were selected. An initial exploratory questionnaire was used to identify what particular farm animal welfare concerns people had (if any) so that appropriate welfare issues could be selected for the CV survey.

Following this initial survey, two particular farm animal welfare issues were chosen: (i) the production of veal using 'crates' and restricted diets and (ii) the production of eggs using battery cage systems.

A questionnaire was designed with the aim of eliciting four main types of information.

1. The extent to which respondents were 'concerned' about farm animal welfare issues.
2. The livestock product consumption patterns of respondents.
3. 'Willingness to pay' (WTP) of respondents to see federal legislation to (i) ensure that veal was only produced in the U.S. under conditions where calves were given adequate housing and nutrition (ii) ensure that the use of battery cages in egg production was banned in the U.S. by the year 2000.
4. Personal information about respondents such as their age, income etc..

This paper focuses on those aspects of the study relating to the 'veal issue'.

The questionnaire was carefully pretested and piloted. In particular, the wording of the WTP questions was given much consideration together with supporting statements containing information about the two welfare issues. Animal welfare is an emotive issue and it was important to present factual information to respondents in a dispassionate way.

Two aspects of WTP elicitation have a particularly important influence on responses. The first is the exact nature of the hypothetical scenario presented to respondents and the second is the 'payment vehicle' or means by which respondents are asked to pay. Related to this second aspect is the means by which WTP is elicited. There are a number of different ways including the use of a simple open-ended question - i.e. 'what is the maximum you would be willing to pay for X?'; iterative bidding techniques where either the respondent or the interviewer chooses the initial amount and then further WTP increments are used until the respondent reaches a maximum; and dichotomous choice or referendum approaches where respondents are each asked whether they would be willing to pay a single stated amount (Yes or No) with the amount being varied over the sample. The latter is thought by many to be the 'preferred method' (Arrow et al, 1993).

For this study, a 'double-bounded' dichotomous choice format was used to improve the statistical efficiency of the method. Essentially, this involves bidding the respondent up or down once, depending on the initial response to the first WTP question. The following extract from the CV questionnaire shows the scenario statement, payment vehicle and format of the WTP questions that were used.

"Currently in the U.S. veal is produced by keeping young calves (from 1 day old) in small individual stalls where their movements are severely restricted. They are fed on a liquid milk replacer diet deficient in iron to ensure white meat. They are then slaughtered after about 15 weeks. Around 1.2 million calves are used to produce veal in the U.S. each year."

"Imagine that the Government is developing legislation to ensure that all veal producers give calves suitable pens so that they can move about without difficulty and that they are fed on a diet which contains sufficient iron and fibre for good nutrition. The Government realises that such legislation will incur some cost and that ultimately this must be paid for by people in the U.S. in some way. The Government is intending to establish a Veal Calf Fund which could only legally be used to ensure that farmers complied with the legislation (including, where appropriate, helping them to change over to new production methods)."

"(i) Would you support legislation which ensured that U.S. veal was only produced under conditions where calves were given adequate housing and nutrition? Please circle one only. YES NO NO OPINION

(ii) Would you be willing to pay an increase of $3* on 1994 Federal Taxes

required of each person in the U.S. to support this legislation? (Taxes in subsequent years would not be affected). YES NO NO OPINION

(iii) If YES to ii, would you be willing to pay $6* YES NO
If NO to ii, would you be willing to pay $1* YES NO "

The questionnaire was administered to students during class time, with students being asked to fill in the questionnaire themselves and to answer the questions in sequence and not to return to previous questions to change their responses. Data from the questionnaires were then coded and analysed using SAS and LIMDEP (an econometric computer program).

RESULTS

Concern about FAW

Some 81% of respondents stated that they were concerned that farm animals may be mistreated or may suffer in the process of producing food and other agricultural products (22% said that they were very concerned). Around 21% of respondents purchased particular animal products because they thought them better for animal welfare, whilst 50% avoided particular products because of animal welfare concerns.

When asked whether they thought particular livestock practices were acceptable; 89% considered the use of veal crates to be unacceptable (65% thought it very unacceptable) compared, for example, to 72% who considered the use of battery cages unacceptable (29% thought it very unacceptable). Respondents were asked to give a rating of their degree of concern about various issues (from 0 - no concern to 10 - of extreme concern). Farm animal welfare had a mean rating of 6.2, compared, for example, to 7.9 for cruelty to pets (the highest rating of concern amongst six selected issues - three environmental and three animal welfare).

Veal legislation and 'willingness to pay'

Seventy-four percent of respondents stated that they would be willing to support federal legislation to ensure that U.S. veal was only produced under conditions where calves were given adequate housing and nutrition (16% would not and 10% had no opinion).

When asked whether they would be willing to pay a specified amount in additional taxes for 1994, 67% said yes. The stated mean WTP of respondents was $ 6.20 (including those who had no stated WTP - i.e.

those that responded 'no' to WTP questions). There are a number of reasons why a third of respondents said 'no' to WTP questions (and were therefore recorded as having zero WTP). For example, some of these people may have had a positive WTP, but the amounts that they were asked to respond to were higher than this, and so they responded 'no'. Others may have objected either to the scenario presented (for example they may have objected to the use of a Veal Fund which could give grants to producers) and/or to the payment vehicle (i.e. payment via taxation). Some would perhaps have no concerns about veal production, and so would have a zero WTP regardless.

In such studies, it is important that there are 'follow-up' questions asking respondents to explain their responses. In this way, not only can the reasons for 'no' responses and zero WTP be gauged, but also this provides some evidence as to whether or not respondents have correctly interpreted the scenarios and WTP questions and have thought through their responses in some reasoned way. Some 85% of respondents gave reasons for their responses to WTP questions. Of these, 6% objected to the use of legislation in this context, 14% objected to payment through taxation and 27% stated some other objection to the scenario. In some cases, it is difficult to gauge how these objections have influenced people's WTP. In the case of those who responded 'no' to all WTP questions, objections to the scenario or the payment vehicle formed 89% of reasons given.

In order to explore possible determinants of WTP and to help interpret people's responses to WTP questions, probit and logit regression models were explored. Two factors were found to be particularly significant determinants of whether people responded yes or no to WTP questions - (i) the WTP amount and (ii) their stated degree of concern about farm animal welfare. This provides some further validation of the method since it would be expected that the higher the amount that people are asked to pay the less likely they are to say yes and that the more concerned they are about farm animal welfare the more likely they are to respond yes to WTP questions.

DISCUSSION

The aim of this survey was to explore the application of the CV technique to animal welfare issues. Wherever possible the guidelines for best CV practice suggested by Arrow et al (1993) were followed.

Results obtained from this survey should only be used with reference to assessment of the CV methodology, since the sample used was non-representative of the population generally. No conclusions as regards the general population should, therefore, be derived from the results of analysis of this sample either in terms of people's concerns about farm animal welfare or people's WTP.

However, the results of the survey do suggest that the CV methodology can be applied to animal welfare issues and produce reasoned (and apparently reasonable) WTP responses which are compatible with people's stated concerns about animal welfare.

The key question with any CV study of this kind is are people's stated WTP an accurate reflection of their true WTP (i.e. what they would actually pay if they had to)? This is a difficult question to answer and further studies of this kind relating to animal welfare would help to address it by providing comparative estimates. The literature documents a number of areas of potential bias of WTP estimates (Cummings et al, 1986). It is not within the scope of this paper to consider each of these, but one particular aspect deserves further attention when applications to animal welfare issues are involved. When asked to value one specific good, such as the provision of better calf welfare, respondents may report a higher value for a larger class of goods, such as an expression of their concern about the welfare of farm animals generally. This has been referred to as 'part-whole bias' (Mitchell and Carson, 1989). There is certainly a strong possibility that such bias could affect CV studies of animal welfare and such studies must guard against this and contain follow-up questions which test for it. Such bias can inflate WTP estimates significantly.

CONCLUSIONS

The application of the contingent valuation method to animal welfare issues would appear to be worthy of further exploration. It is a means by which people's perceptions about animal welfare issues can be explicitly recorded together with their support for policy initiatives designed to improve the welfare of animals. People's estimated 'willingness to pay' to see improvements to animal welfare, for example through legislation, provides a means by which quantitative estimates of the extent to which people support policy can be derived. Such studies must be carried out carefully according to a number of guidelines and primary estimates of WTP from these studies should be treated with some caution. However, the pitfalls of the CV method are well-documented and the problems of

potential biases can be addressed.

Well-designed and well-executed studies should provide useful inputs, about people's perceptions of animal welfare and of policies designed to improve animal welfare, into the policy debate. They should also provide policy makers with valuable additional information on which to base their policy decisions.

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THE COST OF WELFARE - THE FOOD CONSUMER'S VIEWPOINT

J P McINERNEY*

It is widely quoted that, with concerns over food sufficiency a thing of the past, the most important issues confronting agriculture now are the environment and animal welfare. If so this threatens the proverbial double-whammy for the livestock farmer, who may get it in the neck for both what he does to the countryside through intensive grassland production and the disposal of wastes and what he does to the animals. The welfare issue has certainly gained increasing public prominence - witness the recent demonstrations over UK calf exports into European veal crate production systems - and seems likely to become important to many more people. Far more considered attention by scientists, economists and other objective analysts must be paid to this aspect of farming technology if policy developments are to be guided by balanced information as well as sentiment.

ASPECTS OF ANIMAL WELFARE

A major difficulty in developing a structured approach to welfare analysis is defining the appropriate questions. Much of the public concern is *issue oriented*, focusing on specific components of livestock production systems such as veal crates, BST, abattoir procedures, etc. The same is true of legislation which, when it leaves the world of laudable generalities, is specified in terms of particular practices - debeaking, tail docking, castration - which are controlled or prohibited (Baker, 1986). In both cases the dominant theme is of things perceived to be cruel or inhumane, rather than any concept of the animal's overall wellbeing.

This kind of binary, acceptable/unacceptable, approach is fine for defining thresholds but does not give much help in making choices within the realm of acceptable production practice. What is needed for this purpose is information equivalent to an index of welfare that can be assigned to *systems* of production, within which there will be procedures and characteristics judged as having both positive and negative contributions to welfare. Thus, for example, the popular concerns about modern livestock production ignore what might be termed the 'husbandry aspects of welfare' - the attention given to animal health, nutrition, and providing an environment of shelter and security that, although primarily directed at exploiting economic productivity, is also regarded as beneficial to the animal. Whatever their anthropomorphic or ethical concerns over the way we treat animals, the public, as food consumers, have an interest in promoting these dimensions of production methods since greater animal productivity means cheaper livestock products.

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*Agricultural Economics Unit, University of Exeter, Lafrowda House, St German's Road, Exeter, EX4 6TL, UK.

It is often asserted that better animal welfare itself results in greater productivity, as though the case for improved welfare is self-evidently economic as well as ethical - see, for example, the Centre for Agricultural Strategy symposium (Carruthers, 1991). However, this proposition can only be true in very restricted contexts. In general, the economic process of livestock production is one of exploiting the animal as a resource (McInerney, 1988) and therefore one of asserting the interest of humans over that of the animals concerned. Thus, there is no avoiding the fact that livestock production operates against the essential welfare of the animal as defined in any absolute sense.

As economic pressures for greater efficiency and lower cost production impinge on the food system, livestock farming finds progressively more effective ways of exploiting the animal's potential, subject to the defined thresholds of inhumane methods. This process ultimately creates increasing discomfort among increasing numbers of people, who do not wish their own benefit (through cheaper food) to be advanced further at the expense of farm animals. The more public awareness there is about the nature of livestock production processes, the greater the negative connotations associated with terms such as 'intensity'; and the more society is able to pursue priorities other than cheap and plentiful food, the more people will object to modern livestock farming methods (or even to the place of animals in human food supply).

However, such preferences do have economic consequences. For any society and its food production system there is an unavoidable conflict between the human interest as reflected in livestock productivity (and hence product prices) and the farm animal interest as manifested in its perceived welfare. The nature of this conflict has been explored in an earlier paper to this Society (McInerney, 1991), and what follows develops from the thesis presented there. There may be possibilities for developing new production methods, or using existing ones more effectively, to improve the welfare of farm animals at no financial cost or reduction in their productivity - for example, improved building design, more careful management and better 'husbandry' in the traditional sense. However, such opportunities are relatively limited and, to a large extent, improvements in animal welfare imply the acceptance of an increase in the cost of livestock production. It means sacrificing some economic benefits that have been gained by exploiting the animal's biological potential, or incurring more costs in tending its wellbeing. This may happen by reducing the intensity of livestock production (lower input levels or housing densities), eschewing the use of certain inputs (hormones) or production practices (farrowing crates), providing specific conditions (straw bedding, outdoor grazing) thought to be more appropriate, or simply spending more time in caring for the animal. The range of things that people perceive to represent better welfare is very wide, and in general seems to be associated with going back to an earlier technology and more 'natural' husbandry systems. Regardless of the scientific validity of these presumptions about what is better for animals, it is what people believe that becomes the reality. In this sense, as discussed in my earlier paper, animal welfare is simply a subset of human welfare.

PRODUCTION COST VERSUS CONSUMPTION COST

Arguments about the possible economic implications of improved animal welfare seem always to be couched in terms of the additional costs of livestock production as measured at the farm level. This then comes to be seen as an equivalent reduction in the incomes of producers, and so not surprisingly welfare regulations appear as an imposition on farmers. But that represents far too narrow an understanding of how economic systems work. In principle,

anything that results in more resources being used somewhere in production represents simply a higher real cost to society of gaining that product. How that extra cost is distributed throughout the interconnected chain of firms and associated value adding processes is another matter entirely. For the complex sequence of transformation processes that constitute food production, which starts in the agricultural inputs industry and ends up in supermarkets, there is no *a priori* basis to assert where the impact of any cost increases will be felt. There is certainly no reason to presume that cost increases incurred at the farm level have to be absorbed as income reductions at the farm level - they can equally be transferred to appear as equivalent price increases somewhere further along the chain or in the final food product.[1] In terms of the total economic system it does not particularly matter where cost increases impinge. The society collectively is worse off, regardless of which particular individuals or groups bear the impact. (It may, of course, be judged *politically* preferable for one group - farmers, low income families, foreigners, Conservative voters, chairmen of privatised industries, etc. - to be more or less disadvantaged, but that is outside the ambit of economic analysis.)

There is a distinct lack of information on how, and to what extent, particular improvements in animal welfare might affect the resource costs of livestock production. The presumption in many cases (such as in the demands to ban BST or to restrict the journey times in transporting livestock) seems to be either that the cost consequences are insignificant, or that economic implications are totally irrelevant to the decision. However, it is inappropriate to adopt this position without recourse to any information at all. Structured studies to estimate how any technique change will affect livestock production costs are entirely possible - indeed, the whole methodology of farm management analysis was developed originally to do just this - and there is a genuine need for such work to be undertaken. At present the data available seem to relate largely to different methods of egg production (e.g. Elson, 1992), and in the later sections of this paper we have to rely on plausible estimates of resource effects.

Even so, we must remember that the impacts of welfare changes on farm-level costs is merely the starting point of economic analysis. Despite a tendency by many to react as though any negative effects felt by producers (especially if they are farmers!) are the major concern, it is just as important to consider the impact at the consumer end of economic processes - if only because it relates to many more people. The effect of animal welfare improvements on food consumers depends on an array of technical and economic considerations, including the length and complexity of the value-adding chain and the demand conditions for the products concerned.

ANIMAL WELFARE AND FOOD PRICES - THE ECONOMIC FRAMEWORK

From the standpoint of economic analysis there are two questions to be posed. First, how will a change in practice in a particular livestock production enterprise affect the retail price of the food product derived from it? And second, how will that change in price affect the wellbeing of food consumers? The procedure for answering these questions is to pursue an increase in farm level production costs through the food chain to prices on the supermarket

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[1] The recent rise in the price of coffee beans has not been manifested simply in higher incomes of coffee farmers, or lowered income to Nestlé's, Sainsbury's or the operators of coffee bars; it has resulted in a higher price for a jar (or cup) of coffee.

shelf, compute the likely change in consumption level and expenditure, and then evaluate the impact of that change on the overall food budget. The essence is encapsulated in the question "how will the banning of sow stalls affect the price of bacon in Sainsbury's, and so what?".

Agriculture does not, of course, produce food. It produces a raw material that is progressively transformed through the use of further resources in other industries - collecting, processing, combining, manufacturing, packaging, storing, and distributing, etc. - into what we recognise as food on the supermarket shelf.[2] The value added in this way is just as much a part of the food production process as is farming. Overall it accounts for almost two-thirds of the value of food consumed, though obviously this proportion varies widely between products such as lettuce, cheese, bread, beer or a restaurant meal. In livestock products the value added proportions are lower in the case of eggs, which undergo relatively little transformation before being presented to the consumer as 'food', compared to many processed dairy products or sausages (which presumably may validly be considered as both livestock products and food!).

In general, the less the agricultural raw material contributes to the price of the final food product (i.e. the higher the post-farmgate value added) the less a rise in farm level costs will affect food price. Table 1 shows the estimated contribution of the agricultural component to the retail price for various livestock-based food products. This suggests, for example, that a 10% increase in the farmgate price of milk implies a 2.4% increase in the price of cheese.

Table 1 Value added and demand characteristics for various food products

Food product	Farmgate price as % of retail price	Price elasticity of demand	% share in household food expenditures (1993)
Liquid milk	32	-0.16	7.9
Cheese	24	-1.32	3.6
Beef	36	-1.39	4.8
Pork	38	-1.79	2.0
Bacon and ham	26	-0.80	2.4
Poultry meat	44	-0.44	4.1
Eggs	64	-0.08	1.3
(All livestock products)			(44.7)

Source: MAFF, *National Food Survey*.

Economic theory explains that, in general, higher prices lead to reduced consumption. The extent of that adjustment is captured by the price elasticity of demand (ϵ). This measure of consumer responsiveness to price is calculated as the percentage change in quantity purchased relative to the percentage change in price. Its significance is not simply in reflecting consumption adjustments, since it also indicates what happens to monetary expenditure on the

[2] Or, increasingly nowadays, as 'food' on the plate in the restaurant or fast-food emporium. Some 21% of total food expenditures in the UK in 1993 were on meals bought away from the home (CSO, 1994).

commodity. If the elasticity figure is greater than 1, a given percentage price increase will cause a larger percentage reduction in purchases, and as a result less total money will be spent on buying the commodity. By contrast, an inelastic demand ($\epsilon < 1$) results in purchases falling by proportionately less than the price rise, with the consequence that expenditure on the commodity increases.

It is the availability of relevant substitutes that largely determines demand elasticities. For food in total there is no substitute in the consumption pattern, and so its overall demand is very price inelastic. By contrast individual food products can substitute for one another, and so at the specific commodity level the price elasticities are generally larger - though varying quite widely depending on the product in question. Table 1 shows elasticity estimates for a number of livestock-based food products.

IMPROVED ANIMAL WELFARE AND FOOD PRICES

We now attempt a fairly speculative exploration of how production costs, and hence farmgate prices, of various livestock products might be affected if certain adjustments in practices designed to enhance animal welfare were to be imposed. As already stated, there is little hard data on this because questions have not previously been posed in a research context to measure the resource use impacts of specific welfare improvements. Consequently we can only proceed at present on a crude case study basis.

A number of welfare-related issues that have claimed popular interest are selected and listed in Table 2. Best estimates of their effect on production costs have been obtained, largely by seeking the views of people with knowledge about livestock production - a process that might be termed loosely as reliance on expert systems rather than scientific method! These estimates cannot claim empirical precision, but the orders of magnitude are believed to be defensible. In the last analysis, even if they are over- or under-estimated by as much as 100%, the broad conclusions drawn from the analysis turn out not to be fundamentally different.

Applying these cost increases to the value added proportions (from Table 1) yields estimates of their ultimate impact on the retail price of relevant food commodities.[3] In general the impacts on dairy and red meat products are decidedly small, both because the welfare improvements have relatively minor cost implications and the farmgate product represents only about one third of the value of the final food item. It is only in the case of poultry products, where the nominated welfare-friendly systems result in much higher production costs and the

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[3] Note the analytical process is simply one of passing an increment in resource costs along the length of the food production chain and relating it to the final commodity value; in this sense it is perhaps more correct to say we are estimating the impact on the retail *cost* of food. In practice it is not certain that all the extra costs will carry through into prices, nor that additional margins will not be created by food processors or distributors, and so actual shelf prices may change by more or less than calculated. It would require specific information on industrial organisation, market behaviour and pricing policies of the various companies in the different parts of the food supply system to be precise about these points. However, this does not alter the fact that the cost to the economy of food supply changes by the amount calculated.

commodities produced have less value added before reaching the retail level, that better welfare seems to have a significant economic impact on the price of food.

Table 2 Consumer effects of animal welfare changes

Welfare change	Estimated effect on livestock production costs (%)	Effect at retail level		Impact on weekly food expenditures	
		Commodity	Price change (%)	pence per person	% of total food budget
Introduce BST	-8	Liquid milk	-2.56	-2.27	-0.17
		Cheese	-1.92	+0.27	+0.02
Ban hormones	+4	Beef	+1.44	-0.57	-0.04
Limit transport times to 8 hours	+3	All carcase meat	+1.14	-0.47	-0.04
Ban sow tethers and crates	+5	Pork	+1.9	-0.43	-0.03
		Bacon & ham	+1.3	+0.06	-
Ban broiler systems	+30	Poultry meat	+13.2	+3.6	+0.27
Ban battery cages	+28	Eggs	+17.9	+2.87	+0.22

The general conclusion indicated by these fairly simple calculations is not really surprising. It is that many improvements in animal welfare could be gained quite inexpensively in terms of the real cost of food production. While a 5 or 10% increase in production costs may seem significant from the livestock farmer's standpoint, the consequent 2 or 3% rise in the prices for a subset of food products is far less remarkable to the consumer and to the economy. Indeed, it is well within the range of commodity price changes experienced due to seasonal and other common factors.

ANIMAL WELFARE VERSUS CONSUMER WELFARE

The final step in our procedure is to place the computed commodity price changes into the context of the consumer's overall food budget. First, the significance of any price rise is clearly greater if the commodity is a major item in the consumption bundle (eggs account for only 1.3% of consumer food expenditures whereas milk and cream amount to 11%). Second, if demand is price elastic the price rise results in reduced expenditures on the commodity, freeing money to be spent on other things. The penultimate column of Table 2 indicates the estimated change in the amount spent on each of the listed food products if the welfare improvements were implemented to cause the price changes shown. The last column of the table expresses this as a proportion of the total household expenditure on food. The figures all relate to an average weekly expenditure on purchased household food of £13.21 per person in

1993 (MAFF, 1994), and cover only *direct* purchases by the household. Some of the calculated price increases would find their way into other expenditures - such as for meals out or the price of manufactured food commodities like cans of Irish stew, ice cream and cakes - but these effects will be of secondary importance.

In terms of the average household, the tabulated effects are minor both in absolute and relative terms. The price rises following animal welfare improvements would all induce small reductions in consumption, but in some cases result in higher expenditures on the commodity ($\epsilon < 1$) and in others expenditure reductions ($\epsilon > 1$). Either way the effects on the household food budget are very small, in no case causing the total estimated expenditures to change by more than one quarter of 1 per cent. Even in the poorest households (recorded in the statistics as those whose head of household earns less than £140 per week), where average food expenditure per person is some 15 per cent lower, these price rises represent greater - but nonetheless still minor - reductions in consumer welfare.

CONCLUSIONS

This analysis is in every sense crude and indicative rather than exact and definitive. It cannot claim to represent a detailed accounting of the costs to the food consumer of improved animal welfare, but it does demonstrate by its procedure that what many livestock farmers regard as significant and unwelcome impositions on their production methods have only marginal effects in terms of the food economy. Potential production cost increases ranging from 5 to 30 per cent are factored down through the food chain to result in commodity price rises of, at worst, 2 to 20 per cent. A commodity price rise of 20 per cent seems at first sight to be a matter of great concern, but it is the most extreme change likely as a result of any of the welfare improvements under popular discussion, and it relates to a commodity (eggs) that accounts for only 1.3 per cent of the food budget for the average British household. Placed further in context, it implies an extra expenditure of less than 3 pence per person per week. In the face of monetary sums of that magnitude, much of the *economic* opposition to the costs of better animal welfare simply trickles into the sand.

The argument over welfare is, of course, not solely an economic one - but its economic dimensions are just as relevant a part of the information framework as are scientific assessments of animals' stress, the weight of public preferences, and ethical propositions about human responsibilities and animal rights. It is quite feasible, as argued elsewhere (McInerney, 1991), for animal welfare standards to be treated as a quality characteristic of the final food commodity and determined by pluralistic preferences expressed through the food market (as is the case already for 'free range' eggs or 'traditional' meat). However, the reality is that to a large extent the different preferences are being expressed through political action - i.e. by demonstrations, lobby group pressure and competitive publicity. In these circumstances different ethical questions are raised - particularly about the validity of one group in society (those strongly in favour of welfare reform) acting to impose *their* preferences on another group (those unconvinced or unconcerned that livestock husbandry practices should be modified). Can better animal welfare be considered as essentially a consumer issue to be resolved by personal choices made on food markets, or is it a 'public good' that all members of society should be forced to pay for? Should vegetarians have as much influence in this matter as consumers of livestock products?

There is nothing in the analytical methods of economics or of veterinary epidemiology that provides an answer to these essentially political questions. Economic analysis can, however, offer some indicators to inform the debate and help those seeking a balanced viewpoint, and this is what this paper has tried to do. It underlies the elementary proposition that if people genuinely demand (and hence place a value on) better welfare conditions for farm animals, then by definition they are prepared to incur costs up to that valuation in order to satisfy those preferences. The calculations presented here suggest the costs that might have to be incurred in terms of higher food prices seem to be very small and of minor consequence to the economy. [4] In the light of this there seems little *economic* basis not to proceed with many of the reforms that are advocated. Certainly an emphasis on the farm-level costs, or the assumptions that any costs will be borne by livestock farmers, should not be allowed to dominate consideration of the issues.

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[4] There would, of course, be adjustment costs in moving to any new husbandry practices.

TOOLS AND TECHNIQUES

METHODS FOR THE ASSESSMENT OF DISEASE ON LIVESTOCK PRODUCTIVITY

ANDREW JAMES[1]

In the economic analysis of animal health constraints, it is necessary to estimate the effect of disease on productivity (rather than the quantity of production). Productivity refers to the efficiency of production, and in its simplest terms is a ratio of output per unit of input.

In practice, for agricultural enterprises, productivity is normally expressed as a ratio of economic margin per unit of the most important limiting resource (usually land). Thus the most common measure of productivity in agricultural enterprises is margin per hectare. This allows farmers to compare the efficiency with which alternative enterprises utilise their limited land resource to generate profit. It also allows comparison of alternative production systems for the same crop.

Margin per hectare is often difficult to apply to livestock enterprises, because livestock tend not to be associated with a particular area of land. In intensive production systems for pigs and poultry, very little land is used (at least in *per capita* terms). In these enterprises, which are not generally alternatives for crops, other measures of productivity such as margin per unit of capital investment or per animal-place are used. Where grazing (mainly ruminant) livestock are kept entirely on planted pastures, it may be possible to express their productivity as margin per hectare. Often, however, this is not possible and in these circumstances it has been normal practice to use the margin per head as the measure of productivity. It is argued that this is an inappropriate measure of productivity, especially in less intensive production systems, and its use has led to incorrect analysis of livestock economics, and animal health economics in particular.

Grazing livestock derive an important part of their feed intake from forage, which usually requires land. However, they generally do not occupy a fixed land area for the whole year or growing season. Forage may be derived from permanent and planted pastures, crop residues and other sources. In many situations, grazing livestock have the function of converting a forage resource, at least part of which would have no alternative use, into usable offtake. It is argued by a number of authors, including James (1984), Villamil (1986), Upton (1989) and James & Carles (1994) that a better general measure of grazing livestock productivity is the margin per unit of forage resource. This can be calculated from a set of production parameter estimates, which are used to estimate:

- the annual offtake per head;
- the variable costs per head per year;
- the forage intake per head (in terms of metabolisable energy by using ration formulae, allowing for purchased feed); and,
- from these, the margin per unit of forage.

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[1] Director, Veterinary Epidemiology and Economics Research Unit, University of Reading, Department of Agriculture, Earley Gate, P.O. Box 236, Reading RG6 2AT.

If margin per head is used in economic analysis of livestock production, the results always favour the large, high-producing breeds and production systems. The margin per unit of forage, on the other hand, examines the efficiency with which the production system converts forage, which is the main limiting resource for grazing livestock.

Conceptually, the margin per unit of forage is very similar to margin per hectare, as forage is related to the land resource. It is used because animals are more directly related to the forage resource than to the land. If the forage resource is measured in terms of its metabolisable energy content, the production potential of the forage resource is allowed for, which is not the case for land. Thus, direct comparison of the efficiency of livestock enterprises using forage resources of different quality is possible, whereas direct comparison of gross margin per hectare for a crop enterprise on land of differing agricultural potential would not be appropriate.

The procedure to calculate this measure of efficiency has been implemented in a computer program, the Livestock Production Efficiency Calculator, LPEC, (PAN Livestock Services, 1991). This program is used to demonstrate the advantages of using margin per unit of forage as a measure of the efficiency of grazing livestock productivity. It should be noted, however, that similar approaches have been adopted in other programs, for example by Baptist (1992).

EXAMPLE: THE ASSESSMENT OF INFERTILITY

The assessment of fertility has been selected as an example because it is an exceedingly difficult subject for gross margin analysis, and because infertility is an effect of many livestock diseases. The example selected concerns a dairy herd of 100 cows, rearing its own replacement heifers but selling male calves at birth. The economic effect of increasing the calving rate from 90% to 100% is to be calculated.

Changes in fertility affect many aspects of the production system. The herd structure will be affected by the increased number of young stock. Milk production will increase because of the larger number of lactations. Feeding requirements will change because of the new age structure of the herd, the increased production levels of the herd. In many farming situations forage is a limiting factor, and the increase in feed requirements may mean that fewer animals could be kept at the higher production level.

In enterprise or partial budget analyses based on gross margin per cow it is all too easy to omit these effects. The additional lactations and gestations imply higher levels of feeding, and it is far from simple to calculate the additional requirements. The valuation of additional calves presents problems if they are not to be sold at birth. In the example cited, the female calves would probably be reared to increase the supply of heifers from which to select replacement cows. In some dual-purpose production systems it is the policy of farmers to introduce all heifers into the breeding herd, and to cull cows while they are young and have a high slaughter value. The implications of changes in fertility in such systems are very complex.

The results of gross margin analysis for calving rates of 90% and 100% using the LPEC program are shown in Table 1. The unit of forage in these calculations is the carrying capacity unit (CCU). This is defined as 100 MJ of metabolisable energy per day, which is a more convenient scale than a single megajoule.

Table 1. LPEC analysis of infertility

Parameter		Calving rate 90%	Calving rate 100%
Herd structure as % of total :	Cows	51%	49%
	Heifers	49%	51%
Stocking rate (No. animals per CCU):	Cows	1.30	1.24
	Heifers	1.25	1.31
	Total	2.55	2.55
Mean feed requirement (MJ of ME per day):	Cows	108	115
	Heifers	39	39
Gross margin (£ per CCU per year):	Cull cows	223.16	211.91
	Surplus heifers	-	33.87
	Bull calves	43.15	45.52
	Milk	1394.64	1471.44
	Non-feed variable costs	-449.36	-426.69
	Purchased feed	-644.39	-678.38
	GROSS MARGIN	567.20	657.66

This calculation shows all of the implications of the change in fertility. Fewer cows can be maintained on the fixed forage resource, because of the increased number of heifers. If it was required, the proportional increase in forage production required to maintain the same number of cows could be calculated from the proportional decrease in the stocking rate of cows (1.3 / 1.24).

After the improvement in fertility, surplus replacement heifers are produced because the culling rate is assumed to remain constant. These are counted as production, even if they are "re-invested" to increase the herd size. It would also have been possible to specify that the surplus heifers be sold as calves, or that the cow culling rate be increased to absorb the additional heifers while maintaining a constant herd size.

USING LPEC TO ESTIMATE THE EFFECTS OF DISEASE

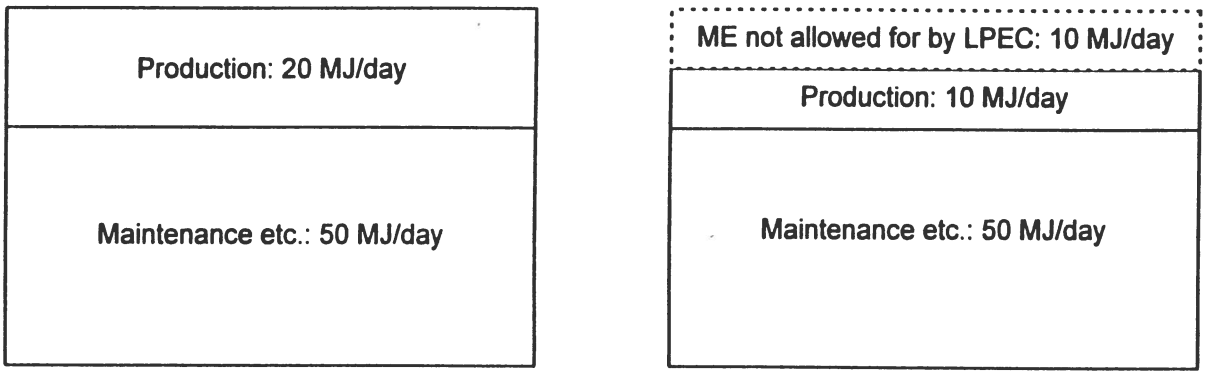
LPEC calculates the feed requirements according to the level of production. This creates a potential problem in assessing the effect of disease. Disease may cause low feed conversion efficiency in the individual animal, but unless data on disease effects on feed conversion efficiency are available, it is not possible to correct for it. However, it is generally found that this error is not very significant. If animals have depressed milk production due to mastitis for example, LPEC will "credit" them with the ME requirement for the lost production. However, if a manual adjustment is made to "debit" this ME, there is very little effect on the estimate of the cost of mastitis.

This point can be illustrated with a numerical example. Suppose that a healthy cow requires 70 MJ of ME per day, of which 20 MJ is required to meet its requirement for milk production. An equivalent cow with clinical mastitis might suffer a 50% loss of milk production. LPEC would therefore calculate the ME requirement of the cow affected by mastitis at only 60 MJ per day, on the basis of its reduced milk yield. In fact, it is likely that the feed requirement of the sick cow would be

similar to that of the healthy one (although many diseases including mastitis are known to depress appetite).

Therefore, LPEC would under-estimate the feed requirement of cows affected by mastitis. The effect of the error on the result of the calculation is illustrated in Figure 1:

Figure 1. The effect of mastitis on the LPEC index



Healthy cow

Production: 20 units
Actual ME requirement: 70 MJ/day

Actual productivity: 20/70 = 28.6%

Cow affected by mastitis

Production 10 units
Actual ME requirement: 70 MJ/day
LPEC ME requirement: 60 MJ/day

Actual productivity 10/70 = 14.3%
LPEC productivity 10/60 = 16.7%

Although the LPEC calculation understates the effect of mastitis on productivity, the error is quite small in relation to the overall effect of mastitis. It is also the case that the true effect of mastitis would lie somewhere between the LPEC assumption of a complete saving of ME for lost production and the opposite extreme in the calculation above that feed intake would not be depressed at all. It seems that the main economic effect of reduced production due to disease is through the fact that diseased animals will use a higher proportion of their total energy intake for maintenance rather than for production.

ESTIMATING PRODUCTION PARAMETERS

In order to use LPEC for estimating the effect of disease, a comprehensive range of production parameters must be specified, with and without disease effects. In many situations, it is not possible to maintain estimates of all relevant production parameters. However, it is then possible to use standard values of the unknown parameters. This will create no more error than using a less comprehensive method analysis, in which fixed values of many parameters would be implicit. Using LPEC, it is also possible to conduct sensitivity analysis to assess the importance of any possible error due to unknown parameter values.

Livestock production parameters fall into three basic categories:

Rates e.g. calving, mortality or culling rate. These all express the expected number of events for one individual in a defined period of time, usually one year. The expected number of events,

especially where it is less than one, is often treated as a probability. Thus mortality rate may be expressed as x% per year. Rates are calculated as:

$$\text{Rate} = \frac{\text{No. events}}{\text{Mean population} \times \text{Observation period}}$$

The product of the mean population and the observation period is the number of animal-years observed.

Time-limits e.g. age at weaning, time between weaning and maturity. These are expressed as the mean time between two events for one animal, usually in terms of years. Thus mean age at weaning (time from birth to weaning) might be expressed as x years, and mean time from weaning to maturity as y years. Time limit parameters could in principle be estimated by taking the mean interval for a group of animals. However, this is often impractical or undesirable for two reasons:

i) The period of observation needs to be at least as long as the time limit to be estimated. For age at first calving in cattle, for example, this could be five years or more.

ii) In any finite period of observation, the sample of intervals observed will be biased toward the shorter intervals.

These problems may be overcome by using an indirect method of estimating the time limit based on the number of animals reaching the end of the time period during a defined period of observation (N) the number of animal-years observed AY and the rate of loss for other reasons (r).

$$A = \frac{1}{r} \ln\left(\frac{AY}{N} r + 1\right)$$

Note that the term AY/N in this equation is the reciprocal of the rate N/AY expressing the expected number of events per animal per unit of time.

Quantities e.g. lactation yield, weight at weaning or maturity. These express a mean value of a quantity, and must be measured in some unit such as litres or kilograms.

CONFIDENCE LIMITS AND SIGNIFICANCE TESTS

The same method can be used to calculate confidence limits for both rate and time-limit parameters. Since the estimates of time-limit parameters are based on rates, the confidence limits for the underlying rate can be calculated and converted to upper and lower confidence limits for the time-limit estimate.

The estimated rate, R, is the expected number of events per individual per unit of time, calculated from the number of events (N) divided by the number of animal-years (N). This will often follow a Poisson distribution with mean R. If the number of events observed is greater than about 15, then the Poisson distribution approximates to the normal, and the standard error of the rate estimate, R, is calculated from:

$$SE_R = \sqrt{\frac{R}{AY}} = \sqrt{\frac{N}{AY^2}}$$

Confidence limits can then be calculated from the table of the normal distribution.

The significance of a difference between two rate estimates, where each estimate is based upon at least 15 events, can be calculated from:

$$d = \frac{R_1 - R_2}{\sqrt{SE_1 + SE_2}}$$

and d is referred to the table of the normal distribution.

Where rates are based upon small numbers of events, the probability (P_B) of any number of events (B) can be calculated from the formula for the Poisson distribution:

$$P_B = \frac{e^{-R} R^B}{B!}$$

This calculation could be used repeatedly to calculate the (asymmetric) confidence limits of the rate estimate.

A chi-squared test can be used to test for significant differences in any number of rate estimates $R_1, R_2 \ldots R_n$. An overall rate estimate, R, can be calculated and used to calculate expected numbers of events for each group under a null hypothesis that there are no differences in the true rates. Provided that the expected number of events in each group is reasonably large, say not less than 5, the test statistic is:

$$\chi^2 = \Sigma \frac{(O-E)^2}{E} \quad \text{with } n-1 \text{ d.f.}$$

The method for calculating confidence limits for quantity parameter estimates presents no particular problems where the estimate can be assumed to follow the normal or 't' distributions. Thus for large samples, say where n is greater than 30, the estimate of the mean will follow an approximately normal distribution irrespective of the underlying distribution, due to the effect of the central limit theorem. For small samples, means of normally-distributed variables will follow the 't' distribution. Where estimates can be assumed to follow the normal or 't' distributions, confidence limits and significance tests can be calculated according to the standard methods.

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PROBLEMS ENCOUNTERED IN THE PRACTICAL IMPLEMENTATION OF GEOGRAPHICAL INFORMATION SYSTEMS (GIS) IN VETERINARY EPIDEMIOLOGY.

A. D. PATERSON *

SUMMARY

In recent years, much has been written about the application of Geographic Information System (GIS) technology in the field of disease control. However, the majority of these publications describe applications for which the development of GIS itself is the central theme, and which are carried out by large, multi-disciplinary teams, that often include a GIS specialist. The published works that result, have been strongly selected for success - in one form or another. Therefore a bias is introduced against documenting those inappropriate applications of GIS that waste many man days of time.

This paper - as part of a session on "Epidemiological Tools and Techniques" - aims to highlight some of the practical issues that hinder the use of this technology as a "pick up and use" tool in disease control. It is aimed at those workers who have not used GIS before, but wish to have an overview of the potential pitfalls. This will enable them to come to a reasoned decision as to whether or not GIS would be an appropriate tool to employ in their work. Due to the intended readership, very few GIS technical terms appear in the paper. The emphasis is not on what can be done with a GIS (as often this is only restricted by the input of resources), but rather, what direct benefit may reasonably result from the use of a GIS, when balanced against the input of time and resources required. The paper will concentrate on those issues that are unique to GIS, and do not form part of a conventional information system.

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* Research Fellow, The Veterinary Epidemiology and Economics Research Unit (VEERU), Department of Agriculture, University of Reading, PO Box 236, Earley Gate, Whiteknights Road, Reading, Berkshire, United Kingdom, RG6 2AT.

INTRODUCTION

Geographic Information Systems (GIS) are rapidly evolving into an important tool, applicable to many aspects of disease control. However, the technology is not yet mature, and only in the past three or four years have development resources been devoted to increasing ease of use, instead of functionality. As a result of which, this technology remains in the domain of the GIS specialist. This is analogous to the situation that existed twenty years ago, when for the same reasons, the use of statistical analysis software was confined to the statistical/computing specialist.

GIS is widely used in a number of disciplines, including, utility management, environmental monitoring, emergency response management, urban and regional planning, and marketing. A valuable role of GIS is the tendency for it to bring together many different disciplines. However, there is a tendency for workers from one discipline to see visually attractive GIS techniques being used in another discipline and mimic them, without much thought as to their usefulness.

The visually attractive nature of the output from a GIS, is both a major strength and weakness. There is a tendency for both the users of the GIS, and the readers of the output, to be seduced by the attractive graphics, and to forget the basic rules of data management, analysis, presentation and interpretation of results. Without understanding the technology, it is difficult for a naive reader to question underlying weaknesses inherent in the output.

Papers employing GIS can be broken down into a number of categories:

- Development of GIS itself for use in animal disease control
- Those aimed at investigating spatial analysis techniques used by other disciplines and assessing their validity for use in animal disease control
- Direct, practical application of GIS to animal disease control

When does an information system become a geographic information system?

It is important to realise that there are very few differences between a conventional information system and a GIS. This can be seen in Fig. 1, which shows a diagrammatic representation of a geographic information system. Those items that are unique to a GIS are identified by being contained within rectangles. When using a GIS, it is important to adhere to the usual rules essential to the successful use of a conventional information system.

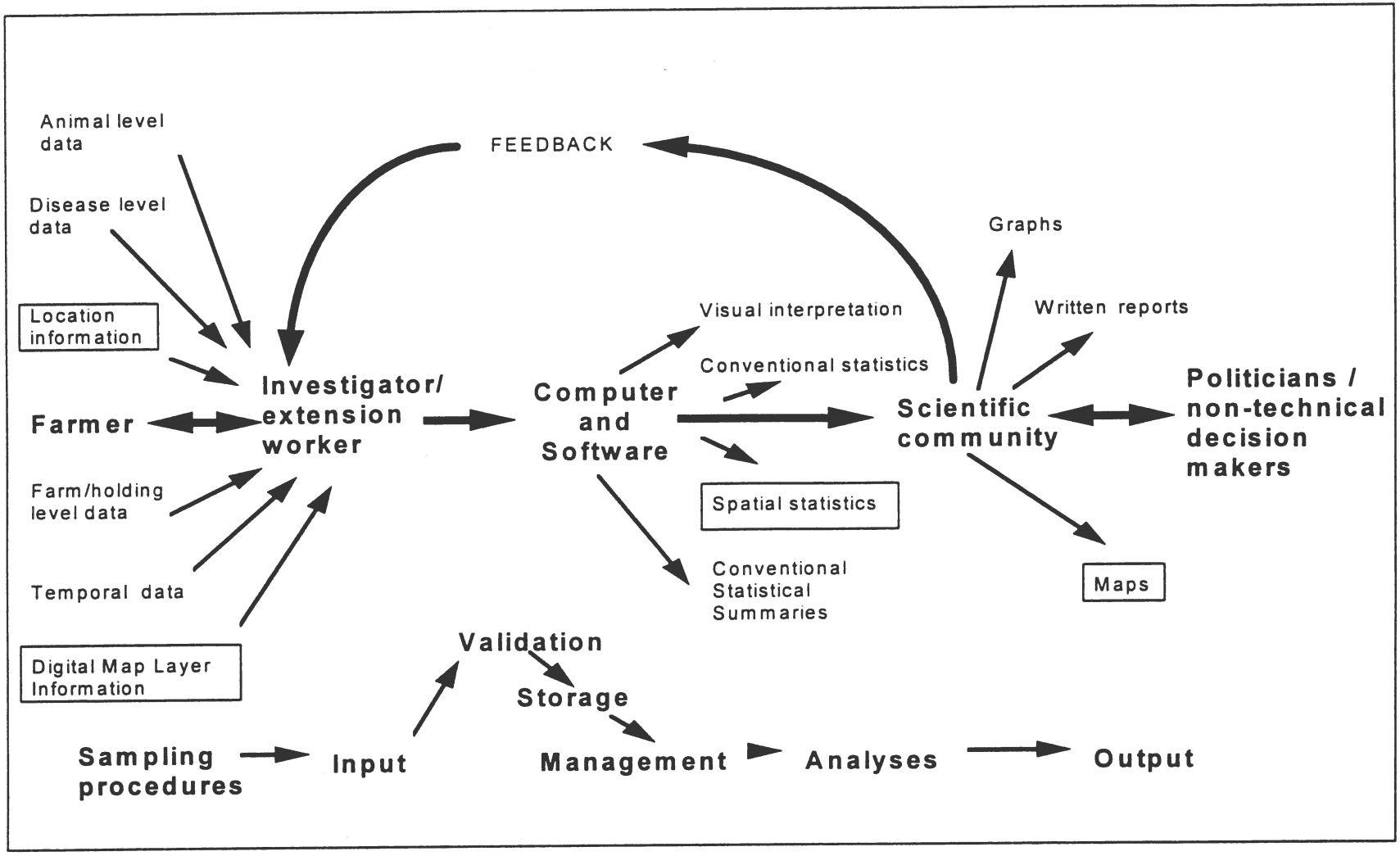

Fig. 1 Diagrammatic Representation of Information flow within a Geographic Information System.

(features unique to GIS are enclosed within boxes)

SPECIFIC AREAS THAT CAUSE PROBLEMS TO THE NEW USER OF GIS

Specific areas that need to be addressed, are outlined below in order of importance, related to the degree in which they restrict the wider use of GIS by small research teams.

INPUTS

Digital maps

Perhaps the most important limitation that precludes GIS from being a pick up, and use technology, is the lack of useable, ready digitised maps. Even in the developed world it can prove extremely difficult to obtain the information required. The following are common reasons:

- the map is available, but at the wrong resolution
- the map is in a different format from that required by the software
- the map is available, but too expensive
- the map is of poor production quality
- essential layers are missing e.g. administrative boundaries, or layers have been input from source material of different resolutions, such that they do not align correctly
- the information in the map is out of date
- the map is unavailable, or not in the public domain

The cost of digitised map data is likely to fall dramatically over the next ten years, due to advances in the use of tools such as satellite imagery and global positioning systems. As more organisations use GIS, the volume of digitised data available will increase, and consequently as volume rises, the cost is likely to fall. The development of an electronic " pay as you use" library accessed via modem or the Internet - similar to the Kodak library for computer artwork and photographs - is being investigated by companies such as Bartholomew. However, due to many technical and administrative issues, such as copyright problems, it is likely to be several years before this is a commercial reality. At the present time, the main users of digital map data are in the commercial sector, and therefore it commands a real market price. This price truly reflects the high cost of gathering and keeping high quality geographic information up to date.

When faced with some of the above problems, many researchers attempt to digitise their own maps, greatly underestimating the time and level of skill required. Digitising from printed maps is not a viable option for the following reasons:

- it is highly skilled
- it requires an enormous amount of time - especially if correct quality control measures are taken.
- it requires the purchase of additional hardware
- it introduces many additional levels of error

Problems of resolution: Even when the required digital map layers are available, they often have to be obtained from different sources. As a result of which the layers are of different quality,

having been input at different resolutions. At best this is only inconvenient, resulting in anomalies such as farm buildings in the middle of lakes, or bridges with neither roads or railways. The time taken to check and rectify these errors is enormous.

Location information

When the decision is made to use a GIS as an afterthought, at the end of the data collection period, it is often the case that there is no easy way to relate location information e.g. latitude and longitude to the other data. Even when this is possible, it is often found that the location information is only at e.g. district level, when what is required is farm level location data.

For example, one may have a list of sero-survey results from sampled farms, but no co-ordinates for the farms. There are two ways to approach this:

- Use a geographical positioning system (GPS), and gather the information in the field
- Use pre-existing paper maps to work out latitude and longitude

This process is time consuming and often inaccurate due to the inadequacies of available paper maps. The proper use of a relational database can speed the process. The use of satellite imagery is as yet too expensive and requires too much technical knowledge to interpret and correct.

Sampling procedures

Procedures for the random sampling of information of relevance to animal health are poorly documented and an appropriate standard set of sampling tools are still the subject of development through collaboration between epidemiologists and spatial statisticians.

ANALYSES

Spatial statistics

One of the basic principles of epidemiology is that disease is not randomly distributed within populations. Epidemiologists have looked for patterns - both spatial and temporal - for many years, in an attempt to link underlying causal factors with observed disease outcomes. Thus, it is natural for spatial statistics and epidemiology work together, however, at the present time there are no standard set sampling or spatial statistical analysis tools, that may be understood or applied by most workers in the field of veterinary epidemiology.

Spatial statistics have the potential to provide a powerful method of testing epidemiological hypotheses about patterns of disease occurrence. Three issues are relevant to disease control:

- is a disease clustered - hypothesis to test for random distribution within a geographic area?
- do two diseases or a disease and a potential risk factor have the same distribution?
- are there relationships between the values of the same variable at different locations?

It is possible to determine spatial relationships using conventional statistical methods, however, development and application of appropriate spatial techniques that are already used in ecology, geography, statistics and econometrics will allow workers to objectively quantify the magnitude and significance of spatial associations. Many analyses require custom written software, although commercial packages such as SpaceSTAT and S-Plus, now offer powerful spatial analysis modules, many components of which remain to be evaluated for use in epidemiology.

Conventional statistics

It must not be overlooked that conventional statistical analyses will often be sufficient to analyse and describe the required characteristics - the use of spatial statistical methods is not essential simply because the data has a geographical component.

Visual interpretation

The ability of the human brain to infer from visual images, the usefulness of this should not be underestimated. It is possible to use the graphic output of GIS to great effect, especially when describing information to non-technical decision makers. Several points relating to this issue are raised in the following section on output.

OUTPUT

Graphic

Due to the ease of use of most modern computer software packages, a "Jack of all trades" attitude has developed, and many of the tasks that were the reserve of the specialist are now sufficiently straightforward to allow them to be carried out in house by the research team alone. Increased computer literacy, the advent of the word processor, and the laptop computer, has meant that many more scientist type their own manuscripts directly. Improved graphics software allows the production of exhibition quality figures and graphs, apparently without the need for the skills of a graphics design department. In the case of a GIS, a major component of its usefulness is the ability to represent output in map form. Very few users have received even rudimentary training in graphic design e.g. in the use of shapes and colours, or training in cartography. At best, many of the maps produced are simply unpleasing to the eye, and at worst they are misleading - in the same way that axes on graphs can be manipulated intentionally or unintentionally, to alter the apparent meaning of the data. The correct use of shape and colour is of special importance when

much of the output from GIS is being used to portray information to non-technical recipients who are neither familiar with the subject, or the inherent strengths and weaknesses of GIS.

Use of shapes: It is common to represent variation in magnitude using similar shapes e.g. ellipses, of different sizes, however, it is common to vary the width or diameter of the shapes in proportion to the variation in magnitude. This is incorrect, as the human brain perceives variation in size of shapes as variation in area - not in the variation of a linear dimension such as width e.g. a circle twice the diameter of another has an area four times greater, and thus the perception of difference in size is markedly distorted.

Use of colours and shading patterns: The inappropriate use of colour combinations and shading patterns results in maps that are tiring to read, and difficult to interpret. A useful ground rule for any graphic output is that if the main point of the map cannot be inferred within thirty seconds, then it is likely to be too complicated, or incorrectly designed, and has therefore lost its purpose of getting across information in an abbreviated, and easily assimilated form.

Cartographic layout of maps: There is more to producing a map than drawing lines and symbols at the correct location on the page, there are cartographic conventions that should be adhered to, especially if the output is to be used by people outside one's field. Some time should be spent learning about the proper design and layout of maps, not only to improve the communication of the information, but also because of the overall impression of quality of work that results.

Hand drawn and shaded maps

Many maps are available as clip art libraries, that can be used with graphics packages. The manual shading of such clip art often returns the best balance of output versus input.

RECOMMENDATIONS FOR THE USE OF A GIS BY SMALL RESEARCH TEAMS

Factors discouraging the use of a GIS

Small research teams should not consider using a GIS if any of the following apply:

- There are no suitable base maps available in a ready digitised form.
- The GIS is for a "one off" purpose.
- There is not at least one member of the research team with a good, all round knowledge of computing. i.e. normally use computers for more than word-processing and dataset manipulation.
- There is not sufficient time to allow one man-month for a member of the team to become familiar with GIS in general and the chosen software in particular.

IMPORTANT FIRST STEPS IN STARTING TO USE GIS

- Enquire and find out if anyone else in your organisation has tried to use GIS in the past - many organisations have a GIS package gathering dust on a shelf. Find out what the GIS was being used for, and if it is not currently being used, find out why not?

- Find out if anyone else in your organisation is also interested in using GIS, as it may be possible to share the hardware, software and manpower costs between several departments. As discussed above, GIS does not currently lend itself to the "take off the shelf and use" approach, and the most efficient use of this technology is through the adoption of corporate standards and the development of in-house expertise.

- Before purchasing or using any software, allow at least one week for background reading on the principles of GIS alone, as many of the components of GIS are completely unfamiliar. There are a number of very good introductory texts for the newcomer to GIS, some of particular note are:

    - Understanding GIS: The ARC/INFO® Method (Environmental Systems Research Institute Inc., 1994)

    - Geographical Information Systems: Principles and Applications Volumes I and II (Maguire, D. J. 1994) Longman GeoInformation.

    - Handling Geographical Information: Methodology and Potential Applications (Masser, I. 1994) Longman GeoInformation.

    - Cartographic Design and Production (Keates, J. S. 1993) Longman GeoInformation.

    - GISTutor 2 - on screen, computer based tutorial (Wijnamaalen, E. 1992) Longman GeoInformation.

    - Spatial Analysis and GIS (Fotheringham, S. and Rogerson, P., 1994) Longman GeoInformation.

    - Mapping Awareness - monthly periodical from Longman GeoInformation

  In particular, the publishing house Longman has devoted itself to developing up to date reference material for users of geographical information.

- Great care should be taken in the choice of software, do not compromise flexibility in the future for ease of use in the initial set up period. Major considerations are:

    - the software in use by related groups with whom you work - you should aim to standardise as much as possible with other groups with whom you are associated.

- do not cut corners on the software budget - the cost of its purchase reflects only a fraction of the true cost of implementing a GIS.

- backup technical support is essential from either your research group, or the company marketing the product.

- Allow one man month of training and familiarisation, before expecting to be able to use it as a tool.

CONCLUSIONS AND GENERAL COMMENTS

- A GIS is an information system like any other, and the rules that apply to successful conventional information system also apply to a GIS.

- The use of a GIS should be planned and incorporated into the experimental design from the beginning, bearing in mind that, correct spatial sampling procedures appropriate to animal health information and spatial statistical analysis remains a weak point in the application of GIS.

- The addition of location information to a dataset after it has been collected is a laborious and error prone task. The gathering of location information should be planned alongside, and be an integral part of the design of the sampling/survey protocol. i.e. The use of the GIS should be planned from the beginning, it should not be added as an afterthought.

- Often individual items of spatial information required are missing and not available "off the shelf", e.g. a layer describing the distribution of a particular vegetation type.

- The use of GIS for "one off" projects is rarely justifiable in terms of the time required.

- A GIS is not essential if you wish to represent output on a map - you may simply be producing a sophisticated computer graphic using an interesting, but expensive technique.

- Beware of producing misleading output due to ignorance of the use of colour and graphic/cartographic design.

- A hidden advantage of employing GIS, is that it does encourage interaction and co-operation between different disciplines.

- GIS is not yet a mature technology ready to "pick up and use". The learning curve is steep and requires a wide background knowledge from range of disciplines.

- GIS is becoming more sophisticated, however, there is still a lack of tools for advanced spatial analysis relevant to the fields of epidemiology and disease control. However, do not underestimate the usefulness of conventional statistics and visual interpretation.

- GIS offers the ability to undertake procedures which were difficult or impossible using traditional database management systems, mapping or geographical analyses. The technology is still at an early stage, and has not yet come close to its full potential (Openshaw, 1987 and Goodchild *et al,* 1992).

- If GIS is to fulfil its potential as a general purpose tool for handling spatial data, it needs stronger analysis and modelling capabilities, with an improved user interface. Burrough (1992) states that "at present, geographical information systems are powerful tool boxes in which many of the tools are as strange to the user as a robot-driven assembly plant for cars is to the average home handyman". He calls for the development of intelligent GIS where a knowledge base is available alongside the GIS, to aid the user in the choice of the best set of procedures and tools to solve the problem within the constraint of the data, quality of data, costs and accuracy available.

- There is not a widespread training in spatial statistics and many readers will not be able to infer correctly from your results - an information system does not begin at the keyboard and finish at the printer.

- GIS is enveloped in fashionable high-tech mystique of computer technology and attractive computer graphics. Even in the case of the "successful" applications it is often difficult to see any purpose for the GIS other than for the production of colourful computer graphics. The ability to produce coloured maps containing only relevant layers of information, is a valid use of GIS, as long as many weeks are not required for their production. The use of an established GIS for this purpose is acceptable, however, to set one up for this purpose alone, is more difficult to justify unless considerable quantities of maps have to be produced on a regular basis.

- In many of the commercial application of GIS, the use is mainly for information retrieval problems, and querying, rather than analysis in the statistical sense.

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DISEASE AND PRODUCTION MODELLING: DEVELOPING ACCESSIBILITY AND USEFULNESS

S.K.Sivam BVSc CertCHP MSc MRCVS*

Modelling is an increasingly fashionable and useful tool in veterinary epidemiology and economics as it is in many other fields. In this paper the important underlying themes in structural models are addressed, the advantages and disadvantages of the main types of model are highlighted, and some general points are discussed. This is done primarily to assist those who wish to use modelling but for whom many texts are impenetrable or intimidating.

THE ROLE AND SCOPE OF MODELLING

Just as it is current to think in terms of production systems to represent the range of factors that influence the nature of livestock production carried out in a place, so it is pertinent to think of "disease systems". A disease system encompasses the range of influences (including diverse ones such as geographical, cultural, social and economic factors) which affect the distribution of disease and its determinants. Disease and production systems are complex biological and management systems and a structural model is an ideal environment in which to examine the interactions within the system. This is an argument for modelling to be more widely used and understood; this in turn needs a type of modelling which is accessible and useful. In veterinary epidemiology, modelling holds particular promise for evaluation of the economic impact of disease and control measures, and in testing hypotheses relating to the epidemiology of disease.

It is necessary to make clear what is to be included in the definition of "model" for the purposes of this paper. Most texts and papers refer to two uses of the term "model":-

a) Statistical models use the process of induction to assess empirical evidence for an hypothesised relationship. Such models "will infer causality without a knowledge of the pathways or processes leading to the observed phenomenon." (Hurd & Kaneene 1993). Statistical models analyse "surface phenomena" (adapted from King & Soskoline 1988). Statistical models are also referred to as "associative" (Hurd & Kaneene 1993), "empirical" (Thrusfield & Gettinby 1984), or "functional" (Bailey 1974 quoted in King & Soskoline 1988) models.

*Veterinary Epidemiology & Economics Research Unit, Department of Agriculture, University of Reading, Earley Gate, Reading.

b) Structural models are deductive; they extrapolate consequences of pre-determined relationships that are components of a system too complex to calculate by informal methods. Thus structural models are particularly suited to the study of disease and production systems. Structural models "attempt to portray underlying mechanisms" (King & Soskoline 1988). Clearly these models go further in establishing likely cause and effect and are to be preferred to purely statistical modelling, where possible. Structural models are also referred to as "process" (Hurd & Kaneene 1993), or "explanatory" (Thrusfield & Gettinby 1984) models.

This paper only deals with structural models. However it should be noted that statistically defined relationships are often used in structural models.

Structural modelling lacks a fixed set of clear definitions; this is partly because the subject is rapidly advancing and partly due to apparent conflicts in methodology of modelling and the difficulty of understanding much literature about modelling. A sound classification hierarchy of modelling is given in Hurd & Kaneene 1993.

CONCEPTS COMMON TO ALL MODELS

The design of a model, rather than the output, is arguably the most important part of modelling because the designer is forced to specify unequivocally (and usually quantify) the relationships between parts of the system as represented in the model.

Structural features in common: Whatever the type of model there are certain features which are common to all. This underlying sameness is a fundamental starting point for the study of all modelling if one is to see the simplicity in models and not be overwhelmed by their apparent complexity.

a) The population of interest is divided into groups or "compartments". For disease models these compartments (groups) might be "susceptible", "infected" and "recovered"; i.e. each compartment represents an epidemiologically distinct grouping. The model will define the relationship (usually over time) of each compartment with another.

For production models the compartments will represent different states of productive capacity.

b) There are "flows" between compartments and into and out of compartments, e.g. representing deaths and births. A simple example is shown in figure 1.

c) There are "influences" or "effects" upon the flows between and into and out of the compartments. For example, vaccination may reduce the rate of flow between susceptible and infected; early treatment of disease may reduce the outward flow of deaths from the infected group.

d) The influences and effects and flows are modelled as rates, probabilities and time-limits (see glossary).

It is important to note that all models, with their apparent complexity of structure and terminology, have such uniform and simple (structurally) beginnings. This structure is typically represented as a flow chart as in figure 1. It is the means of implementing the model that can differ so much.

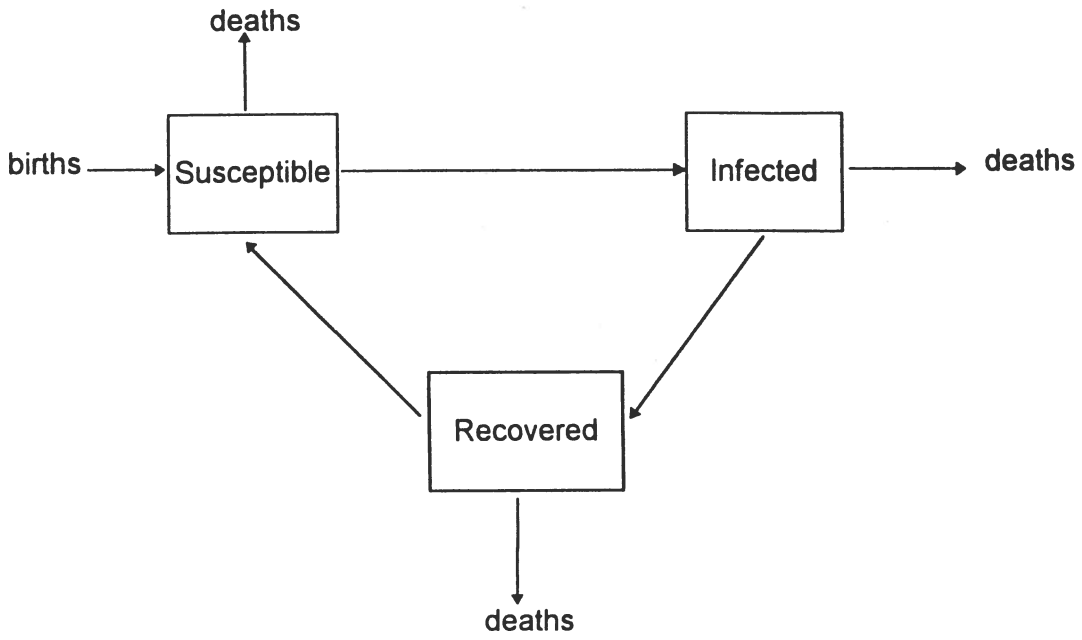

Figure 1: The structure of a very simple disease model: This type of structure is common to all model types.

It is theoretically possible to build other types of model in which such certainty about a group or individual's "state" is not tenable; e.g. this could be done by applying different types of theory e.g. fuzzy logic, in which uncertainty or a range of possibilities about an individual's state can be taken into account.

Problems common to all types of modelling.

Just as the fundamental structure of all models is the same, so are the major problems of any modelling exercise.

a) Data quality. This problem is particularly acute in modelling where it is possible to create elegant constructions without any basis in reality.

b) Models are created to mimic the general and important patterns and features of a system. This general nature of models means that it is usually invalid to apply them to the circumstances of individuals or highly localised situations. At this "micro-level", the influence of random effects is more pronounced; furthermore the generalised pattern on which the model is based is made up of many, often very different, individual (micro-level) circumstances. Application of the generalised model to an individual situation is likely to lead to erroneous results, just as assumptions about a nation's characteristics are often a poor way to judge an individual from that country.

c) In disease modelling a central problem is how to estimate the rate at which infectious individuals infect susceptibles, the contact rate (see glossary). It is extremely difficult to estimate this figure and related figures such as the "basic reproductive rate" (see glossary). This is a major problem with the construction of disease models. When estimates are made it is very difficult to tell whether the "rate" is truly characteristic of the disease or only the specific circumstances in which the "rate" was measured.

d) The appropriate calculation of production parameters, e.g. calving rate, and the appropriate use of these parameters, e.g. calving interval is a common theoretical

problem. Where rates or proportions are incorrectly calculated or applied this inevitably reduces the validity of the model.

STOCHASTIC AND DETERMINISTIC MODELS

The term stochastic implies some random or chance element whereas deterministic implies predictability. In this paper the use of terms stochastic and deterministic are applied only to the means of constructing the model rather than to the true nature of the system under observation.

It is sometimes difficult to decide if a system is deterministic or stochastic, e.g. many games of "chance" are entirely predictable in outcome if you have enough information to make that prediction. In all systems there are phenomena that appear random. This does not mean that the behaviour of the system is intrinsically without order, but just that we have insufficient information to determine or predict the behaviour. These aspects are usefully modelled using a stochastic process.

The use of a stochastic element in a model is similar to a sampling exercise; each run of the model is analogous to taking one sample and the range of results gives a distribution of outcomes; this distribution would be expected to be clustered around the average result. The average result is generally what would be produced by a deterministic model.

Whether a model is stochastic or deterministic is important in the interpretation that can be put on the results; if it is stochastic the model needs to be run many times to give an idea of the range of likely outcomes. It may be harder to perform sensitivity analysis because the random processes may mask any real difference due to the test change in starting parameters.

Stochastic models can be used to demonstrate risk (a frequency distribution of possible outcomes) that is associated with the system being modelled. This cannot be done with deterministic models that give only one result for any one set of parameters. This is especially important in planning interventions because, e.g. the stochastic model gives the proportion of occasions a project may fail even if the average outcome is a success.

ENVIRONMENTS FOR MODELLING.

Classifying models is difficult because there are so many ways of approaching the task. Whilst this paper does not set out to give a new hierarchy for classifying models it is useful to recognise two prominent environments in which models are constructed.

The environments are the:-
a) Analytical.
b) Iterative Simulation.

There is much terminology that is used to classify and sub-classify models, e.g. continuous-entity, continuous-time, stochastic, etc. This terminology and the myriad ways of cross-classifying models can be very confusing and not very illuminating when trying to understand basic features of different types of model. It is a

reasonable generalisation that the environment in which a model is constructed dictates the other sub-categories into which the model fits. This generalisation provides a useful starting point from which to compare the modelling environments.

In general, analytical models attempt to define all the relationships of interest in a system with mathematical equations. Iterative simulation models use a range of mathematical and programming techniques to simulate changes through time (and space); there is no dependence on defining relationships with equations.

FEATURES OF THE ANALYTICAL ENVIRONMENT

Disease systems and to a lesser extent production systems were modelled before the widespread availability of computers; these models were inevitably purely mathematical, i.e. analytical. In these models complex biological systems were represented by a series of equations The purely mathematical nature of these models allowed a solution to be found to the model which would otherwise have been impossible to address in any sort of quantitative fashion (i.e. before the arrival of computers). Ross (1911), provides us with an early example of the application of analytical modelling to the dynamics of malaria.

The overwhelming use of differential equations in analytical models means that the analytical environment has been most suited to problems involving smooth changes in dependent variables with respect to time. Such an environment is classically best suited to model physical systems acted on by Newtonian or classical electromechanical forces. Clearly biological systems need to be viewed in a similar fashion if one is to use analytical techniques to model disease or production systems.

Because of the form of analytical models they are usually deterministic and continuous-entity models (i.e. individuals are not identifiable within the population). This convenient approximation to reality is good where the population is large, but makes such models unsuitable for examining small populations. Analytical models tend to look at the "big picture" where local and/or small-scale effects are ignored or glossed over.

The effects of the natural constraints that the analytical environment places on models can make them conceptually elegant and the output can be very clear given their (usually) deterministic and focused nature. However it may be necessary to assume away much reality to formulate these elegant models and this goes hand in hand with some very complicated mathematics once the models progress past the simplest level. The complexity of some of the mathematics cannot be overstated.

Analytical models have played an important part in the development of theory relating to disease dynamics, epidemic theory and transmission of disease, e.g. the basic reproductive rate (R_0), minimum size of population to sustain disease; mass action principle (see glossary). A whole science of studying biological problems within the analytical environment has developed; this is especially true in the field of ecology, so much so that a new text by Scott & Smith 1994 refers to the study of diseases using analytical modelling as "ecological epidemiology". Ecological epidemiology has all the advantages and disadvantages of the analytical environment and represents what has been a dominant ideology in disease modelling.

An example of a paper that shows many of the attributes typical of analytical models is by Nowak & May 1994: In this they apply analytical modelling to an important idea of basic infectious disease dynamics, that of the evolution of virulence. The mathematics in the paper is complicated but the methodology allows the development of very interesting and important arguments relating to a "big picture" subject.

There are a number of other specific problems relating to analytical models:-
a) Heterogeneity is the variation within the population, e.g. due to breed or sex: It is important epidemiologically and in production studies. If we ignore heterogeneity then we must assume that all individuals are the same. This may often be a satisfactory simplification, but clearly in many circumstances this would be inadequate. In analytical models heterogeneity is difficult to deal with. Where change is modelled against more than one variable (usually time in uncomplicated models) then the mathematics becomes rapidly more complex, e.g. partial differential equations are used. Also there are specific theoretical problems, e.g. in the use of "waifw" (who acquired infection from whom) matrices (for a full discussion the reader is referred to Anderson & May 1991). Modelling heterogeneity in analytical models is difficult and in some cases such models may prove to be mathematically intractable.

b) It is problematic to change parameters, e.g. rates during a run of a model. The model has to assume a steady state of those rates governing the system. It is also awkward to model delays and lags and to build in stochastic effects using a purely analytical environment.

c) Numerical integration methods have to be used to solve differential equations on digital computers. This apparently arcane problem to the non-mathematician can be of great importance as the method used to simulate continuous time in the stepwise fashion of a digital computer can cause problems in how a solution is achieved and hence can affect the reliability of that solution.

FEATURES OF THE ITERATIVE SIMULATION ENVIRONMENT

The population of interest is represented in compartments as with analytical modelling and there are flows of individuals or groups between these compartments. Time is usually represented in discrete steps. Between each time step the status of individuals and/or groups is updated according to rates, probabilities and time-limit parameters, e.g. each day the variable for the age of an individual or group may be increased by one. The term 'iterative' is used because of this process of updating the status of individuals or groups as time progresses, step by step.

The relationships between parts of a system do not have to be stated only in equations. In contrast to analytical models where there is often a deliberate degree of abstraction, in iterative simulation models it is far easier to relate to the way in which parts of the model are represented and modelled. This is not a "necessary" difference, but it is a usual one. This difference may seem trivial, but when trying to understand and validate the model this will become very important.

Iterative simulation models are very flexible and a variety of mathematical or programming techniques may be used to simulate the system. Iterative simulation

models depend upon computing power for their execution and as computers have become more readily available so many more workers are starting to use the iterative simulation environment.

The primary problem with iterative simulation is that the user must learn to program. Learning to program is certainly much easier than learning advanced mathematics, but it still takes a considerable effort and it is assumed that the person embarking on this is already familiar with computers and is reasonably numerate.

STRUCTURE OF DISEASE OR PRODUCTION MODELS: MODELLING HETEROGENEITY.

It is not possible to describe the detailed structure of all production or disease models. But there are some general principles that can be highlighted.

The early stages of model development will always involve building a flow-chart and defining the objectives of the model clearly. For most veterinary epidemiological problems that are not of the "big picture" variety one must describe the population of interest in some detail. This entails representing demographic structures and modelling the rate of additions and losses to the population. On top of this herd model "template" the events (usually disease) can be superimposed.

Heterogeneities within the population, e.g. between ages, or spatial distribution or management types are usually crucial. Modelling heterogeneity is the key to the difference between simple models, e.g. classic chain-binomials (see glossary) and the more complex models. Heterogeneity can be modelled in the iterative simulation environment quite easily, unlike the analytical environment.

PROPRIETARY MODELLING SOFTWARE

Now on the market are several software products that are designed for building models, e.g. SB ModelMaker 2.0 (SB Technology), Stella II 3.0 (High Performance Systems Inc.). These packages predominantly use differential equations, but are not a straight-forward analytical modelling environment. The distinctions so far described become blurred.

Proprietary modelling software is becoming quite sophisticated and is undoubtedly of great potential, although they are still not as widely used as they might be in modelling disease and production; one example of their application is given by Ahlgren, D.J. & Stein, A.C., 1990 which examines the dynamics of AIDS.

Proprietary modelling software is characterised by their easy-to-use graphical user interface and the output of the model run can be tabular or graphical. These types of features remove the need for much tedious programming. One can draw the flow-chart on the screen and then specify the relationships between them and then run the model.

The most recent packages allow reference to look-up tables, permit time lags and even altering the values of key parameters during the run. It takes a matter of hours to become familiar enough to learn to use these types of package. Thus they have immediate appeal as a user-ready and user-friendly modelling package. If one wants to bring modelling to the masses then this is undoubtedly the medium for

doing so. Although these packages are predominantly analytical, the adaptability of the more recent releases seems to make them almost as flexible as iterative simulation modelling.

The problems with these proprietary modelling software packages are not immediately apparent and indeed may not apply to all potential users. The packages will not allow the more advanced modelling of disease and production systems where there is much heterogeneity, e.g. age structure, exposure status and spatial heterogeneities. They are not as conceptually flexible as the blank canvas presented by the iterative simulation environment and they are unlikely to be able to handle the more advanced analytical models because of the complexity of the mathematics.

If one strong argument for modelling is the process that needs to be gone through to define and then build the model rather than the actual output, then these models may be ideal as a medium for acting out the ideas put forward about a model's structure. Furthermore they offer great appeal as a teaching medium before going onto studying the more advanced means of model construction.

CONCLUSIONS.

The modelling environments discussed aim to achieve improved understanding of disease and production systems. They use the same ideas of compartments or strata and flows between them. This forces the relationships between parts of the system to be made explicit and they have to be quantified in relative or absolute terms.

The two environments described represent two ideologies rather than two completely and necessarily different means of modelling; it is the way in which these environments have been used make them seem so different. For most veterinary applications where non-specialists (and non-mathematicians) wish to frame modelling problems they need a modelling environment that is relatively easy to use and very flexible. There is no doubt that iterative simulation modelling fulfils these requirements better than analytical modelling.

Proprietary modelling software makes such a visible distinction less clear cut. The ease of use and flexibility of this type of software may make it preferable to iterative simulation modelling when fairly simple problems are being framed. For more advanced modelling, iterative simulation remains preferable because this environment does not constrain the way in which the model is formulated. In circumstances where the mathematical expertise is available and the nature of questions are of a general kind then classical analytical modelling retains a place.

GLOSSARY

Basic Reproductive Rate (R_0)	"The average number of secondary infections produced when one infected individual is introduced into a host population where everyone is susceptible." Anderson, R.M. & May, R.M., 1991.

Chain-binomial model	The population is divided into compartments and then in each time period a proportion flows from one compartment to another according to a probabilistic rule (which can be deterministic or stochastic).
Contact Rate	The number of contacts that an infectious individual makes per unit time with susceptible individuals.
Mass Action Principle	"The net rate of spread of infection is assumed to be proportional to the product of the density of susceptible people times the density of infectious individuals" Anderson & May 1991.
Probabilistic	Probabilistic models are those in which elements of probability theory are applied. Probabilistic models can be either stochastic or deterministic.
Time-limit parameter	Measures of productivity that give the time period taken for an individual to achieve a certain state, for example time to weaning after birth, calving interval.

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SOCIETY FOR VETERINARY EPIDEMIOLOGY AND PREVENTIVE MEDICINE

APPLICATION FOR MEMBERSHIP

Name .....

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Please enclose the membership fee (£10 sterling) along with this application form. Overseas members without British bank accounts are requested to pay 2 - 3 years in advance. Cheques should be in £ sterling and drawn from a British bank. British members should pay future dues by standing order (forms are available from the Secretary or Treasurer).

Please send this form to the Society's Secretary:

Dr K.S. Howe
Agricultural Economics Unit
University of Exeter
St German's Road
Exeter
EX4 6TL

Please turn over

INTEREST GROUPS

Please tick appropriate boxes to indicate your interests:

- ☐ Computing, including data-logging
- ☐ Population and animal disease databases
- ☐ Sero-epidemiology
- ☐ Herd health and productivity schemes
- ☐ Animal health economics
- ☐ Disease nomenclature and epidemiological terminology
- ☐ Statistical techniques and modelling
- ☐ Analytical epidemiology (observational studies)
- ☐ Disease control strategies

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. Membership is conditional on the return to the Secretary of a completed application form and a subscription equivalent to the rate for one calendar year. Subsequent subscriptions fall due on the first day of May each year.

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 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. 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 and 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; November 1994