SOCIETY FOR VETERINARY EPIDEMIOLOGY AND PREVENTIVE MEDICINE

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CONTENTS

THE DEVELOPMENT OF VETERINARY EPIDEMIOLOGYΦ

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This paper is dedicated to the late Dr Brian Leech who was a founding figure in modern veterinary epidemiology and statistics in this country. The advice and encouragement he gave to a younger generation of veterinarians, doctors and statisticians has borne fruit in the advances of the last decade.

Boswell once recorded a conversation with Dr Johnson on the subject of hospitality.

"Sir Alexander Dick tells me", said Boswell, "he remembers having a thousand people in a year to dine at his house".

Johnson: "That, sir, is about three a day".

Boswell: "How your statement lessens the idea".

Johnson: "That, sir, is the good of counting. It brings everything to a certainty which before floated in the mind indefinitely".

That last sentence encapsulates what most people think of as epidemiology - the study of disease in quantitative rather than qualitative terms, but it is a concept that floats indefinitely in the mind of the veterinary community and as it is one of the tasks of this society to bring it to a certainty, I want to consider some of the hurdles that we have to overcome.

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Φ*This paper was read at the Society's inaugural meeting, held at Edinburgh on 21st April, 1982.*

THE EMERGENCE OF A SCIENCE

We all recognise that the acquisition of medical or veterinary knowledge depends on an array of sciences and disciplines that range from the largely observational clinical sciences to the purely experimental laboratory sciences such as immunology and biochemistry. Somewhere in the middle of this lies epidemiology and there is still some doubt about its status. Some hold that it is a discipline, and treat it either as field investigation writ large, or as an appendage of one of the microbiological sciences. Others see it as a science in its own right and in advancing their case they have invested it with the trappings of an established body of knowledge - 'jargon', journals and in some instances a methodology which is cumbersome and bogus.

The division of opinion may appear to be nothing more than a semantic argument but it is important. The experimental laboratory sciences have sustained immense achievements over the last half century, but their limitations are now becoming obvious and even the most ardent experimentalist would concede that power no longer comes out of the barrel of a microscope. Quite apart from the limitations imposed by the cost of modern laboratory research, experimental studies can only imperfectly reproduce the natural world where the problems first arise and where the solutions are eventually employed. If epidemiology is seen merely as an adjunct to experimental research, it will be shackled with the same limitations and subject to the same narrow perspectives. It will either continue to be an amateur sport - that of making subjective observations in the field in order to raise hypotheses that can be examined at the laboratory bench, or exist simply to add some respectability to experimental findings that on their own are unconvincing. If on the other hand epidemiology is something more than a discipline then it is a science that can stand on its own feet, develop its own methodology, and increase our knowledge of the natural events that we seek to control.

Sir Harold Himsworth, the distinguished former secretary of the Medical Research Council, advanced another, more mundane reason for defining the status of an emerging discipline or science. He puts it thus:- "Perhaps one of the most difficult problems with which a research organisation can be faced is that of deciding whether a new science has emerged or (which comes to the same thing) whether a further field of natural experience has become accessible to scientific cultivation. The (Medical Research) Council was repeatedly faced by questions of this kind. Almost always these took the form of asking "What is so and so? What is biophysics? ... And of course implicit in any such question is the further question "Is there any such thing?".

"To answer questions of this kind is never easy. By the time that the issue is raised one is always confronted by two conflicting views. On the one hand is the view of those who hold to traditional opinion and see in the proposed development no more than a variation of their own particular knowledge. On the other is that of the protagonists of the proposed development who feel, always strongly, that the concepts of traditional subjects are quite inadequate and that only by approaching the allegedly new field on its own merits can this be developed. The problem is to decide which is right, for the consequences of an erroneous decision are never negligible" (HIMSWORTH 1970). In other words, if epidemiology is a science in its own right it gets direct financial and administrative support, but if it is something less then it lives at the coat tails of the other biomedical sciences.

Himsworth points to two considerations upon which the answers to these problems turn. The first is one of quality and he invokes Trotter's dictum "Quackery is the result of a premature attempt to apply the methods of a science to the domain of a practical art" (TROTTER, 1932), or as he himself puts it "Have the data in the field concerned been sufficiently defined to be susceptable to scientific analysis and if so, are methods available to allow this to be done". The second consideration is one of distinction: "is the field of natural experience that it is proposed to investigate different from that related to other scientific subjects and as such something that can become a source of knowledge that they cannot supply? If the answer to this question is 'yes' and a new field of natural experience has indeed become accessible, then for this to remain tied to the concepts derived from experience in other fields cannot but retard scientific progress. If on the other hand the answer is 'no' and we conclude that the allegedly new field of experience is no more than a part of one already under cultivation then the proper course is clearly to strengthen its links with endeavour in this field rather than to unbalance effort by providing for its independant development".

It has become clear in the last decade that veterinary epidemiology is now meeting these two criteria and therefore warrants consideration as an independant science. One of the best examples of current developments is the study of Foot and Mouth disease (FMD) epidemics. M Hugh Jones working with L.P.Smith of the Meteorological office (Smith & Hugh Jones 1970) plotted the occurence of FMD in Shropshire and Cheshire during the 1967/8 epidemic and suggested that the virus could have been disseminated by wind. This was a piece of work in the direct tradition of Snow and the Broad street pump and it added a new dimension to epidemiological work in the government veterinary service. Since then the epidemiological data have been refined by staff at Animal Virus Research Institute, Pirbright to include estimates of virus excretion and, together with meteorological evidence, have been used to provide a predictive model of FMD dispersion which is of demonstrable benefit in dealing with outbreaks of the disease. (Gloster, Blackall, Sellers and Donaldson 1981). The work fulfils Himsworths two criteria in that the data are susceptible to scientific analyses and the field of natural experience that it investigates, i.e. the spread of disease, is a distinctive source of knowledge.

THE INFLUENCE OF MEDICAL STUDIES

Before going on to discuss the development of veterinary epidemiology I want to reflect on the development of epidemiology in the medical field because it is a science that has heavily influenced and in some ways stultified its veterinary equivalent.

Medical epidemiology was, until the second world war, largely the epidemiology of infectious disease. We are all familiar with the development of public health epidemiology, i.e. the identification and tracing of infectious persons and agents. This discipline contributed greatly to the control of acute infectious disease at a time when more direct methods were unavailable but its very success combined with the advent of antibiotics and mass vaccination campaigns made public health epidemiology redundant. It was replaced by a completely different field of activity, the study of causation in chronic or rare diseases. Doll (1959) identified the link between smoking and lung cancer and this was followed by a series of investigations into relatively small effects in large populations, including studies on the thromboembolytic effect of the contraceptive pill (Vessey and Doll 1968) and the measurement of the deleterious side effects of certain vaccines.

Methodologies were developed to analyse these effects e.g. case control studies, and present-day medical epidemiology bears little relation to its pre-war progenitor. It satisfies Himsworth's two criteria for a science; thanks to modern data handling systems the data are well defined and susceptible to analysis, a methodology has been developed, and it is a distinct area of activity in that one cannot conceive of any other way in which one could approach the problems that it has dealt with.

The current field of activity in medical epidemiology can be glimpsed from the contents page of Volume 1 (1979) of Epidemiologic Reviews (Fig 1), and the list of papers is particularly interesting in that it allows us to identify the points at which modern medical epidemiology and modern veterinary epidemiology diverge. Two of the papers deal with the epidemiology of cancer - Burkitts Lymphoma and breast cancer- and cancer enquiries aceount for a large part of current activity in medical epidemiology. But cancer is thankfully a relatively uncommon disease and one which manifests itself in middle or later life. Farm animals do not live to enjoy middle or old age and rare diseases do not attract research funding in the veterinary field because they represent little economic loss to the livestock industry. I can think of two veterinary studies that are analagous to Burkitt's investigations - jaw tumours in sheep on the North Yorkshire moors (Macrae and Head 1978) and rumenal carcinomas in Masai cattle (Plowright and others 1971) but this kind of epidemiological investigation is uncommon.

Fig.1. Epidemiologic Reviews Vol.1 1979

Dedication and Introduction
Epidemiologic Aspects of Legionellosis
The Transmission and Outcome of Hepatitis A, B, and Non-A, Non-B.
The Epidemiology of Burkitt's Lymphoma: Evidence for a Causal Assocation with Epstein-Barr Virus
St. Louis Encephalitis.
A Review of the Epidemiology of Human Breat Cancer
The Effects of Exogenous Female Sex Hormones on the Fetus.
Epidemiology of Chronic Mucus Hypersecretion and Obstructive Airways Diseases.
Epidemiologic Patterns of Blood Pressure in Children
Postneonatal Mortality
Reflections on the Work of the Atomic Bomb Casuality Commission in Japan
Epidemiology and Health Policy

Several of the other papers listed deal with infectious disease - infectious hepatitis, legionnellosis and St Louis Encephalitis. The latter paper falls into the category of public health epidemiology, but the paper on infectious hepatitis describes epidemiological investigations into the various modes of transmission, some of which were carried out before the infectious agents were identified. Infectious hepatitis is a deadly disease and transmission experiments in human beings are unthinkable, but in the veterinary field such experiments would be the natural first step with little demand for the indirect evidence afforded by the epidemiological approach.

Two large fields of endeavour in medical epidemiology are therefore denied to veterinarians and the methodology carefully developed on the medical side may be inappropriate to veterinary studies where a more direct approach bears ample fruit; veterinary epidemiologists must beware of attempting to determine causality by methods that are unnecessarily complex.

THE MEASUREMENT OF DISEASE

How then is modern veterinary epidemiology to develop? As is often the case the best way of answering is to ask the direct question - "what is the objective"? The objective of much of modern medical epidemiology has been to determine causality in situations where experimentation cannot produce the answers. Veterinary epidemiology has rather broader horizons; causality is a minor concern and its objectives are to produce quantitative values that supplement the qualitative results of experimental research to provide a rational and comprehensive basis for action to control disease or to maintain health. For too long judgements on animal disease control in the agricultural sector have been based in experimental results supplemented by anecdotal evidence of the effect of the disease in the field. The very nature of the modern agricultural industry demands something better.

A good example of the production of quantitative values is a recent retrospective enquiry into breakdowns in herds infected with Br. abortus. French experimental studies (PLOMMET and others 1973) showed that it was possible for female calves born of infected dams to maintain a cryptic infection (seronegative) until they were advanced in their first pregnancy when they aborted and infected neighbouring stock. In these experiments 4 out of 22 female calves harboured infection in this way and if that proportion were reflected in the brucellosis scheme in this country where it has been the practice to slaughter out only the adult stock in heavily infected herds there would have been widespread outbreaks of infection in allegedly clear herds. The matter was of some concern and was resolved by a retrospective examination of the records of all herds where adult animals were slaughtered (Wilesmith, 1978). The maximum risk was calculated at 2.5% of hiefers, born of infected dams, aborting or otherwise disseminating Br. abortus in re-established herds and this result allowed a rational judgement to be made on the slaughter policy.

I have said that causality is of minor concern and that is, of course, a statement that can be made in relation to current veterinary science as a whole. We already know the cause, in terms of infectious agents or biochemical deficiences, of most of the diseases that confront us. Our energies are largely devoted, on the experimental side, to devising new and better tests for the presence of infection or deficiency, and on the epidemiological side to measuring contributing factors, notably in diseases of intensive livestock systems. This has led us, as epidemiologists, to devise techniques for measuring environmental effects and has faced us with the problem of obtaining an objective measure of disease as opposed to infection. The mastitis cell count is a notable example of a measurement which enables us to gauge the effect of various husbandry and hygiene practices on subclinical mastitis and at the same time allows us to provide advice founded on a basis of fact. A cough counter (Miller unpublished) attempts to provide a similar measure for respiratory disease and we need further developments of this kind to help us in investigating so-called 'multifactorial' disease.

Apart from this investigation of disease determinants veterinary epidemiology is increasingly concerned with the evaluation of production and economic effects of disease. This takes us into the field of preventive medicine, hence the title of the proposed society. To some extent we are responding to pressure from the livestock industry and the best example of the benefits that we have been able to offer in return is the herd health recording systems that have been pioneered by the universities and by general practitioners. It is appropriate here to return to the need for measures of disease such as the mastitis cell count, or for objective measures of productivity - the basic tools without which preventive medicine is in danger of falling into Trotters definition of quackery.

SURVEILLANCE

I have pointed to some of the achievements of veterinary epidemiology but looking back over the past decade, and in particular at the international conferences that mark the state of the art, one must reach the conclusion that a great deal of time and energy has been taken up with information gathering. At the 2nd International Symposium on Veterinary Epidemiology and Economics held in 1979 there were no less than 22 papers in the section on information gathering and 10 on the analysis and interpretation of epidemiological data. The number of papers which could be said to describe work that actually solved problems or tested hypothesis were remarkably few. This is understandable; a fledgling science is usually preoccupied with techniques - the benefits come later. But it would be wise to steer a course between the Scylla of making subjective observations in the field and drawing from them quite untenable conclusions and the Charybdis of gathering information for its own sake. Our experience at the Epidemiology Unit, Weybridge has been that 'surveillance' - a beguiling word - can quickly consume vast resources in staff time and thought that are better directed to facing the real problems that we are required to solve. Some form of continuous surveillance of disease is necesary but I would hesitate to advocate continious monitoring that cannot, at least, be justified as a adjunct to commercial or statutory routine activity. The alternative is to have detailed knowledge of populations, their numbers, their distribution and their age structure, something that is sadly lacking in the companion animal sector, and to mount point prevalence surveys, finite longitudinal investigation, case control studies and other exercises that are designed to answer considered questions.

THE NATURE OF SCIENTIFIC ENQUIRY

The current emphasis on information gathering sometimes seems to stem from a misunderstanding of the nature of scientific enquiry: the assumption that the accumulation of data inevitably leads to the formation of hypotheses. Himsworth gives as an example of scientific method and the development of a hypothesis the observation that if sufferers from rhematoid arthritis became pregnant or developed hepatitis they achieved a temporary remission from the illness. Hench, after satisfying himself that these reports were valid, formulated the hypothesis that in pregnancy there was an overproduction of steroids. This was tested and led to the use of steroid therapy. I can think of a similar example that is of more direct interest to epidemiologists - Sir Norman Gregg noticed that epidemics of rubella were followed by the birth of deformed babies. The hypothesis that the virus damaged the foetus was proved correct and led to the vaccination of girls before pregnancy. In the veterinary field Wilesmith (personal communication) tested the hypothesis that tuberculosis might be present in badger population outside the known infected areas in the west of England. He found that the probability of cattle herds acquiring the infection was higher in areas densly populated with badgers and concluded that the hypothesis was correct, a conclusion borne out by subsequent field studies.

In each of these cases the human mind intervened to note a peculiarity and to draw a conclusion. Quite often in veterinary and in medical epidemiology, data seems to be accumulated in such a way as to obscure a pecularity rather than to throw it into relief and it often needs a certain amount of patient reflection rather than grinding statistical analyses to bring out the significant features of the data. Currently we are looking at the spread of Aujeszky's disease between pig herds. A great mass of information has been accumulated on the outbreaks in East Anglia and it was only when these were plotted by geographical location and year of notification that it became apparent that there was a well defined pattern suggesting local spread. The spread is rarely from one set of premises to its nearest neighbour but it is almost inevitably confined to an area less than 3KM in radius. This pattern is now being faithfully repeated in clusters of outbreaks in other parts of the country; we do not know what is responsible for it but the next step is to raise hypotheses and to test them either by recourse to the epidemiological data or by experimental studies. For the former we need additional information such as the location and disease status of other pig units within and without the 3Km circle to determine whether they have suffered inapparent infection and here we rely on the demographic data that have been built up in the past. This iterative process is common to experimental and epidemiological investigation and it was Claude Bernard who commented that "an experiment is essentially only a provoked observation".

To return to Himsworth "the natural phenomena of the clinical field are an integral part of the biological experience. In that this field is now becoming increasingly accessible to the direct scientific approach it is increasingly possible to realize its potentialities as a source of original contribution to biological thought". I can only add that at the end of the day the science of veterinary epidemiology will be judged not by the complexity of its techniques or the obscurity of its jargon but by the distinctive contribution it makes to the advancement of veterinary science; the alleviation of suffering and the improvement of the livestock industry. It is these objectives that we, as a new society, must keep before us.

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DATA RECORDING AND ANALYSIS IN DAIRY HERDS

DAIRY HERD DATA RECORDING METHODS AND USE IN LIVERPOOL UNIVERSITY'S LARGE ANIMAL TEACHING PRACTICE

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The Liverpool University Large Animal Practice attends twentyfive farms in the Wirral Area, with groups of students. Handwritten records of the cases seen have been kept for many years; it is only within the last year that the computerising of records has been started. The recording of herd fertility information has been approached separately from other non-fertility records.

Early in 1982 a microcomputer dairy herd program[1] was acquired to aid in recording herd fertility information. This system is being used for three farms, which also have a weekly herd fertility visit.

A separate system, using a microcomputer database[2] and a hierarchical numeric diagnosis and treatment coding system has been tried for the non-fertility case records. Both systems use an 'Apple II' microcomputer with a language card giving 64 kbyte RAM, an eighty column screen, two 5 inch disc drives and an 'Anadex' 132 column printer.

HERD FERTILITY RECORDING

The Dairy Programs are designed mainly for on-farm use. Thus the herd fertility parts are used, but the feed calculation and gross margin facilities are not used. However, milk recordings for the cows on two of the farms are recorded and I hope that this will be of value in relating disease conditions and production levels.

Each farm has a separate data disc, but all three farms use the same program disc. The first task with a new system is to place initial herd information onto the microcomputer. This is then updated weekly, with a weekly 'action list' being produced.

Initial data input

The initial information required for each herd consists of those items

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shown in the initial input form in Fig. 1.

Cow No.							
Last Calving Date							
Dry (D) or in Milk (M)							
D.I.M.							
305 day yield							
Total yield							
Group No.							
No. of serves							
Previous calving date							
D.I.M.							
305 day yield							
Total yield							
Cumulative fat							
Service dates 1							
2							
3							
4							
Bull used							
P.D. + ve Y/N							
First recorded month							
Milk recordings this lac. 1							
2							
.							
10							
Milk recordings previous lac. 1							
2							
.							
10							

Fig. 1. Initial herd fertility data input form

This form can be given to the farmer for him to fill in, or one may go through his records with him and fill it in. The milk recordings may be taken straight from Milk Marketing Board recording sheets. The form is laid out in the same order as is required by the programs. The milk records may be ignored if one wishes. There are a number of checks within the program to ensure that sensible dates and figures are entered. The initial input may take many hours work for each herd, but once it has been done, the weekly updating is quite rapid.

Weekly updating

Updating is done weekly by the farmer filling in a 'weekly activity sheet' as shown in Fig. 2. The efficiency with which these forms are filled in and returned varies; with one farm we obtain as much information as possible for the previous week at the time of the weekly herd fertility visit or phone him for the information. The design of the 'action list' printed out each week means that cows will remain on it until they have been served, pregnancy diagnosed positive, calved, dried off or sold. Thus, by going through the action list with the farmer, one can ensure that one obtains all necessary information except for any new cows entering the herd.

Leahurst herd fertility activity sheet

Farm ____________________ Week ending/Input date ____________

Bulling Not served		Served			P.D.in calf	Calved	
Cow No.	Date	Cow No.	Date	Bull	Cow No.	Cow No.	Date

Herd and group changes

Cow dried off		Cows barren	Group changes		Cows sold		New cows		
Cow No.	Date	Cow No.	Cow No.	New Group	Cow No.	New Group	Cow No.	Date Calved	Group

Fig. 2 Weekly input 'Activity Sheet'

Herd fertility reports

A range of different reports may be obtained on either the screen or as a printout on individual cows or on groups of cows, which may be selected by a number of different parameters, e.g. yield over 30 kg.; cows calving in a particular month; cows with a particular sire. The amount of information printed out for a group of cows chosen in this way may be as detailed as one wishes to choose.

There is a standard 'Action Reminder' which we print out and send to each farm every week. This report contains details of the following:-

(i) Cows due to calve
(ii) Cows to dry off
(iii) Cows due 1st service (from 60 days post-calving)
(iv) Cows due for repeat service
(v) Cows seen bulling three weeks before
(vi) Cows due for P.D.
(vii) A list of barren cows
(viii) Cows with a possible fertility problem (served more than three times, or dry but not P.D.+ve)
(ix) Herd statistics

Many of the items in the action list simply aid the farmer in herd management. Encouraging farmers to record cows seen bulling, but not served, gives a list of these cows three weeks later to bbserve for bulling again; this helps to make the farmer serve cows earlier. The lists of cows due for first service and cows due for P.D., gives us the group of cows to see at the next weekly visit. This list is extracted from the rest of the report and any cows which were seen the previous week have shorthand notes on the previous week's findings and treatment added so that a comprehensive list and case details can be taken on the weekly herd visit. Figure 3 shows the veterinarians' visit list.

Cows due 1st service

No. of visits			Cow No.	Calving Date	D.I.M.
4	Lo-Sm., Ro-Sm, Fol	PRID	75	22/11/82	88
1	Lo-Cl., Ro-Fol,	Pg	96	11/12/82	69
1	Lo-Fol, Ro-Old Cl	Watch	137	1/12/82	79
1	Lo-Fol, Ro-Nil	Watch	165	13/12/82	67
3	Ro-Cl	Pg	173	1/12/82	79

Cows due to P.D. and Problem cows

No. of visits	Last visit		Cow No.	Calving date	No. of serves	Latest	Days Since
0	(To P.D.)		32	11/8/82	3	22/12/82	58
2	Lo-Nil,Ro-Fol	- Watch	49	28/9/82	1	9/11/82	101
2	Lo-Cl,Sm.Fol,Ro Nil	- Pg	92	24/7/82	1	21/11/82	89
0	(To P.D.)		151	13/9/82	2	15/12/82	65

Fig. 3 Veterinary visit sheet

Some simple shorthand notation is used including 'Lo' - left ovary; 'Ro' - right ovary; 'Fol' - follicle; 'Cl' - corpus luteum, 'Ut' - uterus; 'Pg' - prostaglandin.

The herd statistics are shown in Fig. 4. Numbers and herd percentages of milking cows, dry cows, cows PD +ve, cows served and not PD'd and cows not served are given, and a current and projected calving index. These herd statistics help us to follow a herd's progress.

Herd statistics

Nos. of cows

	No.	%
P.D. confirmed	41	37.3
Served not P.D.	31	28.2
not served	23	20.9
Cows in Milk	95	86.4
Dry	15	13.6
Cows in herd	110	100.0

Avg. ltrs. last recdg.		24
Avg. % diff		1
Days to 1st serve		77
Herd Calvg. Index - latest		395
' - projected		396
Barren cows		3
Conception % to serve No.	1	55
	2	32
	3	8
	4	3

Fig. 4 Herd statistics printout

A small amount of disease, or other information, such as cow sires, may be stored as 'cow codes'. This allows one to allot up to ten codes to each cow; but this information cannot be dated. Thus, one can record if an individual cow has a history of milk fever, distocia, mastitis, or lameness. One can subsequently search the herd for all cows with a particular code, e.g. milk fever, and print any further information on cows selected. Thus, one could produce a list of cows which might be prone to milk fever, together with their expected calving dates. The recording of each cow's sire and milk yields enables one to relate sire groups and production levels with recorded conditions.

USE OF A MICROCOMPUTER DATABASE FOR RECORDING OTHER CASE RECORDS

A microcomputer database[2] has been set up to record some basic information, including diagnoses and treatments of all cases seen on a few farms within the last year. The following is an example of a case record (Fig. 5).

Record No.	43	
Case No.	83	
Farm Code	W	
Date 1st seen	27/5/82	
Diagnosis 1	136	(Left displacement of Abomasum)
Diagnosis 2	---	
Treatment 1	425	(Laparotomy)
Treatment 2	437	(Replacement)
Treatment 3	---	
No. of revisits	2	
Outcome	-	

Fig. 5 An individual case record

The codings are numeric to allow for ease of database searching. They are also hierarchical; the first diagnosis code number representing one of nine body systems, as shown in Fig. 6.

Numeric code	System
000	Systemic
100	Digestive
200	Respiratory
300	Metabolic
400	Musculo-skeletal
500	Nervous/Spec.Sense
600	Skin & Mammary
700	Urogenital
800	Cardiovascular

Fig. 6 Main system code groups

The second figure in the code represents a sub-division of the main system. For example code 100 represents the digestive system, code 130 represents the ruminant forestomach, as shown in Fig. 7. The specific condition is given by using the third figure in the code which in the example record in Fig. 5 is 136. This represents left displacement of the abomasum. This can also be seen from Fig. 8.

The database allows searching on any one of the factors within a record. Thus in the above example one could pick out all the cases with conditions of the ruminant forestomach by searching on the first two digits (13̲0);

Numeric code	Sub-system
100	Digestive
110	Mouth & Pharynx
120	Oesophagus & Stomach
130	Ruminant Forestomach
140	Small Intestine I
150	Small Intestine II
160	Large Intestine
170	Rectum & Anus
180	Peritoneal Cavity
190	Miscellaneous

Fig. 7 Sub-system codes for Digestive System

whereas if one wished to see only details of cases with left displacement of the abomasum one would search on the code 136.

Numeric code	Specific conditions
130	Ruminant forestomach
131	Bloat
132	Grain overload
133	Traumatic reticulitis
134	Simple indigestion
135	Vagus indigestion
136	L.D.A.
137	R.D.A./Torsion
138	Sq. cell carcinoma

Fig. 8 Specific 3-figure condition codes

DISCUSSION

I have described two systems being used to aid the recording of Dairy Herd Data. The Herd Fertility system is efficient at keeping routine individual cow fertility data up to date, but it is limited in its recording of non-fertility information. The separate database is an attempt to record this other information. The numeric codes are readily searched, and their hierarchical nature allows one to build up a code for an individual case in a logical progression, enabling one to be as detailed or as generalised as a particular case allows. However, the numbers are extremely difficult to remember and my next aim is to produce a similar system using alpha codes which are more easily remembered. Such a system will probably require a larger capacity microcomputer. Hopefully the case recording facilities and herd fertility and production data will eventually be combined into one system to allow cross-referencing of data.

HEALTH AND FERTILITY DATA RECORDED BY MEMBERS OF THE DAIRY HERD HEALTH AND PRODUCTIVITY SERVICE

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and D.A. WHITAKER, M.A., M.V.Sc., VET.M.B., M.R.C.V.S.*

The Dairy Herd Health and Productivity Service (DHH&PS) operates at the University of Edinburgh, Royal (Dick) School of Veterinary Studies, in conjunction with Dalgety Spillers and practising veterinary surgeons. It provides a system for monitoring and assessing health and performance in commercial dairy herds and acts as a stimulus to the maintenance and improvement of productivity (Kelly and Whitaker, 1982).

A vital component of this service is the recording of data on a monthly basis. Unlike many of the systems which have been developed (e.g. Blood et al., 1978; Martin, 1982; Russell, 1983) no attempt has been made to record detailed diagnoses or to introduce a coding system. Only by requesting basic information has it been possible to maintain a high return rate of data from a relatively large number of farms.

MATERIALS AND METHODS

Computer system

The DHH&PS programs are written in Fortran IV and operated on a Digital RT-11 minicomputer. Data is stored on floppy disks.

Data input

Two hundred and fifty farms throughout the UK participate in the service. Average herd size is 118.

Participating farmers maintain day-to-day health and fertility records using a pre-printed barn sheet. At the end of each month these are accumulated on a data sheet II (figure 1) which is distributed to all the parties concerned.

Recorded are the number of cows culled, and the principal reason for culling, such as yield, infertility, mastitis, lameness, age and other, which includes deaths.

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Number of Cows in Milk Incl. Heifers at End of Month

Number of Cows Dry at End of Month

Number of Cows Sold Because of

Yield

Infertility

Mastitis

Lameness

Age

Other

Number of Cows Treated for

	VET	FARMER
Infertility		
Mastitis		
Dig Disease		
Hypomag.		
Hypocalc.		
Ketosis		
Lameness		
Other		

Mastitis Cell Count ('000 cells/ml)

Number of Cows Served

	AI	BULL
First Time		
Second Time		
Third Time		
Fourth Time +		

Pregnancy Diagnosis by

	+VE	-VE
Milk		
Vet		

Fig. 1 Monthly data sheet II

Treatments for disease are identified as those treated by the veterinary surgeon and those by the farmer. The categories are infertility, mastitis, digestive disease, hypomagnesaemia, hypocalcaemia, ketosis, lameness and other. Each case is recorded once only, even if treated by both farmer and veterinary surgeon, and even if treated on successive occasions for the same disease incident. Routine procedures, such as foot trimming or dry cow therapy, are not entered as "treatments" but may appear as "other" with an explanation.

Fertility events recorded are the number of first, second services, etc., differentiating between AI and natural means, and the results of pregnancy diagnosis by veterinary surgeon or by milk progesterone testing.

Although financial details are not recorded directly for the DHH&PS, all members participate in a recognised dairy costings service.

Data output

The individual farm data is analysed quarterly and a Herd Health Report (figure 2) is issued to both the farmer and his veterinary surgeon.

Quarterly comparisons of improvement and deterioration can be made and constructively discussed.

In spite of only basic information on reproductive factors being requested, the indices produced provide clear markers of performance, management standards and trends in fertility efficiency. The chief function of this is to stimulate a more detailed investigation on the farm so that control measures can be instituted as early as possible.

RESULTS AND DISCUSSION

The major difference between DHH&PS and other systems is in the simplicity of the recording system. In the report on Jointex (Anon., 1976), the principal reason given by farmers for withdrawal from herd health schemes was the burden of record keeping. Only by easing this as much as possible and by ensuring that output has practical value on the farm has it been possible to maintain the co-operation of 250 farmers throughout the UK. Our present system has evolved over six years to achieve the current average monthly data return rate of 80%.

Data for approximately 29,000 cows has been made available for epidemiological purposes. Whilst the major reasons for culling of dairy cows have been fairly well documented, there is little information on the national incidence of some diseases. Most published information is based on treatments recorded by practising veterinary surgeons. The pitfalls of this are illustrated by the 5.5% incidence of lameness in dairy cows reported by Russell and others (1982), compared to the 25% incidence found in DHH&PS herds (Whitaker, in press).

Discussion of recording methods depends entirely on the purpose for which they are kept. The purpose must be clarified and stated at this symposium.

Dairy Herd Health & Productivity Service

Dalgety Spillers

QUARTERLY HERD HEALTH REPORT FOR THE PERIOD ENDING DEC 1982

NAME

FARM CODE

		Last Quarter	This Quarter	Same Quarter Last Year	12 Months Ended DEC 1982		COMMENTS
Ave. Number of cows of milking age in herd		151	147	137	142		
Number of cows sold because of	Yield	0	0	0	0	0.0 %	
	Infertility	3	1	1	11	7.7 %	
	Mastitis	2	0	0	7	4.9 %	
	Lameness	6	0	0	8	5.6 %	
	Age	0	0	1	4	2.8 %	
	Other	1	2	1	4	2.8 %	
	Total	12	3	3	34	23.9 %	
Number of cows treated for	Infertility	8	8	6	72	50.6 %	
	Mastitis	16	19	14	54	37.9 %	
	Digestive Upset	0	0	0	0	0.0 %	
	Hypomagnesaemia	0	0	0	0	0.0 %	
	Hypocalcaemia	0	5	0	10	7.0 %	
	Ketosis	0	0	0	1	0.7 %	
	Lameness	5	19	29	74	52.0 %	
	Other	0	0	0	2	1.4 %	
Ave. Mastitis cell count ('000 cells/ml)		197	138	175	173		
Number of cows served by AI	First Time	36	43	44	134		
	Second Time	14	17	23	56		
	Third Time	4	5	7	24		
	Fourth Time +	6	3	1	23		
Number of cows served by bull	First Time	0	1	0	1		
	Second Time	0	2	0	2		
	Third Time	1	0	0	1		
	Fourth Time +	0	3	0	3		
Percentage of cows of milking age in herd receiving a first service (target 100+)		-	-	-	94.8 %		
30 day first service non-return rate % (target 70-80)		54.8	57.8	42.5	56.7		
Pregnancy Diagnosis	Milk + ve	0	0	0	0		
	Milk - ve	0	0	0	0		
	Vet + ve	40	20	0	102		
	Vet - ve	2	1	0	10		
Negative rate of milk tests % (target less than 15)		0.0	0.0	0.0	0.0		
Pregnancy rate of cows examined by vet % (target 95 +)		95.2	95.2	0.0	91.1		

Fig. 2 Quarterly Herd Health Report

Either accurate detailed data from a very small number of "sentinel type" herds is required, in which case the more complex systems may be suitable, or else accurate but relatively superficial data from a large number of herds is more useful, in which case our type of system is appropriate.

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A COMPUTER PROGRAM FOR USE IN PRACTICE TO RECORD AND ANALYSE FERTILITY, DISEASE AND TREATMENT DATA FROM DAIRY HERDS

HUGH BOYD*, DAVID B. ANDERSON** and IAN WILLIAMSON***

In 1977 Glasgow University bought a mainly large animal veterinary practice in Lanark to be run on a commercial basis and to be used for student teaching. Herd fertility control was an area developed by the practice which initially made use of a computer program to handle fertility data in the Veterinary School (Boyd, 1972). On this well tested basis a new program was written with the needs of the veterinary practice strongly in mind. The objectives of the new program, which was named DAIRYCOW, were:-

1) Low cost in terms of establishment and running

2) To be understood by farmers and to be useful for them

3) To be helpful to the veterinary surgeons in the practice.

DESCRIPTION OF THE PROGRAM

Information required

The general principle used has been to cut down to the minimum the information collected; only information which appeared likely to be used is gathered. This, of course, means that compromises have to be made but this applies to any program however apparently all-embracing.

Identification of the cow: name or number and current lactation number.

Reproduction data: calving date, normality of calving and of associated events, non-service oestrus dates (up to 3), service dates (up to 6) with bull used, breed of bull, natural service or artificial insemination, and result of pregnancy examination.

Diseases: a simple, flexible, coded system which each user can modify according to needs. Records are as follows:

Date	Disease	Type	Comment
27/01/83	E. coli mastitis	L.F.	T.Delta

Culls and Deaths: these are coded as voluntary culls, involuntary culls and deaths.

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Storage in the computer

The computer used is a 64K Tandy microcomputer with expansion disk drive and printer. The program also runs on a Tandy Model 3 and is being modified so that it can be run on Glasgow University's ICL 2976 mainframe computer. One program disk serves all the farms. Each farm has a disk which contains three files:-

1) Current lactation events and diseases.

2) Previous lactation events and diseases.

3) Cull cows.

A cow's record remains on file for eighteen months after which it is removed from the file. This allows retrospective analysis for the previous year but does limit the time over which comparisons can be made. If it is planned to compare different years, it is necessary to take hard copy at least once a year.

Action lists

The action lists are produced primarily for the farmer but they offer the veterinary surgeon a simple review of the status of the herd. If many cows are overdue for oestrus recording or overdue for service, it is a warning that efficiency is slipping.

The categories for reporting on the action lists are as follows:-

1) Cows overdue for oestrus occurrence.

2) Cows overdue for first service.

3) Cows due for pregnancy diagnosis.

4) Repeat breeders (3 or more services).

5) Returns (pregnancy diagnosis negative).

6) Calving due in 90 days.

A calendar is also produced which highlights likely forthcoming events.

The targets for the production of these action lists are easily controlled according to the specific needs of the farmer or veterinary surgeon.

Fertility Analysis

Although the farmer is interested in an occasional check up on the overall fertility picture, the main beneficiary of fertility analysis is the veterinary surgeon for whom analysis ought to point out areas of weakness which require intervention.

Fertility analysis is always out of date because it is essential to allow time to elapse for the completion of the various events between calving and conception and pregnancy diagnosis. For example, if an analysis of calving conception intervals is done for a group of cows which calved up to 90 days before the date of the last visit, some of the cows will not have been served, some will have been served but not yet confirmed pregnant and a few will have been confirmed pregnant. As only cows which have been confirmed pregnant can supply data for calving to conception interval analysis, only the "successful" cows will be included and many "unsuccessful" cows will be excluded, because they have not been served or are not pregnant by the time of analysis. Thus premature analysis of calving to conception intervals will give not only incomplete results but inaccurate results with a misleading bias in an optimistic direction. This applies to calving to first service and service to service intervals also.

A little thought makes it clear that premature analysis of conception rate produces a bias towards a poorer than true result because return to service (that is failure) is recorded before confirmation of pregnancy.

In DAIRYCOW the cows selected for fertility analysis are those which calve in the 12-month period between 18 and 6 months prior to the date set or date of visit. This is likely to be about correct for the analysis of intervals but rather more historical than strictly required for conception rate.

All calculations are based on confirmed events; calving to first service intervals are calculated only for cows which have a first service; calving to conception intervals are only for those which are confirmed pregnant; conception rate is based only on cows positively entered as pregnant. The calving to first service and calving to conception intervals are presented as histograms with groupings of three-week intervals; an average interval and standard deviation are shown. Both intervals are also calculated on a lactation number (age) basis.

One table presents the numbers of cows which receive one, two, three, four, five and more than five services respectively. This is useful information where pregnancy diagnosis is not available and can give an indication of the success rate of services.

Inter-service intervals are presented in a visual form: each interval is marked as a star against a day number from 1 to 99 and more than 99. The effect is that of an ungrouped histogram. Intervals are also grouped as "normal" (18 - 24 and 36 - 48 days) and "abnormal" (less than 18, 25 - 35 and more than 48 days).

Monthly conception rates both for first and all services are presented.

A Summary Table presents herd average calving to first service and calving to conception intervals and first service conception rate for the period defined. Culling rate is also shown.

The decision to use these particular fertility parameters was made on the basis of use of the more complicated and wider ranging analyses in the original program. They are subject to change if users, that is veterinary surgeons, indicate there is a need to change.

Disease analysis

The basis for decisions about disease classification and analysis was - what do veterinary surgeons want from the system? Modification will come from user need and the results of scientific disease surveys when these produce results relevant to practitioner use.

The disease table gives a monthly incidence for all diseases for each individual farm and can be presented in a variety of ways. It is also possible to compare the fertility of disease groups or treatment groups with the rest of the herd.

Individual cow disease and fertility histories can be listed as required.

PRACTICAL DIFFICULTIES INVOLVED IN DEVELOPMENT

The practical difficulties stem from two areas, firstly there were problems imposed by the limitations of the microcomputer itself, and secondly there were problems stemming from the running of the system in practice, gaining co-operation from farmers and so forth. Each of these will be dealt with in turn.

Program development problems

There was no choice available as regards the hardware to be used, the Glasgow University Practice had already installed the Tandy system to handle the practice accounting and therefore the fertility program had to run on this system. It was decided to use a compiled version of the BASIC language, this gave certain advantages as regards the speed and size of programs which were developed and provided some useful programming tools not available in other languages.

The amount of disk space available using the system's twin 8" floppy drives forced a number of decisions. It became apparent that the best method of disk allocation would be to incorporate all the programs and static data files on one disk, and all the dynamic files on a second "data" disk. Each farm would be allocated one such data disk. It was decided that it would be unlikely that the system would ever have to deal with herds of more than five hundred cows. This figure gave a reference point from which file size calculations could be made. Careful consideration was given to the amount of information which was to be stored about each cow regarding the number of non-service and service heats and records of disease and treatment. When these parameters were finalised it became apparent that historical information could only be amassed for one previous lactation.

The data entry program was the next most important consideration. The entry of information had to be as fast as possible, the slower the data entry the fewer the herds which may be managed. To expand on this point, the microcomputer was originally installed in the practice to handle the accounts and is not available for use on fertility management all of the time. As well as being quick it was crucial that the data entry program minimised operator time, to this end a batch entry process was developed. This solution has proved to be satisfactory during testing and commissioning.

Having chosen a batch entry system it became important to develop a series of error checking routines. During the testing of the system it became apparent that the original error traps were too stringent. This caused the amount of time taken to update the file to increase as mistakes were rectified. The error traps have been gradually refined with the experience of many users and will, in some instances, attempt to indicate and correct wrongly entered data.

The reporting programs provided few development problems. The experience gained in developing another system (Boyd, 1972) helped in setting out the parameters for these reports. The choice of producing largely graphical output for the analysis program has proved beneficial from the point of view of both veterinary surgeons and farmers.

Operational problems

The main operational problem which has been encountered has been data retrieval. It was important that the farmer should not be involved in a great deal of extra recording owrk but that the system should be convenient for him to use. Three different methods of data collection have been tried.

1) Individual record cards and herd sheets: This method proved difficult to operate in two respects. Firstly some farmers were unwilling to allow the information to leave the farm in this form and secondly searching through the information to collate data entry forms was tedious, because the information was not readily translated into a form suitable for the computer.

2) Duplicate pad: These pads were produced quite cheaply be a local printer. They are laid out in a form which ideally suits program input without compromising the ease of recording. The farmer or herdsman's observations are translated for input by the computer operator. The only problem encountered has been the "non user-friendly" environment within the cow shed!

3) Carbonised sheet within plastic wallet: This appears to be the best solution yet tried. The idea is similar to the above but has the advantage that the sheet is protected within the envelope.

STANDARDISED RECORDING SYSTEM

Whilst, from the point of view of national records and analysis, the benefits of a standardised recording system are obvious, the problems faced in introducing such a system are manifold. The number of different computerised recording systems which have been developed, particularly over the last two years, is large and the developers of these systems may be reluctant, or indeed unable, to change their systems to conform.

It is reasonable to assume that each individual program has been developed to solve a particular problem. The problem is not merely to develop a computerised dairy herd health and fertility recording system and it would be an oversimplification to suggest such. There are many other variables which one must take into account: e.g. to which group should the programs be geared (farmers, veterinary surgeons or research workers); and how advanced is the existing recording system and should the computer try to emulate this and so forth. Each individual system of programs will have been developed with factors like these in mind, and will, we hope, provide a suitable solution to the problem as defined.

There will be certain factors which are common to each program. There are a number of items which each individual designer will have included and these items will be the basic essentials required to operate any system of this nature. These items can be fairly readily enumerated and include figures for each of the following:-

1) Number of cases of mastitis, lameness and digestive disorders.
2) The incidence of these conditions at given times of the year.

3) The effect of these conditions on the fertility of the herd.
4) The effect of these conditions on the culling rate.

When developing a national system, it is items such as these which should be concentrated on and a general consensus should be reached as to which are most valuable and most readily accessible. It would also be necessary to define the minimum amount and type of information which has to be recorded to define any specific event. In the Glasgow University system, four items define an event:-

1) The date of the event.
2) A code which describes the nature of the event.
3) A two character "type", e.g. LF signifies Left Fore.
4) A ten character comment to further elucidate symptoms or treatment.

It can be seen that this coding system, although simple, gives an acceptable method of recording the event. As an example the system differentiates between twelve different types of lameness at the first, or code, level. In standardised system it may not be possible to incorporate this amount of detail although it would be preferable to see slightly more information than rough outline headings, such as mastitis or lameness.

When these items have been agreed it would seem feasible to then produce a standard means of representation. This representation could take a number of forms, and each system could then produce output in the form most appropriate to that system. The presentation of the data may be in the form of a magnetic medium, for example, a standard IBM 8" floppy disk format. As an alternative, a printed form of the data may be produced, suitable for machine processing or manual input.

It may be necessary to introduce some financial or other incentive to gain co-operation in the collection scheme, as the individuals running the system will be put to some inconvenience in order to produce these reports. The inconvenience may stem from the amount of time taken to develop a reporting program and, indeed, to run this against the various farms' data.

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DATA RECORDING AND ANALYSIS IN DAIRY HERDS

R.W. BLOWEY, B.Sc., B.V.Sc., M.R.C.V.S.*

For the past 14 years the practice has been operating a fertility control programme in dairy herds and more recently has instigated a mastitis monitoring system. Both recording systems are extremely simple and both are manually operated. This paper describes the scheme and some of the data obtained from them and discusses possible future trends.

Fertility Monitoring

Visits are made to farms at either two or four-weekly intervals, depending on the size of the farm and the requirements of the farmer. At the surgery there is a box for each herd, containing individual cow cards, an example of which is given in Figure 1. A few days prior to the visit the cards are sorted and a list is constructed of those cows which we consider require examination, the basic examinations being as follows:

PC = post calving check. A manual per vaginum examination, looking for gross evidence of endometritis in the cervical mucus.

An = anoestrus. Cows which have not shown oestrus by 6-8 weeks post calving.

PD = pregnancy diagnosis; usually 7-9 weeks post-service.

One list is sent to the farmer (Fig.2) and a copy is retained by the veterinary surgeon who is to carry out the visit. On receipt of the list, and usually on the evening prior to the visit, the farmer deletes those animals no longer requiring attention, viz. 'An' cows which have been served and 'PD' cows which have returned to service. The remaining animals are retained for examination. Whenever possible the same veterinary surgeon visits the farm at the same time and on the same day of the week, this having been arranged in advance to cause least disturbance to the farming routine, usually immediately after morning milking. Results of the fertility examinations are written onto the checklist, the farmer retaining one copy for his information, the other being returned to the surgery, together with a record (Fig.3) of all other fertility events which have occurred since the previous visit.

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					Date	Trmt	Date	Trmt	Date	Trmt
Ident				Abort						
Calving date				Cleanse						
PC				Endo						
1st oestrus				Pyo						
2nd				Cysts						
3rd				Nymph						
1st service				CL						
2 nd				CL expr						
3 rd				Kamar						
4 th				Ov. inact						
5 th				LH						
6 th				Implant						
7 th										
PD - ve				Lame						
PD - ve				Mastitis Mild						
PD + ve				Mastitis Vet						
Calving Index				Milk fever						
				Hypomag						

Fig.1 Individual cow record card

<u>Mr R Phillips</u> <u>Routine Visit Tuesday 12.4.83</u>

17 PC (c.28.3.83)
22 PC check (16.3.83) 29.3.83 w/o
27 An (c.15.2.83) 8 weeks
33 An check (c.30.1.83) 10w. 29.3.83 R11 PGK
41 PD (s. 22.2.83) 7w
55 PD (s. 12.2.83) 9w
60 PD check (s. 10.2.83) 9w
67 An (PD-ve 29.3.83; LO cyst PG)

Fig.2 A typical check-list of animals to be examined

CALVINGS		OESTRUS NOT SERVED		SERVICE DATES		
COW	DATE	COW	DATE	COW	DATE	SERVICE NO.

Fig.3 Data sheet compiled by the farmer

This information is now used to update the individual cows cards, ready for the construction of a new list for the next visit.

Analysis of the data is a vital part of the monitoring and this is carried out every six months (Fig.4). Data is analysed by month of calving and the performance of each month's calving group is assessed. As there is a delay in approximately two months from calving to service and a further two months from service to manual pregnancy diagnosis, the data will always be at least four months retrospective.

Taking the month of November 1982 (Fig.4) as an example, it can be seen that 43 cows calved and by April 1983 30 of these had been confirmed pregnant. Five were culls (either to be sold or having died or been disposed of already), which means that there were 8 cows which had not been confirmed pregnant by April 1983. The mean calving to conception interval of the cows which conceived was 87 days and this was achieved without any extreme values (ie. a range of 47-115 days) and with a very good first service conception rate of 60%. The minimum calving to the first service interval for all cows in that month was 43 days, although clearly this cow did not conceive, since the range of calving to conception intervals started at 47 days.

Mr R Phillips — Fertility Analysis Correct to April 1983

Month of Calving	October	November	December
No. of cows calved	31	43	26
No. conceived	22	30	16
No. sold/died	3	5	2
No. not yet Pregnant	6	8	8
Mean Calving-Conception Interval	101	87	82
Calving-Conception range	45-124	47-115	50-94
Calving-1st Service period (minimum)	45	43	45
1st Service CR %	52	60	56
Predicted Calving Index	384	370	366

Means - Calving - Conception Interval = 90.3 days
% CR to First Service = 54.5%
% Cows not yet Pregnant = 24.4%

Fig.4 Part of a six-monthly herd fertility analysis.

This analysis is sent to the client together with a table indicating how his results compare with the other herds monitored (Fig.5) and an accompanying letter indicating how his results compare with his previous figures and discussing any corrective measures which may be necessary. If there have been any other health problems on the unit then their incidence and possible control measures are also mentioned and the fertility analysis then becomes the basis of a general farm health report. Mastitis incidence is calculated and discussed in the same report.

Mean herd fertility data

Includes all calvings from June 1981 to May 1982 inclusive.
Data compiled in September 1982.

Herd No.	Mean days calving -conception (ideal 82)	Conception Rate % (First Service)	% cows sold/died	% cows not yet pregnant
1	102	66	19	-
2	89	53	22	1.6
3	98	52	10	3
4	101	45	15	7
5	93	51	14	17
6	99	53	10	7
7	93	53	5	-
8	92	47	10	1
9	103	59	16	7
10	83	55	11	7

Fig.5 Results obtained from ten herds.

Mastitis Monitoring

The basic information is collected by the herdsman in a small loose-leaf booklet supplied by the practice. As mastitis cases occur, each cow is allocated a page and deails of the date of treatment, quarter affected, antibiotic used and bacteriological results (if any) are recorded (Fig.6). Cow pages are then arranged in numberical or alphabetical order in the booklet so that they are easily found should further cases occur in the same cow. Every six months the booklets are recalled and the performance of each herd calculated as shown in Fig.7. The analysis is divided into a 'whole herd' section, where mastitis incidence and tube usage are assessed on a herd basis and, secondly, on the basis of the performance of the cows which have actually had mastitis during the preceeding 12 months. The first part gives an idea of the extent of mastitis within the herd and the second gives information on recurrence rates. A fuller explanation of the column headings in Fig. 7 is given in Fig.8.

Data collected from 31 herds over the three-year period up to March 1982 has been analysed and consists of 114 herd recordings, each recording being a six-monthly analysis of the previous year's results for a particular herd. Mean figures are given in Fig.9. The annual milk sales and rolling mean leucocyte counts suggest that the herds recorded were above average and undoubtedly they were the better herds within our practice. However, the mastitis incidence (27% of cows affected each year and 52 cases per 100 cows) was surprisingly high compared with the 12% and 17% figures respectively found by the Ministry of Agriculture's National Mastitis Surveillance Scheme. The figures varied considerably between herds, with one herd reaching 54% of cows affected over a 12-month period, while another herd has had a consistently low incidence, varying from 4% to 7% of cows.

Cow No.: ....

DATE	QUARTER	TUBES	SAMPLE

Fig.6 A page from the herdsman's mastitis recording book

Herd number	No. of cows	Rolling mean cell count	Mean herd yield (ann. sales)	For whole herd: % cows affected	For whole herd: Cases per 100 cows	For whole herd: Tubes used per cow	For whole herd: Tubes used per case	For mastitis cows: Average no. cases	For mastitis cows: % which recurred	For mastitis cows: Quarters per cow
1	65	321	5800	38	60	3.5	5.7	1.6	15	1.4
2	81	745	6000	21	30	0.9	2.9	1.5	12	1.3
3	46	275	5850	19	40	4.1	9.4	2.2	45	1.2
4	134	267	5178	21	30	1.2	4.6	1.2		1.2
6	95	346		29	70	9.8	13.5	2.5	33	1.6
7	110	333	6500	27	70	2.7	3.8	2.6	40	1.6
8	132	272	6036	28	60	1.8	2.9	2.2	29	1.6
9	50	441		30	70	2.1	3.1	2.2	36	1.4
10	60	210		18	60	1.7	2.8	3.4	35	2.2
11	110	314		25	50	1.3	2.3	2.2	41	1.3
12	80	456		34	40	1.9	4.6	1.2	3	1.1
13	107	264	7121	4	5	0.2	3.8	1.2	20	1.0
14	123	252	6000	20	40	3.3	8.6	1.9	15	1.6
15	110	557		35	60	4.6	7.7	1.7	20	1.3
16	116	305	6127	27	50	1.4	2.9	1.7	16	1.5
17	95	668		20	30	3.5	11.6	1.5	14	1.3
18	127	236		22	40	1.7	3.8	2.0	36	1.3
19	105	217		30	70	4.1	6.0	2.2	28	1.6
20	65	304	5847	45	50	2.3	4.2	1.2	-	-
21	88	323	5097	29	80	2.6	3.3	2.6	34	1.7
22	110	332	7090	44	90	2.5	2.8	2.1	22	1.6
23	100	177	5500	18	30	0.6	2.2	1.5	15	1.3
Mean		346		26.5	51	2.6	5.1	1.9	25	1.4

Fig. 7 A 'League Table' derived from mastitis data analysis

For the whole herd -

% cows affected - this is the proportion of cows in the herd affected in one or more quarters over a 12-month period.

cases per 100 cows - defining a 'case of mastitis' as one quarter affected once, this figure is the total number of cases which occurred, divided by the total number of cows in the herd x 100

tube usage - intramammary antibiotic tube usage is calculated from the client's sales invoices over the same 12-month period. It does not rely on the herdsman and is therefore an independent figure. It does not include dry cow preparations.

For mastitis cows -
i.e. data relating only to those cows which had mastitis over the previous 12 months.

Average number of cases - if there is a herd problem of down-calving mastitis in all four quarters or a high incidence of repeat treatments, this figure will be high.

quarters per cow - this figure will be high in the down-calving mastitis situation, but low if the problem is one of continually recurring cases.

% which recurred - this expresses the number of cases which required one or more repeat treatments during the 12-month period. However it does not give any information on the total number of repeat treatments carried out. This information is included in the figure of 'average number of cases' above.

Fig.8 Elaboration of column headings from Fig.7

Despite this however, the intramammary antibiotic tube usage (2.67 tubes/cow/year) is similar to the national average (2.54 tubes/cow/year). The mean recurrence rate of treated quarters over a 12-month period (17.85%) was disappointingly high and possibly reflects the quite significant incidence of chronic Staphylococcal and Streptococccal infections which still exists within the herds.

Cell Count (x 10^3)	314 ± 123
Annual milk sales/cow (Lt)	5,913 ± 705
% cows affected within a herd	26.98 ± 10.34
Mastitis cases per 100 cows in herd	52 ± 28
Antibiotic tube usage -	
- per cow in herd	2.67 ± 1.75
- per clinical case	4.83 ± 2.87
For clinically affected animals	
- cases per cow affected	1.4 ± 0.027
- % recurring within 12 months	17.85 ± 8.89
- quarters per cow	1.41 ± 0.25

Fig.9 The Mean ± 1.0 SD for 114 herd recordings

Linear regression analyses have been carried out on the data and the results are given in Fig.10. Increasing cell count was positively correlated with an increased proportion of cows affected, again suggesting that a major component of the mastitis in our herds was associated with Staphylococci and Strep. agalactiae and Strep. dysgalactiae. This was further substantiated by the fact that there was a positive correlation between recurrence rates and cases per cow in the herd, indicating that the greter the incidence of mastitis within a herd, the higher was the change of a 'chronic carrier' developing. Routine bacteriology on all cases was not carried out however. The negative correlation between recurrence rate and tube usage was also interesting in this report, suggesting that if an infected quarter was not adequately treated, then there was a much greater chance of recurrence.

	114 Recordings	31 herds
Cell count v % cows affected	R = 0.2825[aa]	R = 0.2073
Cell count v cases per cow in herd	R = 0.056	R = 0.1144
% recurrence v cases per cow in herd	R = 0.46[aa]	R = 0.45[a]
% recurrence v tubes used per case	R = -0.07	R = -0.4522[a]
% recurrence v cell count	R = -0.1202	R = -0.18

a significant at 0.01 level
aa significant at 0.001 level

Fig.10 Regression analyses of data

It is worth recording that there was no correlation between decreasing cell count and increased cases per cow and that the data does not therefore support the view that by discontinuing dry cow therapy, cell count will rise and act as a preventive measure against environmental mastitis.

We have found that a simple routine analysis of mastitis incidence such as this has several uses. Firstly within a herd it gives some information on the type of mastitis which is likely to be the most prevalent (i.e. environmental or chronic staphylococcal/streptococcal infections) or whether there are simple a few chronic cows present. It also provides a means of monitoring the progress of any control programme and this is most important. Secondly between herds it allows an objective assessment of where problems actually exist. One farmer's opinion of what is an acceptable mastitis incidence will be very different from that of another and often the practitioner needs numerical data to convince the herdsman that more effort in control is needed. Finally the herdsman is made aware of mastitis. Many take a personal pride in trying to improve performance and by providing them with a six-monthly 'league table' their enthusiasm is continually stimulated. In addition, it means that records of mastitis are being kept and chronic carrier cows can be more readily identified and culled or treated accordingly.

Discussion

There can be no doubt that objective monitoring will become a much more important facet of disease control in the future. The farmer already examines his margin over concentrates, financial achievements and compares them with targets and it is logical that figures on disease incidence will be reuired to know which conditions are at an above-average incidence on a particular unit. Conversely one may wish to demonstrate that a herd problem does not exist and that there are only a few isolated cows causing difficulties. Equally, when a control programme is in operation, it is of value to be able to monitor its progress. Fluctuations in performance will occur with fertility, mastitis or any other disease. These may be due solely to chance, but only with a system of monitoring incidence can we hope to identify some of the causes. Disease recording has two separate objectives, firstly for use on an individual farm and secondly on a national basis for disease evaluation. For the latter I believe that a standardised form of recording is essential, although we should at least initially restrict our attention to phenomena which are relatively easy to record, e.g. mastitis, lameness or displaced abomasum. Other diseases may often be only slight variations from normality (e.g. calf pneumonia, scouring or digestive disturbances) and recording of these becomes much more difficult.

Individual farm recording is somewhat different and requires a different approach. The on-farm system should ideally record only data which can be extracted and used for the benefit of the farm. The system in use should be simple and easily understood by the farmer and his advisers. It should be selective, in that the parameters of disease recording are figures which the farmer becomes accustomed to using. It needs to be like a second language, viz. used regularly and therefore easily understood. I feel that one of the great problems of computerisation is that the machine is so efficient that in some areas it has outpaced our knowledge of disease. For an on-farm system, it is pointless receiving sophisticated analyses of fertility data if the personnel associated with the farm was unable to handle its interpretation.

Our own manual mastitis monitoring scheme has been described and even in its present form I feel that it offers an adequate routine service to the farm. Computerisation would undoubtedly produce faster results, but I have serious doubts over whether this would be cost-effective. On the fertility side the situation is different however. It would be a great advantage to both farmer and veterinarian to have the capability of carrying out routine analyses of inter-oestral intervals, heat detection rates and several other criteria.

As dairy herds progressively increase in size, attention to individual cows becomes more difficult. On the other hand, margins are being eroded and with feed the largest single item in the costs of production, attention to the detail of feeding will be vital. Despite the installation costs, computerised individual out-of-parlour feeding is becoming very popular and this lends itself very readily to careful control over concentrate intakes, e.g. using the Brinkmanship system. In the future I feel that there will be a greater tendency to cull individual animals, rather than treat them, especially as nursing facilities become less availble. The farmer will want to know which, if any, of the disease conditions of his unit are at a level where either control and/or treatment are cost-effective and he will be acutely aware of the efficiency of utilisation of the feed. Both these areas need sophisticated recording and analysis systems, but in addition an 'interpreter' will be required to select those items which particularly need attention. The practising veterinarian is one obvious choice of person for this post, but there are plenty of others who would readily fill the gap for us.

I believe it is up to us to show the interest and competance in this field and to maintain the momentum which is already gathering. If we prove ourselves to be the source of the new ideas, then it is only natural that the farmers will come to us for help and advice in the future.

COSREEL - COMPUTER SYSTEM FOR RECORDING EVENTS IN ECONOMICALLY-IMPORTANT LIVESTOCK

A.M. RUSSELL*

Much data about individual farm animals are potentially available, in the sense that someone becomes aware of them. Some are lost because the observer believes them to be unimportant and keeps no record. Other data are kept, but in a way that makes them useable with difficulty and only by the recorder. Yet most, and probably all, of the potentially available data could be useful not only to the farmer and his veterinary surgeon, who are the principal recorders of livestock data, but also to the whole livestock industry as a basis for epidemiological research. A system is needed to facilitate this collection and use of livestock records by farmers and veterinary surgeons, which can also assemble a large databank for research purposes.

COSREEL could form the basis of such a system. It has been developed to run on a large computer, and to handle full lifetime data about cattle, sheep and pigs. A wide range of types of data can be recorded; veterinary events in particular can be recorded in considerable detail (Russell, 1980, Russell and Rowlands, 1983). COSREEL has been used at this institute since 1975, and for shorter periods in six commercial farms and veterinary practices, to provide the usual listings for herd management (Rowlands, Lucey and Russell, 1982). It is also being used to provide data for research (Rowlands, 1982). The success of this project suggests that COSREEL could be developed to provide a suitable information system for wider use by the livestock industry.

Three questions need to be considered:

Coding:	what data to record and how to code them?
Retrieval:	how to process and present the data?
System organisation:	where and how to collect, input, store and retrieve the data?

CODING

Obviously, data must be entered into a computer in accordance with rules which define the meaning of each item, i.e. they must be coded, and the codes should be as short as possible to keep input time to a minimum. Management events (Table 1a) can be input relatively easily using codes which are both short and easy to remember, because the range of alternatives

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for each item is small, or because the data are numeric. For example, in COSREEL, "123 O 120283" is sufficient to indicate that cow 123 was in Oestrus on 12/3/83, and "234 W 130383 456" to record that cow 234 Weighed 456 Kg on 13/3/83.

Table 1. Events which may be recorded by COSREEL

a) Management events

Freeze-branding	Weaning
Weighing	Body-scores
Oestrus-not-served	Drying-off
Service	
Disposal	
Start | of period spent by female with male	
End | when service may have occurred	
Movement between premises	
Parturition (calving, lambing or farrowing)	
Assignment to feed groups	
Assignment to | experiment	
Return from | experiment	

b) Veterinary events

Pregnancy diagnosis
Post-mortem examination
Tests on animals or samples from them
Veterinary attention - Routine or Prophylactic purposes
Infertility investigation
Therapy

Veterinary events (Table 1b) are more difficult to describe because the subject is inherently complex, and the coding arrangements need to cope with this complexity in as logical and straightforward a way as possible. For example, an organ may need to be referred to in a diagnosis with an indication of the abnormalities present, as the subject of a surgical procedure, as the source of a sample for bacteriological tests, or as the site of injection of a medicament. Similarly, a particular bacterial species may need to be quoted in a diagnosis as the cause of an abnormality in an organ, in the result of a test on an animal or sample from it, or in vaccination or antiserum therapy. COSREEL veterinary codes use both letters and numbers, the former as abbreviations or initial letters, and the latter where the data have some numerical significance. These codes are linked together using punctuation marks, which serve to separate groups of codes from one another and to indicate their clinical relationship. In the above example, the coding for an organ (or a bacterium) is the same however it is used, but its position relative to other codes and symbols differs.

The various aspects of veterinary attention are listed in Table 2, and any selection of these may be recorded on each occasion that a case is examined. The strings of characters defining different aspects are separated from each other by a space. The first character of each string is a symbol (Table 2), and the codes which are allowed to follow it depend upon the aspect being described.

Table 2. Aspects of veterinary attention, which may be recorded by COSREEL, and the symbols leading strings of each type

Symbol	Aspect	
?	Diagnosis	
%	Surgical	treatment
#	Medical	treatment
"	Vaccination	
'	Antiserum therapy	
@	Local	symptoms
$	General	symptoms
&	Therapeutic management changes	
:	Experimental medication	
	Case progress assessment	

Diagnoses begin with a ? followed in curved brackets by 3 characters, usually letters, to define the organ involved (Russell and Rowlands, 1983). The first of these letters identifies the body system to which the organ belongs, and the other two letters indicate the organ. Thus ?(RLU) indicates a diagnosis involving the Respiratory system, specifically the LUngs. These would be followed by pairs of letters separated by slashes to indicate the abnormalities present. Thus ?(RLU)CG/IN indicates that the lungs were congested (CG) and inflamed (IN). The veterinary surgeon can record the diagnosis as simply as this, or may make it more detailed. For example, the organ, or parts of it, may be defined more accurately by location characters (e.g. L for left) placed after the organ letters, and separated from them by a comma. The severity of an abnormality may optionally be indicated by a number ranging from 5 (= normal) up to a maximum of 9 (most severe) placed after the abnormality. A cause (e.g. P for Parasites) may also be suggested using a single letter placed after the abnormality (or after the severity). Thus ?(RLU,L)CS8/IN7P means fairly severe consolidation (CS8) and moderately severe inflammation caused by parasites (IN7P) of the left lung (RLU,L). Appropriate combinations may be selected from codes for 140 organs, 25 locations on the animal, 75 abnormalities and 291 causes, comprising 23 of a general nature and 168 bacteria, viruses and parasites.

Diagnoses of systemic diseases are constructed similarly, except that the 'system' letter is D. This is combined with 2 letters to indicate the type of disease; DIN, DME, DDE, DPO and DNS respectively for INfectious, MEtabolic, DEficiency, POisoning, and Non-Specific diseases. The 2 letters for abnormality are replaced by codes for the specific disease. Thus ?(DIN)SA means the infectious disease SAlmonellosis. Combinations of systemic and systematic diseases are allowed, for example ?(DME)HC(GPL)RE means a diagnosis of the metabolic disease (DME) hypocalcaemia (HC) and retention (RE) of the placenta (G=genital system, PL= placenta). Seventy-eight systemic diseases affecting cattle, sheep and pigs may be described, and also 14 types of dystocia.

Strings of characters describing the other aspects of veterinary attention listed in Table 2 may be assembled in a similar way.

This coding system enables simple conditions to be described briefly, whilst permitting greater detail to be recorded when required.

RETRIEVAL

Analyses may be considered at three levels:

1) Routine

Managers of dairy herds and their veterinary surgeons need regular guidance in two main areas; the maintenance of fertility and monitoring of lactation performance. COSREEL can provide weekly information for the veterinary surgeon about the cows now ready for pregnancy diagnosis, and those which need infertility investigation. All veterinary events and management events relevant to fertility which have occurred since the last calving are itemised, so that the most appropriate treatment can be selected. Two weekly lists are available to the farmer; one shows the lactation performance and fertility state of each lactating cow, and the expected calving date of each cow in calf. The information is arranged so as to highlight problem animals which do not conform to the normal herd pattern. The observation of oestrus is especially important in successfully maintaining dairy herd fertility, and another list shows those cows which are likely to be in oestrus on each day of the coming week. Graphical representation of milk yield, both actual and expected, for the whole herd, and also for subdivisions by lactation number and calving month, is also available to the farmer. This presents data for the past year in a form which can be understood easily, and it enables periods of good or poor performance to be related to management factors such as diet.

2) Occasional

Other analyses of a herd's performance are required less frequently, and COSREEL provides a variety of such facilities. For example, fertility analyses are available which show calving to first service and calving to conception periods as histograms, and mean conception rates to different service numbers and bulls can help in understanding fertility problems. Graphical representation of conception using cumulative summation (Q-sum) charts may also show how periods of good or poor fertility are related to management factors. Programs are available to list calves for vaccination, castration and dehorning, cows for Brucella testing, and for classifying mastitis and other diagnoses during any recorded period. Analyses of this type contribute to decisions about herd management policy, and may also be valuable in understanding disease problems when these appear.

3) Research

The database, produced by the farmer and veterinary surgeon during their normal operation, provides opportunities for epidemiological research, which have not been available hitherto. Two examples of such a use are given below.

Heritability of longevity: Few cows in dairy herds die of old age; most are culled when their usefulness falls below a critical level. The farmer considers the fertility, disease history, lactation performance and other factors in making this decision. Retrievals were made of the lactation performance, length of life and sire of all cows which had produced at least one calf at the institute since 1975. Figure 1 shows the average values for each bull with at least 10 daughters. Three bulls had daughters which yielded poorly and did not live long. Apart from these, there is little variation in lactation performance among the daughters of the remaining bulls, and little relationship between milk yield and longevity. The productive life of a cow does not start until about 3 years of age, and the mean productive life of the daughters of different bulls varied by a factor of about 3. Much of this variation is likely to have been due to differences in fertility and disease susceptibility. It seems probable that bulls could be selected by this means whose daughters would continue to satisfy the farmer's requirements during a long life, and not at the expense of yield performance.

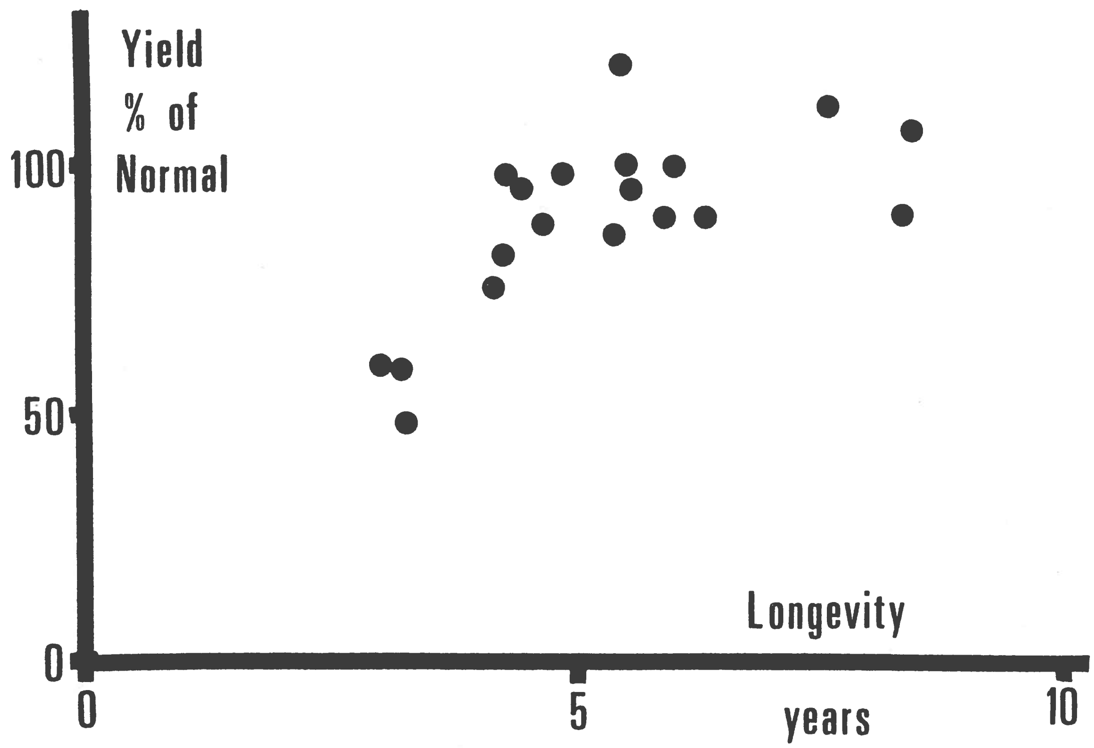

Fig. 1 The relationship between longevity and milk yield of the daughters of different bulls

Coincidence of disease: The diagnoses of 6 important diseases of adult cows (Table 3) were retrieved. For each pair of diseases, cows which had been affected by the first were identified, and further classified according to whether or not they had also suffered from the second. Proportions, averaged over all age groups were then calculated for each of these pairs to show the relative incidence of each second disease in cows which respectively had and had not suffered from a first disease. Table 3 shows, for example, that mastitis was 6.1 times as likely to have occurred in cows which have also had ketosis than in those which have not. The link between retained placenta and uterine disorders is easily explained. The strong association of ketosis with retained placenta, mastitis and solar ulcer implies that these conditions are linked metabolically, as does the negative relationship between hypocalcaemia and solar ulcer. Observations such as these can be a starting point for more specific experimental work to investigate the underlying mechanisms.

Table 3. The occurrence of different pairs of diseases in the lives of dairy cows

	No of cases	Retained placenta	Mastitis	Solar ulcer	Milk fever	Ketosis	Uterine disorders
Retained placenta	41	-	1.7	2.9	2.4	5.3	9.7
Mastitis	200	2.5	-	4.6	1.1	6.1	1.8
Solar ulcer	45	2.9	2.2	-	0[a]	5.8	2.6
Milk fever	24	2.5	1.0	0[a]	-	1.5	1.0
Ketosis	32	4.2	1.8	5.1	1.5	-	1.7
Uterine disorders	66	16.6	1.4	2.7	1.0	1.9	-

[a] No cow had both milk fever and solar ulcer

Cows which have had a disease listed on the left are more likely by the factor shown to have a disease listed across the top than cows which have not had the first disease. These diseases can occur at any time in the animal's life, and no temporal relationship is implied.

SYSTEM ORGANISATION

COSREEL runs at present on the ARC ICL System 4 computer at the ARC Computing Centre. A postal service is provided to 4 farmer/veterinary surgeon pairs, and two other pairs have their own terminals on the farm and in the practice to allow direct input of data and retrieval of analyses. Direct links enable these users to enter data and retrieve up-to-date output more rapidly, and users like the closer involvement with their data. The main disadvantages are the telephone costs and the procedure for data input, both of which can be much improved by the use of a small computer in the practice, and perhaps on the farm as well.

One way of handling livestock data has been the installation of small computers on farms so that data collected there can be stored and accessed easily. However, this offers extremely limited facilities for storing veterinary data, and means that the veterinary surgeon cannot be involved in herd analysis. This approach also makes the comparison of results from different herds almost impossible, particularly if they use different recording systems.

An alternative arrangement is to process and store all data, veterinary and management, on a larger computer in the veterinary practice. Whilst easing the problems of compiling full life histories for each animal, and possibly making comparisons between herds, some problems remain. The separation of farmers from their records is undesirable, and requires the regular transfer of records to the practice for entry, and of listings for management in the reverse direction. There is a trend towards the automatic collection of numerical data about milk yields, feed intake and body weight. This requires some computing capacity on the farm for logging and processing the accumulated data before transfer to the practice computer. An improvement would be to make all of these transfers between farm and practice computer by electronic means.

The next logical step, exactly analagous to the centralisation of farm records in the veterinary practice, is to keep both farm and veterinary records on a larger regional computer, to which practices and farms would have free access. This would allow comparisons between practices of disease and fertility rates, for example, and would release practices from the responsibilities of maintaining their farmers' data, without interfering with its use. At this level of centralisation, reliability and security of the records would be much easier to ensure. Analyses for local use and for research would become easier, more valuable because of their greater coverage, and would cause no inconvenience to other users of the system. This is the arrangement which COSREEL currently resembles most closely.

CONCLUSIONS

A widespread system for recording all types of livestock data in a common database could simplify the recording process for farmers and veterinary surgeons, and also provide them with valuable assistance in herd management. The database, containing full data from many herds and veterinary practices, could provide data for epidemiological research relating performance with disease.

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DAISY - HEALTH AND FERTILITY MONITORING FOR DAIRY HERDS

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DAISY, the Dairy information system, is a suite of computer programs that have been developed to satisfy the need for better monitoring of dairy herd performance in order to cut costs by improving herd management and health, i.e. by shortening calving intervals, improving calving patterns, reducing culling rates and improving margins (Brooke, 1980; Stephens *et al* 1981).

The forerunner of the DAISY system was MELBREAD, which ran on the University of Reading mainframe computer (Eddy and Esslemont, 1973; Esslemont and Ellis, 1975). The limitations of the mainframe system (batch processing, slow turnaround) were particularly apparent when it was expanded to an integrated Dairy information system, DANDAIR (Stephens *et al*, 1981).

This led to the development of DAISY 1 in 1978, initially as an experimental "interactive display" system, written in Fortran, for operation on a Computer Automation (C.A.) minicomputer (VEERU, 1980). DAISY 1 was designed from the outset as a stand alone, single user system, with data and programs held on diskettes, to be situated on or near the farm.

The success of the new system resulted in the abandonment of the mainframe computer in favour of the new, relatively low cost, minicomputer concept (Stephens *et al*, 1981). Nevertheless, initial cost considerations meant that the DAISY 1 system would only be cost-effective on the largest of dairy farms, but the shared use of a machine proved successful, based around a machine in the veterinarian's practice office. DAISY 1 has been in regular commercial use in the UK since 1979, and now runs on 5 identical minicomputers at 4 sites in the South of England, handling data from 250 UK herds (30,000 cows), and 40 French herds (1500 cows). DAISY 1 is continuing to provide a valuable service to its users (Collick, 1982; Eddy 1982). The programs are continually being upgraded to cope with the changing needs of farmers - this continuing development of DAISY 1 (and the development of DAISY 2) is now self-financing at Reading.

However, DAISY 1 can only run on the C.A. minicomputer for which it was initially written, and it would have required considerable programming time to adapt the Fortran programs to run on another machine. It was felt that DAISY should run on as many machines as possible, and the rapid development of microcomputers since 1980 meant that microcomputers now had the capability to run programs of DAISY's complexity. In addition, it became obvious that microcomputers would continue to become better and cheaper, and that hardware price was a very important factor in rate of adoption of agricultural software (Stephens *et al*, 1981). The decision was therefore made to rewrite the DAISY programs for microcomputer usage in a transportable language that would make it machine independent and therefore portable. The language chosen was the MicroCobol system operating under BOS, the Business Operating System, which is supported by a large software house in the UK and Europe and also in North America (Esslemont *et al*, 1981).

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BOS would run on about 25 microcomputers in 1981, and it will now run on more than 50. This, and the continuing development of microcomputers (the advent of the 16 bit chip and the hard disc) has vindicated the original decision to aim DAISY 2 at microcomputers and to write it under BOS.

In DAISY 1, and MELBREAD, health and fertility records were collected using a two-digit code based on the early Melbourne model. The code incorporated three levels, i.e. Reason put forward, Finding, and Treatment, e.g. Code 42 is for a cow that is presented for oestrus not observed, where a corpus luteum is found and the treatment is prostaglandin.

This coding system allowed quick data entry which could be easily validated, and the simple two-digit codes were found to be easy to remember. But the system was difficult to adapt as more treatments became available as 99 codes was the limit. Therefore, the chance was taken in designing DAISY 2 to create a new health and fertility coding system (Esslemont *et al*, 1982).

DAISY 2 FEATURES

DAISY 2 was developed in 1981/82 and was released in late 1982 (VEERU 1982). There are now five DAISY 2 systems installed on micros in the UK, handling data of 30 herds (6000 cows) on a commercial basis.

Portability

DAISY 2 is a suite of nearly 300 programs, written in MicroCobol under BOS. It can operate on more than 50 different micros at present, and this number is growing all the time. It has been designed for flexibility and ease of operation.

Operation

The DAISY 2 system is controlled by the operator from a series of on-screen menus. The operator is taken from one menu to the next by answering questions put on the screen by DAISY.

Detailed individual cow records are maintained, and herd size is limited only by the capacity of the microcomputer's attached storage devices.

DAISY 2 also keeps a continuously updated summary of each cow's status, health and fertility and production history for the current lactation, which can be viewed on the screen or printed during data entry and amendment.

Animal identification

Cow identification is by an alphanumeric "cow name" of up to 5 characters which are set for each herd in one of five standard formats:

1. 99999 e.g. 256
2. X9999 e.g. A256 where A is code for year of birth
3. 9999X e.g. 256A ------ ditto ------
4. XXXXX e.g. Daisy

Bull identification is both by a unique short alphanumeric code of up to 7 characters and by a long name of up to 19 characters. A cow can be labelled with a certain bull code if that cow is not to be served by any other bull.

DAISY 2 copes with calf identification by a 10-character alphanumeric code, but does not presently integrate heifer data.

Lactation-oriented records

All data stored on DAISY 2 is lactation-record oriented, i.e. associated with a particular lactation of a cow. The calving of a cow "seals up" the previous lactation, so that any new data entered will go onto the latest lactation record.

DAISY 2 DATA ENTRY

Data entry is not restricted to any particular frequency with DAISY 2, but may be done as often as the operator wishes. All data entry is performed easily using formatted screens by means of simple responses to questions and prompts.

During data entry the printer keeps track of what data has been entered or amended by means of a "data log", which serves as a check against original data sheets at the end of the job.

DAISY has many complex checks built into the programs to ensure that only reasonable data is accepted. If an unexpected value or event is entered, DAISY will display a "comment" or an "error" message, depending on the type of data, and the type of irregularity detected. All data is kept in detail on a cow's record, until past lactations are voluntarily archived by the operator in order to leave more room on the microcomputer's storage devices for the addition of more current lactations.

Production Data Entry

Production data can be entered onto DAISY in various ways, depending on how it has been collected.

Milk yield: Milk yield can be entered easily for one, two, or three milk recordings per cow to cater for different on-farm practices. Recordings entered for the same cow on the same day will be added together, and the facility exists to enter a two character code against any data as a C.A.R. (condition affecting record). The C.A.R. will be permanently associated with that milk record. DAISY will accept an unlimited number of milk recordings for a single cow lactation. Data is checked as it is entered, and any up or down variation compared with previous records over an operator-defined level is "flagged" by DAISY, resulting in a warning message being shown on the screen and on the printer's data log.

Milk quality: Fat, protein and lactose can be entered for dates on which a milk yield has already been entered for a particular cow.

Weight and score: Weight and score can be entered separately or at the same time through a common screen. Variation is "flagged" in the same way as described for milk production. Weight and score can alternatively be entered in association with a health and fertility event (e.g. service) by being entered through the appropriate health and fertility data entry screen.

Group: Groups are identified by an alphanumeric code of up to 4 characters which is associated with a group long name of up to 20 characters, e.g. the code HY3X might be the high yielding, three times daily milking group. Groups can be defined and added by the operator. DAISY keeps a continuous history of a cow's movements between groups which can be viewed during data entry or amendment, as described.

Health and Fertility Data Entry

The basis of the DAISY health and fertility coding system is that a cow is presented for examination or action for a particular "Reason", e.g. calving, milk fever, oestrus not observed, heat, service, etc. When put forward, certain important features about the case are noticed ("Findings"), a "Diagnosis" may be made, which may or may not be related to the original reason for the examination, and certain "Treatments" or "Actions" are performed.

For each "Reason", there is a separate list of "Findings", "Diagnoses" and "Treatments" that are applicable; this list is stored in the DAISY Table File. The list is readily accessible to the user, so that additional codes may be added, or existing codes may be amended. Identification of Reasons, Findings, Diagnoses and Treatments is in a common format: a 4 character alphanumeric code which is attached to a 20 character alphanumeric long name. To enter any one of these onto a cow's record, the code is entered by the operator, and the long name is retrieved from the Table File and displayed on the screen. Both the code and the long name are shown on DAISY printouts.

Health and fertility Reasons currently fall into two categories. The "system-defined Reasons" are an integral part of the DAISY programs, and the "non-system-defined Reasons" can be determined by the operator. The system-defined Reasons currently include such events as calving, abortion, heat, service, pregnancy diagnosis etc. The non-system defined Reasons may include any events that the operator wishes to record, e.g. mastitis, lameness, milk fever etc. There is a specific list of Findings, Diagnoses and Treatments associated with each Reason.

The coding system of DAISY 2 is therefore more flexible than that of DAISY 1. In fact, there is theoretically no limit to the number of "Reasons" on file, or the number of Findings, Diagnoses, and Treatments for each Reason. Practical limitations will apply in terms of capacity of storage devices and speed of operation of the programs. The DAISY 2 systems so far installed have been supplied with a pre-defined Code Table File, modified to individual needs.

The DAISY 2 revisit system is a particularly powerful tool for better herd's health management. If a cow requires a revisit for any reason, the DAISY operator can set up a revisit "flag" at the time of entry of the original event. The revisit can be set up days, weeks, or months ahead. Several outstanding revisits can be held on an individual cow's record. Cows with revisit "flags" outstanding will be picked up by DAISY when generating certain reports (e.g. the Vet's Action List, A7). When the revisit data is entered onto DAISY, the revisit "flag" is unset so that the cow will not be included on A7 reports, but the fact that the revisit was made is retained on the cow's record.

Identity and History Data Entry

Summaries of past lactations and pedigree information can be entered onto the cow's record in this program.

Data amendment

Amendment of previously entered data that is in error is easily done by calling the appropriate record onto the screen, making the change and then accepting it. The amendment is checked against the rest of the record, and the updated record is redisplayed on the screen. Error and comment messages are again displayed and printed on the data log.

DAISY 2 REPORTS

There are three types of reports that can be generated once sufficient data has been entered onto DAISY 2 :

1. Action Lists
2. Herd Data Review
3. Brinkmanship Reports

Action Lists

Action lists are produced in several different formats:

a) Pocket size summary for the herdsman, 5 inches wide;
b) Farmer's copy, containing more information on each cow, 13 inches wide;
c) Full width report, usually for the vet or the farm office, containing full details of every cow selected.

Each list can be sorted by various criteria, which the operator can choose, e.g. cow name, calving date, expected next calving date, drying off date, lactation number, group, etc.

Cows to be dried off: The operator specifies the start date for the report, the period in days the report is to cover, and the length of the dry period. A special feature of this report is the mastitis history; the number of cases recorded in the current lactation is shown (only up to six cases) together with the number of days into lactation that each case occurred, therefore showing whether the cows suffered chronic repetitive attacks, or a series of apparently unrelated attacks of mastitis. Cows that are overdue for drying off are "flagged" with an asterisk next to the cow name.

Cows due to calve: The operator must specify the start date and the end date for the report. The output options for this action list include a month-by-month calving pattern for all pregnant cows in the herd. Cows that were assisted at their last calving are flagged, and any problems that occurred within 30 days of the last calving are also listed, e.g. milk fever, retained placenta, mastitis, vulval discharge. Thus likely problem cows can be identified and given special attention.

Cows not yet served: This lists the cows that have not been served since calving, together with information for each cow on production level, days since calving, number of heats since calving, date of the days since last heat, etc. High yielding cows are flagged. This is the first of three reports which cover all cows not yet confirmed pregnant. These three reports allow the farmer to:

a) spot cows requiring special post-calving examinations as the result of calving problems;
b) identify cows not yet seen in heat after calving which should be examined;
c) identify cows with unusual reproductive cycles; and
d) maintain a check on heat detection.

Cows PD negative, serve again: This lists all cows that have been served and have subsequently been found to be empty by pregnancy diagnosis. These cows must be carefully observed for heat if they are not to have long calving intervals.

Cows for pregnancy diagnosis: This list includes all cows that have been served but have not yet been tested for pregnancy.

Cows pregnant then odd event: If a cow aborts, is served, or is recorded as on heat after having been diagnosed pregnant, she will be included on this list.

Cows for the Vet to see: The date of the last Vet visit and the date of the next Vet visit are entered by the operator, and then the following intervention targets are entered for the herd:

a) the days after calving that a cow should be seen in heat; and
b) the number of days after calving by which time cows should have been served.

The operator then specifies the PD policy for the herd (i.e. whether cows are milk PD'd only, Vet PD'd only, or whether both are used). The cows for the Vet to see are then chosen, based on criteria selected by the operator from a list of 19 possible criteria. The Vet's copy of this report is a full health and fertility and productivity history of every cow that is to be seen, together with the reason(s) each cow is to be seen. The Vet list can be run on the morning of the Vet's routine visit if there is a computer on the farm, so that the list is completely up to date.

Cows with status NS or CU: This list is effectively a culling list, showing all cows that are labelled NS (not to be served again) or CU (to be culled).

Herd Date Review

The Data Review reports allow the whole herd or chosen cows to be listed for comparison with one another or with targets. The reports can also be used to check entered data against the original recording forms.

Health and fertility datalist: Full or summary reports on the health and fertility history of a selected group of cows in past or current lactations can be produced by use of this option.

Herd production reports: These are full or summary reports of the milk yield, score, weight etc of chosen cows.

Feeding group report: This report allows the analysis of cows productivity by feeding groups.

Herd reproductive performance analysis: This report is a comprehensive analysis of the month-by-month reproductive performance of the whole herd over a selected 12 month period. The herd is divided into monthly calving groups, and for each group the number served since calving, submission rates, conception rates, average dry period etc., is calculated.

Individual cow lactation summaries: These are two page reports for each cow, suitable for filing after each complete lactation. The report includes a summary of production and health and fertility data for the completed lactation, and a plot of milk yield over time.

Brinkmanship Reports

The Brinkmanship reports are a linked set of 3 programs (B1 to B3) designed to cope with the tedious arithmetic involved in using the Brinkmanship system of dairy herd management. The use of these programs depends on weekly milk recording, the plotting of milk yield graphs for each month of calving group, and skilled assessment of the nutritional value of the forage available. It can cope with in-parlour and out-of-parlour feeders, either of which can have the variable component of the feed allocated to it.

B1 - Herd milk production summary: In this report, the following information is shown for each month of calving group:

number of cows in the group, and average age at calving in months
average peak yield and average yield so far
average expected milking rate
average yields for the last 3 milk recordings
weekly change of average yields over the last two dates

B2 - Weekly management report: The Weekly Management Report is produced after forage values and concentrate feeding levels for each group are entered by the operator. For each cow in the herd, the following information is listed:

lactation number, status and calving date
days open, number of serves, date of last serve, and sire number
number of cases of mastitis so far
days in milk, peak yield so far, total yield so far
last 3 milk recordings, C.A.R. (if any) for the last milking
percent weekly change between last 2 recordings
expected 305 day milk rate
daily concentrates required for the last 2 recording dates

Feedlist: The feedlist lists the concentrate requirements for each cow in parlour, in an out of parlour group ration, and in an out of parlour feeder (if the farm has one). The Feedlist comprises 4 parts:

a) Managers report   b) Parlour feed list
c) Group totals   d) individual cow margins and group margins

DISCUSSION

The DAISY 2 programs are one of the most comprehensive and flexible computerised management aids available to dairy farmers and their veterinarians today. The use of DAISY reports in conjunction with regular veterinary visits can lead to a reduction of calving to conception periods by improving heat detection and improving conception rates. Lower culling rates and higher margins over concentrates enable more efficient milk production and therefore greater farm profits.

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A DAIRY COW HERD AND PRODUCTIVITY PROJECT IN THE WEST OF SCOTLAND

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THE DEVELOPMENT OF THE PROJECT

In the autumn of 1976 Mr Brian Martin a private veterinary practioner from the practice of McKenzie, Bryson and Marshall of Kilmarnock, Ayrshire, approached the West of Scotland Agricultural College with a proposal for the establishment of a research and development project to investigate the feasability of developing a comprehensive programme of preventative medicine, disease and fertility control; intensive technical, husbandry and management advice which might ultimately be offered to commercial dairy farmers as a 'package deal'.

Brian Martin had long been an advocate of the need for much greater involvement by practitioners in prevention and control rather than in merely curative medicine. He also had a keen appreciation of the need to demonstrate to farmers that the financial benefits from prevention and control would outweigh the costs incurred.

The College welcomed his proposal and an inter-disciplinary project team was set up. This consisted of, on the veterinary side, Brian Martin plus the Head of the College's Veterinary Medicine Division (who is also the Regional VIO) and the VIO at Auchincruive; others were the Director of the College's Advisory and Development Service, representatives of the local Area Advisory Office and College specialists in animal husbandry, agricultural chemistry and agricultural economics.

The objective was "To assess, in terms of improved productivity and profitability, the effects of a planned programme of veterinary, husbandry and management advice on certain dairy herd".

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Initially, six pilot dairy herds with a total of 652 cows were used to develop the programme and additional herds have since been included. In 1981/82, fifteen herds with a total of 1455 cows were involved in the project.

The study is limited to adult dairy cows and includes calving heifers whose first lactation performance may be adversely affected by disease in the pre-calving period. Young stock are excluded because of difficulty in evaluating the cost of disease in non-productive cattle.

ESTABLISHING BASELINE DATA

In order to measure the costs and benefits of a programme of fertility control, preventative medicine and intensive advice it was first necessary to establish the base line levels of herd health, fertility, management procedures, productivity and profitability on participating farms. This was done as follows:

Health Records: calvings, disease incidents, culling and death were recorded for each individual cow.

Fertility Records: every calving, non-service oestrus, service and drying-off date were recorded. Farmers were not told that this data would be used, retrospectively, to assess the fertility management status of the herd in order that baseline management performance would not be influenced.

Management Procedures, Productivity and Profitability: these were established from data obtained by advisers and through cooperators being included in the Milk Production Systems Investigation (MPSI). MPSI has been operated by the College since 1972 and this scheme's data on herd numbers, milking and dry cows, calvings, disposals, transfers, milk production and feed use are recorded monthly. Each cooperating farmer receives a monthly 'feedback' of data showing average milk production per cow in herd per day and per month, concentrate use per cow and per litre, the contribution of forage to production and monthly margins over concentrates in total, per cow and per litre. After a year in the scheme a monthly comparison is also given of "this year" with "last year" plus a twelve month rolling average of milk production, concentrate fed and margin over concentrates. Farmers record other variable costs of milk production so that, at the end of each year, financial results can be presented to the gross margin stage (per cow and per hectare) and physical performance expressed in terms of averages per cow and per litre.

Other Records: included the veterinary costs incurred by cooperators plus the nature and extent of any existing disease control measures.

A fundamental feature of base-line establishment was that no veterinary, technical or management advice was offered to farmers, unless specifically requested, so that base-line performance was not influenced by action taken as a result of such advice. Inevitably, the very act of keeping records stimulated some thinking and farmer-action but only to a minor extent.

BEYOND THE BASE-LINE

Following completion of the base-line year, recording has continued - but in greater depth.

Health records are kept as before but mastitis and lameness are recorded in greater detail. In cases of mastitis a milk sample is taken, the causative organism identified and this and the affected quarter recorded. In the case of lameness, the affected foot and the nature of the lameness are recorded.

For health problems, curative measures and preventive advice are given where necessary. Investigation into the possible causes and nature of some disease incidents has been a continuing activity.

Originally fertility records were kept on sheets which set target dates for first oestrus, service and conception but this has been superceded by computerized methods. A fertility control programme designed to reduce calving to conception interval to no more than 85 days has been implemented through a monthly veterinary visit.

Recording through MPSI has continued. Results are discussed at group meetings of cooperating farmers and management advice given. Targets for the herds' physical and financial performance for twelve months ahead are established using the College's Dairy Herd Long Term Forecast computer program which produces both tabulated print out and a production graph which enables actual performance to be logged against predicted performance.

Forage and other feeds are analysed and winter rations are calculated using the College's COWRAT computer program. A representative number of cows are blood sampled some 3 or 4 weeks after housing and also after the start of summer grazing. The biochemical affray of appropriate metabolic parameters is used to check the nutritional status of the herd.

Monthly bulk milk samples are collected for analysis of compositional quality, cell count and bacterial count as measures of herd nutritional status, sub-clinical mastitis and 'cleanliness of milk'.

The cost of veterinary, laboratory and advisory inputs are recorded so that the cost of the programme can be calculated.

Currently the project consists of the continuation of monitoring, recording and advisory programmes together with the production of action lists for farmers in fertility control.

With a number of specialists being involved, there were pressures for the recording of a large amount of data. Some has been found to be of limited value and abandoned eg daily milk yields, measurements of parasitic burdens, and analysis of herbage for grazing and conservation. It was necessary to investigate these aspects to determine that they were, in fact, superfluous.

Conversely, some items have been added to the programme. Because Leatherjackets (Tipula spp) are a problem in the area, count-sampling is undertaken in January-February and any necessary action recommended. Advisory letters are sent to cooperators at appropriate times giving advice on silage making, feeding cows at grass, control of mastitis, inspection of milking plant, prevention of milk fever, hypomagnesaemia and summer mastitis. Cooperating farmers meet twice yearly to discuss the physical and financial performance of their herds and any other matters of importance. ATB courses on foot care and oestrus detection have been organised.

COMPUTERIZATION

During the development of the project it became evident that the volume of data could not be handled and analysed manually. The need to provide action lists for farmers to follow in the fertility control programme, together with the recording of data on each individual cow, including breeding, exacerbated the problem.

Various methods of data recording and processing were examined and it was decided that a computer-based system was necessary. The ARC's COSREEL program and Reading University's DAISY system were investigated and assessed. Despite their merits, neither of these programs was entirely suitable to meet the needs of the project and the amount of analysis which would be required. In the circumstances it was decided that the College should write its own "tailor made" program and a start was made in 1980. The program - known as VIRUS (Veterinary Investigation Recording User System) - has been written and developed by the two co-authors of this paper.

VIRUS Details of the program were published in 1982*. VIRUS is mounted on a microcomputer, however various options with regard to large scale analysis of the aggregate data from all farms, which would be outwith the ability of a microcomputer to handle, are possible via communication links to a mainframe computer. Currently the program is run on a Northstar Horizon microcomputer with printout on a Tandy LP3 printer. The program is written in MBASIC and will run on any microcomputer using a CP/M operating system.

To obtain the recording flexibility needed for a development project, a database type of structure has been adopted. This enables any number of recordings to be made for each cow and allows for the program to be easily amended to record additional items of information. The present amount of recording permits the lifetime history of over 400 cows to be stored on one floppy disk.

The main features of the program are currently:

a) storage of individual cow records
b) production of fertility control action lists for farmers
c) production of a monthly and annual monitor of herd fertility
d) fertility analysis for each herd
e) conception analysis for each herd
f) monthly and annual health monitor for each herd

a) **Storage of individual cow records**

These contain a full lifetime history of each cow including breeding information, health and disease events, calving and calf data, milk yields, all fertility events and culling/death data.

b) **Fertility control action lists**

These are produce under the following headings:

Cows due to be dried off in the next 30 days
Cows due to calve in the next 30 days
Cows not observed in oestrus by day 42 after calving
Cows in target service period
Cows due for pregnancy examination
cows served twice or more and not pregnant
cows confirmed pregnant

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* Martin, B, Mainland, DD and Green, MA "VIRUS: A computer program for herd health and productivity" Veterinary Record (1982) **110**, 446-448

Under each heading, comprehensive data is provided for each animal giving, for example, identity; lactation number; previous (or predicted) calving date; previous history (eg dystocia or milk fever events at previous calving - providing an 'early warning' system), etc. A full listing of entries under each heading is given in previous publications (Martin, Mainland and Green - op cit).

An action list is printed and sent to farmers before the practitioner's regular visit which is carried out on a fixed day of each month for each farm. The practitioner nominates the minimum number of days from last service at which he wishes to carry out examinations for pregnancy. The findings are coded (eg PR = pregnant; NP = non-pregnant; CL = Corpus Luteum) on to the action list which is then returned to the computer operator for entry into the program and updating of the following month's action list.

c) **Fertility Monitor**

The fertility performance of herds is monitored monthly and cumulatively and is compared with performance in the previous year.

The following information is presented:

Number of cows calved
Number of cows seen in oestrus
Mean days calving to first oestrus
Number of cows served
Mean days calving to first service
Number of cows which have conceived
Mean days calving to conception
Potential number of oesturs observations
Actual number of oestrus observations
Mean days between oestrus observations
Oestrus detection rate (%)

d) **Fertility analysis**

For each herd, performance is summarised under the following headings:

i) Days from calving to first oestrus

ii) Days from calving to first service

iii) Days from calving to conception

e) Conception analysis

Performance is summarised under the following headings:

Conception to first service
Conception rate for the herd
Conception rate of cows to different bulls

For both d) and e) above, comprehensive information is given as described in Martin, Mainland and Green (1982 - op cit).

f) Health monitor

Disease events are recorded and analysed monthly, cumulatively and with comparative figures for the previous year. Disease incidents can be expressed as percentages of cows in milk (eg mastitis) or as percentages of cows calved (eg milk fever). All results are periodically scrutinized by members of the project team to identify needs for advice or for further investigation.

Codes

All items entered as data are coded, mostly as two or four letter abbreviations. The farmer records some data on simple farm recording sheets requiring 'tick' entries.

For certain other events, a simple coding list is provided. All data are entered into the program in coded form to simplify and speed up operation. However, all visual displays, action lists and other printouts are translated by the program into full text - essential for clarity, interpretation and farmer acceptance.

FURTHER USES OF THE VIRUS PROGRAM

The program is being developed towards analysis of data for the presentation of Research and Development reports. Long term, use of the program would make it possible to search for genetic differences in sire progeny groups and cow families in their susceptibility to infertility and diseases such as mastitis and lameness. Provision will also be made to search data for other relationships.

The existence of the VIRUS program has attracted interest from a wide range of sources. In October 1981 two veterinary practices, one in Gloucestershire, one in South Wales, representing a practioners' computer user group, studied the program and then purchased it from the College to be operated in seven veterinary practices in England and Wales. The University of Edinburgh has also expressed a wish to use the program on one herd for teaching purposes. ARC Compton have studied the program and enquiries to purchase the software have also been received from Canada and South Africa.

RESULTS FROM THE PROJECT

The project will continue to 30 April 1984 when an assessment of the results will be made and a report issued.

MODELLING

POPULATION BIOLOGY AND CONTROL OF OSTERTAGIASIS IN FIRST YEAR GRAZING CALVES

B. T. GRENFELL* and G. SMITH*

We present a mathematical model of the epidemiology and population dynamics of Ostertagia ostertagi and parasite control by anthelmintic treatment. We use the model to assess the relative impact of various anthelmintic control strategies, focusing on the effects of continuous intraruminal release of the drug via a sustained release device (Jones, 1981). Model predictions are compared with observed patterns in field trials.

MATHEMATICAL MODEL

The model comprises nine coupled first order differential equations which describe the rate at which parasites enter and leave various stages in the life cycle (Fig. 1). The rate of change in the abundance of individuals in each stage with respect to time is determined by:

(1) Stage development time
(2) Stage mortality
(3) "Emigration/immigration" processes (translocation, infection)
(4) Fecundity of the reproductive stages

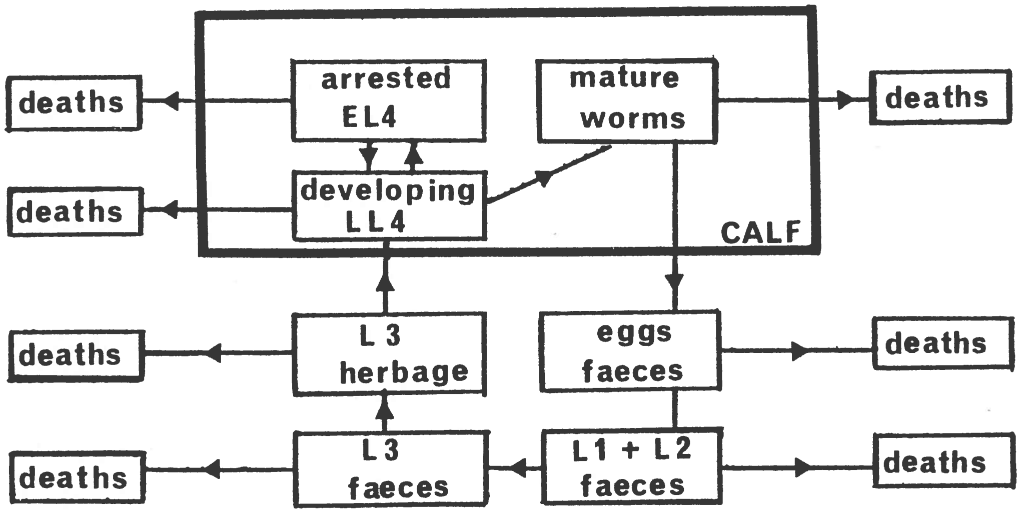

Fig.1 Life cycle of O.ostertagi

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The total number of parasites varies in time as a result of the influence of density-dependent and density-independent processes on the stage specific rates listed above. As examples, we describe two of the model's most important components: the effect of climate on the development and survival of the free living stages of O.ostertagi (density-independent), and variations in the fecundity of mature worms (density-dependent).

DEMOGRAPHY OF THE FREE LIVING STAGES

We have reanalysed the results of a long series of field plot experiments carried out by Persson (1974) (L. Persson, pers. comm.). Persson placed fresh faeces containing known numbers of O.ostertagi eggs and L3 larvae on small field plots at intervals throughout a two year period. The faeces and plots were regularly sampled, and the parasite numbers in each sample estimated using calibrated extraction procedures. Persson interpreted his results in terms of the variations in air temperature and rainfall that occurred during the period of the experiment.

(a) Non infective free living stages (Eggs, L1 and L2 larvae)

The rate of change in abundance of the non-infective free living stages (E(t)) in Persson's experiments is given by

$$\frac{dE(t)}{dt} = -(\mu_1+\sigma(T))E(t) \qquad (1)$$

where μ_1 is the average instantaneous *per capita* death rate. The average instantaneous *per capita* rate of development, $\sigma(T)$ is shown as a function of T, the average temperature prevailing for the duration of the experiment on each plot. The value of T can be calculated from the climatic data provided by Persson (1974).

An approximate estimate of $\sigma(T)$ can be obtained via the formula

$$\sigma(T) = \frac{1}{D(T)} \qquad (2)$$

where D(T) is the number of days between the deposition of faeces on the plot and the sampling date when infective larvae were first recorded.

The development rate of the non-infective free living stages was found to be a simple linear function of the average temperature (Fig. 2) but it is important to note that the development rate so measured is about half that measured in the laboratory (Fig. 2). Young *et al*. (1980) report a similar result.

(b) Translocation and survival of the infective stages (L3)

The movement of infective larvae from the faeces onto the herbage in Persson's experiments may be approximated by the following equations:

$$\frac{dF(t)}{dt} = -(\mu_2+\gamma)F(t) \qquad (3)$$

$$\frac{dH(t)}{dt} = \gamma F(t) - \mu_3 H(t) \qquad (4)$$

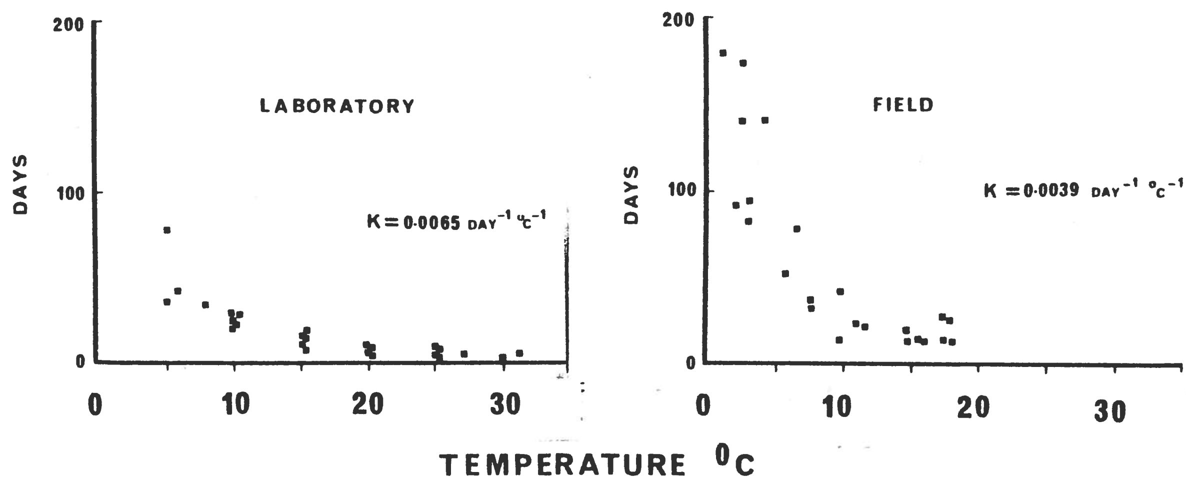

Fig. 2 Temperature-dependent development times of the non-infective free living stages of O.ostertagi. Laboratory data from Ciordia and Bizzel (1963), Gibson (1980), Pandy (1972), Rose (1961) and Young et al. (1980). K = 1/(development time x temperature).

Changes in the abundance of L3 larvae in the faeces and herbage (F(t) and H(t) respectively) are determined by their mortality rates (μ_2 and μ_3 respectively) and the migration rate (γ) between two phases.

Contrary to our expectations we could find no evidence that the values of μ_1, μ_2 or γ varied with either the prevailing climate or the age of the larvae. Assuming a multinomial distribution for the observations, a joint maximum likelihood fit of observed and expected L3 counts yielded the following parameter estimates:

Parameter	Estimate (/larva/day)	Standard Error
μ_2	0.0284	0.00002
μ_3	0.00887	0.000014
γ	0.00884	0.000016

There was no improvement in the agreement between observed and expected L3 counts if mortality and immigration were made explicit functions of (say) temperature, rainfall, or soil moisture deficit. The observed and expected results based on the model represented by equations (3) and (4) are given in Fig. 3.

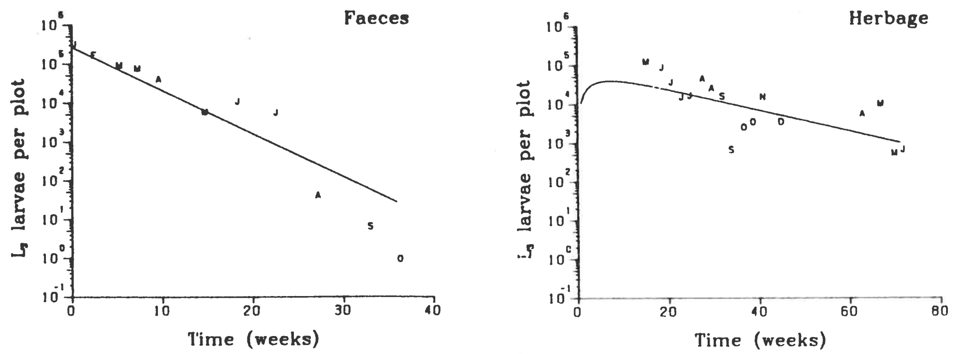

Fig. 3 Observed and expected third stage larval survival in faecal pats and on herbage

VARIATIONS IN THE FECUNDITY OF THE MATURE WORMS

Experimental studies demonstrate that the daily faecal egg output in calves infected with O.ostertagi rises rapidly to a peak in the two or three weeks following patency, then declines in an apparently exponential manner. The pattern is similar whether the calves have been infected once only with L3 larvae (Murray et al., 1970), or subjected to continual daily infection (Michel, 1963, 1969; Burden et al., 1978).

The results of two long-term trickle infection experiments reported by Michel (1969) can be described by the following equation:

$$\frac{dR(t)}{dt} = \lambda e^{-\delta_1 t}(1-\delta_2 P(t))P(t) \qquad (5)$$

where R(t) is the total faecal egg output per calf per day. We found that R(t) depended on the mean intensity of infection (P(t)) and the time (t) since the start of the experiment. A biological interpretation of the functional form described by equation (5) above is that the marked decline in fecundity observed by Michel and others is due to a host response that is related in some manner to the extent of the antigenic stimulation or abomasal damage that occurs during the course of the infection.

A least squares estimation procedure yielded the following values for the constants λ, δ_1 and δ_2.

Parameter	Estimate	Standard Error
	379.65	30.6
	0.016	0.0082
	2.39×10^{-5}	6.7×10^{-6}

Fig. 4 illustrates how well the model describes the results.

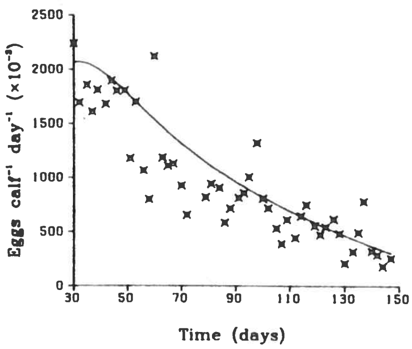

Fig. 4 Observed and predicted mean total daily faecal egg output from calves infected with 1000 L3 larvae/day

OBSERVED AND PREDICTED EPIDEMIOLOGICAL PATTERNS

Having illustrated how we set about assembling the model's various components, we now compare predicted epidemiological patterns with those observed in the field. In the simulations that follow, we assume that calves are turned out on the 7th May and housed on the 1st November. The stocking density remains at 10 calves ha^{-1} throughout, and the density of overwintered

L3 larvae is 500kg^{-1} (dry herbage) on the 1st April. For simplicity, the simulation results are presented in terms of daily faecal egg counts, and the density of L3 larvae on the pasture (Fig. 5).

We begin by considering the epidemiology of an untreated outbreak of ostertagiasis under temperate European conditions. We then assess the impact of three different anthelmintic control options, namely;

(i) Four discrete doses applied during the 'midsummer rise'.
(ii) Continual intraruminal release of drug from a sustained release bolus with an expected life of 90 days. The device is administered to the calves on the day before turnout.
(iii) As (ii) above, but the bolus is administered in mid season, at the start of the 'midsummer rise'.

Typical observed epidemiological patterns in the absence of anthelmintic control and arising from the use of early and mid season boluses, are displayed in Fig. 6.

The drug used is Morantel tartrate, which has been shown to reduce both the survival and fecundity of the parasites, when administered in a bolus.

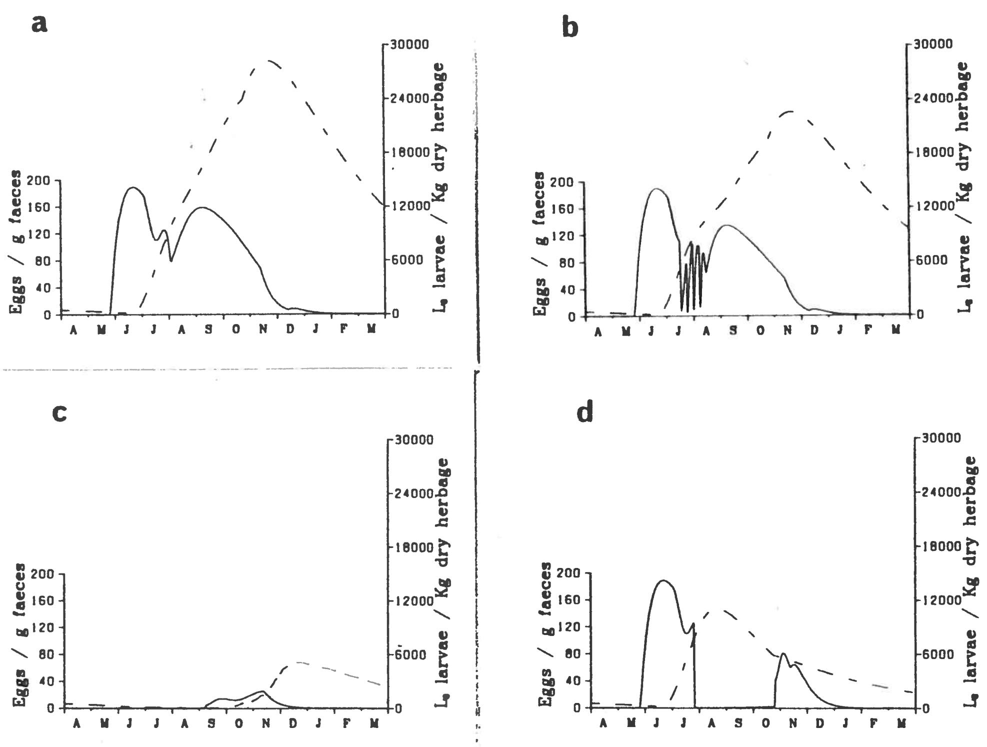

Fig. 5 Predicted variations in pasture larval contamination (solid line) and daily faecal egg counts (dashed line)

(a) No anthelmintic control
(b) Four single doses during July and August
(c) 90 day early season bolus
(d) 90 day mid season bolus

(a) Untreated controls

The observed patterns are naturally variable due to the sampling difficulties associated with overdispersed distributions (of parasite numbers per host). Inspection of Fig.s 5 and 6, however, shows that the model captures the essential features of a 'typical' outbreak of ostertagiasis; namely, the "midsummer rise" in the abundance of L3 larvae and the double peak in daily faecal egg counts. This double peak is a consequence of the changing balance between the number of mature parasites and their per capita rate of egg output.

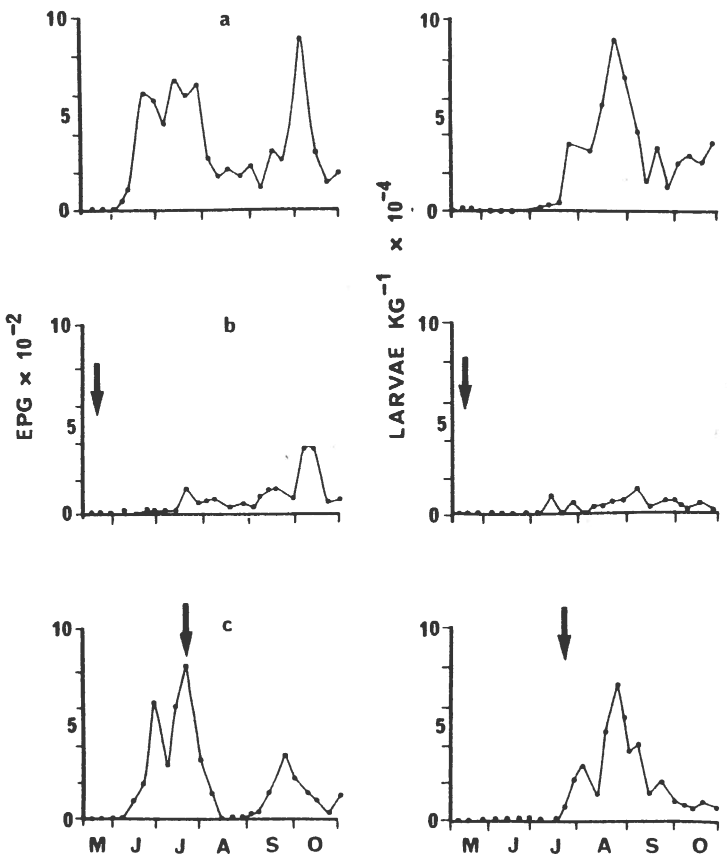

Fig. 6 Results from field trials (Armour et al., 1981)

(a) No anthelmintic control
(b) 90 day early season bolus (see arrow)
(c) 90 day mid season bolus (see arrow)

(b) Chemotherapy and Chemoprophylaxis

Both the observed and predicted results indicate that a 90 day bolus applied just prior to turnout is a very effective means of reducing pasture larval contamination. The "midsummer rise" is virtually eliminated. The application of a similar device in mid season is much less effective.

A series of discrete doses (a conventional regime) leads to short term reductions in the mean intensity of infection and daily faecal egg output but the overall level of pasture contamination is almost indistinguishable from that of the untreated control groups. It should be stressed that our "conventional regime" assumes that the calves are set stocked on the pasture throughout the grazing season. Our simulation is a striking illustration of why conventional dosing must be accompanied by a sensible grazing management policy (i.e. aftermath grazing) if it is to be of any benefit.

CONCLUSION

The mathematical model of the epidemiology and control of bovine ostertagiasis outlined above successfully mimics the typical pattern of disease in the field, in the presence and absence of control by anthelmintic application. It is important to note that the model was constructed independently of the field data used to validate its properties.

During the construction of the model we found:

(a) that there was no evidence in the data presented by Persson (1974) that the migration rate of the free-living infective larvae or their mortality varied with the prevailing climate or the age of the larvae and

(b) the total daily faecal egg output rate per calf per day was a declining exponential function of time since first infection and a quadratic function of adult worm burden.

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MODELLING ANIMAL DISEASE USING METEOROLOGICAL DATA

J GLOSTER*

For many years man has realized that animal diseases and weather are often closely related. The financial penalties of disease have encouraged much time and effort to be spent on trying to elucidate these relationships. Fundamental research workers, epidemiologists and modellers are involved at various stages in this work. The research worker provides the fundamental knowledge of the disease and the epidemiologist studies the pattern of disease spread in the field. The modeller synthesises the results of the other two and attempts to explain past disease patterns and to provide a practical means of forecasting the pattern of future disease levels. Whilst the research worker can make precise measurements of important parameters e.g. an animal's skin temperature, the practical modeller must work without the advantage of such specialised information, and devise schemes that use basic data obtained perhaps several tens of kilometres from the site in which he is interested.

In his work the modeller finds it convenient to distinguish between the direct weather challenge to pathogen numbers (including effects of weather on an intermediate host), the direct effects of weather on the primary host, and the effects of weather on immune function (including synergistic effects). In addition he also has to consider the biological response times involved since these will determine both the time available to management for useful intervention and the resolution of the environmental data required. These will range from a period of months down to a few hours. The type of model proposed will also influence the resolution of the input data. Models based on broad associations of disease with environmental variables may only require values of data averaged over a period of months. Others, for example where the development phases of a life cycle of a parasite are simulated will require daily or hourly data. In the latter case useful advice on future disease spread may be limited by the period ahead for which environmental data can be adequately forecast (climatological averages can always provide some basis for projection forward in time).

The object of this paper is to indicate the types of meteorological data which are currently available to the modeller and then describe some prediction models which have successfully used these data.

AVAILABILITY OF METEOROLOGICAL DATA

Each year large quantities of meteorological data are collected and archived by the Meteorological Office in a form accessible to the modeller. Smith (1975) concluded that with the possible exception of astronomy no other science has a comparable treasury of information. This contrasts quite markedly with the limited quantity of data for some diseases.

Meteorological data comes from a variety of sources and these include synoptic, climatological, agro-meteorological, health resort and rainfall stations. Observations at synoptic stations are taken and supplied to the central Meteorological Office; most of these stations report three or six hourly, but some make hourly observations. Measurements at the other stations are usually made once daily, although some keep autographic records. These data are forwarded to the Meteorological Office monthly.

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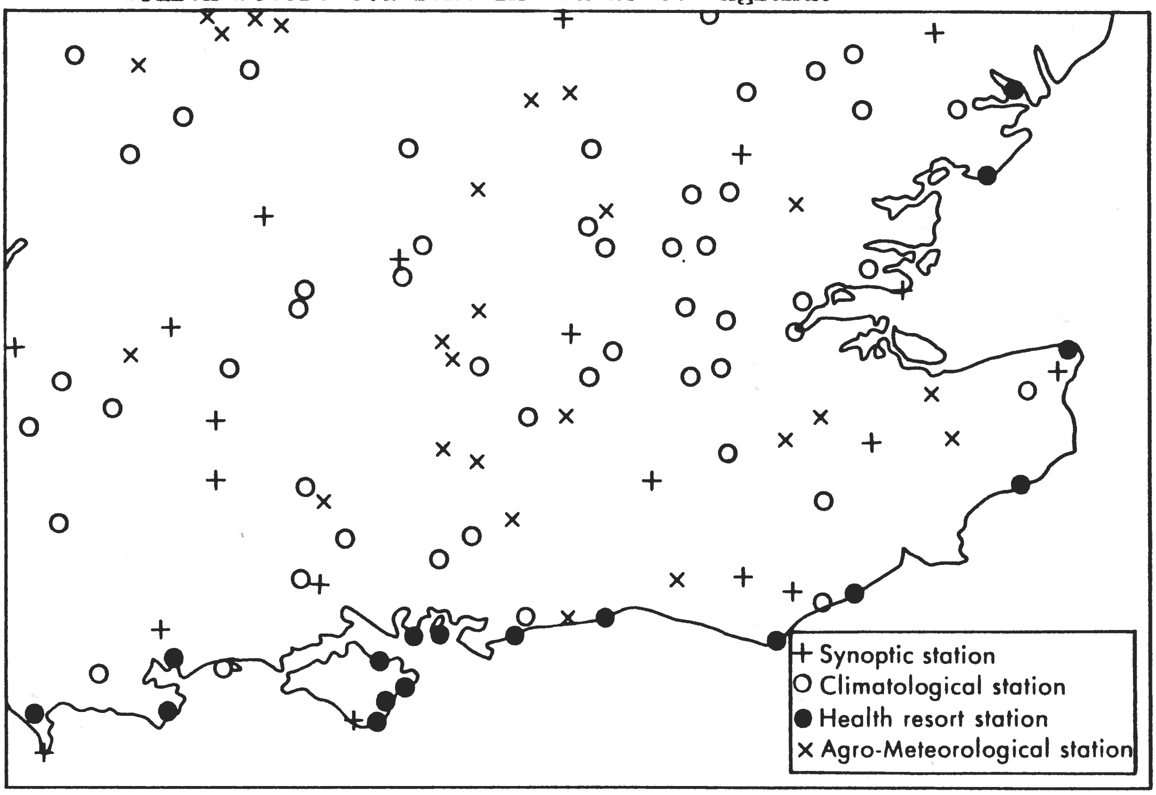
In the United Kingdom on 31 December 1981 there were 153 synoptic, 364 climatological, 84 agro-meteorological, 38 health resort and 5451 rainfall stations (Meteorological Office Annual Report, 1981). Table 1 summarises the individual weather elements that are usually recorded by the various stations and Figure 1 the distribution of these in the Southeast of England (the stations where rainfall data alone are measured are not included).

Table 1. Meteorological elements measured for each type of observing station

STATION TYPE	METEOROLOGICAL ELEMENTS MEASURED
RAINFALL	Rainfall and snowfall accumulations
CLIMATOLOGICAL	Air temperature (including extremes), rainfall and snowfall accumulations, present weather, wind speed and direction, visibility and total cloud amount. Some stations record sunshine totals, atmospheric pressure and soil temperatures.
AGRO-METEOROLOGICAL	As climatological but with emphasis on soil temperatures at different depths, grass minimum temperature and state of ground.
HEALTH RESORT	Particular emphasis on maximum temperatures and sunshine totals. Some stations take similar observations to climatological stations.
SYNOPTIC	Present and past weather, windspeed and direction. amount, type and height of cloud, visibility, temperature (including extremes), humidity, atmospheric pressure and pressure tendency, rainfall and snowfall accumulation, state of ground, sunshine totals and grass and concrete minimum temperatures.

Fig 1. Distribution of synoptic, climatological, agro-meteorological and health resort stations in Southeast England.



REPRESENTIVITY OF METEOROLOGICAL DATA

Whilst there is a wealth of meteorological data the modeller must always bear in mind how representative these data are of the conditions experienced by a particular animal or group of animals. For example, standard measurements of air temperature are taken in a Stevenson screen (a white louvred box, supported 1.2 metres above the ground). The 'effective temperature' of a new born lamb huddled in the shelter of its mother, some kilometres from the observing site may well vary considerably from that taken in the Stevenson screen. Hence the modeller must take great care when using standard meteorological data, and adapt it where necessary. A general description of the representivity of each of the major meteorological elements is given by Smith (1975).

In many cases an understanding of the weather processes in the planetary boundary layer enable meteorologists to deduce the environmental conditions at a greater resolution in time and space than the basic data available; for example an estimate of hourly air temperature may be obtained when only values of daily maximum and minimum temperature are available.

EXAMPLES OF MODELS USING METEOROLOGICAL DATA

Two operational models which use some of the data mentioned above, are described below in some detail. The first model uses standard meteorological data, taken at the nearest synoptic station (Gloster et al, 1981). The second model uses forecast meteorological data; in this case a relationship established between the standard data and those meteorological conditions experienced by a group of animals some 20 kilometres away was required in order to develop the practical model (Starr, 1981).

In addition reference is also made to a further group of models which use data taken at less frequent intervals (Ollerenshaw, 1980). These models are included to show that useful predictions of future animals disease patterns can, on occasions, be made even if the relationship between the weather and disease incidence is only empirical.

Model 1 - Foot-and-Mouth disease

Foot-and-mouth disease (FMD) is an infectious and highly contagious viral disease which predominantly affects cattle, sheep, pigs, goats and deer. The Ministry of Agriculture,Fisheries and Food (MAFF) is responsible for control of any disease outbreak in England and Wales. In order to control disease rapidly MAFF need to be able to estimate those areas where the disease is likely to spread. FMD has been shown to be capable of spreading through many routes, one of which is through airborne virus (Henderson, 1969; Smith and Hugh-Jones, 1969; Wright, 1969; Hugh-Jones and Wright, 1970; Sellers and Forman, 1973).

Affected animals excrete virus into the atmosphere over a period of a few days. This virus forms a plume which is carried downwind to susceptible livestock who then become infected. To arrive at an estimate of the virus concentration C (particles m^{-3}) in the air it is necessary to know the strength of the source and the dispersive capacity of the airflow. The source strength, Q (number of particles released per second) can be estimated from the number and type of animals affected (Sellers and Parker, 1969; Donaldson et al, 1970 and 1981; Sellers et al 1971). Dispersion is controlled by atmospheric turbulence which can be broadly parameterised (e.g. using wind speed and the atmospheric heat flux which can be estimated roughly from the elevation of the sun, cloud cover and state of the ground). From these parameters and the downwind range, x, the dispersion coefficients σ_y and σ_z (in the crosswind and vertical directions) may be estimated for use in the classical Gaussian dispersion description of plume spread (Pasquill, 1974). Assuming that virus is emitted and inhaled by livestock close to the ground the downwind particle concentration can be expressed as

$$C_{xy} = (Q/\pi \ U_{10}\sigma_y\sigma_z).\exp(-y^2/2\sigma_y^2) \qquad (1)$$

where U_{10} = 10m windspeed

Values for U_{10}, σ_y, σ_z and the directions to which virus is transported can change considerably over a few hours. Consequently it is usually necessary to use data with the best possible resolution i.e. hourly, if available. The number of synoptic stations which provide these data are relatively small and the distribution of stations is far from ideal. However for many atmospheric conditions the short-coming in basic data may not be too serious. When FMD occurred on the Isle of Wight during March 1981 there was a strong southerly airflow over the South Coast (Donaldson et al, 1982). The weather which existed on the Isle of Wight would have been very similar to that experienced at this time at Hurn Airport, 30 kilometres away. However, if the same outbreak had occurred when the winds were light in strength and variable in direction the pattern of disease spread would have been much more difficult to predict from off-site data.

Model 2-Lamb Mortality

Lamb mortality during and soon after birth is a major source of loss to the world's sheep industry (Symposium of the Scottish Agricultural Colleges, 1975). A MAFF survey in the South of England during 1974 and 1975 indicated that on many farms lamb losses from birth to 6 weeks were 20% or more. Some of these losses could have been attributed to the weather which existed during the critical first few hours, days and weeks of the lambs' lives. Livestock can be affected by the weather both indirectly, through the availability of food, and directly as a result of exposure to rigorous conditions (Blaxter, 1962, Obst and Ellis, 1977).

Alexander (1964) measured the metabolic rate of a lamb under various combinations of air temperature and coat condition in a climatic chamber. He showed that the metabolic rate rose in response to an increase in heat loss, so that the body temperature was stabilised. Heat loss was shown to increase as temperature fell and when air movement or evaporation from the coat increased. In addition to the heat loss by temperature and air movement Smith(1973) suggested that it was necessary to allow for the heat loss caused by a 'radiative' environment which would be most apparent under clear sky conditions; a value of up to -5°C was suggested as the modification which should be applied to the air temperature to provide an allowance for night-time radiation losses.

The data mentioned above were used to estimate the heat loss in a study of neo-natal lamb losses near Reading, England (Starr, 1981). Measurements of temperature, windspeed and rainfall were made at lamb height in the field and they were compared with those at the nearest synoptic station. Cloud type and amounts were only available from the synoptic station.

The study showed that some 75% of lamb deaths occurred on days when the heat demand over 24 hours exceeded 70 x the hourly metabolic heat production of a lamb under 'non-stressed' conditions.

Once the relationships between lamb mortality and heat loss and standard meteorological data and the environment experienced by the lambs, had been established it was possible to try to use these relationships in subsequent years. A trial forecast service for the collaborating farmer was devised in which estimates of heat loss were made for his flock using standard data alone. The 24 hour period beginning at 08.00 local time was divided into 6 four-hourly periods and forecast values for temperature, windspeed and the likelihood of precipitation were computed. The results were employed in an algorithm to provide a 'wind chill' index. On 21 March 1981 a severe 'wind chill' forecast was issued and the farmer responded by housing his young lambs. A nearby farm lost 43 such lambs on the same night. Table 2 shows the forecast that was issued on this occasion.

Table 2. Wind chill forecast 21 March 1981 (Starr, 1981)

Meteorological Office RAF Upavon. Forecast 'Wind chill' stress factors for New-born lambs at Rushall Farm, Bradfield, Berkshire, March, April, May 1981.

Period LT	0800 to 1200	1200 to 1600	1600 to 2000	2000 to 2400	0001 to 0400	0400 to 0800	TOTAL INDEX
Forecast temp °C	10	11	10	09	08	08	
Forecast wind speed knots	22	22	22	20	18	18	
Rain?	YES	YES	YES	YES	YES	YES	
Forecast stress factor	17	17	17	16	16	16	99

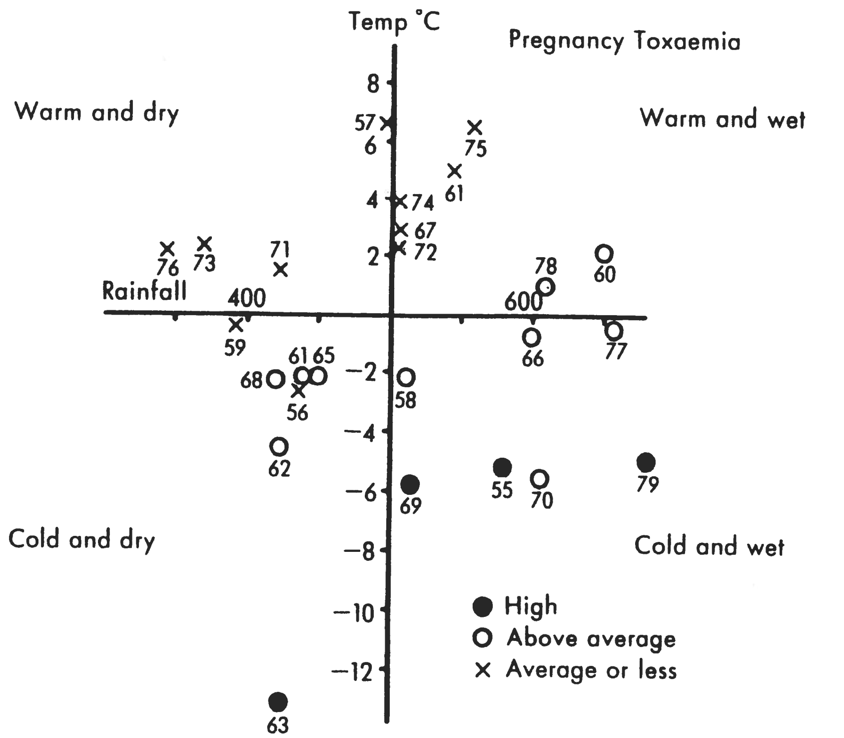
Total >95 severe wind chill, 90-94 danger, 80-89 warning, <80 no danger.

Empirical relationship models

On occasions the level of disease may be predicted using less complicated models based on simple empirical relationships. An example of this is the model used by the Central Veterinary Laboratory, MAFF to predict the likely incidence of pregnancy toxaemia (Ollerenshaw, 1980). Pregnancy toxaemia is a stress disease, experienced in late pregnancy by ewes carrying twin lambs. Greatest stress is produced by a combination of cold and wet conditions, but the disorder can arise in extreme cold or wetness alone.

A model was constructed which uses simple meteorological data, averaged over the whole country; departures of monthly mean temperature from long term average and monthly rainfall expressed as a percentage of long term average were the two elements chosen. By summating the monthly figures a simple numerical assessment of winter weather can be obtained. Figure 2 shows the incidence of disease, split into three categories (high, above average and average or less).

Fig 2. The level of pregnancy toxaemia in relation to winter weather (see text for explanation of axis).



Ollerenshaw (1980) concluded that the results show that although the parameters used to identify the level of these diseases are not the most sensitive or reliable they can, if interpreted with care, help to distinguish those years when the disease is likely to cause problems to the farmer. The same technique has been used by Ollerenshaw to predict levels of swayback and nematodiriasis.

ACKNOWLEDGEMENTS

The author wishes to thank Dr Ollerenshaw and Dr Starr for granting permission to quote from their published work.

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A MATHEMATICAL MODEL FOR THE CONTROL OF PARASITIC GASTRO-ENTERITIS IN LAMBS GRAZED ON INITIALLY CLEAN PASTURE

G. PATON* and R.J. THOMAS**

Many parasites causing disease in domestic livestock respond predictably to climatic factors. There have been two distinct approaches to forecasting the incidence of these diseases, namely the construction of empirical forecasting models based on climatic indices (e.g. Ollerenshaw and Rowlands, 1959; Thomas, 1978) and the formulation of prediction models based on biological development rates (e.g. Gettinby et al., 1974; Gettinby et al., 1979; Gardiner et al., 1981).

More recently a model for parasitic gastro-enteritis in lambs, based on a mathematical representation of the dynamics of the life-cycle of *Ostertagia circumcincta* was successfully used to predict the pattern, on a day to day basis, of the number of infective larvae on a permanent pasture grazed by ewes and lambs between April and October during 1973 and 1974. In formulating the model particular attention was given to the influence of temperature and moisture on development and survival from the egg to the infective third larval stage. In addition the establishment of the infective stage in the lamb, adult fecundity and various mortality rates were incorporated in the prediction system.

One important, and as yet virtually unexplored aspect of modelling parasitic diseases, is its use to enhance understanding of parasite epidemiology. It is in this area that the model described by Paton et al (in press) is particularly significant. It has been suggested that on initially clean pasture there will be one summer generation of parasites in the lambs arising entirely from ewe derived larvae and possibly a second generation in the autumn (Thomas and Boag, 1972). However using the prediction model to analyse the relative contributions made by the ewes and the lambs to the summer wave of infective larvae during 1973, indicates that at least 45% of this total was attributable to the lambs.

In this paper, the prediction model is used to illustrate the importance of correct timing of anthelmintic treatment of the lambs early in the grazing season.

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THE LIFE-CYCLE AND EPIDEMIOLOGY OF O. CIRCUMCINCTA

O. circumcincta is a trichostrongylid abomasal parasite of sheep. The sexually mature female worms produce eggs which are passed out in the faeces of an infected sheep onto the pasture. After hatching the parasite passes through first and second non-infective larval stages (L1 and L2) to reach the infective third stage (L3). Temperature and moisture conditions prevailing in the micro-climate of these free-living stages determine their rate of development and survival. After ingestion, development proceeds through a fourth larval stage and an immature adult stage to reach the adult form.

On initially clean pasture the peri-parturient rise in ewe egg output provides the initial source of infection for the lambs. There is a marked time lag before these eggs give rise to a major summer peak of infective larvae on the pasture, and the work of Paton et al (in press) indicates that the first infective larvae to appear produce early infection in the lambs which then itself contributes to the summer larval wave. This peak larval population results in a massive increase in the lamb worm burden which in turn gives rise to a further generation of infective larvae in autumn. If as suggested, the early lamb infection contributes significantly to the summer wave of infective larvae, then anthelmintic treatment of the lambs should influence the size of the larval population, and the timing of such treatment might well be critical to its effect.

PREDICTION MODEL

The availability of infective larvae

Since the ovine faecal pellet is small, the development and survival of the pre-infective larval stages of the parasite are likely to be subject to moisture limitations. As far as development from the egg to the L1 stage is concerned, it is assumed that the pellet initially retains sufficient moisture so that the duration of this relatively short development phase is only dependent on temperature. However, the duration of the L1 to L3 phase of development will be determined by the prevailing temperature and moisture conditions.

As temperature rises above a threshold of $4^{o}C$, below which no development occurs, the rate of development increases for both the egg to L1 phase and the L1 to L3 phase. By using temperature recordings the duration of both phases of development in the field can be predicted using the development fraction technique as described by Gettinby et al (1979). From laboratory work by Salih & Grainger (1982) the development times have been determined for both the egg to L1 stage and for the L1 to L3 stage at constant temperature assuming non-limiting moisture conditions. The relationship between the period of development, D, at constant temperature, T, is given by a set of equations of the form

$$D = a - bT \qquad T > 4$$

where a and b are constants which change over different temperature ranges. These constants have been evaluated from the experimental data. Account is taken of varying temperatures using the mean temperature, $\bar{T}_i$, in the above formulae in order to calculate the fraction of development occurring on day i. $\bar{T}_i$ is defined to be the average of the maximum and minimum temperature occurring on day i, $\max(T_i)$ and $\min(T_i)$ respectively. Thus the fraction of development predicted to occur on day i will be

$$F_i = \frac{\alpha_i}{a - b\bar{T}_i}$$

where α_i is an estimate of the proportion of day i for which temperature exceeds 4^oC and development occurs,

$$\alpha_i = \begin{cases} 0 & \max(T_i) < 4 \\ \dfrac{\max(T_i) - 4}{\max(T_i) - \min(T_i)} & \min(T_i) < 4 \text{ and } \max(T_i) > 4 \\ 1 & \min(T_i) > 4 \end{cases}$$

In this application the method has been modified to incorporate a moisture effect for the L1 to L3 development phase. Where development from the L1 to L3 stage is being considered it is assumed that if moisture conditions on a day are not adequate then no development takes place regardless of the temperature on that day. An assessment of the adequacy of moisture conditions in the environment of the parasite is determined by an approach which involves consideration of rainfall history and herbage density. The pasture is considered moist on day i if rain falls on day i or on either of the two immediately preceeding days. If this condition is not satisfied it is assumed that the pasture may still be moist if either rainfall has exceeded a threshold of 10 mm in the 7 day period immediately preceeding day i and herbage density during this period has on average exceeded 2500 kg per hectare, or if rainfall during the 15 day period prior to day i exceeds 15 mm while at the same time average herbage density for the period exceeds 3000 kg per hectare. These criteria were chosen based on the relationship existing between herbage density and moisture during 1973 and 1974 from Waller, Dobson, Donald & Thomas (1981).

For any specified period of time the daily development fractions can be calculated and summed. The completion of development is predicted to occur when the sequential sum of the development fractions first exceeds 1. Thus, knowledge of the development time from the egg to the L1 stage and from the L1 to the L3 stage makes it possible to predict the availability of infective larvae from successive egg cohorts contained in the faecal deposits of infected sheep.

The additional requirement of a single day of rainfall is assumed to be necessary before newly formed infective larvae are considered to be available for consumption. This condition is required as some form of migration from the site of the faeces into a consumable position on the sward is necessary. This requires the presence of a moisture film.

The number of infective larvae

The size of the infective larval population on pasture fluctuates daily as it is dependent on past levels of adult worm fecundity, the rate of establishment of adult worms and the rates of mortality of all stages of the parasitic life-cycle.

A set of simple equations of the form

$$J_{i+16} = c - dL_i$$

has been used to determine the proportion (J_{i+16}), of larvae ingested on day i (L_i), which becomes established as mature adult worms sixteen days later. The constants c and d, which have been obtained from the experimental work of Waller (1975), change over different ranges of larval intake.

The model also takes into account the fact that the weight of herbage and hence the number of infective larvae consumed by a lamb will be age-dependent.

It is extremely difficult to ascertain the fecundity of the adult female O. circumcincta worms as there is evidence of great variability in egg output between individual lambs. However from studies by Boag and Thomas (1977) and Jackson and Christie (1979) it has been possible to simulate egg production from lambs grazed on initially clean pasture by the equations

$$E_i = \begin{cases} 0.225\ A_i & 0 < A_i < 2000 \\ 240 & 2000 < A_i < 5000 \\ 80 & 5000 < A_i \end{cases}$$

where A_i is the adult worm burden on day i and E_i is the number of eggs per gram of faeces deposited on day i.

From a study by Salih and Grainger (1982) the daily survival probabilities for the egg to L1 development phase and the L1 to L3 development phase assuming non-limiting moisture conditions are taken as 0.98 and 0.9 respectively. However in view of the pre-infective larval stages susceptibility to lack of moisture a 'moisture effect' on survival is incorporated in the model for this phase of development. From studies by Gibson and Everett (1972) and Gibson and Parfitt (1977) the daily survival probabilities of the infective larvae and adult worms are estimated to be 0.97 and 0.96 respectively. For each of these development phases the proportion surviving n days is described by the probability formula p^n where the parameter p denotes the daily survival probability.

Operation of the prediction model

The prediction model combines the formulae which determine the availability and number of infective larvae. Thus, the dynamics of the parasitic life-cycle can be simulated in response to temperature and rainfall during the grazing period. To use the model it is necessary to specify certain parameters of the animal management system under study. In particular the daily weight of herbage intake and daily faecal output per day of the ewes and lambs must be estimated. The area of the pasture, the availability of herbage on the pasture and the stocking rate are also needed. In addition, in order to initiate the prediction model the egg output of the ewes (measured as epg of faeces) must be estimated during the period of the peri-parturient rise in egg count.

Paton et al (in press) give a detailed account of the site, helminthological and meteorological data which was used to test the model originally. These data relate to studies carried out in 1973 and 1974 at Cockle Park, Experimental farm, Northumberland.

Drug control: Within the operation of the model it is assumed that the only effect which the application of an anthelmintic drug to the lamb has on the system is to remove 99% of all adult and developing stages inside the lamb on the date of application. Clearly, the anthelmintic will also produce a marked effect on the egg output of the lamb on the date of application and on the sixteen subsequent days when few mature adult worms will be present.

RESULTS

The predicted patterns obtained for the magnitude of the infective larval population on permanent pasture at the Cockle Park site are for the year 1973 when ewes and lambs were grazed on initially clear pasture.

Observed pasture larval contamination levels and those predicted in the absence of control.

Figure 1 shows the observed pattern of the infective larval population on pasture during 1973 described by Waller et al (1981) and the trajectory obtained using the prediction model.

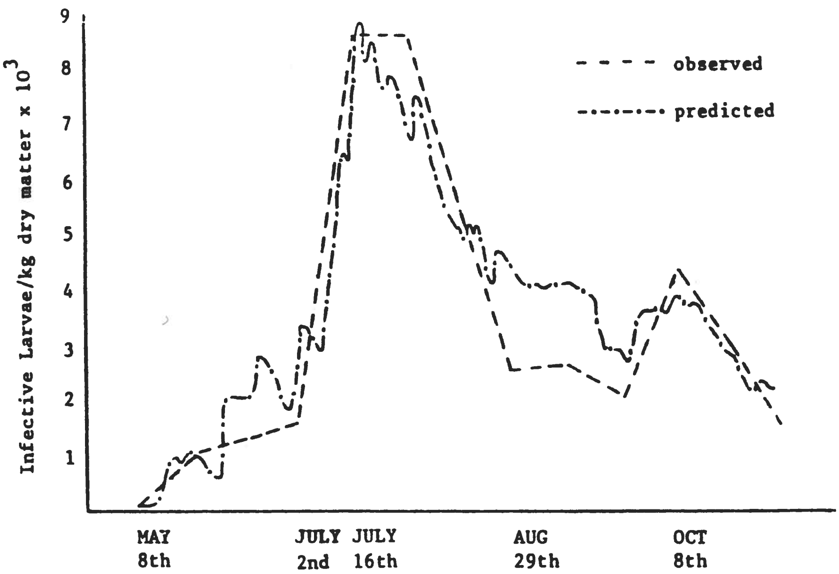

Fig. 1 Observed geometric mean O. circumcincta pasture larval counts and those predicted for 1973 in the absence of drug control.

Geometric mean levels of pasture larval contamination have been used to represent the observed pattern since data collection was replicated in different paddocks. Consequently, the predicted pattern of pasture larval contamination has been obtained using initial conditions which are geometric mean levels of ewe egg output.

Clearly, there is a good overall agreement between the observed and predicted patterns. Infective larvae are predicted to appear on pasture on 21st May. This date coincides with that of their first observed appearance. Observed levels increase slowly, reaching a level of approx. 1600 L3 per kdm by 2nd July. Thereafter the observed pasture larval contamination level rises rapidly to a peak of 8500 L3 per kdm on 16th July. The summer peak is in fact predicted to occur on 17th July. The observed level of 8500 L3 per kdm is maintained for approximately two weeks before declining to a level of approx. 2500 L3 per kdm by 29th August. This level is maintained for a few weeks before increasing to a second peak of approx. 4300 L3 per kdm on 8th October. The predicted date of the autumn peak coincides with that observed.

Predicted pasture larval contamination levels following the application of drug treatment to the lambs.

The consequences of administering an anthelmintic drug to the lambs on 11th June 1973 and on 27th June 1973 are both considered in relation to their subsequent impact on the trajectory of the infective larval population on pasture. The trajectories obtained using the prediction model under these two drug regimes are shown in fig. 2.

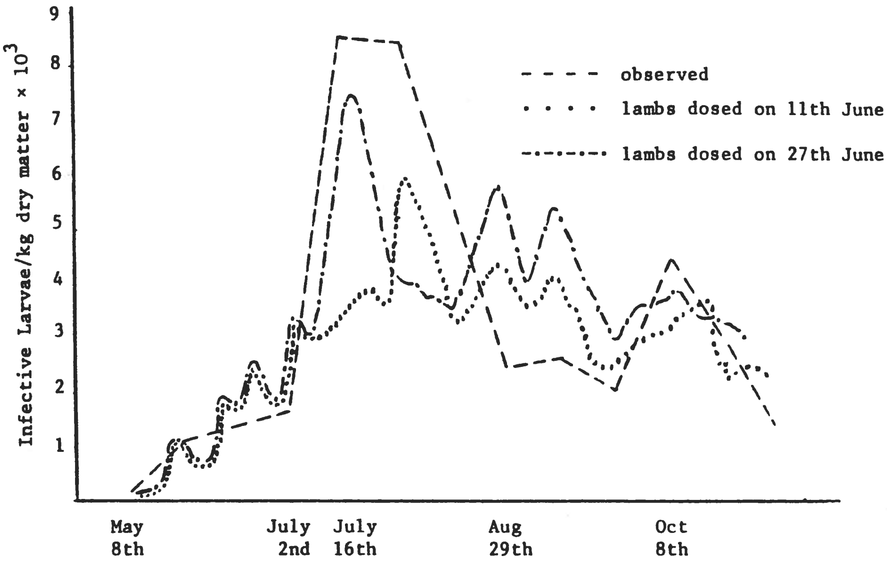

Fig. 2 Observed geometric mean O. circumcincta pasture larval counts and those predicted under two drug control regimes.

Figure 2 illustrates that for lambs dosed on 27th June the predicted larval levels follow the same general pattern as did the predicted levels when no drug control was applied. The summer wave of infection occurred at the same time with a rapid escalation to the slightly lower peak of approx. 7400 L3 per kdm. However in contrast to the trajectory predicted in the absence of drug control, the high levels of pasture larval contamination are not sustained and in fact decline to approx. 4400 L3 per kdm by 30th July.

For the lambs dosed on 11th June the predicted trajectory is totally different from that obtained when no drug treatment is applied. In this case there is no rapid rise in the level of pasture larval contamination until early August when a peak of 5600 L3 per kdm is predicted. Once again however, this peak is not sustained. Pasture larval levels are predicted to fall to approx. 3250 L3 per kdm by late August and thereafter to fluctuate, never exceeding a level of 4500 L3 per kdm for the remainder of the season.

DISCUSSION

Although the anthelmintic drug treatments were applied to the model only 16 days apart the resulting trajectories of pasture larval contamination obtained were very different. In practice, in the case of lambs grazed on initially clean pasture, dosing lambs in early June has been regarded as unnecessary. However the prediction model has indicated that in a year when weather conditions are favourable for parasite development, dosing lambs in early June may substantially reduce the magnitude of the summer wave of infection to which the lambs are exposed. Consequently, the possibility of the lambs acquiring large worm burdens and becoming clinically diseased may be considerably reduced. On the other hand, if drug treatment is not administered until the end of June, the model indicates that the drug treatment may have relatively little impact on the magnitude of the peak of the 'summer wave'. Thus this drug treatment may fail to prevent the onset of severe parasitic gastroenteritis. These conclusions on the impact of correctly timed drug treatment further support the findings of Paton et al (in press), namely that even on initially clean pasture, lambs can make a very significant contribution to the summer wave of infection.

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MODELLING BOVINE TUBERCULOSIS IN BADGERS

W.J. TREWHELLA* and R.M. ANDERSON*

In South West England the badger, Meles meles, is a reservoir host for bovine tuberculosis, Mycobacterium bovis, being implicated in the transmission of the disease to cattle (Zuckermann, 1980). This paper describes the formulation of a simple mathematical model to examine the population dynamics of bovine tuberculosis in badgers. The first section deals with a review of the disease epidemiology, and a summary of information on badger population dynamics. A preliminary model is described in the second section and various modifications to its structure examined. The dynamics of disease regulated badger populations, as determined by the model's prediction are then discussed in relation to the available empirical evidence.

ESTIMATION OF PARAMETERS AFFECTING BADGER POPULATION AND DISEASE DYNAMICS

Information on the dynamics of disease free badger populations is derived from a literature review of badger studies in Britain and Europe. Information on the badger's productivity, the age structure and sex ratio in a population, and the typical life expectancy, is used to estimate per capita birth and death rates, and the population's intrinsic growth rate (Table 1). The review provides the basis for the model's assumptions concerning the pattern of population growth in the badger, and the nature of the density dependent population regulation.

Table 1. Badger population dynamics

Productivity (cub/♀/yr.)	1.6	Per capita birth rate:	0.6 $yr.^{-1}$
Sex ratio	1:1		
Mean life expectancy (yrs.)	2.6	Per capita death rate:	0.4 $yr.^{-1}$
		Population intrinsic growth rate:	0.2 $yr.^{-1}$
Carrying capacity (km^{-2}):	low : <2		
	medium : 2-5		
	high : 5-10+		
	very high: 20		

There is limited information on the dynamics of the disease in badgers excepting data on the prevalence of infection in badger populations. Estimates for the length of the incubation and infectious period come from two sources. Little, Naylor and Wilesmith (1982) describe laboratory experiments on a small

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sample of naturally and artificially infected badgers. Cheeseman et al. (1982b) have trapped and clinically examined a badger population. There is no effective method of detecting infection in live badgers other than by examination in various excreta for the presence of M.bovis (Little et al., 1982). The length of the infectious period is variable. Some badgers die quickly from the disease (35 and 75 days in laboratory experiments) others live for over a year in the field, or for three and a half years in the laboratory. During this time they are still able to release infectious organisms.

The fact that bovine tuberculosis in badgers is most commonly found in the South West, where badger densities are high, indicates a relationship between density and prevalence of infection (Zuckermann, 1980; Gallagher and Nelson, 1979). So far, in the South West, the disease has been found in badgers at densities of five adults/km^2 and above (Cheeseman et al., 1982a).

For the South West region (1971-1981) the mean prevalence of diseased badgers was 13.7%, as determined from badgers killed in connection with official investigations (MAFF, 1977-1982). This average figure hides the temporal and spatial differences seen in disease prevalence between local badger populations (Cheeseman et al., 1982a). There is insufficient temporal data on disease prevalence to comment on any possible oscillatory trends. There is, however, an oscillation of between eight to twelve years in the incidence of the disease in cattle herds in the South West, from approximately 1960 onwards (Wilesmith, pers. comm.). This may reflect some similar behaviour in disease prevalence in badgers or badger densities.

MODEL CONSTRUCTION

A deterministic, compartmental model is used (see Fig. 1) in which the badger population is divided into three classes: susceptible badgers, infected but not yet infectious animals, and infectious badgers. These classes have population densities X, H, and Y respectively; the total badger population, N, is given by N = X + H + Y. As badgers show no immunity to bovine tuberculosis (MAFF, 1979), there is no category for recovered (immune) animals.

BASIC MODEL

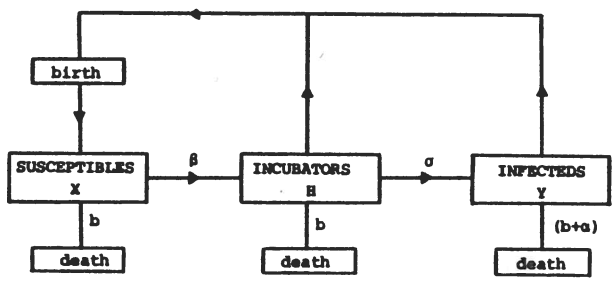

Fig. 1 Diagrammatic flowchart of badger/bovine T.B. system

The flow of individual hosts between compartments is controlled by the following rate parameters:

a is the per capita birth rate
b is the natural death rate
β is the disease transmission coefficient
σ is the rate at which incubating individuals become infectious (1/ = incubation period)
α is the disease induced death rate (1/(a+b)) = life expectancy of diseased badgers

As density dependent regulation is believed to act on individuals prior to reaching maturity, we assume in our model that it acts on the reproductive rate. The per capita death rate is considered to be constant with age. In its simplest form, the per capita birth rate is linearly related to the population density, N, such that the net rate is $(a-\gamma N)N$, where a is the per capita birth rate and γ measures the severity of density dependent constraints. In the absence of the disease the growth rate of the population is described by the logistic equation,

$$dN/dt = (r-\gamma N)N \qquad (1)$$

where γ is determined from estimates of population growth rate, r, and a knowledge of typical badger densities in various habitats ($\gamma=r/K$).

The rate at which badgers acquire tuberculosis is considered proportional to the number of encounters between susceptible and infectious individuals, βXY, where β is a disease transmission coefficient, estimated from the threshold density of susceptible badgers required for disease presistence (see Anderson et al., 1981). Badgers are assumed to pass from the incubation to infectious state at a per capita rate σ, where $1/\sigma$ is the incubation period. Infectious animals are assumed to die at a constant rate, α, where $1/(\alpha+b)$ is the average life expectancy during the infectious period. All three classes are taken to be capable of reproduction.

The above biological assumptions lead to the three coupled non-linear differential equations which represent the basic model for the dynamics of tuberculosis within badger populations:-

$$dX/dt = (a-\gamma N)N - bX - \beta XY \qquad (2)$$

$$dH/dt = \beta XY - bH - \sigma H \qquad (3)$$

$$dY/dt = \sigma H - bY - \alpha Y \qquad (4)$$

For the total population, N, summing the above equation gives:

$$dN/dt = (r-\gamma N)N - \alpha Y \qquad (5)$$

The above formulation can be simply modified to include other forms of density dependence, and to alter various assumptions concerning disease transmission. If most density dependent changes occur at population levels close to carrying capacity, as indicated by ecological studies of mammal species (Fowler, 1981), the functional response relating population growth rate to density, changes from the linear logistic form to a curvi-linear form (see Fig. 2).

Within an infected social group, the close contact between mother and cubs places the cubs at a high risk of infection during their first few months of life. A component of vertical transmission can be introduced into the model for those cubs which directly enter the incubating class as a result of this contact.

Badgers may also contract the disease from contaminated pasture. The rate of transmission of the disease then becomes proportional to the number of encounters between susceptible badgers and the density of infectious spores in the environment. The model can be modified to include both forms of transmission.

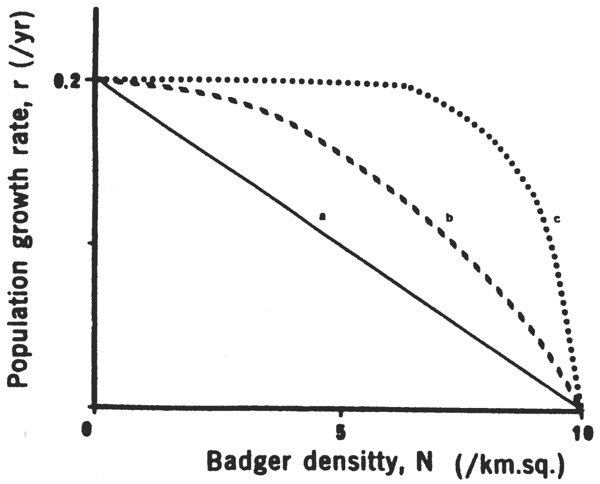

Fig. 2 Population growth curves
(a) logistic (b) mild large mammal type
(c) severe large mammal type density dependence

Typical of certain bacterial diseases, such as tuberculosis, is the existence of carriers - apparently healthy, symptomless individuals who are capable of transmitting the disease (Bailey, 1979). As carriers can play an important role in the endemic maintenance of a disease (Anderson, 1982), the effect of including a carrier class is investigated.

Seasonal rates, notably in birth and disease transmission terms, can also be included in the model.

It is possible to redefine the model so that the number of badgers in each disease class becomes a function of the badger's age. Such a reformulation of the model allows an alternative method of estimating the disease transmission parameter.

Deterministic formulations of disease processes can often provide detailed insights into epidemiological processes in large populations. On a smaller scale, chance effects due to demographic processes (the precise timing of a birth or contact between badgers) often induce patterns different from those predicted by deterministic models. It is possible to translate the above deterministic model into a stochastic formulation and employ Monte Carlo simulation techniques to examine small scale local effects.

THE DYNAMICS OF THE DISEASE IN BADGER POPULATIONS

An analytical consideration of the basic model of badger/bovine tuberculosis interactions shows that the disease will persist in the badger population providing the basic reproductive rate of the infection, R_o, is greater than or equal to unity. R_o is defined as the expected number of secondary cases produced during the lifespan of an infectious badger introduced into a population of K susceptible badgers. For the basic model, R_o is given by:-

$$R_o = \frac{\sigma\beta K}{(b+\sigma)(b+\alpha)} \qquad (6)$$

and from this expression the threshold density of badgers, K_T, for the long term maintenance of the disease is given by:-

$$K_T = \frac{(b+\sigma)(b+\alpha)}{\sigma\beta} \qquad (7)$$

With $R_o > 1$, the disease regulates the badger population to a density N*, where N* < K (K is the disease-free carrying capacity of the habitat). Fig. 3 shows how the disease-induced population depression d, (where d = 1-N*/K) varies with the badger carrying capacity, K, for typical disease and badger parameter values (see Table 3) and two levels of threshold density. For all but poor habitats, with low carrying capacities, the model predicts a fairly high degree of population depression. As yet there is no observed confirmation from field studies of such a predicted decline in badger numbers caused by the disease.

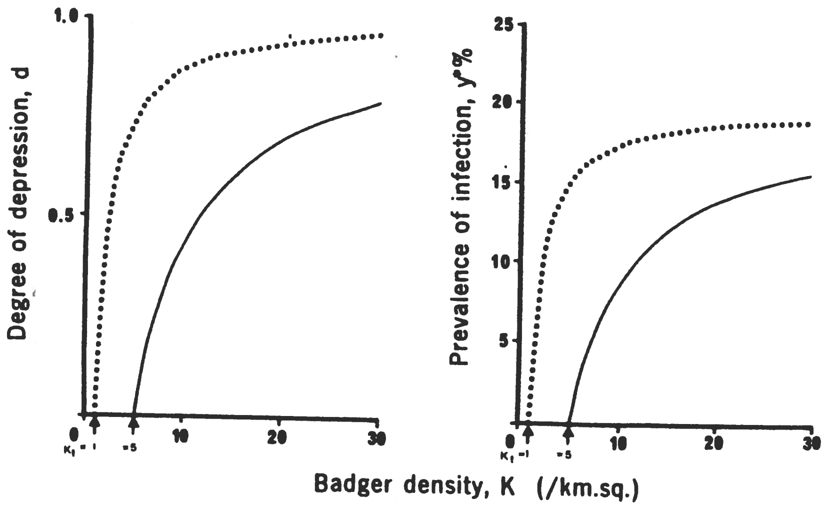

Fig. 3 The degree of disease induced population d, and the prevalence of infection y*, for the basic model

Table 3. Disease parameters used in model

Disease induced mortality rate α	1 yr^{-1}
σ, where $1/\sigma$ = incubation period	4 yr^{-1}
Threshold density K_T	1 and 5 km^{-2}
Disease transmission coefficient	0.308 if K_T = 5 km^{-2} 1.54 if K_T = 1 km^{-2}
Unless otherwise stated, disease free carrying capacity,	K = 10km^{-2}

The model predicts that the disease prevalence increases with carrying capacity, and so provides some support for the conclusions of Zuckermann (1980). Mean prevalence levels in the South West seem to be in the region of 14%, ranging between 8-20%. Figure 3 shows that for medium to high badger population densities, the predicted levels of disease prevalence fit fairly closely with those observed. This close fit provides indirect corroboration for the chosen values of the parameters α and K_T.

Over a wide range of parameter values, simulations using the basic model, give rise to damped oscillations in both badger density and disease prevalence, leading to a stable, diseased controlled equilibrium (see Fig. 4). The periodicity of the oscillations is of the order of 18 years for the typical parameter values used.

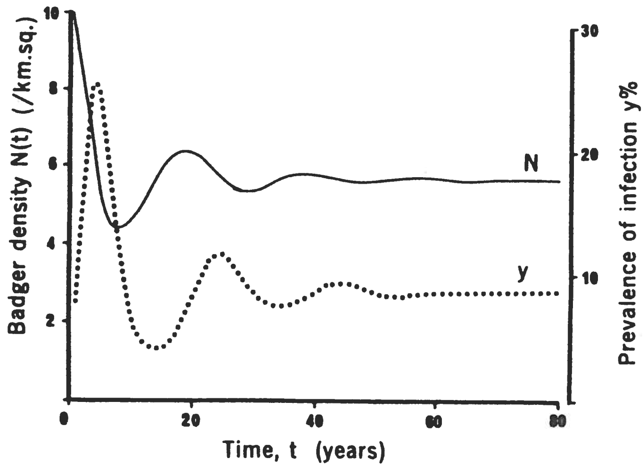

Fig. 4 A numerical solution of the basic model, eq.(1)-(3) Kt=5/km.sq.

The combination of vertical and horizontal transmission lowers the threshold density for maintenance of the disease, and also lowers the equilibrium population density of badgers. With a large component of vertical transmission, the period of the oscillations and the damping time to equilibrium are increased. Transmission from a reservoir of infection on pasture alone,has little effect on the prevalence or equilibrium population density levels. There is, however, an increase in the oscillating period and the damping time. The large mammal type density dependence has little effect on the dynamics given the typical birth and death rates of badgers. Seasonality in either birth rate or transmission terms results in an increase in the damping time of the oscillations.

In both the carrier model and the age structured model, the degree of population depression appears to be less than that predicted by the basic model; this would seem to approximate more closely current beliefs concerning the impact of bovine tuberculosis on badgers.

Use of the stochastic model suggests some component of movement of diseased individuals between communities is necessary to prevent disease extinction in large areas, or 'stochastic fade out' of the disease in local patches.

DISCUSSION

The basic model may provide a reasonable reflection of certain aspects of the dynamics of badger/bovine tuberculosis interactions, notably the relationship between disease prevalence and badger density. The modifications introducing carrier individuals and a non-linear form of density dependent regulation of badger populations are the most justified. The introduction of an age structured diseased population seems to overcome one problem of the basic model, notably the considerable degree of disease-induced population depression which is predicted by the basic model, but not observed. Further information on disease parameters - notably the disease induced mortality rate, average disease prevalence, and the threshold density, would increase the accuracy of the model's predictions. Field work such as that now carried out and described by Cheeseman et al. (1982b) namely monitoring the disease in live badger populations, removal experiments where the badger densities are previously determined, and controlling badgers by trapping, as is now the policy, will all help to provide such information.

Any long term badger control policy needs to be based on a detailed understanding of the ecology and dynamics of badger populations. With such information, and employing a model framework, it should be possible to predict the level of effort needed to maintain a badger population below the threshold for disease persistence. Preliminary investigations suggest that in good badger habitat a high level of effort might be needed. However, more research is required to understand how badger populations are naturally regulated, and how quickly they are capable of recolonising areas following removal.

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A PREDICTION SYSTEM FOR THE LIFE-CYCLE OF THE SHEEP TICK, *IXODES RICINUS L*

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Sheep and cattle in many upland regions of Europe are susceptible to outbreaks of babesiosis, louping-ill, tick-borne fever and tick pyaemia, all of which are transmitted by the sheep tick *Ixodes ricinus L*. This parasite has a life-cycle of three distinct, morphological stages: larva, nymph and adult. Each stage undergoes a phase of activity within the matt vegetation, an attachment phase when the tick attaches to a host to extract a blood meal and a development phase in which stage to stage development takes place. In the adult stage, the latter consists of a pre-oviposition phase and an oviposition phase when eggs, which later develop into larvae, are deposited on pasture by adult female ticks. Development takes place in the vegetation according to the prevailing microclimatic conditions with the entire life-cycle taking up to six years to complete depending on conditions.

Recently, much work has been carried out with a view to improving the understanding of the dynamics of the tick life-cycle (Gray, 1980, 1981, 1982, Gray et al, 1978, Gardiner et al, 1981, Gardiner and Gettinby, in press). Gardiner et al (1981) reported on a procedure for predicting tick development in terms of the prevailing field temperature conditions and the rate of change of development with temperature. The predicted results were found to agree, in the main, with those observed in the field. In a later paper, Gardiner and Gettinby (in press) incorporated this procedure, together with information on activity, attachment and oviposition, into an overall model of the tick life-cycle in order to predict the level and timing of tick activity throughout the year.

In this paper, a brief outline of the components of this model will be given. The model will then be examined in an endemic tick area of Ireland and will incorporate the following changes to some of the components, as suggested by Gray (priv comm):

(i) Delay from early July to early August the onset of the "diapause" phenomenon which prevents development occurring in autumn fed ticks and their progeny until spring of the following year. This delay will enable July engorged ticks and their progeny to develop normally over the autumn and winter periods.

(ii) Vary the likelihood of each tick stage attaching to available hosts. Assume this to be high for adults, less so for nymphae and least for larvae.

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(iii) Assume all autumn adult activity takes place on 31st August each year. This date tends to coincide with the autumn peak of adult activity in Ireland.

The model was computed using meteorological data from Co Wicklow, Ireland. The results will be compared with the findings of Gray et al (1978) from the same area of Ireland.

MODEL COMPONENTS

To describe the tick life-cycle, it is necessary to take into account the rates of development, mortality and fecundity associated with each tick stage. To quantify these factors requires the existence of relevant experimental data from which appropriate estimates can be obtained. In addition, it is also necessary to have knowledge of the complete dynamics of the tick life-cycle. Models to describe these factors, based on existing experimental findings, are outlined below and are combined into an overall model of the tick life-cycle.

Development

With the aid of the experimental data of Campbell (1948), it was possible to determine the relationship between temperature, T, and development time, D(T), for each of the development phases of the cycle. More details of these relationships and the methods behind predicting development time can be found in Gardiner et al (1981). The form of relationship depends on the timing of tick engorgement with spring fed ticks being understood to be those fed between March and June and autumn fed referring to ticks feeding between July and October. Examples of the relationships obtained include

$$D(T) = \frac{a}{T^b} \tag{1}$$

for pre-oviposition in spring fed adult females and

$$D(T) = \exp\left(\frac{1}{a+bT}\right) \tag{2}$$

for eggs deposited by July fed females. The constants a and b are determined from experimental data.

Development prediction must take into account the between day and within day temperature variations. This can be done by calculating the amount of development on day i as

$$\int_{t_1}^{t_2} \frac{1}{D(T_i)}\,dt \tag{3}$$

where the daily temperature, T_i, can be described by a sinusoidal function of the time of day, t. The terms t_1 and t_2 refer to those times during the day when temperature passes through the threshold temperature below which no tick development takes place. Development is predicted complete whenever the sum of the daily amounts of development first exceeds one.

Those ticks which undergo diapause have been assumed to re-commence development on 1st March of the following year. This development will take place according to a lower threshold temperature since exposure to low temperatures during winter can condition the tick to develop at lower temperatures than would be the case for non-diapausing ticks (Campbell, 1948).

Activity and Engorgement

On completion of each development phase, the newly developed ticks undergo a period of acclimatisation before commencing activity within the matt vegetation. According to data obtained by Lees and Milne (1951), the rate at which ticks in each stage of the cycle become active varies according to their month of emergence. For example, August emergent adults can be estimated to be potentially active in the subsequent months September, October and March with probability 0.06, 0.44 and 0.19 respectively. Similar figures can be determined for other months of adult emergence and also for larval and nymphal emergence.

Each monthly period of potential activity has been split into four separate active and inactive phases, as suggested by the experimental findings of Lees and Milne (1951). Unlike Gardiner and Gettinby (in press), each activity phase is now assumed to be of three days duration with the inactive phases varying from four to five days. During each day of activity, a tick is assumed to be able to contact and attach to a host only if daily temperature exceeds an activity threshold of 7°C (MacLeod, 1936). The proportion of each tick stage to attach successfully to a host has been assumed to vary according to stage with larvae lowest at 50%, nymphae at 65% and adults at 80%. Once attached, engorgement may take place with larvae, nymphae and adult females assumed to feed for three, five and eight days respectively (MacLeod 1932).

Egg Output

The pattern of daily egg output during the oviposition phase of adult female *I ricinus* can be described, for each day, r, by the skewed gamma curve

$$N(r) = \frac{T.\int_{r-1}^{r} t^{\alpha-1} e^{-t/\beta} dt}{\int_{0}^{D} t^{\alpha-1} e^{-t/\beta} dt} \qquad (4)$$

where T is the total egg output and α and β are parameters which depend on the time of peak egg output and the predicted duration of oviposition, D. This expression allows for output to peak early and decline gradually until complete, as appears to be the case in most ixodid ticks. Total egg output has been assumed to be 2000 for spring fed females and 1000 for autumn fed females. These are approximate average outputs for I ricinus females in the field (Gray, 1981).

Survival

The survival rate of sheep ticks varies according to time of year and the appropriate phase of the life-cycle. Using data from Gray (unpublished observations), Daniel et al (1976) and Lees and Milne (1951), it has been possible to estimate the survival rates of those phases subject to some form of tick mortality. For example, the rate of survival of larvae emerging in September and October and overwintering in the unfed state can be estimated at 0.75 and 0.85 respectively (Daniel et al, 1976).

Meteorological Observations

By comparing predicted and observed development times, Gardiner et al (1981) suggested that soil maximum and minimum temperatures may be the most appropriate temperature base for tick prediction work. Thus, to run the development component of the life-cycle prediction system, it would be necessary to have daily soil maximum and minimum temperatures. Such temperatures are not generally part of meteorological data but can be determined from recorded screen temperatures using harmonic analysis (Bocock et al, 1977). Using data from Rathdrum meteorological station, Co Wicklow, Ireland, for the years 1975 to 1979, this method enabled appropriate soil temperatures to be estimated for use in the tick prediction simulation.

RESULTS

The simulation follows the path taken through the life-cycle by the progeny of 150 adults active on pasture on 31st August 1975. It has been assumed that 50% of adults are female (Campbell, 1948). The results of the predictions are shown in Fig 1 and refer to the cumulative numbers of active larvae, nymphae and adults for each month of the year.

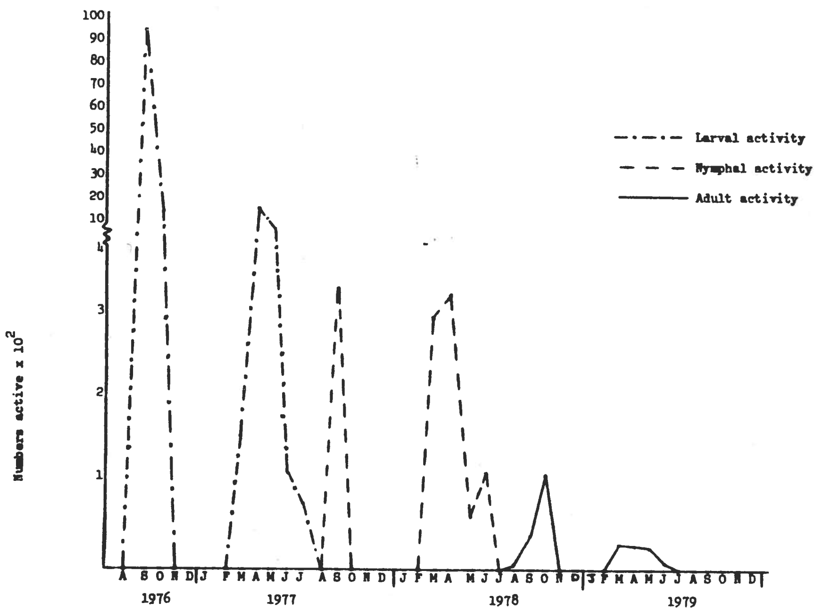

Fig 1: Predicted level and timing of activity of ticks stemming from adults active on 31st August, 1975.

It can be seen that larvae stemming from these autumn fed females first became active in the autumn of the following year with activity continuing until July of 1977. The subsequent nymphae commenced activity a few months later though most nymphal activity was delayed until the spring of 1978 with peak spring activity occurring in April of that year. Adult activity also began in the autumn and continued, after the winter period, until June 1979. Gray et al (1978) also found similar general patterns of tick activity though the timing of peak activity was different from that suggested by the predicted results.

The results also indicate that autumn active females can have a life-cycle duration of from three to four years. Of the 50,000 eggs deposited by the 50 autumn fed females, only 26.43%, 2.19% and 0.48% reached the respective activity phases of the larval, nymphal and adult stages of the life-cycle. In addition, when the activity component of the model was applied to the potential numbers of active adults in each month, it was found that only 238 adults would reach the active adult phase. As the simulation only began with 150 adults, this result suggests that tick numbers may remain relatively stable over the duration of the cycle, as is likely to occur in nature.

DISCUSSION

The results that have been obtained suggest that larval and adult activity are generally higher in autumn than in spring with the reverse occurring for nymphal activity. In many areas, this high peak of autumn larval activity may not occur as many of the newly emerged larvae, though capable of activity, appear to delay the onset of activity until the following spring period (Gray, priv comm). This delay is known as "behavioural diapause" and may also influence the nymphal and adult stages.

It can also be concluded that as the tick cycle progresses there can be some interchange between the spring and autumn tick populations in that spring engorged ticks give rise to autumn engorged ticks of the next stage. Change from autumn to spring population is only likely to occur in larvae fed during the month of July as these larvae develop without entering diapause unlike those ticks feeding in August, September and October which generally enter diapause, delaying development until the following spring. These conclusions agree with those of Donnelly (1978) and Gray (1982) on the probable paths ticks must follow to complete the life-cycle but are not in agreement with the distinct separation of spring and autumn populations put forward by Campbell (1948).

One major problem regarding tick simulation work is the difficulty in obtaining appropriate data on tick attachment, feeding, survival, etc, on which to base parameter estimation. Host attachment, for instance, is very much host dependent and, therefore, difficult to quantify. Survival also is liable to depend on locality and type of vegetation of the tick habitat. It is therefore difficult to determine these parameters accurately for as complex a life-cycle as that of the sheep tick though as the simulation results indicate, tick numbers varied little over the duration of the cycle. This suggests that the estimates used within the simulation are acceptable. Changes to these parameters would only influence the number of ticks reaching the respective activity phases and not the timing of occurrence of these phases.

As the model stands, it is a reasonable description of a relatively complex parasitic system. Certain additional alterations, however, could be made to the components of the prediction system to further enhance the results that would be obtained. These include

(1) Lowering the development threshold temperature from 7°C to 5°C for those non-diapausing ticks which are undergoing development throughout the winter period. It could be assumed this change comes into operation at the beginning of March.

(2) Assume that prolonged exposure of diapausing ticks to temperatures exceeding 21°C will result in the elimination of diapause and the commencement of normal development.

(3) Amend the likelihood of activity in autumn emergent ticks to account for the possibility of behavioural diapause delaying the onset of activity till the following spring.

Each of these changes will have some effect on the prediction of the timing of tick activity. The first two will affect the rate of development while the latter will influence the level of tick activity in both spring and autumn. Incorporation of these and other changes to the components of the prediction system may help to identify those characteristics of the cycle of particular importance in certain localities. In this way, it may be possible to arrive at a localised tick prediction system for application in tick endemic areas.

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COMPANION ANIMAL EPIDEMIOLOGY

TRENDS IN PET POPULATIONS

R.S. ANDERSON*

Accurate statistics on companion animal populations are difficult to obtain and thus the incidence of any or all diseases affecting this population is even more difficult to establish. In the few attempts which have been made in this country to quantify the incidence of small animal disease, the results are usually related to a sample of all animals presented at veterinary clinics (Mason, 1970; Evans, Lane and Hardy, 1974), although a few (Fennell, 1975; Walker and others, 1977) have related sample surveys to the total population, using various assumptions. A fuller review of the problems implicit in estimating disease incidence based on retrospective case studies and a method of calculating risk factors is given by Willeberg (1977).

The present paper deals with some aspects of the pet population in the U.K. and elsewhere and is based on the most reliable sources presently available, although the methodology and reliability of the estimates are not necessarily comparable between countries.

Most of the countries in Western Europe are represented in Table 1 which shows that the U.K. has the largest dog and cat population after France. There are at least 28 million dogs and 25 million cats in the European countries shown - data from countries such as Luxembourg, Greece and Spain are not available. The United States, however, with about 78 million dogs and cats exceeds the total population of Western Europe. In the countries of the European Community about 50% of all households owns a pet of some kind and 33% owns at least one dog or one cat.

The ratio of dog (or cat) to human populations shows a remarkable variation from one country to another, ranging from 4 dogs per 100 people in Japan to 20 dogs per 100 people in the United States. There are many cultural and other factors which may contribute to such major differences in pet ownership between countries such as Japan and the United States, but it is more difficult to account for the substantial differences which also exist between neighbouring countries of comparable standards of living and culture (e.g. W. Germany, 5.5, and France, 17.2 dogs per 100 people).

In theory, these populations have a considerable potential for rapid change in numbers. Since about 13% of dogs in a sample of the U.K. population are under 1 year old, and have, therefore, entered the population in the last 12 months, then, in a stable population, 13% must also be removed from the population during the same period. If none of the dogs which were removed from the population in one year were replaced, then the total population would decrease by 13% in the 12 month period. Obviously this is unlikely and in fact dog and cat populations are remarkably stable year on year (Table 2) and seem to be stabilised at a characteristic (if markedly different) level for each country. The dog population in the U.K. increased from about 5.45 million in 1975 to 5.54 million in 1979, an increase of about 1.6% whereas the cat population increased from about 4.71 million to 4.90 million (+ 4%) during the same period.

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Table 1. Dog and cat population (millions) and relationship to human population (animals/100 people)

Country	Dog	Cat	Ratio/100 people of Dogs	Ratio/100 people of Cats
European				
1. Austria	0.499	1.005	6.0	13.3
2. Belgium	1.150	1.016	11.8	8.3
3. Denmark	0.680	0.850	13.3	16.6
4. Finland	0.415	0.435	8.7	9.1
5. France	9.192	6.662	17.2	12.5
6. Germany	3.370	3.190	5.5	5.2
7. Italy	4.390	4.535	8.0	8.3
8. Netherlands	1.260	1.396	9.1	10.0
9. Norway	0.280	0.405	6.8	9.9
10. Sweden	0.800	0.795	9.6	9.6
11. Switzerland	0.335	0.565	5.3	9.0
12. Great Britain	5.823	5.157	10.4	9.3
Subtotal	28.194	26.011		
Non-European				
13. Australia	2.339	2.033	16.1	13.9
14. Canada	4.085	4.870	16.9	20.0
15. Japan	4.470	2.320	3.9	2.0
16. United States	44.363	34.256	20.0	15.4
Subtotal	55.257	43.479		
Grand total	83.336	69.290		

Table 2. Estimated number of pets owned in Great Britain

	1975	1977	1979
Dogs	5,455,000	5,482,000	5,542,000
Cats	4,714,000	4,793,000	4,897,000

Table 3. Distribution of dog and cat population by TV region

TV region	Cat Number owned '000	Cat % of total population	Dogs Number owned '000	Dogs % of total population
London	1672	33	1175	22
Midlands	988	20	1082	20
Tyne Tees	141	3	318	6
Yorkshire	538	11	759	14
Lancashire	548	11	826	15
South	688	14	590	11
Scotland	322	6	473	9
Anglia	510	10	499	9
Wales/West	709	14	733	14
	5015	100	5340	100

Table 4. Ratio of dogs to cats in the North and South of Great Britain

		Dogs : Cats
North	Scotland	1.5 : 1
	Yorkshire	1.4 : 1
	Lancashire	1.5 : 1
South	London	0.7 : 1
	South	0.9 : 1

Table 5. Percentage of households owning a dog or cat in relation to age of housewife

	Age of housewife			
	18-34	35-44	45-64	65+
Dog ownership %	23	32	27	11
Cat ownership %	20	23	27	18

Table 6. Percentage of households owning a dog or cat in relation to presence of children

	Presence and age of children in years			
	0-5	0-5 and 6-15	6-15	None
Dog ownership %	18	29	36	19
Cat ownership %	21	21	30	14

Table 7. Percentage of households owning a dog or cat in relation to type of dwelling

	Type of dwelling				
	Detached	Bungalow	Semi-detached	Terraced	Flat
Dog ownership %	31	18	25	25	10
Cat ownership %	25	13	18	19	12

Table 8. Percentage of householders owning a dog or cat in relation to social class

	Social class			
	AB	C1	C2	DE
Dog ownership %	23	22	26	20
Cat ownership %	24	21	20	13

The number of households with multiple pets also remains fairly stable with 13% of dog owning households owning two or more dogs and 23% of cat owning households owning two or more cats. About 3% of all households owns a dog and a cat, or in other words, about 7% of households classed as dog or cat owners owns both a dog and a cat.

There are several interesting differences between regions in their propensity to own a dog or a cat (Table 3). Although 26% of all households are in the London TV area, 33% of the total cat population is found in this area, but only 22% of the dog population. Scotland, with 10% of the total households, has only 6% of the cat population and 9% of the dog population. This trend to a higher relative %age of dogs relative to cats in the North compared to the South is shown more clearly in Table 4, dogs outnumbering cats in the three TV areas of the North of England and Scotland, with the ratios reversed in London and the South.

Dog and cat ownership levels relate to various demographic factors such as the age of the housewife (Table 5), the presence of children (Table 6), and the type of dwelling (Table 7), although clearly many of these factors are interactive. While social class is also a factor in pet ownership (Table 7), it seems to be less influential than some of the other demographic factors.

Data such as that described are clearly relevant to the establishment of the disease level in a particular population, but the link between population in a particular area and the disease level is dependent on the relationship between the area surveyed and the area which is drawn upon by the practice or practices which service it, on the proportion of affected animals which are presented to the practice, on the level of participation within the practice and on the percentage of practices prepared to participate.

There is undoubtedly a great deal of information which could contribute substantially to our knowledge of the epidemiology of companion animal disease - and consequently to its prevention. The problem is - how to collect it. I hope some progress will be made in answering this problem in the course of the present meeting.

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[Abstract]

THE EPIDEMIOLOGY OF CANINE PARVOVIRUS INFECTION

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Canine parvovirus (CPV) is a new canine virus which first arose in 1978. Infection was recognised virtually simultaneously in America, Australia and Europe, and this unusual pattern of disease has yet to be satisfactorily explained. CPV causes two distinct syndromes: myocarditis in young pups and enteritis in older pups and adults. The occurrence of myocarditis reflects infection in a totally susceptible population; this syndrome was common in 1978-79, but in 1981-82, as the disease became endemic, it became increasingly rare. Enteritis in 1978-79 was recorded in dogs of all ages; it is now found mainly in pups from six weeks to six months of age, which are exposed to infection as maternally derived passive immunity wanes. The extreme resistance of CPV to physical and chemical agents means that infection is commonly acquired from the environment, particularly in boarding and breeding kennels, and veterinary establishments.

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DILATED PUPIL (KEY-GASKELL) SYNDROME IN CATS

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In February 1982 Key and Gaskell briefly reported an apparently new syndrome in cats characterised by persistent bilateral pupillary dilation, depression, inappetence, dryness of the oral, nasal and conjunctival mucosae, prolapse of the third eyelids, constipation and in some cases, regurgitation. No common features such as previous illness or exposure to toxic agents were apparent and post mortem examination had not helped in suggesting an aetiology. Following the report, cases were seen with increasing frequency and in September, Nash, Griffiths and Sharp (1982(a)) confirmed and expanded the initial clinical observations, recording occasional bladder atony and loss of anal sphincter tone, and reporting histopathological changes in autonomic ganglia from affected cats. These authors reviewed the available information on the new syndrome, now referred to variously as the Dilated Pupil Syndrome, Key-Gaskell Syndrome or Feline Autonomic Polyganglionopathy, later in 1982 (Griffiths, Nash and Sharp) reporting the pathological changes to involve ganglia other than those in the autonomic system. However, the majority of the clinical signs could be associated with involvement of the parasympathetic system, with the overall impression of the pathology said to be that of a primary effect on the neuronal perkaryon probably affecting protein synthesising apparatus. There was still no indication as to the aetiology of the condition and treatment was merely supportive and symptomatic, consisting primarily of fluid therapy, laxatives and parasympathomimetics such as the local, ocular use of physostigmine or pilocarpine. The prognosis was guarded, with some animals showing a slow improvement and return of appetite, while others deteriorated and had to be destroyed. Where,as was the case in the majority of cats, regurgitation was associated with a megoesophagus, the oesophagus seemed rarely to return to normal size, even where regurgitation ceased, and urinary bladder dysfunction carried a poor prognosis.

The failure to identify an aetiology, despite attempts at both the Bristol and Glasgow veterinary schools to isolate causal organisms or toxins, and the fairly clear-cut nature of the clinical syndrome made the disease an obvious candidate for epidemiological study. Similar types of information were obtained prospectively by groups at the Bristol, Liverpool and Glasgow schools based on questionnaires applied to cases seen both at the schools and in general practice. It was apparent by this time that the syndrome was being seen throughout the United Kingdom, and following a suggestion in December 1982 that it might be associated with the use of treatment for flea infestation (Bedford, 1982), some initial epidemio-

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logical results were presented (Nash, Griffiths and Sharp, 1982(b); Gaskell and Rochlity, 1982).

Of the 140 cases in the Bristol/Liverpool series, no sex predisposition was found (72 [52%] females and 67 [48%] males) and cats of all ages were affected (range 10 weeks to 10 years). The distribution of cases between urban (29cases:21%), suburban (56 cases; 40%) and rural (53 cases: 39%) was difficult to assess in the absence of a control population but did not suggest an overriding influence for this factor. The results with respect to the use of treatment for fleas were similar in the two series; in the Glasgow series 58% of 86 cats, and the Bristol/Liverpool series 61% of 124 cats, had been so treated, with a roughly equal distribution within these figures for the use of the three main anti-flea preperations (51 cats with spray, 40 with powder and 40 with a collar). Again. while no data were available from a control, ie. unaffected population, it would seem that while treatment for fleas was common, it was not a feature of all cases, much less the use of a single product or method of flea control.

In keeping with the failure to isolate a causal organism, particularly viral, from samples or tissues from affected cases, the epidemiology of the condition did not suggest an infectious agent. In only three instances (in 140) in the Bristol/Liverpool series were more than one cat affected in the same household, despite the presence of other cats in 77 (66%) cases.

Other questions on diet, exposure to household substances and toxins, and other treatments in the recent past, failed to identify a consistent factor in these cases. Similarly, epidemiology has not identified any factors influencing survival which seems to depend more upon the diligence and nursing ability of the owner than on any other factor of the case. It is of interest that while now well recognised in the United Kingdom, no cases have been reported from other countries, though the condition has been recognised in the Channel Islands

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THE PRESENT AND FUTURE CONDITION OF COMPANION ANIMAL EPIDEMIOLOGY IN THE UNITED KINGDOM

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'Companion animals' are defined in this paper as dogs, cats, the smaller domestic pets, and horses. Equine disease problems have more in common with companion animal conditions than with diseases in farm animals in terms of diagnosis and approach to control; diseases in farm animals frequently being presented as herd incidents with economic implications. The role of epidemiology in companion animal medicine is also more akin to its application in human medicine than to its aims in farm animal practice. The large animal practitioner now is concerned with disease manifested by poor herd performance and productivity (Morris, 1982), whereas the small animal practitioner still is involved with disease in the individual. It is now apparent that many diseases have either poorly understood or complex causes - for example, the 'Key-Gaskell' Syndrome - which may be elucidated by epidemiological investigation. New and enigmatic outbreaks of infectious disease - for example, canine parvovirus infection - similarly may benefit from epidemiological study.

OBJECTIVES AND PREVIOUS STUDIES

Epidemiological objectives include an increase in the understanding of the natural history of diseases. This involves investigation of disease dynamics and distribution, and the detection of causal associations. An essential component of such work is morbidity recording.

Morbidity recording

The recording of morbidity rates in defined segments of animal populations is an integral part of case-control and cohort surveys. Morbidity data also indicate the extent of a problem and therefore guide preventive strategies and research priorities. With that role, they are only of value if they result in action; too often morbidity data have been collected redundantly for their own sake. Serial morbidity figures can be used to indicate the degree of effectiveness of preventive and therapeutic procedures, for example in intervention studies and drug trials.

The veterinary companion animal literature contains many reports of disease in more than a single animal. The distinction between a large collection of

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clinical reports and a small epidemiological survey may be unclear. The best criterion for this distinction is probably the prime aim of the work: if it is to collect data from a population and to make inferences from those data, then it is an epidemiological exercise. Parasitological surveys in small animals, notably of endoparasites, have been popular since the beginning of this century (Nuttall & Strickland, 1908) with a flurry in the 1970's. Most of these were restricted either to specific areas such as London (Oldham, 1965; Turner & Pegg, 1977; Nichol et al., 1981; Nichol, 1982), Liverpool (Niak, 1972) and Oldham (Holt, 1976), or to specific cohorts such as greyhounds (Jacobs & Prole, 1976), puppies (Holt, op. cit.) and show dogs (Jacobs & Pegg, 1976). Occasionally animals have been divided into cohorts according to age (Jacobs & Pegg, op. cit. ; Jacobs & Prole, op. cit.; Turner & Pegg, op. cit.), sex (Jacobs & Prole, op. cit.) and to whether anthelmintics had been administered (Holt, op. cit.). Temporal trends and dynamics also have been investigated (Jacobs, 1976; Walker & Jacobs, 1981 and 1982). In most cases, with some exceptions (e.g. Hutchison, 1957), the value of the results is limited by small sample sizes. Sometimes pets were not represented in relevant surveys (e.g. Cook, 1965). Endoparasite surveys have also been undertaken in horses (e.g. Dixon et al., 1973; Thompson & Smyth, 1975).

The impetus for these studies frequently was given by reports of the zoonotic significance of the parasites concerned: Oldham (1965) in response to the first report of human retinal larval granulomatosis in Great Britain due to Toxocara (Ashton, 1960) and the survey undertaken by the East Anglian Region of the British Small Animal Veterinary Association [BSAVA] (Else et al., 1977) in response to descriptions of the significance of human toxocariasis (Bisseru, 1968; Woodruff, 1970).

Ectoparasite prevalence in pets has been investigated in part of London (Beresford-Jones, 1981) and on a limited national scale (Geary, 1977), but the results of the latter survey have not been analysed fully.

There has been no attempt to assess the morbidity of a wide range of small animal diseases nationally, although individual practices have recorded broad categories of disease occurrence and of control strategies (Evans et al., 1974). Recently, an attempt has been made to identify major problems in horses, using a questionnaire (Report, 1981). Wastage in the thoroughbred from conception to four years of age also has been assessed (Jeffcott et al., 1982).

Detection of causal association

The last 20 years has seen the emergence of the concept of the multifactorial nature of many diseases (Schwabe, 1982), the various factors forming a 'web of causation' (Schwabe et al., 1977). This has stimulated the development of survey and analytical techniques which allow quantification of the effects of causal variables (Willeberg, 1980). These methods have been used widely in North America to assess risk factors, for example, those associated with canine elbow disease (Hayes et al.,1979) and bladder cancer (Hayes, 1976). This work has been facilitated by a large data base, the Veterinary Medical Data Program (Priester, 1975), which has enabled morbidity rates and risk factors to be measured for many diseases - especially tumours (Priester & McKay, 1980).

Causal studies similar to the American ones have been undertaken rarely in this country, due, in part, to the absence of a suitable data base, and due, in part, to a lack of awareness of the epidemiological techniques which are available.

The best-known national causal survey concerned feline urolithiasis. The BSAVA formed a working party in 1972 to investigate the problem following allegations that dry cat food was responsible for an increased incidence of the syndrome, and their report was published (Barker & Povey, 1973). It recommended further studies and so a larger investigation was undertaken under the auspices of a BSAVA/Pet Food Manufacturers' Association working party. The findings were tendentiously redacted (Report, 1977; Walker et al., 1977) and resulted in correspondence, sometimes acrimonious, relating to the survey's design and conclusions (Bennett, 1977; Jackson, 1977). Other research (Willeberg, 1977) has strengthened the working party's findings: that the syndrome has a multifactorial aetiology and that a high level of dry cat food (or low level of water) intake is a causally associated determinant.

Many diseases would benefit from similar investigations; dermal, aural and dental syndromes being obvious candidates.

Investigation of disease dynamics

A thorough understanding of the dynamics of diseases has considerable predictive value. Modelling is becoming an important part of large animal epidemiological research, evidenced by other papers presented at this conference.

The topic has received little attention in the companion animal field. In Sweden, where regional demographic data are available, threshold densities for natural canine parvovirus epidemics have been investigated (Wierup, 1983). Similar studies in this country are hampered by a paucity of readily available demographic data [vide infra].

REQUIREMENTS AND ASSOCIATED PROBLEMS

Demographic data

Accurate demographic data are required to provide the denominator in incidence and prevalence rate estimations. They may also assist research into human diseases. Orkney, with a well-defined and accessible dog population, is being used as the site for a long term investigation of an alleged association between canine distemper and multiple sclerosis (Beaton, 1983).

Several demographic small animal surveys have been undertaken in parts of the United States (Dorn et al., 1967; Schneider & Vaida, 1975; Franti et al., 1980). Some information is available in this country (Anderson, 1983) but more is required. There are undetectable segments of small animal populations, such as strays and semi-domesticated animals, which complicate accurate estimations.

Horses pose an even greater problem. Some thoroughbred populations, concentrated in the major racing areas, are easily enumerated, and provide useful populations for epidemiological investigations; but in other regions, they are difficult to estimate. Thoroughbred horses in training are recorded annually, but comprise a small and variable age cohort. The stud books provide information on stallions and on mares and foals through the return of mares, but these are frequently incomplete and out-of-date. Even less information is available on non-thoroughbreds. Some societies are now beginning to blood-type animals and this may be a source of demographic data in the future.

Reliable data on disease and determinants

Data are collected routinely by veterinary practices, clinics and veterinary schools, but they exist as isolated 'pockets' of information. The collation of data from these sources is currently a difficult, time-consuming and costly task, and therefore is not routinely justifiable. There is not a large co-operative data base like the American Veterinary Medical Data Program which can be tapped.

The VIDA II veterinary investigation centre returns and abattoir records provide regular information on disease in farm animals, but similar schemes are not available for reporting companion animal diseases. Information on notifiable equine diseases is recorded routinely and there are attempts to disseminate reports of other equine diseases nationally and internationally. Occasionally, some laboratory summaries are published, for example, of equine infectious diseases (Report, 1983).

Expertise

Epidemiology is a relatively new subject, and is taught to a varying extent in the British veterinary schools (Thrusfield, 1978). It still has to be accepted fully, not only by students but also by colleagues (Blackmore & Harris, 1980). The Swann report on the veterinary profession (Report, 1975) recommended that there be an increase in the teaching of epidemiology and preventive medicine in the veterinary schools, but this suggestion has not been heeded as enthusiastically as was hoped.

All veterinary graduates need at least a basic training in epidemiological goals and techniques so that they can appreciate the value of the subject. The skills currently reside in too small a number of people.

Co-operation

Co-operation in epidemiological investigations is sometimes poor. The East Anglian BSAVA division parasite survey mentioned above had a 92% non-response rate. Non-co-operation is due not only to a lack of appreciation of objectives, but also to prejudice. Recently, at Edinburgh, we were considering a project on a syndrome which occurred in a certain breed of dog. When we contacted the relevant breed society, its representative agreed to co-operate on the condition that our results did not disadvantage its breed; the society was worried lest our findings stigmatised the breed. This sort of attitude is based upon ignorance. Epidemiological investigations should lead to beneficial preventive strategies, not to static morbidity figures. Nevertheless, owners' financial fears, though somtimes based upon fallacies, are real.

A further cause of lack of operation is the length of time over which surveys may be conducted. Investigations which yield quick, direct results are more likely to be supported than protracted studies; epidemiological studies can take a relatively long time.

Funding

There is no organisation analogous to the Agricultural Research Council which can fund extensively national research on companion animal diseases.

Financial support is obtained from a variety of sources. Funds for pet research are available from the Royal College of Veterinary Surgeons' trust funds and other charities and welfare societies. The Clinical Studies Trust

Fund of the BSAVA is designed to sponsor companion animal research. The Animal Health Trust supports small animal and thoroughbred research, and the Horserace Betting Levy Board can award grants for research in non-thoroughbreds too.

Pharmaceutical companies often finance intervention studies and drug trials so that their products can be objectively evaluated [there is no evidence of subconscious bias due to financial inducements in veterinary research, though this has been reported as an emerging problem in human medicine (Mangold, 1983)]. However, it may be commercially imprudent to support epidemiological research which ultimately may reduce the market of therapeutic drugs.

All of these sources are small compared with those which finance farm animal research. They are also more likely to allocate money to projects of defined fixed periods than to continuous monitoring programmes.

PROSPECTS FOR THE FUTURE

Very rapid developments in computer technology have occurred during the last ten years. Small, inexpensive microcomputers, with powerful data handling and analytical potential, are available to all veterinary organisations, including general practices. Computerised data base management systems which allow powerful and flexible querying of data have been applied to veterinary clinical case recording (Burridge & McCarthy, 1979; Thrusfield & Hinxman, 1981). Advances in computer and communications technology now enable structured data to be transported readily from one location to another, allowing data to be shared and collectively analysed (Thrusfield, 1982 & 1983). This approach has already produced results: the linking of computerised demographic and disease data from different sources has assisted in the discovery of vertically transmitted contagious equine metritis (Powell, 1982).

The value of pooled data is widely appreciated. For example, a computerised data base, comprising details of equine colic cases in the United States, has been proposed recently to assist epidemiological investigations and prevention of the condition (Sumner-Smith, 1983). In addition to supplying large amounts of unbiased data, a corporate data base could also act as a relatively inexpensive monitoring system. The development of such a data base, and the problems associated with its inception have been discussed in detail elsewhere (Thrusfield, 1981).

The acceptance of a large integrated data base, which can supply useful epidemiological information, depends upon more than the availability of sophisticated computer technology. There must be a general appreciation of the value of such a system, and this will only occur if epidemiology is 'sold' widely as a valuable commodity. This is a long-term goal, which can be achieved only if the veterinary schools promote the teaching of epidemiology.

In the near future, epidemiological investigations probably will follow the same line as their predecessors. They will investigate diseases which demand solutions, either because they present severe syndromes, clustered in time, or because they are of sufficient interest to arouse curiosity and to warrant financial support. Many chronic and insidious diseases of relatively high morbidity may be neglected, although, eventually, they will have to be tackled. This will require careful survey design and analysis.

Considerable developments in statistical method have occurred, allowing investigation of complex interactions in observational situations. Many techniques, which have been published fragmentarily, are now concisely described in texts - for example, case-control surveys (Breslow & Day, 1980; Schlesselman, 1982). The application of these methods, however, will require a multidisciplinary approach, involving clinicians, epidemiologists, statisticians and mathematicians. The membership of this Society shows that this approach is possible.

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OPEN SESSION

LEPTOSPIRA HARDJO MASTITIS AND ABORTION IN SECOND-CALF DAIRY COWS: A PROSPECTIVE COHORT STUDY

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Leptospira interrogans serovar *hardjo* is well recognised as a cause of bovine mastitis, abortion and premature calving but little information is available on the epidemiology of the disease in infected herds. Serological investigations have shown that clinical mastitis may occur in 4 to 50 percent of dairy cows in a six to eight week period following introduction of the organism into a susceptible herd, and a variable number of abortions may also occur at this time (Sullivan and Callan, 1970; Hoare and Claxton, 1972; Higgins and others, 1980; Pearson and others, 1980).

In light of the high prevalence of infection with *hardjo* in cattle in Great Britain (Ellis and Michna, 1976a; Little and others, 1980) and the increasing number of cases where *hardjo* is implicated as a cause of mastitis and abortion (unpublished data), a prospective study was initiated to investigate epidemiological aspects of *hardjo* infection in a dairy herd once the organism had become established. The results for a second calf cohort that are presented has been published in detail (Hathaway and Little, 1983) and are part of a whole herd study which has recently been completed.

MATERIALS AND METHODS

Herd History

During July and August 1980 an outbreak of *hardjo* mastitis, coupled with sporadic abortions, occurred in a closed dairy herd of approximately 85 milking cows in East Sussex. Analysis of serological data suggested that this was the first introduction of *hardjo* to the herd, but the source was unknown. Approximately 15% of cows of all ages developed clinical mastitis over an eight week period and there was a marked loss in milk production. A prospective whole-herd study was begun in September 1980.

The herd is managed as a normal commercial enterprise, with winter housing from November to April. Silage, concentrates and hay are fed during this period. The breeding programme is restricted to artificial insemination and herd replacements are reared on an adjacent property.

Cohort Studies

A group of 13 first-calving heifers that had been reared on separate summer pasture were introduced to the milking herd at the time of entering winter housing in November 1980. Contact at this time was limited to

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Table 2: Seasonal exposure index to Leptospira hardjo in a dairy herd

	November 1980	January 1981	March 1981	June 1981	September 1981	November 1981	January 1982
No. of Leptospiruric Cows	12	4	2	3	5	15	1
No. of cows sampled	47	45	49	51	45	53	48
Exposure index *	0.26	0.09	0.04	0.06	0.11	0.29	0.02

$$* \text{ exposure index} = \frac{\text{no. of leptospiruric cows.}}{\text{no. of cows sampled.}}$$

separate but adjacent pens and occasional sharing of common yarding facilities. Calving dates ranged from the 16th of January to 23rd of February 1981, whereupon the calving heifers entered the milking herd. All members of the cohort and in-contact members of the adult milking herd were kept under serological and bacteriological surveillance until the end of February 1982. Second calving dates ranged from the 6th of January until 23rd of February 1982. Blood and urine samples were taken at approximately two-monthly intervals. Observation for cases of leptospiral mastitis and any abortions was maintained by the cowman throughout the study.

Serology

Sera were tested in the microscopic agglutination test (MAT) against a battery of 18 leptospiral antigens, which represented 16 serogroups (Hathaway and others, 1982).

Bacteriology

Bacteriological surveillance of cohort members and in-contact cows was carried out by urine sampling as many cows as possible at each sampling period. As it was necessary to provide a minimum of disruption to normal farming routine, the collection of naturally voided urine was the only method that could be employed.

Mid-stream urine samples were collected in sterile 20ml plastic containers and cultured for leptospires within one hour as described by Hathaway and Little, 1983.

Milk samples from a cow that developed symptoms of acute leptospiral mastitis (Sullivan and Callan, 1970; Higgins and others, 1980) on the previous day were collected aseptically from each quarter and immediately cultured.

The method for homogenation and culture of kidney, liver and lung tissue from aborted foetuses has also been previously described (Hathaway and others, 1981; Hathaway and others, 1982). Aqueous humour and blood from foetuses were cultured in the same manner as milk samples, and heart blood was tested for anti-leptospiral agglutinins using the MAT.

A 35 day premature calf was purchased and slaughtered one week after birth. Kidneys, liver, lung and aqueous humour were immediately cultured for leptospires using the same method described for foetuses.

RESULTS

Serological surveillance of cohort members gave negative results from January 1981 to September 1981 when four of the 13 susceptible cows sero-converted to *hardjo* (Table 1) and the titres ranged from 1:400 to 1:1600. A total of eight urine samples from three animals that seroconverted resulted in isolations of *hardjo* from all three. No isolations were obtained from a total of 17 urine samples from seronegative members of the cohort. Isolates were identified as belonging to the Hebdomadis serogroup and typed by factor analysis as serovar *hardjo*.

Table 1: Cohort analysis of Leptospira hardjo infection in second-calf cows in a commercial dairy herd.

COW NUMBER	JANUARY MARCH JUNE		SEPTEMBER		NOVEMBER		JANUARY		CLINICAL HISTORY
	Serology	Urine Culture	Serology	Urine Culture	Serology	Urine Culture	Serology	Urine Culture	
1	0	-	0	-	1:400	+	0	-	Normal calving 17.2.82
2	0	-	1:1600	-	1:400	-	NT	NT	Culled 27.11.81
3	0	-	0	-	1:400	+	0	-	Normal calving 15.1.82
4	0	-	0	-	1:400	+	1:400	+	Abortion 13.11.81
5	0	-	0	-	1:400	+	1:400	-	Normal calving 30.1.82
6	0	-	1:1600	+	1:400	+	0	-	Normal calving 14.2.82
7	0	-	1:400	+	1:100	+	1:100	-	Mastitis 3.9.81 Normal calving 23.2.82
8	0	-	1:400	+	1:400	+	1:400	-	Return to service 16.11.82
9	0	-	0	-	1:400	+	1:100	-	Normal calving 12.2.82
10	0	-	0	-	1:400	+	1:400	-	Abortion 16.11.81
11	0	-	0	-	1:400	NT	0	-	Normal calving 17.1.82
12	0	-	0	-	1:400	+	1:100	-	Normal calving 11.2.82
13	0	-	0	-	0	-	0	-	Premature calving *9.12.81

* Seropositive (1:400) at time of premature calving

NT = not tested

By November 1981, 12 of the 13 cows in the cohort had seroconverted to hardjo, with titres ranging from 1:100 ti 1:400. No titres to other antigens were recorded. Urine sampling revealed a high prevalence of leptospiruria. A total of 39 urine samples from the 12 seropositive cohort members yielded 24 isolates, and ten cows were shown to be shedding leptospires (Table 1).

The last member of the cohort became infected in late November or early December. A titre of 1:400 was found in this cow (Number 13) at the time it delivered a premature calf in December 1981 but this titre was very transient and had disappeared by January. Titres had also fallen to less than 1:100 in four other cows by this time. Titres of 1:100 to 1:400 persisted in other members of the cohort.

The prevalence of leptospiruria in January 1982 was considerably lower than that which occurred in the early stages of infection. Isolates were obtained from only one cow of the 48 cows which were sampled.

Evidence of clinical disease directly attributable to hardjo infection occurred in three of the 13 susceptible cows. 'Mastitis' typical of that caused by hardjo was first observed in cow Number 7 on 3rd September 1981. Leptospiral isolates were cultured from milk from three of the four quarters and were typed by factor analysis as serovar hardjo.

Two cases of abortion in which the foetuses were recovered occurred in November and one cow returned to service (Table 1). Paired sera from the two aborting cows showed stable titres to hardjo of 1:400. They had seroconverted at some time between the 18th of September and 13th to 16th of November, at which time they aborted and the maximum possible time between infection and abortion was eight weeks.

Hardjo was recovered from the kidneys of both foetuses, The only isolate obtained from tissue other than kidneys was isolated from a portion of lung from Foetus 2.

Serum titres in aborted foetuses were 1:5120 and 1:640 respectively. In both calves the lungs were atelectic and the calves appeared to have been born dead. The length of gestation was 204 days and 218 days respectively.

Cow number 8 returned to service on the 16th of November although it had been found to be pregnant at three months of gestation.

A 35 day premature calf was delivered by cow Number 13 on the 9th of December 1981 and a serum titre of 1:400 to hardjo was found. This cow was the only cohort member that had been seronegative at the serial bleeding on the 16th of November, and the titre had dropped to less than 1:100 by January 1982. No isolates were obtained from culture of the calf.

Serial urine sampling of the whole of the milking herd from November 1980 until January 1982 revealed a marked seasonal difference in the prevalence of leptospiruria. High levels of shedding were found in November 1980 four months after the presumed introduction of hardjo to the herd, but the prevalence of leptospiruria detected from January to June 1981 was low (Table 2). A period of peak shedding was again detected in November 1981 but this had fallen to low levels by January 1982. Thus the exposure index for susceptible herd-mates was at a maximum in early winter and at a minimum in late winter and spring.

DISCUSSION

The three most important aspects of this study were: the failure of susceptible animals to become infected for a considerable length of time after exposure to leptospiruric adults, the high prevalence of clinical disease in infected cows, and the confirmation of laboratory diagnostic studies incriminating hardjo as a primary aetiological agent in bovine abortion.

As there are very few reports of prospective epidemiological studies of hardjo infection in cattle (Hellstrom and Blackmore, 1980) information on the factors affecting the prevalence of infection is very limited. Retrospective serological studies have provided evidence that the majority of abortions in which hardjo is suspected as the aetiological agent occur from October to January in the northern hemisphere (Ellis and Michna, 1976b; Little and others 1980). Suggested factors that may influence this marked seasonal distribution are: the high level of moisture in the environment, the winter housing of stock, an increase in urine-drinking by housed cattle, and the fact that winter and spring calvers are passing through the most susceptible stage of gestation at this time (Ellis and Michna, 1976b; Little and others, 1980).

In the present study an endemic focus of infection was maintained in the adult milking cows for at least 18 months, but it is apparent that seasonal factors had a marked influence on the transmission of hardjo to susceptible animals in the second-calving cohort. A high prevalence of leptospiruria was detected in the milking herd in November 1980 but there was no transmission of hardjo to first-calving heifers entering the herd. However, there was limited contact between these cows and the main herd between November 1980 and first calving in January 1981. Despite continuous exposure to leptospiruric animals from January 1981 until September 1981, no infection was transmitted and the reason for this is unexplained.

Transmission to second-calvers was first detected in September while the cows were still on pasture and it is probably that the subsequent propagating epidemic occurred over a short period. Thus housing of cattle was not the trigger factor. The failure of transmission to occur to the majority of fully-exposed second calvers for at least nine months has important implications in dairy herds with endemic infection. If heifers and second-calvers fail to become infected (and naturally immunised) before breeding age is attained, these cohorts are likely to be at risk at the time when they are most susceptible to the clinical effects of *Leptospira hardjo* infection. A serological survey has identified a higher prevalence of hardjo-associated abortions in these cohorts than in adults on some farms in Scotland (Ellis and Michna, 1976b).

Of the 13 second-calvers monitored in this study, clinical disease attributable to hardjo infection was found in three animals (one case of mastitis and two abortions) and it is probably that a further abortion and the premature calving were also attributable to hardjo. The range of clinical symptoms seen in this small group of cows illustrates the importance of the stage of gestation on the expression of disease due to hardjo infection. Coupled with the marked loss in milk production at the time of the first outbreak in July 1980 and the sporadic cases of abortion and mastitis that have subsequently occurred in the remainder of the milking herd (unpublished data), it can be seen that hardjo infection has been an important cause of economic loss on this farm. Milk loss due to sub-clinical infection has also been widely reported (Hoare and Claxton, 1972; Pearson and others, 1980; Higgins and others, 1980) and this is a further possible source of decreased production.

This study is the first prospective field investigation to identify hardjo as a primary cause of bovine abortion. Isolations were achieved primarily in media containing rabbit serum and 5FU to inhibit contaminants and it is possible that rabbit serum may improve isolation rates of fastidious leptospires (Hathaway and others, 1982a). Recent work by Ellis and others (1982a) using specialised media and a dilution technique has resulted in a very high isolation rate of hardjo from aborted bovine foetuses in Northern Ireland. A total of 103 foetuses from herds with a history of undiagnosed abortion were examined and isolates were obtained from 53 (52.5%). When foetal serology and immunofluorescent staining of foetal tissues were included as additional diagnostic tests, evidence of hardjo infection was found in 68.9% of foetuses. When this level of foetal hardjo infection is combined with the evidence from this study that hardjo may act as a primary aetiological agent in bovine abortion, the presence of this pathogen in cattle in Great Britain appears to be a very significant cause of reproductive disease.

The maximum possible time between seroconversion and abortion in this study was eight weeks. Serological studies have indicated that abortion due to hardjo occurs between 6 and 12 weeks after infection of the dam (Hoare and Claxton 1972; Higgins and others, 1980). Experimental infection of a heifer by Ellis and Michna (1977) produced abortion eight weeks after inoculation; by this time the serum titre to hardjo had dropped to 1:100.

The persistence of hardjo titres in individual animals has often been shown to be very variable (Ellis and Michna, 1977; Durfee and Allen, 1980; McIntosh and others, 1981) and similar results were found in this study. It has been suggested that serology is an inadequate method for diagnosing hardjo infection in cattle: Ellis and others (1981) surveyed 200 abattoir cattle for hardjo infection and found that 46.4% of 57 renal carriers had titres of less than 1:100. Ellis and others (1982b) also found that 22.8% of dams aborting infected foetuses were seronegative to hardjo at a serum dilution of 1:10. However, in the present investigation the five cows with clinical disease all had titres of 1:400. Higgins and others (1980) also found all aborting cows to be seropositive. Titres of 1:400 are relatively low for animals in the acute stages of leptospiral infection (Alston and Broom, 1958) but titres of this order are not often exceeded (Gordon, 1979; Higgins and others, 1980). This problem of low titres to the hardjo reference strain (Hardjoprajitno) may possibly be circumvented by the use of local isolates as test antigens (Ellis and others, 1982b).

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EPIDEMIOLOGY OF SALMONELLA AND SHIGELLA INFECTIONS IN IMPORTED LABORATORY PRIMATES (MACACA FASCICULARIS)

G. W. TRIBE*

Cynomolgus monkeys have been obtained from the Far East in large numbers for the past 20 years to satisfy the needs of biomedical research generally and the pharmaceutical industry in particular. They are imported by air freight from enterprises conducted by entrepreneurs who frequently have little understanding of disease control or pathogenesis and who appear to have learnt nothing in this respect during the past two decades. Infection by *Salmonella* and *Shigella* organisms is the norm at time of importation and these bacteria are an important cause of mortality. Fatal illness due to infection accounts for about 10 percent of all imported animals and enteritis is the second most important cause of losses.

Table 1. Post-mortem findings in Macaca fascicularis undergoing post-importation quarantine.

Gross pathological changes	Incidence %
Pneumonia	46
Enteritis	33
Peracute measles	13
Other causes	8

Examination of faecal samples using bacteriological methods provides an indication of the extent of the problem only. This type of investigation is not an exact science for several reasons. First, the methods available for the isolation of *Shigella* organisms are imperfect, there being no specific selective medium available. Second, these bacteria tend to be shed sparingly, even in cases of dysentery or severe diarrhoea and are often overgrown by other organisms such as *Proteus*. Third, it is often necessary to commence therapy as soon as animals arrive at the quarantine station in order to save life and this will clearly prejudice the chances of isolating these organisms. Fourth, it is normal practice to administer polyvalent *Salmonella* antiserum on arrival which inevitably has a bearing on excretion rates. Finally, economic considerations and simple logistics prevent an examination in depth on many occasions. For example, in large-scale outbreaks it is usually only possible to take random samples and to limit these to collection on one day only whereas experience suggests a three day sampling regimen would yield more information.

Nevertheless, a significant number of isolations of both *Salmonella* and *Shigella* organisms have been achieved. Not surprisingly, most isolates were associated with animals manifesting either dysentery or severe diarrhoea.

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Sampling data was drawn from a moving population of 10,000 animals passing through the quarantine unit during a four year period. Batches were imported in groups of 50 and were carefully segregated for the first eight weeks of their stay at the unit.

Table 2. Prevalence of Salmonella and Shigella organisms in Macaca fascicularis undergoing post-importation quarantine

Quarantine period (days)	Health status	No. tested	%age positive Salmonella	Shigella
< 30	Diarrhoea	632	2.7	8.7
> 30	Diarrhoea	328	0.6	3.7
> 30	Normal	1,670	0.2	0.8

Now if these infections were prevalent in feral monkey populations it would be reasonable to expect one of two things. Either Salmonella and Shigella organisms would tend to be relatively harmless to these animals or there would be rather less monkeys living in the wild state. In fact, these infections are not prevalent in wild populations. Carpenter & Cooke (1965) showed this to be so in the case of monkeys and baboons living in Kenya but it was not until 1980 that Japanese workers managed to demonstrate the same thing respecting Cynomolgus monkeys living on the islands of Bali, Java and Sumatra (Matsubayashi & Sajuthi, 1981). This latter study demonstrated quite clearly that monkeys only become infected when they come into contact with human excreta. Monkeys in nature do not, in any event, receive antibiotic therapy and it is clear from a study of antibiotic resistance factors found in isolates of both Salmonella and Shigella organisms what is going on in the Far East respecting the control, or perhaps lack of control, of these bacteria in the human population.

Table 3. Antibiotic sensitivity of Salmonella and Shigella isolates from Macaca fascicularis imported from the Far East

Antibacterial agent	Isolates susceptible (%) Sh. flexneri (58 isolates)	Sh. boydii (18 isolates)	Salmonella Spp. (22 isolates)
Ampicillin	33	83	83
Chloramphenicol	76	89	83
Neomycin	72	83	86
Tetracycline	36	11	50
Sulphonamide + trimethoprim	43	100	68

Sensitivity to and resistance against given antibiotics provides a useful marker for identification in some circumstances. For example, most strains of Shigella imported from the Far East are flexneri 4b but clones peculiar to each area are often readily recognisable from their behaviour on nutrient agar in the presence of antibiotics. This can vary from complete sensitivity to every area of the test disc to the situation in animals obtained from a part of Indonesia where the resident strain of Salmonella typhi-murium is sensitive only to nalidixic acid.

Recent experience has shown that it is perfectly possible to procure disease-free monkeys from the Philippine islands. This was achieved by careful attention to hygiene from the time of trapping until despatch from Manila airport. In particular, careful attention was given to prevention of contamination of feed and water supplies by human excreta, control of flies and rodents and exclusion of ailing animals from the assembly point. In addition, all animals were vaccinated against measles using heterotypic vaccine (Kavak D, Duphar Ltd., Southampton). No cases of Shigella infection were found in batches of 10 and 60 animals processed in this manner and there were no deaths in either batch following importation. Two animals from the batch of 60 were however, harbouring Salmonella typhi-murium. Nevertheless, despite the absence of pathogenic bacteria in the majority of these animals, the effect of contact with humans was manifested by the presence of antibiotic resistance factors in strains of E.coli grown from stools shed by them.

Fig. 1. Arrangement of colonies of monkeys in Bld. 124 at breeding unit found to be infected by Shigella flexneri 4a

B2/B3	c	13
B1	o	8
PC1	r	17
PC2	r	12
1	i	-
2	d	14
16	o	15
	r	

During the establishment of breeding groups of Macaca fascicularis monkeys in the United Kingdom in recent years, considerable attention has been given to excluding Salmonella and Shigella organisms from the stock. This has generally been achieved by testing animals over three days on two separate occasions before regarding them as free from these pathogens. The technique has been successful in the main but there have been notable breakdowns, especially in a large group of 400 animals divided into colonies of 30 individuals. These were confined in large runs with granolithic concrete floors and good drainage but separated only by weldmesh partitions. Shigella flexneri 4a was discovered in a colony in a reception building 14 days post-arrival from the quarantine unit. The organism was sensitive to cephalexin, chloramphenicol, oxytetracycline and nalidixic acid but resistant to all other common antibiotics. This pattern was typical of a strain of Shigella flexneri 4a imported previously from Indonesia and it was concluded that the organism was carried in the colony concerned to the breeding unit although it was not clear how the batch had become infected prior to despatch there. This infection was eradicated by isolation and treatment of infected cases and blanket therapy to all in-contact animals of the group. Unfortunately however, the infection was accidently transferred to an adjacent building containing 13 colonies of monkeys.

Positive isolates were first obtained from B1, a group of weaned offspring. These were treated along with B2/B3 and PC1. Random samples were taken from all colonies following this treatment with negative result but when individual rectal swabs from all animals in 8, 12 and 17 were examined, seven animals were found to be infected. These were isolated and treated while in-contact stock received blanket therapy in the open pens. When colonies 1, 2, 16, 15, 14 and 13 were tested however, negative results were obtained. Serial tests were done on all animals following this regime and all remained negative except for animals in PC1. Subsequent investigation showed this failure was because suckling babies had not been treated and were infected despite that they showed no clinical signs of disease. However, once this reservoir of infection had been eliminated then no further cases were discovered.

Some months later however, two adult animals in PC1 and 3 juveniles in B2/B3 were found to be infected with Salmonella typhi-murium. This organism was completely sensitive to all antibiotics except penicillin. A careful search of laboratory data failed to identify any isolate of this organism with this sensitivity pattern. Moreover, this organism was not recovered from animals in the reception building nor from staff tending them. Because the antibiotic sensitivity pattern was so very different from anything seen hitherto in isolates from monkeys it was concluded that it was unlikely to have originated from the quarantine unit. There were two other possible sources. One was contamination of supplementary diet prepared at corn merchants premises and the other was the presence of mice which had penetrated the building and were nesting in the structure of the ceiling of the sleeping quarters. The only other possibility was that the organism had been transmitted from the quarantine unit some time previously, had not spread significantly and had lost its R-factors. This was, however, considered highly unlikely.

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THE PREVALENCE OF CYSTICERCUS TENUICOLLIS IN SLAUGHTERED SHEEP IN BRITAIN

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Condemnation of meat and offal in selected abattoirs in England and Wales has been studied by the Veterinary Service of the Ministry of Agriculture, Fisheries and Food since 1960. Reports have been published at 10 year intervals since the inception of the study (Blamire et al. 1970; 1980). Conditions recorded in sheep include: abscess, arthritis, bruising, Cysticercus ovis, Echinococcosis, emaciation, fascioliasis, jaundice, pneumonia and/or pleurisy, pyaemia, septicaemic conditions, tumours and other conditions. Cysticercus tenuicollis is not included and, if encountered, it is recorded under "other conditions", this category accounting for over 40% of offal condemnations in sheep between 1969 and 1979 (Blamire et al. 1980).

Studies of cestodes in farm dogs in England and Wales have shown the prevalence of Taenia hydatigena to be between 0 and 55.2%, with the highest prevalence rates in areas of highest population density of sheep (Cook, 1964; Cook and Clarkson, 1971; Williams, 1976; Hackett and Walters, 1979; Edwards et al. 1979). Similar rates have been recorded in foxhounds (Cook, 1965; Williams, 1976; Edwards et al. 1979). The prevalence in foxes is lower, with a maximum rate of 6.4% recorded in Mid-Wales (Hackett and Walters, 1979).

Accurate assessments of the incidence and losses due to C. tenuicollis are difficult to make because the condition is not specifically recorded at most abattoirs. This survey was undertaken to estimate the prevalence of C. tenuicollis in a sample of abattoirs in different parts of England, and to assess the feasibility of including C. tenuicollis as a specific condition in the records of condemnations in the future, so that losses may be estimated on a national level.

METHODS

Abattoirs in Cheshire, the West Midlands and Kent were selected for the survey to represent different sheep populations and different types of abattoir. In Cheshire four small abattoirs killing a maximum of 100 quality prime lambs per day from Wales, were selected. The West Midlands abattoir killed store sheep and cull ewes from all over Britain and had an average turnover of 600 sheep per day. In Kent, the abattoir was of export standard and killed up to 250 quality prime lambs per day, mainly derived from South East England.

A pilot study was carried out in the Cheshire abattoirs between September and December 1981, to establish the criteria for identification of

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C. tenuicollis and method of recording its incidence. Subsequently, the survey was extended to include the other abattoirs. A period of one month in the early summer was selected for the survey so that young lambs would be being killed in Kent and Cheshire. The meat inspectors in Cheshire elected to continue the survey until the end of 1982 for a more complete picture of the problem in their region.

A liver was classified as being affected by C. tenuicollis if it bore fertile or degenerate cysts either on its surface or in its substance. Lesions resulting from the migration of the larvae, such as tracks and spots, were also included if these warranted trimming from the liver. Samples of such lesions were taken for histology and the necrotising, haemorrhagic and fibrotic tracts with caseated or calcified cysticerci were confirmed as being due to C. tenuicollis. The number of livers trimmed or totally condemned were recorded.

In order to put the results of the survey in the context of meat inspection records as they are kept at present, the returns from 59 abattoirs monitored by the Ministry of Agriculture in 1981, and the 1981 returns from a Welsh abattoir and the West Midlands abattoirs were examined with respect to C. tenuicollis and the "other conditions" categories.

RESULTS

The results of the survey are summarised in Table 1. A total of 21,885 sheep were included in the survey. Of these 6,051 (27.6%) were affected with C. tenuicollis. 5,404 (24.7%) of the livers were partially condemned and 647 (3.0%) were totally condemned. The prevalence was lower in Kent than in either Cheshire or the West Midlands. The meat inspectors all found it feasible to include C. tenuicollis amongst the conditions recorded routinely during their inspection. They also considered C. tenuicollis to be responsible for a major part of their time when inspecting sheep.

Table 2 shows the 1981 condemnation returns from 59 abattoirs. The category "other conditions" accounted for 38% of the condemned offal. In practice C. tenuicollis constitutes the majority of this category.

Table 3 shows the 1981 condemnation returns for one Welsh abattoir, and a similar picture to the national one emerges. 42% of condemned offal falls into the "other conditions" category.

Table 4 shows the sheep offal condemnation records for the West Midlands abattoir for 1981. This illustrates the variation in recording systems. Here C. tenuicollis whole liver condemnations are amongst the conditions routinely recorded. The percentage condemned for C. tenuicollis for the whole year of 1981 was greater than that which emerged in the survey, 4.5% compared with 2.7%.

DISCUSSION

There is a large discrepancy between the incidence of C. tenuicollis recorded in this survey and the apparent incidence according to current condemnation records. In view of the observations made at abattoirs prior to the survey, and after working with the meat inspectors, it is not possible that this discrepancy is due to inaccurate identification of the condition. The discrepancy is largely due to the recording methods. In practice, the

Table 1. Prevalence of Cysticercus tenuicollis in sheep in abattoirs in Cheshire, West Midlands and Kent 1981 & 1982

	Total No. slaughtered	Condemnations: No. part offals (%)	No. whole livers (%)	Total no. affected (%)
Cheshire (Pilot Study) Sept.7th-Dec.2nd 1981	2,227	637(28.60)	90(4.04)	727(32.60)
Cheshire Apr.12th-Dec.14th 1982	3,086	882(28.60)	137(4.44)	1019(33.00)
Bromsgrove Apr.14th-May 14th 1982	14,640	3637(25.00)	396(2.70)	4053(27.60)
Ashford June 1st-June 30th 1982	1,932	228(11.80)	24(1.24)	252(13.04)
Totals:	21,885	5404	647	6051
%		24.7	3.0	27.6

Table 2. Ministry of Agriculture, Fisheries and Food
Return of condemnations of carcases and offal in slaughterhouses

Carcases: Total	Carcases: Partial	SHEEP Number slaughtered - 1,780,454	Offal: Total	Offal: Partial
34	3,836	Abscess	34	3,083
77	4,527	Arthritis	77	36
54	1,449	Bruising	54	28
27	238	Cysticercus ovis	27	5,682
1	1	Echinococcosis	1	61,740
1,697	-	Emaciation	1,697	-
98	-	Fascioliasis (fluke)	127	36,561
14	-	Jaundice	14	1
89	990	Pneumonia and/or pleurisy	89	28,882
32	-	Pyaemia	32	-
608	-	Septicaemic conditions/fever	608	-
27	4	Tumours	27	56
367	1,041	Other conditions	388	84,883
3,125	10,789	Totals	3,195	220,960
0.18	0.61	Totals as % of sheep slaughtered	0.18	12.41

Table 3. Abattoir 1 - Welsh

Return of condemnations of carcases and offal in slaughterhouses. 1981

Carcases Total	Carcases Partial	SHEEP Number slaughtered - 98,516	Offal Total	Offal Partial
-	5	Abscess	-	12
-	33	Arthritis	-	-
-	4	Bruising	-	-
-	-	Cysticercus ovis	-	19
-	-	Echinococcosis	-	1,149
2	-	Emaciation	2	-
-	-	Fascioliasis	-	929
-	-	Jaundice	-	-
-	-	Pneumonia and/or pleurisy	-	99
5	-	Pyaemia	2	-
1	-	Septicaemic conditions/fever	4	-
1	-	Tumours	1	-
-	-	Other conditions	-	1,597
9	42	Totals	9	3,805

Table 4. Abattoir 2 - West Midlands

Return of condemnations of carcases and offal in slaughterhouses. 1981

Sheep: Offal

Heads

Abscess	Cysticercus ovis	Orf	Bighead	Total
86	309	44	5	444

Lungs

Lungworm	Hydatid	Pleurisy	Pneumonia	Abscess	Others
80,057	1,341	2,598	13,562	235	32

% condemned - 53.4 Total 97,825

Hearts

Pericarditis	Fatty	Cysticercus ovis	Sarcocysts
801	63	3,363	3

% condemned - 2.3 Total 4,230

Livers

Fluke	C. tenuicollis	Hydatid	Fatty	Abscessed
4,012	8,340	1,184	317	403

B. necrosis	Melanosis	Sarcoma
102	27	1

Total - 14,386
Weight - 10,770 Kilos

Total % condemned 7.8
% condemned due to C. tenuicollis - 4.5

Spleens

Hydatid	Abscessed	Total
35	31	66

Kidneys

Nephritis	Hydronephrosis	Pyelonephritis	Cysticercus cysts
1,519	198	15	565

Lipofuscin 20 Hydatid 3 Total: 2,320

Comparison of sheep diseases encountered at meat inspection between 1960-1968 and 1969-1978

[From Blamire et al., 1970 & 1980]

	1960-1968 34 abattoirs	1969-1978 65 abattoirs (15% of sheep slaughtered)
Mean no. slaughtered/year	2,060,938	1,335,974
Fascioliasis		
Mean no. part offals condemned	136,526	66,444
%	6.62	4.97 (12% in 1969 down to 2% in 1978)
Hydatidosis		
Mean no. part offals condemned	20,899	38,525
%	1.01 (0.86% in 1960 up to 1.75% in 1968)	2.88
Other conditions		
Mean no. part offals condemned	Not reviewed	Approx. 40%

number of partial offals condemned is a figure derived from the total weight of trimmings. The trimmings are generally pooled in a bucket and the total weight is divided by the average weight of a lamb's liver, generally between 1.5 and 2 lbs. This gives a figure for the equivalent number of whole livers condemned and an estimate of the weight of liver lost. The number of livers actually affected and trimmed is far higher, the survey suggesting 28%.

Arguably, the important economic factor is the weight of liver lost, but in terms of disease monitoring the incidence of C. tenuicollis is obscured, as is its importance with respect to the amount of time the meat inspector spends on the condition. If the Ministry's sample of condemnation records represents 15% of the sheep slaughtered every year (Blamire, 1980), then over 1 million kgs of liver are condemned because of C. tenuicollis.

A lower incidence of C. tenuicollis may be expected in areas where T. hydatigena is uncommon, such as South-east and East England (Cook, 1965; Cook and Clarkson, 1971). This is borne out by the results from Kent.

The survey has not shown a seasonal incidence in C. tenuicollis. Variation in the proportion of livers affected is more likely to be influenced by the source of lambs, those coming from farms where pasture is heavily contaminated with eggs being more heavily infected.

Because C. tenuicollis is not specifically recorded it is difficult to establish if there has been any change in its incidence over the years.

Blamire et al. reviews (1970 and 1980) cite hydatidosis and fascioliasis as the most common conditions, although they discuss the incidence of C. tenuicollis and cites a survey in Dyfed (Williams, 1976) where it was found to be 40%. The incidence of fascioliasis has decreased with the improved understanding of the controlling factors, with a period of dry summers and with the availability of effective anthelmintics. The incidence of hydatidosis, on the other hand, has increased since 1960 and has been approximately 3.0% for the last decade. Although the life-cycle of the tapeworm is well-known, the longevity and reproductive potential of the parasite, the fact that hydatid cysts are unaffected by our present drugs and traditional methods of dog husbandry have ensured that the parasite is endemic in certain areas.

C. tenuicollis parallels hydatid in many ways. It is similarly unaffected by drugs and is encouraged by certain dog husbandry practices, but its importance is less widely recognised in the livestock industry. Taenia hydatigena is common in farm dogs in sheep areas and is more widespread in the dog population than Echinococcus. For these reasons it is highly likely that there has been a high incidence of C. tenuicollis for many years and will continue to be unless future recording methods bring to light its true incidence and economic importance, which would then encourage its control.

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CASE-CONTROL STUDIES IN THE EVALUATION OF SEROLOGICAL DATA FROM RESPIRATORY DISEASE OUTBREAKS IN CATTLE

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The case-control study approach to examine the etiology of respiratory disease in cattle may be useful as it allows comparison of many etiological agents simultaneously in an economical manner. This paper explores the usefulness of the case-control method for the study of infectious agents in complex multifactorial diseases, a field in which it has not been widely applied.

Willeberg (1979) suggested a rational approach to solve multifactorial health problems, which involved four phases;

1. A description of the disease situation relative to the frequency of occurrence and differences in time, geographical units and host characteristics.

2. An analysis for disease determinants including estimates of the disease enhancing effects of the causal factors involved in the particular situation.

3. A cost/benefit analysis as a basis for a suitable control programme.

4. Surveillance of the control programme for efficacy, cost, side effects etc.

Analysis for disease determinants involves an observational study which is usually conducted on only a sample of the population. Such samples are commonly selected in one of three ways:

1. Random cross-sectional sample which allows estimates of the prevalence of disease in groups and exposure to putative factors to be made.

2. A case-control study, identifying cases and selecting suitable controls.

3. A cohort study in which the incidence of disease in animals exposed and not exposed to a putative factor is compared.

An estimate of the disease enhancing effect of any factor is readily measured by the relative risk which is a ratio of the risk in those exposed and those not exposed to the factor (Cornfield, 1951). An estimate of the relative risk can be made from a case-control study by use of the odds ratio providing certain criteria are met.

In respiratory disease of cattle a wide range of environmental, management and microbial factors have been described as risk factors (Pritchard, 1980). Numerous attempts have been made to satisfy the Henle-Koch postulates but with limited success. Amongst the obstacles to satisfying these postulates has been the technical difficulty of demonstrating the presence of agents, especially viruses in cases of the disease. The development of specific serological tests led to the development of new criteria for proof of

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causation based principally on immunological evidence (Evans, 1976). A unified concept of the criteria for establishing causation was developed by Evans (1976) and applied to cattle respiratory disease by Thomson (1980). The first three criteria involve the analysis of disease determinants viz:

1. Prevalence of disease should be significantly higher in those exposed to the putative cause than in controls not so exposed.

2. Exposure to the putative cause should be more frequent among those with the disease than in controls without the disease when all other risk factors are held constant.

3. Incidence of disease should be significantly higher in those exposed to the putative cause than in those not so exposed as shown in prospective studies.

Evidence to satisfy these respective criteria can be obtained from cross-sectional study (criterion 1), case-control study (criterion 2) and prospective cohort study (criterion 3).

If a serological test for an agent is to be used to produce an estimate of the disease enhancing effect of the putative agent several assumptions must be made, in a similar manner to those made in the use of serology as a diagnostic aid (see Worthington, 1982). These are principally that the test is specific and sensitive and that in the population examined the test has a high predictive value ie. a high proportion of animals with positive results are or have been infected with the agent. In addition it is assumed that a fourfold rising antibody response is indicative of recent infection with the agent.

This paper describes the application of a matched case-control study to an outbreak of respiratory disease in weaned suckler calves and an unmatched case-control study on respiratory disease in 3 groups of unweaned calves, and presents a preliminary analysis of the results.

METHOD

Suckler calf study

The outbreak of respiratory disease in these calves has been reported (Andrews and others, 1981). In Group 1, 18/137 (13%) were treated for respiratory disease and in Group 2, 22/149 (15%) were treated. All cattle were bled on entry to the unit and at approximately 30, 50 and 120 days after entry. Cases of respiratory disease were identified by the requirement for antibiotic treatment following clinical signs for respiratory disease. Cases were matched for age, sex and breed on a random basis. All sera from cases and matched controls were tested and a fourfold rising titre during the period of illness was taken as evidence of exposure. The following serological tests were used:

Complement fixation tests against antigens H. somnus strain DB280, M. bovis strain 5M193, M. bovirhinis strain 5M548, M. dispar strain NCTC10125 and Bovine Virus Diarrhoea (BVD) strain NADL.

Haemagglutination inhibition tests to Parainfluenza 3 virus, ReoI and ReoII viruses.

Agar gel precipitation tests for bovine adenoviruses A and B.

Table 1. Summary of matched case-control study on respiratory disease in housed, weaned, suckled calves and rising titres to 13 putative agents

Agents	Group	Number of pairs a	b	c	d	Odds ratio (e)	Mean odds ratio (f)	C.I. (g)
M. bovis	1	0	3	1	14	2.3		
	2	1	2	0	18	5.0	2.95	0.58,14.9
PI3	1	1	8	2	6	3.4		
	2	14	4	3	0	1.3	2.09	0.77,5.5
ReoI	1	3	6	2	6	2.6		
	2	1	8	5	8	1.54	1.84	0.79,4.27
H. somnus	1	2	3	2	10	1.4		
	2	2	3	2	16	1.4	1.33	0.46,3.7
Adeno A	1	0	1	1	15	1		
	2	0	3	2	16	1.4	1.08	0.34,3.4
ReoII	1	9	1	1	6	1		
	2	1	5	5	15	1	1	0.22,4.43
P. multocida	1	2	5	4	6	1.2		
	2	6	4	5	6	0.8	0.9	
P. haemolytica	1	0	0	1	16	0.5		
	2	4	2	3	12	0.71	0.53	
Adeno B	1	0	0	2	15	0.2		
	2	0	2	1	18	1.7	0.38	
M. dispar	1	0	0	1	16	0.33		
	2	0	0	0	21	1	0.48	
BVD	1	0	0	1	16	0.33		
	2	1	1	3	16	0.43	0.36	
IBR	1	0	0	2	15	0.2		
	2	0	0	0	21	1	0.54	
M. bovirhinis	1	0	0	2	15	0.2		
	2	0	1	3	17	0.42	0.39	

a Control rising titre/case rising titre
b Control no rising titre/case rising titre
c Control rising titre/case no rising titre
d Control no rising titre/case no rising titre
e Odds ratio = (b+0.5)/(c+0.5)
f Weighted mean of combined logarithms of odds ratio
g C.I. = 95% confidence intervals

Table 2. Effect of antibody titre to H. somnus on treatment for respiratory disease in 38 cases and 36 matched controls

Antibody titre to H. somnus	Cases	Controls	Attack rate	Relative risk relative to highest group
-	29	21	58%	2.9
10	5	6	45%	2.27
20	3	5	37%	1.8
40	1	4	20%	1
Total positive	8	15	34%	1.7

Table 3. Estimates of relative risks for specific agents detected by fourfold rising titres in serological tests using odds ratio from case-control method or direct estimation of relative risk of absence of specific antibody at entry to unit for respiratory disease in unweaned calves

	Group A		Group B		Group C	
Factor	Odds ratio	Relative risk	Odds ratio	Relative risk	Odds ratio	Relative risk
Low Ig (SST) = 1	1.36	2.7	2.35	1.4	1.0	4
(SST) = 2	0.75	1.5	2.0	1.3	22.5	4.9
(SST) = 3	1		1		1	
M. bovis	a	3.7	0.5	a	2.1	0.6
BVD	4.3	1.6	1.4	1.4	a	0.6
IBR	a	4.3	a	1.6	a	1.6
PI3	0.9	0.9	0.5	b	a	b
RSV	6.5	2.9	a	1.2	a	b
ReoI	a	2.1	a	1.1	1.7	2.1
ReoII	a	0.7	1.1	1.3	a	1.7
Adeno A	6.6	1.8	a	1.5	a	1.9
Adeno B	3.2	1.8	a	1	1	1.4
Chlamydia	2.2	4.8	1.1	1.3	1.4	0.8
H. somnus	-	-	-	0.34	0.7	1.3
Incidence of respiratory disease	8/29 (28%)		26/40 (65%)		12/20 (60%)	

a No seroconversion or antibody detected at entry
b All animals had antibody on entry

Serum neutralisation tests for Bovine Herpes I (IBR) Oxford strain.

Enzyme linked immunosorbent assay tests for Pasteurella haemolytica serotype AI and Pasteurella multocida.

Relative risks were calculated as described by Mantel and Haenszel (1959) and weighted means calculated as described by Fliess (1973) except for multiple categories where the method of Doll and Hill (1952) was used.

Unweaned calf study

Sera were collected on entry and approximately monthly from three groups of market purchased unweaned, individually penned calves, bedded on straw and fed a hay and concentrate ration and milk substitute. Cases of respiratory disease were identified by requirement for antibiotic treatment. The incidence of respiratory disease during the 10 week study period in the three groups were: Group A 8/29 (28%), Group B 26/40 (65%), Group C 12/20 (60%).

All the tests used in the suckler calf study, except ELISA for Pasteurella, were used on all sera, with the addition of a complement fixation test for Chlamydia and ELISA for Respiratory Syncytial Virus. The sera on entry were also tested using the sodium sulphite test (SST) for immunoglobulins (M. Gitter, personal communication). Group A sera on entry were also examined by radial immunodiffusion test for bovine IgG. Mean and standard deviation of IgG level for SST scores were SST=1, 1067 (982); SST=2, 1944 (1286); SST=3, 2920 (2920); SST=4, 4000 (not done).

The odds ratios were calculated for exposure to low SST score or to rising antibodies to agents during the period of the epidemic (ie. using case-control analysis as in the suckler calf study). The relative risk of a low SST score or the absence of specific antibody to an agent was estimated by the ratio of the attack rates.

RESULTS

The results of the matched case-control study are summarised in Table I. While M. bovis, Parainfluenza 3, ReoI, H. somnus and Adeno A have relative risks greater than one, confidence intervals of these ratios calculated as described by Fliess (1973) all include one. Analysis of the effect of antibody detected on entry to the unit in the 38 cases and 36 matched controls was made. The presence of antibody to H. somnus was associated with a reduced risk of treatment for respiratory disease related to antibody titre.

The odds ratio of presence of rising antibody and treatment for diseases and the relative risk of absence of specific antibody for the 3 groups of unweaned calves are summarised in Table 3. The relative risk (RR) of SST=1 was 2.7, 2.3 and 4 for the 3 groups and RR of SST=2 was 1.5, 1.3 and 4.9 for the 3 groups respectively. In comparison the odds ratio varied widely being 1.36, 2.35 and 1 for SST=1 and 0.75, 2.0 and 22.5 for SST=2.

Except for BVD, RSV, Adenovirus and Chlamydia in Group A and M. bovis in Group C there was little evidence of the presence of the agents tested for during the period of the epidemic.

In Group A both the absence of antibodies to RSV on entry and seroconversion during the study period increased the risk of treatment for disease. No evidence for the presence of RSV was found in Groups B and C during the epidemic period. The relative risks for absence of antibody to Adeno A was consistently greater than 1 (1.8, 1.5 and 1.9) and the odds ratio were also high when seroconversion occurred. Adeno B and Chlamydia gave a similar pattern.

DISCUSSION

Although the estimates of relative risk obtained from case-control studies are frequently biased (see Sackett, 1979) matching can reduce such bias so long as the analysis takes the matching into account (Seigel and Greenhouse, 1973). The selection of controls in outbreaks of respiratory disease in cattle is usually limited to pen-mates or other animals on the farm, since interfarm differences in exposure are considerable. As respiratory pathogens are believed to be highly infectious a comparison of the incidence of antibody in cases and pen-mate controls may be thought to be of little use in establishing the association between agents and disease. The results of these two studies suggest that such comparisons can detect such differences. The confirmation that these techniques detect a high relative risk for low colostral antibody levels, which has been described in many studies (eg. Williams and others, 1975), also suggests that these techniques may be useful. The relative strengths of the associations between seroconversion to agents can be readily ranked by this method. As Cornfield (1959) pointed out, etiological research frequently involves a search for regularity in many sets of data so that one can generate hypotheses from one set of data which can be readily tested on other sets. In this respect the use of odds ratios from 'serological' case-control studies coupled with an analysis of the relative risk of absence of specific antibody appears to merit further examination in order to make reliable estimates of the disease enhancing effects of putative causal factors.

The odds ratio is subject to numerous biases, most commonly confounding bias where the estimate is distorted due to the mixing of the exposure variable with the effect of confounding variables. For example it appears, surprisingly, that the absence of IBR antibody in Group A is associated with increased risk of treatment when no evidence of seroconversion to IBR was seen during the epidemic. Theoretically this may be due to confounding of IBR antibodies with antibody to, say, Chlamydia; the calculation of second stage relative risk can control for such confounding, as can multivariate analysis. Another important potential source of bias in the present study is misclassification of cases and controls, although the treatment protocol was applied in both studies without a knowledge of the serological data.

If an assessment were to be made of the relative strengths of the relative risk of the various agents in order to rank them, then the sensitivity and specificity of the tests used, the dynamics of the antibody response and the relationship between antibody response and the disease process would need to be of a similar order to permit valid comparisons to be made. Interestingly, the order of magnitude and rank of the relative risks in the current studies are broadly in agreement with those calculated from data obtained by Stott and others (1978) when comparing seroconversion and isolation rates for various agents during periods with and without disease in a beef rearing house (see Pritchard, 1980).

The analysis of serological data by case-control method may be of use in clinical practice but will be more useful in observational studies aimed at determining the current putative agents involved in cattle respiratory disease. Clearly, however, because of the variation in distribution of agents, a large number of cattle groups will need to be examined. Serology is one of several methods which can be used to assess exposure to an agent. Other methods include isolation of agent and demonstration of specific pathological or histopathological lesions. In clinical practice it is important to consider clinical, epidemiological, pathological, microbiological and serological evidence as a whole. The determination of relative risk and/or odds ratio appears a potentially useful method for the preliminary analysis of serological data. In order to take account of confounding between variables a multivariate analytical technique such as discriminant analysis should be used.

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PRELIMINARY OBSERVATIONS ON A SERIES OF CLINICAL OUTBREAKS OF ACUTE LAMINITIS IN DAIRY CATTLE

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Laminitis is an important metabolic disease of dairy cattle. It tends to occur in high yielding herds and affects cattle in early or peak lactation. The acute disease is characterised by tender footedness, bunching of the feet, heat in the feet and reluctance to walk (Maclean, 1965); these signs are the result of pain due to a diffuse aseptic inflammation of the corium of the hoof. The cause of the disease is not fully understood, but a number of predisposing factors have been identified (Pinsent, 1981; Edwards, 1982). These include acidosis, high concentrate feeding, low forage:concentrate ratio, lack of exercise and sudden introduction to cubicles. Control measures which seek to minimise ruminal acidosis and changes around calving have also been established (Weaver, 1979). In general, these will effectively reduce or eliminate the acute clinical disease.

However, a number of herds which do not fit this classic picture of excessive concentrate feeding and acidosis have been seen in the last two winters. The well-tried control measures were either already in use or were found to be ineffective in reducing disease. Five such herds suffering from 'atypical' acute laminitis have been studied. In each case, heifers were much more severely affected than cows; in three herds the disease was confined exclusively to heifers. On four of the farms 100% of heifers were affected. Onset of clinical disease began within the first few days or weeks after calving; on one farm, heifers showed clinical signs in the days prior to calving. In each case, onset of clinical signs was dramatic, with animals suddenly becoming tender-footed and sore, shifting from foot to foot and reluctant to move or to rise. In one case, steam rose from the feet. Often nothing but extreme pain was found when feet were examined.

It became necessary to look for other factors which might be involved in pathogenesis of disease in these herds. With this aim a number of possible risk factors have been examined for each of these high incidence herds; five 'low incidence' herds of similar size, yield and general management have been studied for comparison. The preliminary results of these studies will be discussed.

The possible risk factors include aspects of feeding, housing and management which have been implicated in the pathogenesis of acute laminitis.

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1. Factors associated with acidosis. These include concentrate feeding only in parlour, restricted access to silage, poor silage palatability, rapid introduction of concentrate to the ration after calving and no access to long fibre.

2. Changes around the calving period. Laminitis, like other metabolic diseases, is a stress-associated condition, and it is likely that changes in environment, social grouping and feeding will cause considerable stress at a time when metabolism is already rapidly changing.

3. Protein in feed. It is often observed that herds fed excessively high levels of dietary protein have a high incidence of laminitis, although there is no experimental evidence to support this link. Inclusion of concentrated protein supplement to the ration, and level of free ammonia in the silage were examined in these herds.

4. Trace element status. Deficiency of various trace elements have been implicated in pathogenesis of laminitis and these minerals are required for numerous metabolic functions as well as for production of healthy hoof horn. It is likely that trace element status of heifers will be low in many herds due to increased reliance on forage and other home produced feeds, and the use of reseeded pastures and single grass leys. Selection of stock for higher growth and production potential may also increase the likelihood of deficiencies in certain trace elements, (Smart et al., 1981).

5. Housing. Clinical signs of acute laminitis are always much more severe when cattle are on concrete; even badly affected animals may move normally once housed in a straw yard. Poorly maintained concrete, uncomfortable cublicles, dirty passageways etc., may therefore exacerbate the severity of the condition.

RESULTS

These are summarised in Tables 1-7.

Table 1. Herd information

	High incidence					Low incidence				
	1	2	3	4	5	6	7	8	9	10
Yield	6,100	5,600	6,000	6,300	5,800	6,300	7,000	5,200		5,800
Herd size	250	110	180	120	120	120		130		120
High lameness	+	+	+	-	-	+		+		+
History Age of calving	24 m	30 m	24 m	27 m	24-36 m	24 m	24-30 m	24-30 m	24 m	24 m

Table 2. Disease information

	1	2	3	4	5
Year	1982/83	1981/82	1982/83	1981/82	1981/82
Exclusive to heifers	+	Mostly	Mostly	+	+
Onset	Before calving/ or immediately after	5-6 weeks post-calving	2 weeks post-calving	Post-calving	Post-purchase
Incidence in heifers	100%	100%	'most'	100%	100%

Table 3. Factors associated with acidosis

	1	2	3	4	5	6	7	8	9	10
No. out of parlour feeding										*
No fibre added		*					*	*		*
Restricted access to silage					*			*		
Silage 'D' value <60		*								
Poor silage palatability								*		
Increase to max. concentrate feed in <8d	*	*	*			*		*	*	*

Table 4. Protein factors

	1	2	3	4	5	6	7	8	9	10
Silage free NH_3 Nitrogen >5%	**	?	**	*	*		?	**		
Protein supplement (25%+)	*		*		*					

Table 5. Changes at calving

	1	2	3	4	5	6	7	8	9	10
Introduction to cubicles at calving	*	*	*	*	*	*			*	
Introduction to concrete at calving	*	*	*	*	*	*			*	
Introduction to parlour at calving		*	*		*	*				
Introduction to silage at calving			*	*	*	*				
Introduction to winter ration at calving	*	*	*	*	*	*				
Introduction to herd	*	*		*	*			*	*	*
Market/travel at calving					*					
No previous experience in cubicles	*		*	*	*		*			*

Table 6. Factors associated with poor housing

	1	2	3	4	5	6	7	8	9	10
Cubicles	+	+	+	+	+	+	+	+	+	+
Inadequate bedding	*				*			*		
Dirty passages		*				*		*		
Disrepair of concrete					*			*		
Lying-in problems		*			*			*		
Cubicle injuries	*	*	*		*			*	*	

Table 7. Mineral/trace element status

	1	2	3	4	5	6	7	8	9	10
No mineral supplement	*	*	*	*	Not known	*		*		*
Clinical deficiency	*	*	*	*				*		
Mineral problems	(Co, Cu)	(Cu)	(Cu)	(Se, Cu)				(Cu)		
Low blood Cu	*	*	*				*		**	
Low blood GSPx	*		?	?		*			*	
Low B_{12}	**	?	?	*	*		*	*	*	

DISCUSSION

From the results, it is seen that factors associated with acidosis were not found in the high incidence herds; this indicates that some other factor or factors will be causing disease in these herds.

The number of changes around calving is higher in high incidence than in low incidence herds. In herd 4, the incidence of laminitis was dramatically reduced in winter 1982/83 when heifers were introduced to cubicles, concrete, silage and the rest of the herd, several weeks before calving. In herd 5, where newly-calved heifers are bought from market, there was no laminitis in 1982/83 when heifers were bought in early autumn so that they could be gradually introduced to the main herd as they calved, and also gradually introduced to winter feed and housing. One group of heifers was bought and turned out immediately into the herd on concrete and cubicles; several of these animals developed acute laminitis.

High free ammonia in silage was a feature in four out of five of the high incidence herds. On farm 1, heifers fed only silage and 4 lbs concentrate were affected with acute laminitis; free ammonia in this silage was 32%. High protein supplements were fed in three out of five of the high incidence herds and in some of the low incidence herds. In herd 5, 2 kgs of 44% protein supplement were fed; this was excluded from the ration in winter 1982/83 and incidence of laminitis was much reduced.

Free access to minerals was provided in only two of the low incidence herds. A history of clinical copper/cobalt/selenium status was known on several of the farms. Low copper and GSPx was common in both sets of herds. Unfortunately, serum levels of cobalt and zinc do not provide an accurate assessment of body status of these elements and further investigation of these and other minerals is needed.

Poor housing is not a feature exclusive to high incidence herds.

These results are merely the initial findings from a small number of herds, but I feel that they indicate the need for a much more extensive study. Acute laminitis lends itself to epidemiological study because it is a multifactorial disease whose symptoms are discrete and obvious and which tends to affect whole groups of animals. Also, study of the disease under experimental conditions can only provide limited information about predisposing factors on the farm.

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POSSIBLE MECHANISMS OF TRANSMISSION IN CLINICAL OVINE TOXOPLASMOSIS

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The life cycle of Toxoplasma gondii includes two forms of the parasite that are obvious adaptations for transmission. Tissue cysts which are found in the bodies of infected hosts are infective if eaten and form an important reservoir of infection to carnivores. Oocysts which are shed in the faeces of infected cats can survive on the ground for long periods, they may be disseminated in the environment and therefore represent an important reservoir of infection to both carnivores and herbivores. At no other stage in the life cycle are free toxoplasmas sufficiently numerous or resistant to suggest an alternative route of transmission.

Serological survey data indicate a high prevalence of Toxoplasma infection in sheep but only a small proportion of these infections are symptomatic. Clinical ovine toxoplasmosis occurs when susceptible ewes experience their first infection with Toxoplasma during pregnancy. The signs of clinical ovine toxoplasmosis include early embryonic death and resorption, foetal death and mummification, abortion, stillbirth and neonatal death. These signs do not occur at random but depend upon the age of the conceptus at the time of infection. Ewes infected in late pregnancy about(110 days gestation onwards) usually lamb normally though their lambs may be congenitally infected, while in mid-pregnancy (about 70-90 days gestation) a large proportion of foetuses succumb to the infection and are seen as "typical" toxoplasma abortions. Infections in early pregnancy (before about 50 days gestation) commonly cause early embryonic death and resorption leaving an apparently barren ewe. It appears that outbreaks of clinical ovine toxoplasmosis can occur only under rather restricted conditions.

Natural outbreaks of clinical ovine toxoplasmosis presumably result when susceptible flocks are exposed to infection in mid-pregnancy. Although the source of infection and mechanism of transmission in ovine toxoplasmosis are not known their characteristics can be defined to the extent that they must be capable of infecting a high proportion of the susceptible ewes in a flock during a restricted period of pregnancy. Possible mechanisms of transmission appear to be limited to the ingestion of oocysts or to some form of contact transmission. These assumptions may be tested by developing simple epidemiological models.

Infection by oocysts may be continuous or discontinous. If it is assumed that a flock is continuously exposed to infection by oocysts then the proportion of infected ewes should increase with duration of exposure (age) according to the simple Poisson model. There would

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therefore be decreasing proportions of susceptible ewes in successive age groups. This model assigns the greatest risk to the youngest or most recently introduced ewes and predicts a recurrent pattern of disease. Discontinuous exposure to infection by oocysts implies that exposure to infection by oocysts is a random event, that the rate of infection and the time of onset and duration of exposure to infection are independently variable; these three variables determine the characteristics of an outbreak. This model is extremely flexible but it has two important limitations, it cannot account for recurrent patterns of disease nor, in a fully susceptible flock does it allow any restriction of losses to a particular sub-group.

If ovine toxoplasmosis is transmissible by contact, the spread of infection in a flock would presumably fit the simple epidemic model. Outbreaks of clinical toxoplasmosis might be expected to occur when the peak of the epidemic curve coincided with mid-pregnancy. In this model it is necessary to assume some initial stimulus to trigger the spread of infection, mixing sheep prior to tupping is the most likely explanation. The contact transmission model therefore predicts that recurrent clinical toxoplasmosis should be common, with losses restricted to introduced stock.

A review of published accounts of natural outbreaks of clinical ovine toxoplasmosis shows that the disease is typically sporadic, that the introduction of stock is not a consistent feature and that losses are not necessarily restricted to young or recently introduced ewes. These observations can be accommodated only by the discontinuous exposure model.

ECONOMICS OF HEALTH

ECONOMIC EVALUATION OF HEALTH SCHEMES

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There is a growing interest in the economic evaluation of health services on the part of clinicians, specialists in community medicine and others. The purpose of this paper is to explain a framework within which alternative courses of action can be compared systematically, and any value judgements made explicit. Given the state of the art we are unable to quantify and value many of the advantages and disadvantages of alternatives and place them on a strictly comparable basis. Many of the effects of programmes will be assessed in a qualitative, subjective manner and rarely will it be the case that an evaluation points to the superiority of one course of action over all others; trade-offs between different benefits, and between different costs will be involved. This paper examines evaluation techniques, or more precisely cost-benefit analysis, within the field of (human) health services. The principles are applicable, however, in any field of decision making although certain difficulties arise within health service evaluation which may not be manifest elsewhere.

WHY DO WE NEED COST-BENEFIT ANALYSIS?

In health services, as in any other field of public expenditure, choices must be made between alternative policies. The necessity for choice arises from the fact that there exists a very large number of beneficial activities. Resources are limited and inevitably add up to less than the total required to carry out all these activities. Cost-benefit analysis (CBA) is an aid to decision making intended to explore alternative options relating to the provision of services and is one way of approaching this problem of choice: given that value judgements will always be involved it should be seen as an aid, not a solution. Cost-benefit analysis is rooted in the common sense notion that an activity is only worth undertaking if its benefits outweigh its costs.

As in most organisations resource allocation decisions are taken at many levels in the National Health Service (NHS). At the highest level, there are decisions on total expenditure between, say, health, defence and education and divisions between broad programmes - maternity, elderly, mentally ill. At the other extreme are the many decisions taken by individual doctors on the appropriate treatment for given patients. CBA tends to operate at the intermediate level, with projects rather than programmes; for example, how to allocate money within a particular sector rather than how much to allocate to that sector, and with alternative regimens of treatment for a given illness or group of patients rather than for individual patients. This still leaves ample scope for the application of the technique; for example, as Williams (1974) points out it is applicable when considering different methods of treatment,

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different places of treatment and different timings of treatment. This is not to pretend, however, that evaluation is easy to undertake in the NHS. On an organisational level, decision making in the NHS is very diffuse. Power is devolved from the centre and there are many people involved in making resource allocation decisions. This creates problems for the analyst in knowing who it is who requires advice and how it is that final decisions on allocation emerge. One may also encounter ethical difficulties which make it difficult to determine how effective treatments may be. A known treatment may be beneficial but in order to assess whether its benefits exceed its costs a randomised controlled trial is called for which would involve the withholding of a treatment known to impart some good. This would tend to be ruled as unethical and not be permitted.

DEFINITION OF CBA

The basic objective of CBA is to inform decision-making and typically there are at least four stages in any analysis:

(1) Definition of the problem and systematic identification of the alternative options that may satisfy objectives;

(2) Explicit consideration of the costs and benefits;

(3) Presentation of results in the most useful way to aid decision making. This will include a ranking of options in order of preference if possible, together with a sensitivity analysis of the effects of changes in basic assumptions on the ranking;

(4) Subsequent evaluation of the outcome of the decision against the expectations and assumptions that guided it i.e. learning from experience.

In many instances it is not possible, or it would be prohibitively time consuming and expensive to produce a comprehensive CBA. CBA clearly has a cost and the scale of the analysis needs to be adjusted to the size and importance of the investment concerned. The scope of any evaluation will be conditioned by the difficulty of obtaining information and the probability that extra information obtained will change the decision between alternative options. In some instances a 'back of the envelope' assessment is adequate, in others a more elaborate analysis is required. Nevertheless, as Williams (1974) advocates, the use of the 'cost-benefit approach' is helpful to order thought logically even if it is not possible to quantify and value all the benefits and costs. The approach may be illustrated by considering three studies, one each relating to the spheres of decision making mentioned earlier.

SOME CASE STUDIES

Alternative treatments

Community Psychiatric Nurse or Psychiatrist Management of Chronic Neurotics: The study reported in Paykel et al (1980) examined the potential advantages and disadvantages of expanding a nursing service into a clinical area traditionally served by outpatient psychiatry. In a randomised controlled prospective trial, two groups of patients, one receiving care from community psychiatric nurses, the other traditional outpatient psychiatrist management, were followed up at six monthly intervals for a total period of eighteen months. Data on clinical and social outcomes together with the direct (costs falling upon the health and personal social services) and indirect costs (costs falling upon the patient and his family). The study revealed that clinical and social outcomes were comparable; consumer satisfaction was significantly greater among those receiving nursing care. Nursing management whilst initially the more costly treatment, over time proved cheaper than conventional outpatient follow-up and over the eighteen month period the cost difference was not statistically significant (see Table 1).

Table 1. Alternative treatments for neurotics: selected mean costs and benefits after 18 months

Costs and benefits	Outpatients	Community nurses	Significance
Costs			
Health and Social Services	717.33	1115.1	N.S
Transport costs to patient of travel for treatment	2.75	0.91	.01
Travel time (hours) in attendance for treatment	9.72	9.65	N.S
Benefits			
Mean change in symptom score from initial rating:			
-global severity of illness	0.72	0.80	N.S
-social adjustment	0.44	0.23	N.S
Patient satisfaction (low score = higher satisfaction)	2.00	1.38	.05

Source: Paykel et al (1980)

Alternative locations

Institutional or community care for the elderly: It is frequently asserted that community care is cheaper than institutional care. In a study reported in Wright et al (1981) an attempt was made to identify people with similar requirements for help i.e. similar 'dependency', who were being cared for in the major alternative forms of care: long stay hospital wards; local authority residential homes; and in their own homes in the community. The aim of the study was to assess the cost - not only to the state but to the individual as well - of the three alternative forms of care for individuals of a given dependency level (a scale was developed which related to the ability of an individual to undertake various 'activities of daily living'). A selection of the results is given in Table 2.

Table 2. Cost per person per week of alternative patterns of care for the elderly (1976/7 prices)

Type of provision	Dependency group 0	1	2	3	4	5	6	7
Long stay hospital								
-new hospital	(not applicable)					105		
-upgraded hospital						94		
Local authority residential care	48	50	50	52	52	56	59	59
Community care								
-living alone in ordinary housing	39	43	44	46	(not applicable)			
-living in sheltered housing (high capital cost estimate)*	48	52	53	55	(not applicable)			
(low capital cost estimate)*	38	42	43	45	(not applicable)			

Source: Wright et al (1981)

Alternative Timing of Treatment

Screening for Neural Tube Defects (Spina Bifida and Anencephaly): Recent medical developments have made possible the detection of neural tube defects in unborn children and women with affected fetuses offered a termination. The problem was whether all health authorities should introduce a service to screen for such congenital malformations. The issue was studied by a Working Group of the Standing Medical Advisory Committee (Central Health Services Council, 1979). A summary of the results of their deliberations is presented in Table 3.

*Sheltered housing schemes vary immensely in terms of their capital cost so Wright et al included high and low cost estimates.

Table 3. Cost and Benefits of Screening for Neural Tube Defects

Costs	Benefits
(a) Cost (1978/9 prices) to the NHS: £5.50 per woman screened 2,350 per case averted	(a) The birth of fetuses affected by anencephaly or open spina bifida would be averted - about 2-2.5 per 1000 births. Proportion surviving to 5 years is about 15%, of whom 60% would be severely physically handicapped.
(b) Cost to the patient of extra ante-natal attendance: £1 per visit per woman screened.	(b) 40-50% would be stillborn and many would die soon after. Trauma associated with such an event averted.
(c) False negatives. Some affected families would be reassured, incorrectly, because the serum test failed to detect an abnormal pregnancy (about 20% with open spina bifida).	(c) Women with unaffected pregnancies reassured.
(d) False positives, some unaffected women (about 3%) would be caused unnecessary anxiety as a result of a positive serum test and the need for additional investigations.	
(e) One of the tests - amniocentesis - may lead to the loss of normal fetuses (1-1.5%).	

Source: Burchell and Weeden (1982)

All of the examples above adopt what is best described as a 'cost-benefit approach' to decision making. CBA in the health field is unlikely to be able to provide a comprehensive analysis in which all costs and benefits are identified, measured and valued. In most cases costs can be measured and valued, for example staff time and materials. In the case of benefits it is much more difficult to attach a price tag. To take the example of assessing the benefits of a given treatment, what needs to be assessed is the difference between what would have been the time path of an individual's health status without the treatment and the time path with the treatment. Essentially such an assessment requires, at least, three steps:

i. setting up descriptive categories concerned with a patient's state in terms of pain free social functioning;

ii. a relative evaluation process that converts each of the descriptive categories into a cardinal index;

iii. an absolute valuation process that converts the index points into money values, to enable the dimensions of ill health to be aggregated into an overall measure.

The difficulties are obvious. How many categories does one include? There are numerous dimensions to ill health. How does one devise an index which will encapsulate the intensity and duration of each of the dimensions of ill health? How does one attach money values to the index scores? The source of the money values is a difficult problem. Using implicit valuations derived from existing resource allocation, asking individuals how much they would be willing to pay to avoid ill health, court awards or an arbitrary policy decision as a price per health 'point' have been suggested as possibilities (see Mooney (1977) for a full discussion of this problem).

The practical problems associated with measuring and valuing benefits often lead analysts to adopt cost-effectiveness analysis, an approach which assumes that the benefits of the options considered are identical and that a decision can be made on the basis of cost only. In many instances suitable indicators of cost-effectiveness can be devised such as the number of cases avoided and the number of additonal years of life 'saved'. But often, if not always, there are differences in health outcomes between options. It would be seriously misleading if one ignored those items of benefit (or indeed cost) which were difficult to quantify and value. There are many clinical, psychological and sociological instruments available which enable one to measure at least some of the differences in health outcomes. These differences still cannot be valued but they do attempt to quantify at least some aspects of them.

The 'cost benefit approach' attempts to construct a 'balance sheet' of costs and benefits which summarises all the information relevant to a decision. Where possible each item should be quantified and valued but even if no information is available on a particular element of cost or benefit it should be listed.

GUIDELINES

All this may seem obvious and largely a matter of common sense. Nevertheless there are many studies which are unsatisfactory because they are incomplete or because the results are not presented clearly. Below are a number of guidelines which may help to avoid the more common pitfalls.

Identify all relevant options

This is, arguably, the most important stage in the analysis. There have been studies where, in retrospect it is clear that there was a failure to identify all the relevant options at the outset. If option selection is too constrained initially there is a danger that the validity of the later analysis, however sophisticated, may be called into question because not all of the appropriate alternatives have been considered.

Include all costs and benefits

All relevant costs and benefits irrespective upon whom they fall - public, private sector - should be identified and included in the analysis even though not all may be measured or valued in the course of the analysis. This is where CBA differs from the routine financial appraisals carried out in the private sector and relfects its roots in 'welfare economics'. In general, CBA is concerned with the impact of programmes on the welfare of society as a whole rather than the impact on particular sections of society*.

Opportunity costs

A distinction needs to be drawn between a resource cost (the concept appropriate to CBA) and a financial cost. A financial cost occurs whenever money changes hands. A resource cost occurs if resources are devoted to a particular activity when they could have been used elsewhere. Such resources

*This is, of course, not to deny that the distributional consequences of alternative options might be an important consideration in any final decision.

have an opportunity cost: the benefit (lost) that would be derived from using it in its next best alternative use. In many cases financial and opportunity cost will coincide, but this is not always the case and confusion often arises because both are usually measured in monetary terms. An example of where they would not coincide is where staff already owned by a health authority are switched to a new activity without changing the total number of staff employed. The opportunity cost of the activities now forgone should be counted as a cost in the evaluation.

Marginal costs and benefits

The concept relevant for CBA is that of the 'margin'. Is is essential to estimate the incremental or 'marginal' costs and benefits of expanding or reducing a particular activity by a certain amount. For example where capital resources are underused an expansion may simply take up spare capacity and the marginal cost of expansion is simply the additional staff and materials consumed. To include an element of capital costs in such a situation will overestimate the costs involved.

Discounting

The costs and benefits associated with services often do not occur at the same point in time. In some instances the benefits from a programme may accrue over a number of years after an initial input of resources. This is especially true of programmes concerned with prevention; for example antenatal screening for spina bifida or mongolism requires an initial input of resources, whereas the cost savings from such programmes will accrue over a period of years. Conversely some programmes will involve resource inputs over a number of years, for example the special diet used to treat phenylketonuria. It is essential to take into account the differential timing of costs and benefits. The problem of timing can be handled by the process of discounting all costs and benefits to obtain a present value.

It is evident that, say, £1 spent now is considered to be of more value than £1 spent in, say 5 or 10 years time, from the fact that, even in the absence of general inflation, people borrow and lend at interest. The process of discounting allows differences in the timing of costs of options to be accommodated for the purposes of appraisal by reducing costs to a present value, i.e. as if they occurred at the same point in time. Essentially, discounting is a process of assigning lower weights to costs and benefits occurring in the future (see Treasury (1982) for an explanation of the mechanics of discounting).

The rate of discount measures how rapidly the present value of a future £ falls away the further ahead one looks. The public sector when appraising projects uses the Test Discount Rate (TDR) as determined by the Treasury. Currently the TDR stands at a basic 5% (see Treasury (1979) for a discussion of the determination of the TDR). It is often asked how a 5% discount rate can be justified when current market rates of interest are much higher. There are two reasons: the first is that CBA should normally be carried out in constant prices and thus a real rate of discount (to reflect real return on investment) net of the prevailing or expected rate of inflation should be used; second, the 5% represents the rate of return on the marginal project in the private sector. The public sector should not undertake projects which yield a lower return.

CONCLUSIONS

Hopefully, what has emerged from this short paper is that CBA is a way of thinking about problems, a framework that enables the merits of alternative solutions to be systematically compared and quantified wherever possible, which can be applied to most fields of decision making.

CBA has been developed within the public sector as an aid to resource allocation problems in fields where markets do not exist and where there is a lack of 'market signals' to guide the size and direction of investments and where governments are responsible for determining the shape of services offered eg health, defence, road building. Clearly given that veterinary medicine in this country is predominantly a private sector activity there will be fewer instances in which the full panoply of CBA can be brought to bear. Many decisions relating to how a practice is organised and run, whether to purchase new items of equipment and so on will be based on an appraisal of the strictly financial consequences of the options to the practice concerned. There will be situations, however, where a more wide ranging analysis is called for. Typically this will tend to be in those areas where the government has a regulatory role because the actions of individuals have effects not only for the individuals concerned but also upon the public at large. The area which readily springs to mind is that of the prevention of diseases both those specific to the animal population and the wider class of zoonotic illnesses which affect human health as well eg brucellosis. The costs of any preventative strategy may fall upon the individual farmer or pet-owner whilst the benefits fall upon both other animal owners and the population as a whole. A strict financial appraisal of the costs and benefits to the individual owner may lead to a different conclusion from a CBA because these wider consequences are unlikely to be included. An analogy in a different field would be the 'Factory Act' regulation which requires employers to adopt certain 'health and safety measures' in their working premises.

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ECONOMIC CONSEQUENCES OF PREVENTION LEGISLATION

THE CASE OF NON-PASTEURISED MILK

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The transmission of disease from animals to man is often preventable but rarely at zero cost. In situations where those who bear this cost are not the ones who benefit from reduced illness, compliance with suggested prevention programmes may only be achievable through legislation. As an act of government, legislation is a societal decision undertaken in the best interest of society as a whole. As such, society must be made better off by the legislation than it would be without it. This is achieved when the total benefits to society exceed the total costs. Any social inequities which may arise as a result of the legislation can be dealt with through income transfers or other forms of compensation.

While the calculation of costs arising from legislation is, in most cases, relatively straightforward, the same cannot be said for benefits. Essentially, the benefits of preventing human disease arise in three forms. First there is the actual savings of the health care and other resources which would have been consumed as a result of illness. Second there is the value of the work output which will now not be lost due to illness. Finally, there is the value attached to health per se or conversely the value attached to avoided pain and grief, lost leisure time, loss of life, and other such 'intangibles'. Though avoided costs of this third type are not readily measured in monetary terms, they are no less real. To ignore them is to suggest that no value would be attached to their reduction and society would be unwilling to pay anything towards their reduction. This is clearly not the case. By their nature, however, such elements cannot be uncontentiously valued; thus value judgments cannot be avoided. Economic appraisals have the advantage of making explicit those value judgments which are implicit in every decision taken.

Calculation of costs can be complicated by the fact that those at whom legislation is directed can be presented with several alternative means of compliance; with different associated cost implications. For example, the cost of muzzling dogs to prevent hydatid disease will differ from the cost of treating the dog after it becomes ill. Both measures will prevent the transmission of the disease to man. It is difficult to predict total cost when such choice exists. However, as will be shown this does not pose an insurmountable problem.

The example which will be used to illustrate the cost-benefit approach in the appraisal of prevention legislation, concerns a proposed ban on the sale of non-pasteurised milk in Scotland, due to be debated in Parliament in August, 1983 (Hansard 1980). Though non-pasteurised milk represents only 6% of total liquid milk consumption in Scotland (UK Milk Marketing Board 1981) it has been

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responsible for many outbreaks of milk-borne infections affecting hundreds of individuals (Sharp, Paterson and Forbes 1980). With milk-borne brucellosis and tuberculosis no longer a problem in Scotland due to successful herd erradication programmes, salmonellosis and campylobacter enteritis are currently the main milk-borne infections. It has been proposed (Sharp, Paterson and Forbes 1980) that a ban on the retail sale of non-pasteurised milk in Scotland will avoid all future general community outbreaks of such infections. The ban will have no affect on outbreaks confined to farm workers and their families who, it is anticipated, will continue to consume non-pasteurised milk. Against these benefits must be weighed the costs imposed by the proposed ban, on the dairy farming industry.

QUANTIFYING BENEFITS

In this example, the benefits resulting from the proposed ban are viewed solely in terms of reductions in the number of salmonella infections. Though other pathogens are killed by the process of heat treatment (Waterman 1982) and, thus, other milk-borne infections will also be prevented by the ban, it will be shown that the benefits of reduced salmonellosis alone will be sufficient to offset the costs. The additional benefits derived from reductions in other milk-borne infections are merely 'icing on the cake'. This approach is generally applicable to any cost benefit study. If minimum estimates of benefits are shown to exceed costs then accurate derivation of all relevant benefits becomes unnecessary.

It is here assumed that a ban on the retail sale of non-pasteurised milk in Scotland will prevent all future general community outbreaks of milk-borne salmonellosis. Table 1 shows the reported notifications of milk-borne salmonellosis during the period 1970-81 (excluding those confined to farms). There were in all 25 outbreaks affecting at least 3088 people with 11 deaths attributed to salmonellosis. Owing to the wide clinical spectrum of salmonellosis, ill effects may be very mild and in many cases may not be reported or investigated. The figures of Table 1 must, therefore, be regarded as minima.

Table 1. Notifications of milk-borne salmonellosis in Scotland 1970-1981 (excluding outbreaks confined to farms)

Year	Number of outbreaks	Total number infected
1970	2	600
1971	0	0
1972	1	298
1973	0	0
1974	2	37
1975	3	211
1976	2	726
1977	3	51
1978	2	219
1979	3	149
1980	2	78
1981	5	719
Average	2.1	257.3

Table 1 shows no observable decline in notifications over the period. While predictions of future outbreaks in the absence of a ban are necessarily speculative, the absence of any trend of decline in recent years makes it not unreasonable to predict that current number of notifications will continue into future years. The benefits of a ban on the sale of non-pasteurised milk can therefore be estimated as the avoidable costs of two general community outbreaks per year, affecting on average a total of 257 people per year.

VALUING BENEFITS

For the cost-benefit comparison, it will be necessary to place a monetary value on these 257 avoided cases per year. In this exercise the cost per case was determined from a detailed costing of a recent major outbreak of milk-borne salmonellosis in Keith and district in the Grampian region. The source of infection was traced to non-pasteurised milk emanating from a single producer-retailing dairy farm. At least 654 people were affected (448 cases laboratory confirmed), 23 people were hospitalised, and there were two associated deaths. As with any communicable disease outbreak considerable costs were imposed on many diverse agents.

First there are the numerous costs which can be relatively uncontentiously measured in monetary terms. These include the costs of all medical treatment, laboratory investigations, veterinary services, environmental health surveillance, travel, and the lost output by employed persons. In addition, however, there are the costs which are not readily measured in monetary terms but which nevertheless represent real losses. These include the value of housewives' (non-marketed) lost output, the value of time to those who travelled from Keith to visit hospitalised relatives/friends, the value of the 'pain, grief and suffering' to those who were ill, and the value attached to the lives of the two individuals who died.

Hospital costs

The cost of treating the 23 people who were hospitalised (average length of stay = 12 days) include the cost of (a) transportation to hospital (b) drugs (c) investigations undertaken (d) medical and nursing staff time (e) 'hotel' and other costs. Items (a)-(c) are resources consumed as a result of the outbreak and represent financial costs which would have been saved, had the outbreak been avoided.

The costing of medical and nursing staff time however is not as straight-forward. The average cost per patient day does not reflect the actual saving which would have been realised, had the outbreak been prevented. Of greater relevance are the marginal costs i.e. the extra costs of treating an extra patient; which in almost all cases where there is a spare capacity will be less than average costs. In this exercise the less than ideal average costs were used, partly because of the difficulty in measuring marginal costs, but mainly because of the very high bed occupancy rate in the Infection Unit where most patients were kept. When full capacity is neared, the gap between marginal and average costs is narrowed (Cullis and West 1979). For 'hotel' costs (food, linen, etc.), average costs are appropriate. The total cost of hospitalisation was £21,138 as shown in Table 2.

Other costs of treating those affected

The cost of general practitioner services was based on the cost per visit derived from an earlier study in Grampian region (Mooney 1978) multiplied by the number of extra visits resulting from the outbreak. Community nursing staff, senior medical/nursing staff, and administrative and clerical staff recorded the time devoted directly to dealing with the outbreak. This was multiplied by the relevant cost per hour to determine items 1b-1e of Table 2. The total cost of treating those who were ill was £33,738.

Other direct costs

The cost of laboratory investigations, other than those to the hospitalised patients are shown in Table 2 as items 2-4. The figure for veterinary costs represents only that of investigations by public health veterinary bodies and does not include any cost to the farmer of treating infected animals. Had the milk from the infected herd been pasteurised, the outbreak would not have occurred. Costs to the farmer in treating infected cattle would, therefore, have been the same with or without the outbreak and cannot be considered a cost of the outbreak. This is a general rule in costing, and it is important to separate costs which would have occurred regardless of the outbreak, from those which arise directly because of it.

Indirect costs

Items 1-6 of Table 2 are the costs of treating the outbreak. Items 7 and 8 are costs which arose as a result of the outbreak. The figure for item 8 is the value of lost output due to time off work which is represented by the gross cost of employing that labour (Morgan and Davies 1981). Financial transfers such as compensation for lost wages do not represent real resource losses and are not included. There were, in all, 1357 working days lost as a result of the outbreak.

Table 2. Tangible costs of the outbreak (£)

I	Direct Costs					
	(1)	Medical				
		(a) hospitalisation		21,138		
		(b) general practitioners		2,529		
		(c) field work nurses		6,195		
		(d) senior medical/nursing staff		2,000		
		(e) administrative and clerical		1,360		
		(f) others		516		
			Total		33,738	
	(2)	Laboratory investigations (human)			2,112	
	(3)	Laboratory investigations (milk)			27	
	(4)	Phage typing			1,490	
	(5)	Veterinary			910	
	(6)	Environmental health surveillance			6,075	
		Total direct costs				44,352
II	Indirect tangible costs					
	(7)	Travel to visit hospital patients			2,873	
	(8)	Lost productive output			36,864	
		Total indirect tangible costs				39,737
		Total tangible costs				84,089

Intangible losses

Since by their nature intangible losses cannot be valued uncontentiously, ranges of values were used in this exercise showing what are believed to be the minimum and maximum possible values attached to these losses.

Housewives' lost output is often valued at the equivalent cost of employing a working woman of similar age (Department of Transport 1981). In this study we prefer to use the cost of employing a home help as this most closely resembles 'replacement cost'. There were 464 days in which housewives' routine was disrupted due to salmonellosis. Had no housework at all been done during this time the value of the lost output would be £36,888, which was taken to be the maximum estimate. It is likely however that all work did not stop during this period, particularly if there were small children in the family. A mid-range estimate of 50% of lost output was taken and a minimum of 25% as shown in Table 3.

The figure for 'pain, grief and suffering' is based on the methodology used by the Department of Transport (1981) in calculating the cost of road accidents. Since this figure is necessarily imprecise, it was taken as a mid-range estimate with values ± 50% used for the minimum and maximum estimates.

Table 3 shows that by far the widest range is that given for loss of life. Several methods of valuing life have been used in economic appraisals (see Mooney 1977). That which gives the lowest value is the 'human capital approach', which is based on an individual's expected future production. The most recent adaptation of this approach puts a mean value of £109,000 on human life (Morgan and Davies 1981). In contrast the 'willingness to pay approach', based on the amount that an individual would be prepared to pay to reduce a particular risk of dying by some small amount, gives a value for human life as high as £3 million (Jones-Lee 1976). These two extremes are here taken as the minimum and maximum values of the range for the value of lost life with the mid-range value arbitrarily taken as the mid-point between them.

Since salmonellosis is normally non-fatal, it would be inappropriate to equate a salmonellosis related death with the loss of a 'typical' life (i.e. the mean value of life). If the pre-infection condition of the individual was such that he/she had an X% chance of normal life expectancy then the cost of a salmonellosis related death could be assessed at X% of the value of a typical life. On this basis the cost of the two salmonellosis associated deaths in the Grampian outbreak have been taken as 10% of the value of a typical life in the case of the first death (an elderly man who was in poor health before infection) and 90% in the case of the second (an otherwise healthy 6 year old girl who developed colitis). Thus the loss of these two lives is roughly equivalent to the loss of a single 'typical' life.

Table 3 shows the total cost of the Grampian outbreak to be between £236,001 and £3,222,047 depending on the value of the intangible losses. As will be shown however, the upper estimates are of no importance to the cost-benefit analysis. Of more relevance is the fact that the cost of the outbreak was at least £236,001 and the associated cost per case at least £361.

As a ban on the sale of non-pasteurised milk in Scotland is expected to prevent 257 cases of milk-borne salmonellosis per year the benefits of the ban will be at least £92,777 (361 x 257). The high proportion of total cost attributable to the value of lost life shows these results to be sensitive to variations in the number of deaths. However the types of cases arising in the

Keith outbreak are considered to be fairly typical of those which would arise in future in the absence of any ban (Sharp, Paterson and Forbes 1980).

Table 3. Total costs (£) of the outbreak under various assumptions

	minimum	mid	maximum
Intangible costs			
loss of housewives' output	9,222	18,444	36,888
pain, grief and suffering	33,450	66,900	100,350
loss of time	240	480	720
loss of life	109,000	1,554,500	3,000,000
Total intangible costs	151,912	1,640,324	3,137,958
Tangible costs	84,089	84,089	84,089
Total cost of the outbreak	236,001	1,724,413	3,222,047
Number of reported cases	654	654	654
Cost per case	361	2,637	4,927

Quantifying the costs

The main sources of non-pasteurised milk in Scotland are producer-retailer dairy farmers who sell the output of their own herds directly or through a retail outlet. Of 260 current producer-retailers, 37 mainly larger ones, already have on-farm pasteurisers. A ban on the sale of non-pasteurised milk will leave the remaining 223 with the choice of having all output collected by the Milk Marketing Board for central pasteurisation, or of purchasing pasteurisation equipment. In the former case costs will be negligible, as Milk Marketing Board tankers pass by (or near) most producer-retailers anyway, and the marginal cost of pasteurising milk at the large pasteurising plants is insignificant. In the latter case the average cost per producer-retailer has been estimated at £2,297 per year (Cohen 1982) which includes the costs of purchase, heat treatment and maintenance.

Clearly, the more who choose this latter option, the greater will be the total cost. This can be influenced by the amount of subsidy which government is willing to provide. In this case a government grant of 22½% is available. The grant itself, however, is only a financial transfer, shifting the cost burden from the producer to state. It does not itself represent a cost of the ban.

It is assumed in this exercise that the number of producer-retailers who choose the latter option will be small. This view is justified by the fact that there are currently less than 1/7th the number of producer-retailers than there were in 1955 and the rate of decline has been increasing since 1965 (UK Milk Marketing Boards, various years). Clearly producer-retailing, particularly on a small scale is a relatively inefficient way of getting milk from producer to consumer. The ban is likely to act as a catalyst to the further reduction in the number of produder-retailers and consequently the number choosing to continue retailing using on-farm pasteurisers is likely to be small.

The cost-benefit comparison

The minimum total annual benefits from the ban (£92,777) will exceed the cost if up to 40 producer-retailers choose to purchase new equipment (£2,297 x 40 = £91,880). A greater number would require some higher than minimum value for the intangible benefits. However, the mid-value benefits are sufficient to exceed the costs even if all producer-retailers chose this option. As was shown above, that is an extremely unlikely situation with the actual number likely to be very small. The ban could thus fail the cost-benefit test only if some extremely unlikely behaviour on the part of producer-retailers is coupled with the most extreme assumptions about the values attached to intangible benefits.

However, as was mentioned earlier even the minimum benefit estimate of the range understates true total benefits. It is based on reported cases only, and perhaps of greatest importance, the accompanying reductions in other milk-borne infections have not been considered. Thus despite numerous uncertainties the analysis suggests that society will almost certainly be made better off by a ban on the retail sale of non-pasteurised milk in Scotland.

DISCUSSION

The example used here illustrates several important features of economic appraisal as applied to prevention legislation. Since the objective of all legislation must be to make society better off, it can only be justified if expected benefits exceed expected costs. The fact that costs and benefits may not be distributed equitably does not alter this condition. Any inequities can be corrected by compensation (in this case a subsidy on the cost of pasteurisation equipment) leaving society in the better off state. Such transfer payments can be used to encourage the preferred method of compliance when choice exists.

All costs and benefits are relevant regardless of whether or not they are readily measured in monetary terms. Economists have devised several methods of valuing intangibles (see Drummond 1980). Though contention may surround the methodology, valuation of intangibles is part and parcel of the decision-making process, even if only by implication. By detailing the expected resource savings (tangible benefits) the appraisal specifies the minimum value which would have to be placed on the intangibles to justify the legislation, thus making the unavoidable value judgments explicit.

Finally, if partial benefits can be shown to exceed costs, it becomes unnecessary to derive values for all benefits. If assumptions which minimize the value of the included benefits are used, then such partial benefit measurement is unlikely to draw the wrong conclusion. In this example inclusion of other avoided milk-borne infections would only strengthen the conclusion.

Zoonosis is in many instances preventable. To determine which preventive measures ought to be enforced by law calls for more economic appraisals to be undertaken. These relatively low cost exercises may point out many cases of preventable zoonotic diseases where legislation is overdue.

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THE ECONOMICS OF POOR HUSBANDRY: THE COSTS AND BENEFITS OF FERTILITY MANAGEMENT

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Fertility problems in dairy herds cause large financial losses. Several authors, in different countries, calculated the losses due to fertility problems in losses per day extended calving interval. The results varied from less than £0.20 to more than £1.00 per day extended calving index (Dykhuizen, 1981). A mean calving interval of 381 days, like in the U.K. (MMB., 1977/78), would result in a loss of about £1100 per year for a herd of 100 cows (if a loss of 60p. per day is assumed). Lineweaver and Spessard, (1975) calculated a loss of 540 million dollars for the U.S. dairy farmer in 1975, due to fertility inefficiency.

The losses, related to a bad fertility state, are mainly the result of a lower annual milk yield, lower income from calf sales and the involuntary culling of, often very valuable, cows. A factor associated with losses due to lower annual milk yields, is the change in the calving pattern of the herd. only a one year calving index can prevent a cow calving down in the most profitable month of the year, calving down in a less profitable month next year. Calving intervals of about one year allow a farmer to take maximum advantage of the variation in milk prices and yield, calf prices and available feedstuffs every year.

It is important for an adviser to understand which factors influence the fertility state of the herd and what their mutual interrelationships and relations to other factors, (e.g. calving season) are. Certainly it is obvious that many of these factors can be influenced by management.

LITERATURE

The losses associated with fertility problems in dairy herds are the result of extended calving intervals and the involuntary culling of cows.

Losses due to extended calving intervals

Many authors found that the optimal calving interval is 365 days or shorter. (MMB., 1968/69); Bozworth, Ward, Call and Bonewitz, 1972; Esslemont, 1974a; Britt, 1975; Stevenson and Britt, 1977; James and Esslemont, 1979; Dykhuizen, 1981). According to Dykhuizen (1981) losses due to extended calving intervals are associated with lower incomes from milk and calf sales and other components as higher vet. costs, insemination costs and costs associated with labour.

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Longer calving intervals result in higher yields per lactation; the annual milk yield will however be lower resulting in a lower production per cow life (Perdok, 1978). Compensating factors are the feeding costs, assuming that a lower production is associated with lower feeding costs, and the effect of extended calving intervals on the milk production in the next lactation. Van der Lende, James and Esslemont (1979), using a simulation model, calculated e.g. that the average feeding costs of the production of one litre of milk was 6.124 pence for a cow with a calving interval of 365 days and 5.903 pence for a cow with a calving interval of 420 days (silage price : £12.5/ton and concentrate price £110/ton). Calving intervals, longer than one year, not only consist of longer lactations but also of longer dry periods. Bailie (1980) used in his calculations a 0.66 day longer lactation period when the calving interval was extended by one day. Dykhuizen (1981) used figures of 0.8, 0.7 and 0.6 day longer lactations, per day extended calving intervals, for respectively calving intervals of smaller than 365 days, between 365 and 405 days and longer than 405 days. During these longer lactations and longer dry periods more energy can be stored which will be used in the subsequent lactation, resulting in a higher yield in that lactation (Esslemont, 1974a; van der Lende _et al._, 1979; Dykhuizen, 1981).

In countries where the milk is paid according to its fat and protein content the losses due to lower annual milkyield will also be compensated by higher milk prices for the milk in the last part of the lactation (Dykhuizen, 1981).

Losses due to lower milk production depend on the milk price, the yield level and the production effect in the next lactation. A change in these factors is however of minor importance to the total losses due to extended calving intervals (van der Lende _et al._, 1979; Dykhuizen, 1981). The persistency of the milk production is of much more importance. Short calving intervals are of more importance for cows with a low persistency. Dykhuizen (1981), using a simulation model, calculated a reduction of 50% in the total losses when the persistency increased 10% from the initial average value.

A smaller number of calves will be born and the income from calf sales will reduce when the calving interval extends (Esslemont, 1974a; Britt, 1975; Stevenson and Britt, 1977; van der Lende _et al._, 1979; Dykhuizen, 1981). The losses associated with this factor depend on the calf prices. Zeddies (1977) quoted by van der Lende _et al._, (1979) emphasises the importance of the calf prices because of their comparatively larger influence on the economic meaning of the calving interval. Higher calf prices make shorter calving intervals more important. According to Dykhuizen (1981) the influence of changing calf prices on the total losses due to extended calving intervals is of minor importance.

Culling and replacing of dairy cows

Short mean calving intervals can be achieved by culling cows which did not conceive in a particular time after calving. This time may depend on the breeding season, resulting in the culling of cows which did not conceive in this season, or on the number of inseminations which are permitted for each cow before she will be culled. Bailie (1980) calculated e.g. a decrease of 13%, from 13.6% to 0.6%, in the number of culls because of failure to conceive when the fertility factor (detection rate multiplied with conception rate) increased from 20% to 50% (the number of permitted services was 4 meaning 7 permitted cycles when having a detection rate of 60%).

Without mentioning the culling rate for fertility the calving interval is a fertility parameter of less importance (Perdok, 1978; Bailie, 1981; pers. comm.). Total culling rates are about 25% and 25-35% of the culls are made because of reproduction problems (Bailie, 1980). The MMB (1977/78) calculated that 30.7% of the cows culled in 14 dairy farms in Wiltshire were culled because of fertility problems (total number of culls was 240 cows out of 1350). Spooner (1978), cited by Bailie (1980) found a total culling rate of 26.9% (3157 culls out of 11725 cows) of which 35.35% was culled because of breeding problems.

Losses due to low fertility also find their origin in the involuntary culling of cows which did not conceive. If a farmer does not cull he will have the financial losses due to extended calving intervals; if he does cull the losses due to the involuntary cull (Dykhuizen, 1981). Esslemont (1978), quoted by van der Lende et al., (1973), worked with a loss of £150 per involuntary cull. Dykhuizen (1981) writes that the loss of an involuntary cull depends on the age and (future) production of the cow. An average value of Dfl.460 was calculated with a range of Dfl 0.00 to Dfl 2250 = (1 Dfl = £0.21 1981). These losses are lower than losses due to involuntary culls for other reasons than fertility because cows, culled for fertility reasons, most often finish their current lactation (Dykhuizen, 1981)

High culling rates for fertility and thus high culling rates in general result in:-

- fewer cows can be carried, more heifers have to be reared.
- more cows needed for breeding pure
- a younger herd, resulting in a lower yield, extra feeding requirements for growth.
- larger improvement in genetic value of the herd
- replacement costs per cow will be high

(Gartner, 1980)

Heifer rearing and replacement policy are substantial problems in dairy herd management (Esslemont, 1981, pers. comm.). When having high culling rates and low fertility it will be difficult to have enough heifers available which can enter the herd in the beginning of the calving season to maintain the calving pattern or offset the excessive delays in the calving to conception interval of the cows (Esslemont, 1974a). According to Salisbury, Vandermark and Lodge (1978) there should be no delay in the age at first calving to avoid considerable losses. The optimal age at first calving is 24 months, provided that a sufficient weight is achieved (Pack, 1975; Perdok, 1978). As reasons for this age, in comparison with older ages at first calving, higher yields per cow life, lower rearing costs and an earlier entry of genetical potential and invested capital in the herd are given. Gartner (1980) calculated that a reduction in the age at first calving from 36 to 24 months was the most profitable in comparison with other changes in culling rate (from 0.20 to 0.30), calving index (13 to 12 months), a better health or the use of better bulls. 24 month old animals at first calving demand a calving index of 12 months (Bailie, 1980; Gartner, 1980).

Next to the culling rate the age at first calving determines the number of heifers to be reared and the number of animals which can be bred to a beef bull. High culling rates and ages at first calving of about 20% in comparison with

15% when the age at first calving is 24 months (Gartner, 1980), require the breeding of many or perhaps all cows to a dairy bull and thus losing the extra profit from higher calf prices. When heifers also have to be bred to a dairy bull the advantages of less difficult calvings, when using a beef bull, is lost in addition.

Seasonal effects

The effect of a low fertility in a dairy herd expresses itself in the calving pattern. The calving pattern depends on the calving interval, the culling rate and replacement policy (Charlton and Street, 1975). Wood (1969) found, using lactation records of 859 Friesians, that cows calving down in the winter months had higher productions than cows calving down in spring; a cow calving down in, e.g. November would have a 7.8% higher expected yield than if she had calved down in January. Next to this seasonal effect there was an effect of the month of lactation (spring hump seasonality). James and Esslemont (1973) found that the month of calving influenced the M.O.C. (margins over concentrate) markedly. In their simulation model they calculated that a high yielding cow calving down in November and having a 365 day calving interval, would have a M.O.C. of £382.10 in comparison with £318 when the same cow would have calved down in April. Good fertility, i.e. a one year calving interval, does not only influence the milk yield by achieving higher annual yields but also makes it possible to take advantage of more profit every year. Van der Lende _et al_., (1975) also found that the month of calving influenced the losses due to extended calving intervals; the only seasonal factors in their calculations were the milk price and the milk production from forage. The effects of the month of calving and the month of lactation on the yield were assumed to be managerial. According to Wood (1979); pers. comm. , quoted by van der Lende _et al_., (1970), calving-month seasonality is not managerial.

The interval calving to conception.

The variation in the calving interval is mainly the result of variations in the interval between calving and conception, if a constant gestation period is assumed.

To achieve calving intervals of one year the interval between calving and conception has to be 80-85 days (Britt, 1975; Bailie, 1980). The interval between calving and conception, in its turn, can be divided into two intervals: the waiting period, being the interval between calving and the time on which one decides to start inseminating, and the period between the end of the waiting period and conception.

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