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Diagnosis and Epidemiology of Foot-and-Mouth Disease in Southeast Asia

Proceedings of an international workshop held at Lampang, Thailand, September 6–9, 1993

Editors: J.W. Copland, L.J. Gleeson and Chanpen Chamnanpood

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Contents

Foreword

These proceedings report the result of six years' collaboration between the Australian Animal Health Laboratory, CSIRO, Australia, and the Department of Livestock Development, Ministry of Agriculture and Co-operatives, Thailand. At the conclusion of the project, it was agreed that a Workshop be held to allow the benefits of the ACIAR research collaboration to be shared throughout Asia where foot-and-mouth disease (FMD) is a problem in animal production and restricts international trade opportunities. These proceedings will give the reader an up-to-date overview of the FMD situation in Asia as a region and by countries. It also highlights the regional FMD control and eradication strategies as being the most appropriate for the land-based countries. The collective thinking was that a regional approach for the control of FMD is essential.

The Workshop members were welcomed by Dr Wipit Chaisongkram, Deputy Director of the Department of Livestock Development, Captain Ariya Uparemes, Provincial Governor, Lampang and Mr John McCarthy, the Australian Ambassador. The Deputy Minister of Agriculture and Co-operatives, Mr Sawat Suebsaiphon formally opened the Workshop. Mr Wipit highlighted the earlier importance of the FMD and earlier FAO/APHCA activities; Mr McCarthy stressed the importance of FMD as a trade barrier to western markets; and Mr Sawat emphasised the importance that the Ministry places on the control and eradication of FMD. He also complimented the project staff on their well developed spirit of collaboration that was one of the major achievements of the project.

These proceedings represent contributions from 17 countries, four international agencies and some 80 scientists who came together at Lampang in Northern Thailand. It is hoped that this meeting will provide the catalyst for the development of a successful regional approach for the control and hopeful eradication of FMD in parts of Asia. The research findings will be incorporated in the proposed FMD regional strategy, with a new ACIAR project on 'Animal Health Information Systems in Thailand and Australia' crystallising the earlier experience into a working model for the region.

George Rothschild
Director
ACIAR

OVERVIEW OF GLOBAL FOOT-AND-MOUTH DISEASE STATUS AND ISSUES

The first session of the program dealt with some of the broad issues that influence foot-and-mouth disease (FMD) control programs on a global basis. The two speakers addressed key factors for FMD control that arise in a range of environments, and set the scene for the subsequent focus on key regional issues for FMD control in Southeast Asia.

The first keynote speaker was Dr Alex Donaldson from the World Reference Laboratory at Pirbright, United Kingdom, who stressed that the reason for striving to understand the epidemiology of a disease is to be able to design optimal strategies for control and eradication. The epidemiology of foot-and-mouth disease is complex and can vary, particularly under different systems of animal management and husbandry practices. Dr Donaldson discussed the key aspects of the epidemiology of FMD under the following broad headings:

- global occurrence and serotype;
- pathogenesis;
- transmission;
- production systems and environment;
- vaccination and epidemiology; and
- susceptible species and their importance in different environments.

The second keynote speaker, Dr Michel Lombard from Rhone-Merieux Ltd, a leading manufacturer of veterinary biologicals including FMD vaccine, discussed aspects of foot-and-mouth disease vaccines which constitute a small part of the total world veterinary biologicals market and are expensive to produce, purchase and administer. As many countries throughout the world have been successful in eradicating FMD the production of vaccines has declined. In order to maintain and improve the availability of FMD vaccines and products, the production and marketing of them needs to bring a reasonable return to the producers to cover ongoing investment and research.

The performance of FMD vaccine in the field depends on the manufacturer supplying an efficaceous product, the vaccine virus strain being appropriate for current field viruses, and on the effective management of the vaccination program so as to achieve vaccine coverage of not less than 75% of the population at risk. Many countries that have effectively covered these parameters have been successful in the eradication of FMD.

Epidemiology of Foot-and-Mouth Disease: the Current Situation and New Perspectives

A.I. Donaldson*

Abstract

The reason for striving to understand the epidemiology of a disease is to be able to design optimal strategies for control and eradication. The epidemiology of foot-and-mouth disease is complex and can vary, particularly under different systems of animal management and husbandry practices. Although the main mechanisms of transmission are well known and can be prevented by effective action, the measures involved, e.g. stamping out, may be prohibitively expensive for some communities and countries. Thus disease control strategies which are accepted in some countries may not be appropriate for others. To be successful any disease control program must have the support of the farming community who must be convinced of the advantages. This is best achieved by a benefit-cost analysis of the different strategies which are possible before a selection is made, followed by discussions with the farming community before they are implemented.

In addressing the title and subheadings of this paper I will have of necessity to be selective but in so doing I will attempt to identify main features, highlighting those which I believe have relevance to the foot-and-mouth disease (FMD) situation in Asia. I hope some of my remarks will stimulate comment from those in the audience who have greater personal experience of animal husbandry systems in Asia and the constraints on disease control.

Global Occurrence and Serotype

The information which follows has been obtained from the World Reference Laboratory (WRL) for FMD at Pirbright in the United Kingdom; from the Tokyo office of the Office International des Épizooties (OIE); and from the veterinary authorities of the countries mentioned. Table 1 shows data compiled by WRL for the period January–June 1993 based on samples received for investigation.

Unfortunately the picture is not complete, as many countries, particularly those where the disease is endemic, do not always investigate outbreaks and collect samples for serotype identification. In terms of the frequency of outbreaks, regions, countries and zones within countries can be classified as *endemic*, *sporadic* or *free* as follows:

- *endemic* — most of South America, Africa and Asia;
- *sporadic* — Italy, Bulgaria, Israel, the Russian Federation; Malaysia and the Magreb countries of North Africa. In Southern Africa the livestock populations of Botswana, Zimbabwe and the Republic of South Africa are free but the virus is present in wildlife species in game parks; and
- *free* — Central, Middle and North America (including the islands of the Caribbean), Australia, New Zealand, Japan, Indonesia, North and South Korea, Chile, Uruguay, Guyana, French Guyana, Surinam and most of Europe.

The different serotypes of FMD are distributed around the world according to geographical patterns. In South America only types O, A and C are found with O and A predominating. In North Africa outbreaks are generally due to type O. In West, Central and East Africa types SAT 1, SAT 2, O, A and C are found whereas in Southern Africa types SAT 1, SAT 2 and SAT 3 are found but not types O, A and C. Through the Middle East type O is common, followed by A, Asia 1, and occasionally C. In Asia type O predominates though

* Agriculture and Food Research Council, Institute for Animal Health, Pirbright Laboratory, Woking, Surrey GU24 0NF, England.

Table 1. World reference laboratory for foot-and-mouth disease, cumulative report for January–June 1993.

Country	No. of samples	O	A	C	SAT 1	SAT 2	SAT 3	ASIA 1	NVD
Algeria	2	—	—	—	—	—	—	—	2
Bahrain	7	5	—	—	—	—	—	—	2
Bhutan	3	2	—	—	—	—	—	—	1
Bulgaria	1	1	—	—	—	—	—	—	—
Cambodia	7	1	—	—	—	—	—	—	6
Eire	5	—	—	—	—	—	—	—	5
Ethiopia	10	9	1	—	—	—	—	—	—
Ghana	9	7	—	—	—	—	—	—	2
Hong Kong	7	7	—	—	—	—	—	—	—
Iran	12	11	—	—	—	—	—	—	1
Israel	1	1	—	—	—	—	—	—	—
Italy	14	5	—	—	—	—	—	—	3
Jordan	1	1	—	—	—	—	—	—	—
Laos	3	—	—	—	—	—	—	2	1
Malawi	13	—	—	—	—	—	—	—	13
Malaysia	9	4	—	—	—	—	—	4	1
Nepal	30	2	—	8	—	—	—	—	20
Saudi Arabia[a]	22	15	17	—	—	—	—	—	2
Spain	2	—	—	—	—	—	—	—	—
Turkey	8	8	—	—	—	—	—	—	—
United Kingdom	13	—	—	—	—	—	—	—	13
Vietnam	3	—	—	—	—	—	—	3	—
Yemen	2	—	—	—	—	—	—	—	2
Zambia	9	—	—	—	—	—	—	—	9
Total	193	79	18	8	—	—	—	9	83

[a] 12 Samples from Saudi Arabia contained both FMD virus types O and A
NVD = No virus detected
— = Not detected

types Asia 1 and A are also found. Type C occurs rarely despite the susceptibility of a high proportion of animals to this serotype as it is frequently omitted from vaccines. Some countries in Asia have reported just one serotype for several years e.g. type O in Sri Lanka.

An interesting recent finding by WRL has been the simultaneous isolation of more than one serotype from a single sample of epithelial tissue submitted from a field case. In a series of cases two serotypes have been isolated, and in one sample three serotypes. This phenomenon has only been found with samples submitted from countries where the disease is endemic and includes Turkey (Asia Minor), Saudi Arabia, Kenya and Nepal. These findings are clearly very important in relation to vaccine selection for emergency use. The matter is presently under investigation but we do not yet have an explanation.

Before leaving this section it may be of interest to highlight some recent outbreaks of FMD to provide examples of some success stories in eradication campaigns against the disease. Morocco, which was affected by a very severe epidemic extending from east to west across North Africa during 1989–91, reported its last outbreak in September 1992. This was achieved by an extensive vaccination campaign of sheep, cattle and goats. The epidemic was characterised by a high morbidity rate in sheep and mortality in lambs, with only a few outbreaks in cattle.

Zimbabwe suffered an epidemic in its non-vaccinated area in 1991 which severely disrupted its beef export trade to the European Community. By a policy of mainly movement control and ring vaccination, supplemented in some cases by stamping out, zonal freedom has been re-established and the export trade resumed.

A success story in South America is Uruguay which has been free of FMD for over 3 years. This has largely been achieved through a high vaccination coverage of the cattle population and movement restrictions. Interestingly, although sheep outnumber cattle by 2.6:1 it has not been found necessary to continue vaccinating the sheep, and this was abandoned several years ago. This year OIE recognised Uruguay as a *'country free of FMD with vaccination'*.

In regard to Asia, Malaysia suffered outbreaks of type O and Asia 1 in 1992–93 which both began near its border with Thailand. The type O outbreak in the State of Kelantan lasted from June 1992 to July 1993. It was attributed to the illegal importation of cattle. Spread within Kelantan was by contact through common grazing. The Asia 1 outbreak began in December in the State of Perlis. Control of both epidemics was affected through vaccination and restrictions on the movement of animals and animal products (milk and its by-products) throughout the infected and at-risk zones.

The Philippines appears to be making good progress with FMD control. The Association of South-East Asian Nations (ASEAN) has recognised the declarations of Northern Mindanao, Southern Mindanao and the island provinces of Palawan and Batanes as FMD-free zones (OIE Report 1993). Outbreaks continue in Luzon but no major epidemic has been recorded since 1989.

Indonesia has maintained its FMD-free status since 1983 when the last case was reported in Kefumen, Central Java.

Pathogenesis

It is generally accepted that FMD virus most commonly infects via the respiratory route especially in ruminant species where very small doses can initiate infection (Sellers 1971). This is based on studies in which tissues taken from animals killed soon after exposure by different routes and varying doses of virus have been assayed for the presence of virus and its quantity (Burrows et al. 1981; Terpstra 1972). In cattle and sheep the primary region of viral replication is in and around the pharynx. Inhaled droplets or aerosol particles either impinge directly on, or are transported to, the pharynx by mucociliary activity. In pigs there is less experimental data available but results also suggest that the respiratory route is the more usual portal of entry. However, pigs are relatively more susceptible to infection by the oral route than ruminants (Sellers 1971).

Apart from the respiratory route, infection can also occur when there is a break in an animal's integument i.e. its skin or mucosa. In such circumstances very small quantities of virus, comparable to the minimal doses by the respiratory route i.e. 10–15 ID50, can initiate infection through the wound or damaged area. Thus the injection of faulty (live) FMD vaccine, foot-rot in sheep, the feeding of rough fodder, harsh use of milking machines, surgical procedures and damage caused by fingernails during nose restraint of cattle, can all provide entry points for virus.

Following replication in the primary sites of the pharyngeal area and associated lymph glands the virus enters the bloodstream and is carried to secondary sites including the glandular organs, other lymphatic glands, and the epithelial tissues in and around the mouth and feet where vesicles are produced. Vesicular lesions may also develop on the mammary glands of females.

FMD in adult animals does not usually result in a mortality rate above 5% except in rare circumstances. However, in young stock, especially under conditions of dense stocking, a rate of up to 90% may result. This has been seen in piglets in large intensive units in Europe. Death in both age groups is a consequence of a multifocal necrotic endocarditis, mainly affecting the ventricles and leading to impaired cardiac function and ultimately failure.

In those cases where invasion occurs through a lesion in the integument, replication begins in the epithelium and local lymph glands before entering the bloodstream. With deeper introductions of virus, e.g. following surgical procedures, virus can enter the bloodstream directly without local replication.

The length of the incubation period is variable and depends mainly on the virus strain, dose of exposure and the route of entry. With natural routes and high exposure doses the period can be as short as 2 to 3 days but up to 10–14 days with very low doses (Donaldson 1987). In index cases the exposure dose is usually low and the incubation period for the first cycle of disease will probably be long and the clinical signs may be missed as only a few animals are likely to be affected. However, once virus has been amplified through these animals the potential for spread greatly increases and if animals are densely stocked spread is rapid and the incubation period quickly reduced.

Transmission

During the acute phase of disease, which generally lasts 3–4 days, all excretions, secretions and tissues contain virus. Such animals are very potent spreaders of virus and must be destroyed or effectively isolated if further spread is to be prevented. Their products will contain high quantities of virus and must be decontaminated or destroyed if control is to be effective.

An important feature of FMD is that virus excretion occurs before infected animals manifest clinical signs. Excretion in semen and milk can occur for up to 4 days before the clinical phase and sheep excrete airborne virus in their breath for around 24 hours before signs are apparent (Burrows 1968; Sellers and Parker 1969). Thus movement of incubating animals is a hazard.

The species affected can markedly influence spread. Pigs, for example, liberate vast quantities of airborne virus in their breath — one pig is capable of excreting 400 million infectious units of virus per day. By contrast ruminants excrete a maximum of around 120 000 infectious units per day (Sellers and Parker 1969; Donaldson et al. 1982a). The topic of airborne spread of FMD is considered in more detail in a following section.

After recovery from FMD, up to 80% of ruminant species may become persistently infected. These carriers can initiate fresh outbreaks when brought into contact with fully susceptible animals. Pigs do not become carriers and cease excreting virus within 3–4 weeks after infection. The topic of the carrier state has been recently reviewed by Salt (1993). Transmission from carriers to susceptible livestock has not been reproduced under experimental conditions which indicates that there are as yet unidentified factors which predispose to transmission in the field.

The carrier state can also become established in immune animals. Thus vaccinated animals exposed to infection may become carriers. Irrespective of the mechanism of establishment, the site of carriage is the pharyngeal region and virus can be recovered from carrier animals by collecting samples of their esophageal-pharyngeal fluid using a *probang* (sputum-collecting) sampler. The quantity of virus which can be recovered is highest in the first few weeks and then it progressively decreases. Sequential samples from the same animal may fluctuate in titre but even at peak period are generally low in terms of infectivity. For cattle the titre may be up to a maximum of 10^3 plaque-forming units (pfu) in BHK-21 cell assays. Individual cattle may vary greatly in their response. Some animals yield positive samples with a high frequency while others may do so only intermittently (van Bekkum 1973).

The duration of the carrier state varies with the host species, the strain of virus and probably other unidentified factors. The maximum recorded periods of carriage for different species are: over 3 years in cattle; 9 months in sheep and 4 months in goats. Deer and antelope either fail to become carriers or only carry virus for relatively short periods. The African buffalo (*Syncerus caffer*) has been shown to carry virus for up to 5 years and its role in the maintenance of FMD in Africa has been studied in considerable detail. The water buffalo (*Bubalus bubalis*) by comparison appears to have been studied relatively little. Experimental studies in Egypt, Moussa et al. (1979) showed that it can carry virus for up to two months. Reports from Brazil (Samara and Pinto, 1983) indicate that both young and adult water buffalo become carriers without appearance of lesions, although typical generalised lesions were seen in cattle sharing the same grazing area.

The sites of virus persistence in cattle have been investigated by van Bekkum et al. (1966) and Burrows (1966). They used different experimental procedures but both concluded that the chief sites are the pharynx and the dorsal surface of the soft palate. In recent studies at Pirbright, Donn (1993) reconfirmed these findings by both conventional virus isolation and the polymerase chain reaction (PCR) method. The identity of the cells where virus resides in the carrier animal has not yet been determined.

In additional studies at Pirbright the mechanism by which virus in carrier animals evades immune clearance is under investigation. The major detectable difference between carrier and non-carrier cattle has been found to be the prolonged presence in carriers of IgA in the secretions of the upper respiratory and gastrointestinal tracts but its precise role is not clear (Salt 1993).

The carrier is especially important in the non-vaccinating country normally free of disease which suffers one or more outbreaks and fails to eliminate all carrier animals. This could be through a failure of owners to recognise or report disease, the use of partial rather than complete stamping out on an infected premises, or the use of emergency ring vaccination in the face of disease. A number of FMD-free countries have considered the option of using ring vaccination as an adjunct to stamping out and have established vaccine banks for this purpose. This policy has rekindled interest in studies of the carrier state and highlighted the need for reliable tests to differentiate carriers from vaccinated animals so that the former can be identified and removed after emergency vaccination campaigns.

In summarising the different mechanisms of transmission of FMD one can point to animal movement as being by far the most important, followed by movement of contaminated animal products such as milk, meat, offal and untreated hides and skins. Next in this descending list are veterinarians and stockmen who have been in contact with incubating or diseased animals and others such as artificial insemination personnel. Vehicles which have transported infected animals and milk tankers can also be important, especially during the early stages of an outbreak before disease has been recognised and movement controls put into effect. Finally, airborne spread and spread by carriers have to be considered but these mechanisms, though in some circumstances of devastating consequence, are less frequent and require a particular sequence of events.

Production Systems and Environment

The system of animal husbandry and the environment can markedly influence the pattern of spread of FMD in a herd and also its severity. A high stocking density will facilitate spread as the crowding together of infected and susceptible animals will maintain a high level of challenge both from infected animals and the environment. Thus disease in intensive stocking systems is likely to spread rapidly. Italy suffered a series of epidemics starting in 1984, a feature of which was a very high morbidity in large pig herds with high mortality of piglets. Many intensive veal units were similarly affected. Even in vaccinated adult animals FMD may produce a high infection rate and severe disease in certain circumstances. This occurs sporadically in the large dairy units in Saudi Arabia. Many herds there contain several thousand milking animals penned alongside younger replacement stock. A feature during outbreaks has been a high attack rate amongst in-calf heifers and first-lactation cows in spite of multiple vaccination. The underlying causes have not been resolved but heat stress, undercurrent infection, hypersensitivity and reduced immunity through pregnancy may have been involved.

On the other hand, under extensive beef rearing systems such as are found in much of South America and Africa, the spread of disease is generally more insidious. Indeed, in former times in Africa, before modern vaccines became available, farmers commonly practised *aphthisation* in order to accelerate the spread of disease in their herds so the quarantine periods, which were set from the last clinical case, were over as soon as possible. (Aphthisation consisted of rounding up the animals and deliberately spreading disease amongst them through close contact, aided by stockmen deliberately rubbing contaminated cloths on their muzzles.)

The seasonal pattern of outbreaks in parts of Africa has been explained by Rweyemamu (1970) and Dawe (1978) to be a consequence of climate and increased animal contact. During the wet season water-holes are numerous and animals are dispersed, however, during the dry season they congregate at the few water places and there is an increased opportunity for dissemination of virus. Rweyemamu (1970) observed that the first foci of an epidemic in Tanzania began in an area where there was opportunity for contact at watering points between livestock and wildlife towards the end of the dry season. Dawe (1978) suggested that similar factors might explain the association between the dry season and the start of seven out of eight FMD outbreaks in Malawi between 1957 and 1975. The rougher grazing and more abrasive ground at that time of year may also have had an influence by causing more injuries to mucosal and epithelial surfaces producing additional entry points for virus.

The occurrence of FMD at a critical period of a husbandry cycle may have serious consequences. There was a very dramatic example of this at the start of the 1989–90 epidemic in Tunisia which struck shortly after the beginning of the lambing season and spread extensively through the highly susceptible ruminant population. The result was that over 50 000 lambs succumbed to the disease. Fortunately an intensive vaccination campaign of all ruminant animals prevented a repeat occurrence during the following lambing season.

Vaccination and Epidemiology

The aim of vaccination is to protect animals against the production losses which FMD may cause. To be effective the vaccine must be potent, safe, antigenically matched against the strains of virus circulating or likely to pose a threat, and properly administered so as to provide an optimal response. A good vaccination coverage, with strategically applied booster doses should protect both adult and young stock — the former through active and the latter through passively acquired maternal immunity.

It is important to recognise that vaccination will not necessarily prevent immunised animals which are exposed to infection from replicating and excreting virus. Undoubtedly there will be a dampening down effect compared to fully susceptible animals, however, the silently infected vaccinated animal can be an important, and usually unrecognised, disseminator of virus. Of particular danger are: animals which have partial immunity such as young stock exposed to infection around the time their maternal immunity is declining; primo-vaccinated animals challenged before their immunity is well established; animals not vaccinated regularly; and those vaccinated but exposed to a variant field virus. Clearly these problems will be minimised if good quality and antigenically relevant vaccine is properly applied according to the manufacturer's instructions.

A particular situation in which vaccinated animals are likely to be severely challenged and where it is desirable to ensure that they are isolated before coming into contact with other animals is when vaccine is used in the face of disease as part of an emergency control policy. In those circumstances the challenge exposure is likely to be severe and when used in a non-sensitised population will present a severe test of a vaccine's potency. Therefore, vaccines employed for this purpose must be formulated to contain an especially high antigenic payload. In experimental studies Donaldson and Kitching (1989) obtained results indicating that during emergency vaccination programs all FMD-susceptible animals within the vaccination zone should be vaccinated and vaccinated animals should be kept separated from unvaccinated stock at the outer boundary of the zone for at least three weeks.

Returning to conventional vaccines and their routine prophylactic use, a specialised application is when they are used to create a barrier zone to reduce the risk of virus spreading from infected to free zones. This is well illustrated by the strategies adopted by Zimbabwe and the Republic of South Africa to prevent the spread of virus from wild animal reservoirs in game parks to free areas where vaccination is not used. The procedure used is to isolate the wild animals within the parks by fences and to vaccinate the cattle in a band extending outwards from the fences. Beyond these 'red' areas are 'green' areas where vaccine is not used but the cattle and other stock are subjected to regular surveillance and movement controls. Beyond the 'green' areas are the non-vaccinated free areas from whence stock can be taken for export purposes.

Moving further up the scale to the country and regional (multi-country) level, while mass annual vaccination has made a major contribution to the control and prevention of FMD in several countries other additional measures have generally been found necessary to achieve eradication. In particular these include import controls, control of waste food and in the event of suspected cases, rapid reporting, quick laboratory diagnosis and speedy and effective implementation of zoosanitary measures when outbreaks occur.

The proven method of eliminating infection, essentially because it removes the risk of carriers, is total stamping out i.e. the slaughter and disposal of all clinically affected and other FMD-susceptible species on infected premises followed by decontamination. Partial stamping out, that is killing only the clinically affected animals and vaccinating the remainder, increases the risk that carriers will remain.

Stamping out, whether total or partial, requires the cooperation of farmers who must receive full and prompt payment of compensation. It is, therefore, expensive and can only be considered when the expected number of outbreaks is low and when there is a contingency fund to support it. Clearly it is not an option in countries where the slaughter of animals is prohibited on religious grounds.

Susceptible Species and their Importance in Different Environments

Different species of livestock vary in the role they play in the epidemiology of FMD according to their differing susceptibilities to infection, severity of clinical signs and the amounts of virus they excrete.

In former times in Europe pigs were often involved in index cases as a result of consuming contaminated waste food imported from overseas, often from South America. This problem was eliminated by stricter import controls on meat and offal and on swill feeding. The deboning policy for beef entering Europe from South America and from some African countries (Zimbabwe and Botswana) was a key element.

Pigs are potent excreters of airborne virus. One pig can excrete several thousand times more airborne virus per day than a ruminant animal. On the other hand, cattle are readily infected by airborne virus. It is not surprising, therefore, that the pattern of airborne spread which most often has been observed is from pigs at source to cattle downwind (Donaldson 1988).

The factors which favour airborne spread of FMD virus are: a low to moderate wind spread; a high humidity since airborne virus survives optimally above 60% relative humidity; a stable atmosphere, particularly a temperature inversion; an absence of heavy precipitation which could cause a wash-out of virus; and a high stocking density of cattle downwind. Computer-based programs have been developed for analysing and predicting the airborne spread of FMD and have been successfully used under operational conditions (Donaldson et al. 1982b).

In summary, pigs are important in the epidemiology of FMD because of their susceptibility to infection by the oral route and because once infected they excrete vast quantities of virus. Cattle are important because of their high susceptibility to airborne virus and because, as previously mentioned, they may excrete virus in their milk for at least 4 days before disease is evident. Thus pigs can be classified as *amplifying hosts* and cattle as *indicators*, at least in situations where they are fully susceptible, i.e. non-vaccinated, or not naturally immune. However, where cattle are vaccinated and pigs are not, the latter can be both indicator and amplifier hosts. Sheep, on the other hand, can be classified as *maintenance hosts* because they quite often have mild or even inapparent signs which can easily be missed and they can also be short-term carriers. In 1983, for example, infected sheep were transported from Spain to Morocco and then southwards through a series of markets. The presence of infection wasn't realised until several groups of cattle (non-vaccinated) which had been through the same markets subsequently developed disease. A similar pattern was seen a few decades ago in Europe when outbreaks in cattle often started in the autumn following the return of sheep and goats which had been grazing on alpine and appenine mountain pastures to lower ground during the summer months.

Obviously the spread of FMD is favoured when animals from different regions or villages are mixed together under circumstances in which some are infected and a high proportion are fully or partially susceptible. A higher incidence of outbreaks is not unusual, therefore, following the movement of animals along routes used by nomads during transhumance. For example, dairy farms near migration routes in Saudi Arabia quite frequently experience outbreaks soon after Bedouin tribes and their animals have moved by while in Sri Lanka the seasonal incidence of outbreaks in villages increases when animals return from forest grazing areas. In some parts of South America farmers protect their herds by double fences where their properties are adjacent to roads or trails along which animals from other premises are moved on foot, the objective being to prevent direct contact between their animals and those in transit.

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Vaccines for Control of Foot-and-Mouth Disease Worldwide: Production, Selection and Field Performance

M.F. Lombard and C.G. Schermbrucker*

Abstract

Foot-and-mouth vaccines constitute a small part of the total world veterinary biologicals market and are expensive to produce, purchase and administer. Facilities in some parts of the world have underutilised capacity but regulations restrict the serotypes that may be produced. Vaccine seed selection processes are essentially under the control of manufacturers who can produce potent vaccines under good manufacturing practice. Laboratory testing and finally animal challenge determines the suitability of the vaccine strain for field control under particular circumstances. Vaccine strategies have been used successfully in conjunction with other measures to control and eradicate FMD in several countries in recent years. There are many factors which influence the results of vaccination programs in the field and these are highlighted and discussed in this paper.

It is generally accepted that the control of most infectious disease of animals and of man is best achieved through the immunisation of susceptible populations by mass vaccination. Foot-and-mouth disease (FMD) is not an exception and has been successfully brought under control and then eradicated in some regions of the world. This has usually been achieved first by mass vaccination in good control programs followed by stamping out and sanitary prophylaxis policies.

This first step of control of the disease using a vaccination program has been achieved in recent years in many countries thanks to the use of modern, quality-controlled vaccines. As a result, with the success of the vaccination campaigns, the areas covered by routine vaccination programs have steadily declined.

The current world resource for FMD vaccine production reflects the recent use of vaccine and both have been decreasing since 1990. This drop in vaccine production is very obvious in South America where the vaccination programs have been reduced and is also obvious in Europe where eradication was achieved and a positive non-vaccination program applied since 1992.

* Rhone Merieux Ltd, Biological Laboratory, Ash Road, Pirbright, Nr Woking, Surrey, United Kingdom.

The best estimate for cost of production of animal health products worldwide is about US$7 billion per year. Approximately 70% of this cost is incurred in FMD non-vaccinating countries such as the United States, Canada, the European Community (E.C.), Japan, Australia and New Zealand which restricts the interest and the outlets for FMD vaccine manufacture. Cattle health products represent 43% of the total animal health production costs and FMD products are approximately 5–7% of that percentage.

FMD Vaccine Production

At this time, less than 10 years before the year 2000, FMD vaccines form only a small part of the expense of cattle health product production and they are needed for use mainly in countries which suffer from shortage of hard currency. Added to this is a lack of support in the veterinary field by international organisations such as UNICEF which do not include FMD in public health programs. Consequently there is a lack of regular demand and use of FMD vaccines which makes it difficult and relatively expensive to plan for future production. This impairs the availability of the vaccines and reduces confidence in the longer-term prospects for producers. The reduction in profitability inhibits investment in research and interrupts the development and use of new technologies (Vandermissen 1992).

On the other hand FMD is seen as the major contagious disease in the world and increasingly strict regulations are imposed on the multiplication of the viruses for the preparation of current vaccines. Disease security measures, good manufacturing practices and the use of bovine serum only from bovine spongiform encephalopathy (BSE)-free countries are some of the increasing constraints (E.C. 1991). More and more industrialists have therefore turned away from FMD vaccine production and, with a few exceptions, those who persist do not invest further in production or research and development.

For the majority of African and Asian countries, local production of FMD vaccines is uneconomic and the shortage of hard currency prevents the import of vaccines which meet European standards. They often purchase the cheapest vaccine available with little or no regard for the quality. The nature of FMD and its immune response is such that the control of the disease is unusually dependent on the vaccine quality. This has been clearly seen as a significant factor in those areas where the disease has been successfully controlled in contrast to countries which have vaccinated for years and incurred the costs of it without improving control of the disease. The production of FMD vaccines in different countries is shown in Table 1 and discussed in more detail below.

Table 1. FMD vaccine production (in million equivalent trivalent doses for cattle), 1993.

Country	Vaccine types	Doses
SOUTH AMERICA		
Venezuela	O,A	5.3
Colombia	O,A	10
Peru	O,A,C	0.6
Brazil	O,A,C	175
Argentina	O,A,C	87
Uruguay	O,A,C	14
Paraguay	O,A,C	8.4
AFRICA		
Egypt	O	0.3
Kenya	O,A,C, SAT 1,2	?
Botswana	O,A,C, SAT 1,2,3	8
Rep. South Africa	SAT 1,2,3	2
EUROPE		
United Kingdom (Pirbright)	7 types	15
Germany	O,A,C	
Holland	O,A,C	20
Russia	O,A,C	
ASIA		
Turkey	O,A	8
Iran	O,A, Asia	8
Pakistan	O, Asia	0.25
India	O,A,C, Asia	60
Sri Lanka	O	0.01
Bangladesh	O,A, Asia 1	0.1
Myanmar	O, Asia 1	0.01
Thailand	O,A, Asia 1	15.3
China	O	>3

South America

South America is now the biggest producer of FMD vaccines in the world with approximately 300 million trivalent (or trivalent equivalent) doses produced per year (1993). Colombia and Venezuela produce and use bivalent O and A vaccines only while in the other countries trivalent O, A and C production facilities are operated. South America has an over-capacity of vaccine production facilities overall, but the excess capacity can not be used for other continents due to regulations prohibiting the culture of viruses exotic to South America. Chile has eradicated the disease by the use of a programmed vaccination campaign.

Africa

Africa is badly provisioned for FMD vaccine production. With the exception of Botswana and South Africa there are no up-to-date production facilities following modern quality control procedures and standards.

Europe

Europe has had the best recent success in the control and eradication of the disease. It is also the continent with the greatest concentration of FMD vaccine manufacturing and licensing expertise. With the recent achievement of eradication from the European countries and their consequent cessation of vaccination, vaccine production is now below capacity. Within Europe, only the production unit at the Institute for Animal Health at Pirbright in the United Kingdom meets the latest E.C. requirements and the British good manufacturing practice standards (E.C. 1991).

Asia

Asia is the continent where 22 countries officially report the presence of FMD infection. The total cattle population is more than 430 million head and only 10 countries have some form of local vaccine production with a total capacity of 94 million trivalent equivalent doses produced. This is insufficient to cover the vaccine requirements in the region.

With the exception of the few laboratories with technology imported from European companies, most of the production facilities are not operating economically nor satisfactorily from the national and from the quality assurance points of view.

FMD Vaccine Performance

For the control of FMD it is unfortunately the case that vaccination and protection are not the same thing. This can be seen throughout the world where in some areas the prevalence of FMD continues despite comprehensive vaccination programs. The ideal vaccine stimulates the immune system to induce a state of immunity without side effects. As stated by Magrath (1992):

> The quality of a vaccine is an expression of the success of the manufacturer in achieving the maximum potential efficacy with the minimum risk. No vaccine is absolutely efficacious and none is without risk, and it is probably true that although vaccines from different sources may meet the required specification, they will not all have the same characteristics.

The purchase of FMD vaccines of good quality, e.g. meeting European specifications, is not the only factor leading to successful control of disease in the field. The performance of batches of vaccine in laboratory controls is not necessarily the same as their performance in the field (Pay and Hingley 1992). If, as is often stated, vaccine can be considered as a 'weapon' against disease, then the importance of 'the man behind the gun' is evident.

The performance in the field of an FMD vaccine depends on several factors including the selection of appropriate vaccine virus strain, vaccination program strategies and the factors affecting vaccination and coverage in the field. These factors are described in more detail below.

Selection of vaccine strain

The selection of the vaccine strain is a crucial element for the success of any FMD vaccination program. Since this is not a particular subject of this presentation suffice it to say that the essential point is the evidence for a high level of expected protection against current field virus strains.

Virus strain identification includes the complement fixation test and enzyme-linked immunosorbent assay (ELISA). Studies on the potential for protection are not complete if immunological studies are not carried out. Indirect immunological tests include vironeutralisation in cell culture or viroprotection in mice using sera from target species (cattle, buffaloes, sheep, pig . . .) vaccinated with the virus strain planned for vaccine production. The objective is to demonstrate the comparison of the protection obtained with the vaccine strain and field strains to produce good evidence for the degree of protection expected to be conferred by the vaccine planned for use.

Direct immunological tests are carried out by the vaccination of cattle and pigs; study of their serology; and, after 21 to 28 days, the performance of virulent virus challenge test. Ideally, one group is challenged with the vaccine strain and a second group challenged with the most prevalent field strain. Where the cross protection of the vaccine strain for the field strain is below a minimum value of 80%, that vaccine strain should not be used for cattle (minimum 60% protection in the case of pigs).

Vaccination strategy

The vaccination strategy used is the second important factor leading to success or failure for any vaccination program and again the 'man behind the gun' is of major importance. It is not uncommon for the same vaccine to give different degrees of protection in two neighbouring countries. The program for the use of vaccine against outbreaks of disease should be decided in advance. The priorities are fundamentally different depending on the status of the country as a vaccinating or non-vaccinating country.

Non-vaccinating countries, free of FMD

In non-vaccinating countries which are free of FMD, such as the E.C. countries or Indonesia, the national authority should prepare in advance a manual of procedures for dealing rapidly with an FMD outbreak (stamping out policy versus vaccination policy). If a vaccination policy is selected, contingency plans must be prepared to ensure rapid supply of appropriate vaccine; anticipate the availability of cold chain facilities and vaccination equipment; and develop schedules appropriate to the individual localities. The administration of quarantine zones, vaccination programs and their surveillance and the training and coordination of personnel should be planned and provided for.

The vaccination programs must take into account that the animals to be vaccinated are fully susceptible to FMD and that primo-immunisation means a two-dose regimen with a one-month interval. Booster doses should be planned for as early as four months after primary vaccination if there may be any significant difference between the field strain and vaccine strain. Otherwise the booster dose should follow a normal schedule at six months after primary vaccination.

Vaccinating countries

In vaccinating countries several different strategies are possible against outbreaks. These are usually based on ring vaccination round outbreaks with or without stamping-out of clinically infected animals (Ronohardjo 1986). If outbreaks occur in a neighbouring country and threaten unvaccinated and/or vaccinated livestock the country under threat may need to vaccinate in areas adjacent to the border to create a protective belt. This policy may be sufficient to prevent the penetration of the border by the disease provided the control of animal movement and other potential sources of infection is sufficient. Strategies based on these principles have been effective in controlling FMD incursions into Uraguay and Botswana.

Factors affecting FMD vaccine performance in the field

Factors affecting FMD vaccine performance in the field can be summarised into six categories:
- vaccine storage and cold chain facilities;
- vaccine application;
- relationships between vaccine and field virus strains;
- influence of passive maternal antibodies;
- interference of immunosuppressive infections or infestations; and
- the level of management and efficiency of vaccination programs.

The correct conditions of vaccine conservation (storage) and application have been published for decades and are still advised with the vaccine which is exceptionally heat sensitive.

In well vaccinated cattle herds the passive transfer of antibody from dam to calf through colostrum in the first few hours of life and the different rates of waning of these antibody levels, can lead to the persistence of field virus on the farms. This requires careful planning of vaccination schedules, particularly for large dairy farms, which take into account the optimal period when the passive antibody has waned to levels below the protective threshold and where minimal interference with active immunisation is expected. This period usually occurs between three and five months after birth of calves. The primary immunisation of calves should comprise two vaccinations with a one-month interval and thereafter they should be revaccinated at a six-month interval (see Fig. 1).

Interference with immunity by immunosuppressive infections or immunosuppressive infestation by blood parasites have been suspected of impairing the response to FMD vaccination but no conclusive scientific evidence has been published to confirm this.

The level of management and efficiency of vaccination programs have a large effect on the results of FMD vaccination campaigns. Hence, this depends upon the competence of the veterinary

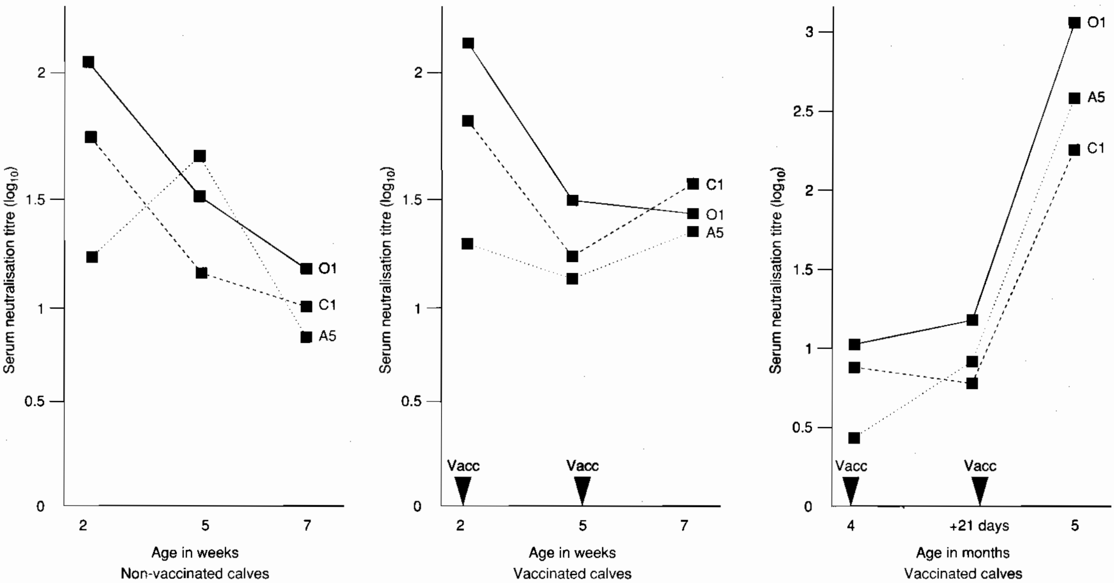

Figure 1. Kinetics of antibodies in vaccinated and unvaccinated calves (born to vaccinated dams) depending on their age (European trivalent commercial vaccine).

services in organising mass FMD vaccination campaigns (Mannathoko 1982). If, as Magrath 1992 said, 'the efficacy of the vaccine may be regarded as an expression of the proportion of those animals vaccinated that are protected from natural infection and the duration of that immunity', then the efficacy of veterinary services may be regarded as an expression of the percentage of animals from the total population correctly vaccinated.

In medical public health it is accepted that for the elimination of measles 95% of children vaccinated must be attained. For rubella this value has been estimated at 86%. For control of Rinderpest in Africa a value of 85% is commonly accepted. It seems that for FMD in tropical climates, which are very favourable for the survival of the FMD virus, a figure of 80–85% is probably necessary but this has not yet been proven. The conclusion is that it would be pointless for veterinary authorities to spend money on a vaccination program for FMD in difficult access areas if the expected vaccine coverage would be much below 80% of the total population.

Conclusion

Throughout the world the production of FMD vaccines has declined due to reductions in regular offtake of vaccines linked to planned prophylactic vaccination campaigns. In order to maintain and improve the availability of FMD vaccines and products, the production and marketing of them needs to bring a reasonable return to the producers to cover ongoing investment, and new developments and research.

The performance of FMD vaccine in the field depends on the manufacturer supplying an efficacious product; the vaccine virus strain being appropriate for current field viruses; and on the effective management of the vaccination program so as to achieve vaccine coverage not less than 75% of the population at risk. Recently, many countries which have effectively covered these parameters have successfully eradicated FMD.

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EPIDEMIOLOGY OF FOOT-AND-MOUTH DISEASE IN THAILAND

Overview

Dr Wipit Chaisrisongkram, Deputy Director-General of the Department of Livestock Development (DLD) in Thailand presented an overview of the FMD situation in Thailand and outlined the strategies already in place and those proposed to reach the goal of FMD control in the country by the year 2000. These include vaccination, identification of vaccinated animals, quarantine prior to movement, issue of movement licences, health surveillance, auction market control and border controls. Good laboratory facilities exist for both diagnosis and vaccine production and recently a Foot-and-Mouth Disease Information Center has been established in DLD to analyse and report epidemiological information such as that obtained through the field studies described below.

Field studies

As part of the ACIAR-sponsored collaborative research project a major study was conducted on the village livestock population in northern Thailand. The study had two aims: to investigate the serological responses of village livestock with a view to assessing the efficacy of the newly introduced trivalent vaccine; and to identify key elements of the epidemiology of the disease in the village production system. The study was carried out in the provinces of Lampang, Lumphun and Chiang Mai in Region 5, Northern Thailand.

In the first paper describing these field studies, Dr Chris Baldock, an epidemiologist of the Queensland Department of Primary Industries, Australia, presented the analysis of a retrospective survey of factors likely to influence the frequency of FMD outbreaks in the villages. Information was presented on the relative importance of risk factors for increased frequency of FMD outbreaks. The most important risk factors identified were purchase of livestock from markets, mingling of animals at grazing and watering and whether or not income from agriculture was the most important source of cash income for the village.

Dr Pornchai Chamnanpood, head of the Epidemiology Section at the Northern Veterinary Research and Diagnostic Center (NVRDC), Hang Chat, described a standard investigation procedure that was implemented to gather epidemiological information from prospective FMD outbreak investigations. The rationale of the approach was explained and the key findings from 11 outbreaks were presented for discussion. It appeared from both this and the former study that transmission in the environment of northern Thai villages requires relatively close contact between animals and that some effective control might be gained from implementing a simple strategy of quarantining newly purchased stock for a period until it is clear that they are not incubating the disease.

Dr Laurence Gleeson of the Australian Animal Health Laboratory, CSIRO, presented the results of a vaccination-monitoring program. Animals were monitored for 19 months, during which time they received four vaccinations at the specified six-monthly intervals. The data was analysed by age group according to whether the animals were seropositive or seronegative by serum neutralisation test (SNT) at the commencement of the program. Regardless of age, it was not until seronegative animals received two vaccinations that greater than 80% of the animals maintained a $\log_{10}$ SNT titre of equal or greater than 1.5 for a full intervaccination interval. The data on serological responses indicated the value of monitoring the response by village livestock.

Dr Chanpen Chamnanpood, also from the NVRDC, Hang Chat, presented results of VIA AGID monitoring of vaccinated animals. Animals selected from the program database were divided into two groups. Those with $\log_{10}$ SNT titres of less than 1.2 to all three serotypes were classed as FMD seronegative and those with a higher titre to at least one were classed as seropositive. At the start of the trial there were no reactors among the seronegative animals and there was an increase to about 10% one month after the first vaccination. Most reactions disappeared by six months after vaccination but returned after revaccination. Vaccination with the new batch of vaccine provoked a substantial reactor prevalence. The seropositive group reactor rate rose from 30% to 70% after one vaccination, and many animals were still seropositive six months after vaccination.

Finally Dr Chris Baldock presented a computer model of herd immunity to FMD which incorporates the village dynamics and vaccination-monitoring results described above. The model indicates that in the village production system in northern Thailand a very high level of vaccination coverage is required to maintain a level of herd immunity above 80%, which is the level that has been hypothesised to prevent epidemics developing.

An Overview of Foot-and-Mouth Disease Control in Thailand

Wipit Chaisrisongkram*

Abstract

The strategies for foot-and-mouth disease (FMD) control in Thailand include vaccination, identification of vaccinated animals, quarantine prior to movement, issue of movement licences, health surveillance, auction market control and national border control. Laboratory diagnostic capability has been increased at the Northern Veterinary Research and Diagnostic Center and the Department of Livestock Development (DLD) is planning to establish a new international reference laboratory for FMD at the National Animal Health and Production Institute. The laboratory at Pak Chong is the national reference laboratory for FMD. Monovalent and trivalent vaccines are produced at the FMD Center at Nongsarai, Pak Chong. A Foot-and-Mouth Disease Information Center has also been established in DLD to gather, analyse and report epidemiological information. The reporting system has the following components: outbreak reporting; structured epidemiological investigations; and monitoring and surveillance of village animal health and production profiles. The field study in northern Thailand to determine the incidence of FMD and the potential for control through vaccination of villagers' livestock has proved a useful pilot project for the monitoring system.

FOOT-and-mouth disease (FMD) is an important disease that causes economic loss to the livestock industry. The disease has been endemic in Thailand since first recorded in 1953 when virus type A15 was confirmed. Types Asia 1 and O1 were subsequently confirmed in 1954 and 1957, respectively. The Department of Livestock Development (DLD) of the Royal Thai Government started disease control measures in 1958. These initially comprised strict control of animal movement; a vaccination program; animal quarantine; sanitary control; outbreak investigation; field surveillance and slaughtering of sick animals. This program was not very successful.

Foot-and-Mouth Disease Prevention and Eradication Project

Since Thailand is located in the central part of Southeast Asia and shares long borders with Myanmar in the northwest and west, Laos in the northeast, Cambodia in the east and Malaysia in the south, it is very difficult for the government to control the spread of the disease by animal movement into Thai territory. DLD has therefore planned a new five-year strategy project, the *Foot-and-Mouth Disease Prevention and Eradication Project*, which started on 1 January 1991. The project emphasises animal movement control, vaccination and new epidemiological techniques. The aims of this project are as follows:

- to decrease the incidence of the disease in the country;
- maintain the FMD-free status of Regions 2, 8 and 9[1]; and
- to promote livestock production and export.

In the first year (1991), the project was implemented in the 16 most high risk provinces and in the second year was expanded to cover all 58 provinces from Region 1 to Region 7. From the third year (1993) onwards the project will cover the whole country.

* Department of Livestock Development, Phyathai Road, Bangkok 10400 Thailand.

[1] A map showing the regional divisions for Thailand is included in the Thailand Country Paper (these proceedings).

Strategies used for FMD Control

At present there are only three virus types associated with FMD outbreaks in Thailand — A, O and Asia 1. Both types O and Asia 1 occur in cattle and type O is found in pigs.

Vaccination

Vaccination of all susceptible animals would require as much as 42 million doses of vaccine per year which is considerably more than is available. Priority setting therefore has to be carried out and vaccination programs have to be targeted to the high risk population of animals. The main concept is to *fully* vaccinate animals in Regions 2 and 7. This requires distribution of a total of 2.8 million doses of trivalent and 4.5 million doses of monovalent vaccines. Animals at risk in Region 1 are also vaccinated. In the south (Regions 8 and 9) which is a vaccine-free zone, only cattle and buffaloes in the areas where animals accumulate are vaccinated.

The northern and northeastern parts of the country (Regions 3, 4, 5 and 6) receive roughly 4 million doses of trivalent and 5 million doses of monovalent vaccines per year. Animals in the borders areas, auction markets, and on the move, are vaccinated with trivalent vaccine (other animals receive monovalent vaccine). Vaccination is conducted at six-monthly intervals.

Identification of vaccinated animals

To keep records of and identify vaccinated animals, the following procedures are followed:

- issue of vaccination certificates; and
- ear tag or tail tag designated with a five-digit code number indicating the original (region–province–district) place of movement.

Quarantine prior to movement

The following quarantine measures are taken prior to movement of animals:

- *0 days*
  - within any no-outbreak area
  - from one FMD-free zone to another free zone without passing through any outbreak area
- *21 days*
  - from any no-outbreak area to any outbreak area
  - within any outbreak area
  - from any outbreak area to any no-outbreak area
  - from any no-outbreak area to or past any FMD free-zone

Issue of movement licences

Movement licences are issued which stipulate: route; vehicle plate-number; disinfection and checkpoint/animal quarantine station to be passed en route.

Health surveillance

Health surveillance of animals which have been transported is carried out by local livestock officers at the destination.

Auction market control

For any animal to be moved to an auction market the following certification must be produced:

- a vaccination certificate must accompany each animal; and
- a movement licence is required for all animals on a truck, stating
  - number of animals,
  - ear tag or tail tag code numbers.

National border control

For movement of animals across the borders animals must be vaccinated against FMD and quarantined for 21 days at an approved quarantine place near the border. The following certification is also required for each animal:

- ear tag or tail tagging attachment;
- vaccination certification; and
- movement licence.

FMD Diagnostic and Reference Laboratories

DLD has two diagnostic laboratories that routinely provide FMD diagnosis. These are:

- the FMD Center at Pak Chong in Nakhon Ratchasima Province; and
- the Northern Veterinary Research and Diagnostic Center (NVRDC) at Hang Chat in Lampang Province.

The FMD Center in Pak Chong is also the National Reference Laboratory for FMD while DLD is planning to establish a new International Reference Laboratory for FMD at the National Animal Health and Production Institute (NAHPI). New techniques such as the enzyme-linked immunosorbent assay (ELISA) have been used at NVRDC to improve FMD diagnosis.

FMD Vaccine Production

Thailand established an FMD vaccine production facility at Nongsarai, Pak Chong in 1960. Both monovalent and trivalent (O, A and Asia 1) vaccines are currently produced. With the recent (1990) completion of new FMD vaccine production facilities at the same Nongsarai site, the production capacity has increased to 10 million doses of monovalent and another 10 million doses of trivalent vaccine per year.

Epidemiology and Information System

Epidemiological techniques and information systems are implemented in order to understand the dynamics of the disease and obtain the essential information for a control program. The Foot-and-Mouth Disease Information Center, which is a part of the National Livestock Information Center (NLIC) at DLD, is responsible for data collection from field outbreak reports, structured epidemiological investigation, monitoring/active surveillance. All this information is compiled, analysed and disseminated to officers concerned, at both administration and implementation levels. The components of the information system are briefly described below.

Outbreak reporting system

An outbreak reporting system is used to monitor the occurrence of the disease in the country. Information from the system is availed in the form of counts, incidence of villages affected and animal morbidity and mortality rates.

Structured epidemiological investigation

Structured epidemiological investigations are used to study aspect of the disease such as risk factors, effects of the disease on productivity, animal movement patterns, reliability of diagnostic test and vaccine efficacy. These are the processes of developing an understanding of FMD in Thailand.

Monitoring/active surveillance

A monitoring program based on animal health and production profiles carried out in random selected villages is being developed for the whole country. At present it is currently underway at NVRDC. Other active surveillance activities are serological testing of livestock at border entry points and/or auction markets.

Conclusion

At present, all control strategies mentioned above, along with new technology and modern equipment such as microcomputers, facsimile machines, short wave radios, etc., provided to each provincial liaison office, have been applied in order to enhance the implementation of the project. ELISA techniques are used at the diagnostic laboratories.

Field study in northern Thailand to determine the incidence of FMD and the potential for its control through vaccination of villagers' livestock is a pilot monitoring system project. The information provided from this project is very useful and is now being used to implement programs in other parts of Thailand.

Data collection methods used in the past which were quite limited and not well suited to the need for control measures, have been improved. Now, information from outbreaks is widely used and can be further analysed to provide a more detailed profile of the situation. Disease-control programs based on such information are much more satisfactory. Weekly and monthly surveillance reports of FMD are provided by the FMD Information Center and NLIC with the object of giving warning to areas under threat of infection. These reports are also of value in planning and policy decision making. The information is also sent to international agencies such as the Office Internationale des Épizooties (OIE) and the Food and Agriculture Organisation's Regional Animal Production and Health Commission for Asia and the Pacific (APHCA).

Factors Affecting the Risk of Foot-and-Mouth Disease Outbreaks in Northern Thai Villages

F.C. Baldock,* P.C. Cleland,† Pornchai Chamnanpood§ and L.J. Gleeson†

Abstract

An epidemiological study was undertaken in Northern Thailand to identify factors which put some villages at higher risk of foot-and-mouth disease (FMD) outbreaks than others. The number of FMD outbreaks experienced in the previous five years as well as data on 145 putative risk factors was obtained by interview from 60 villages during 1991–92. Univariate statistical analyses identified 27 factors worthy of further investigation by statistical modelling using logistic regression. When villages were classified into three FMD frequency groups of 0–1, 2–3 or 4 or more outbreaks in the last five years, the important factors explaining the differences in risk were the total number of cattle and buffaloes purchased in the previous year, the number of neighbouring villages which shared a common water source and the most important source of cash income not being from agriculture. These factors were also the most important variables in explaining the difference in risk when comparing villages with no or one outbreak with those having four or more. It was concluded that the greatest impact on reducing spread of FMD among villages would be obtained through the development of strategies to reduce the likelihood of introduction through livestock purchases and for villagers to take greater care when livestock are grazed with those from neighbouring villages and when sharing common water supplies.

THE livestock industries of Thailand are expanding in both the commercial and smallholder sectors to meet increasing demand from a growing and wealthier human population and to supply emerging export markets. In the smallholder sector, although a change to mechanisation is resulting in reduced numbers of draft animals, beef and dairy cattle populations are increasing and provide an important source of cash income for villagers (Khajarern and Khajarern 1989; Usanagornkul 1989).

Foot-and-mouth disease (FMD) is endemic throughout most of Thailand except for the southern peninsula (Kongthon 1991). Productivity losses due to FMD are not well appreciated when assessed against a general background of low productivity (Ferris et al. 1992). However, as the livestock industries of Thailand have expanded and productivity has increased through improvements in genetics, nutrition and management, FMD has become a serious impediment to efficient production. FMD has thus been targeted by the Department of Livestock Development (DLD) within the Royal Thai Government as its major priority for control and possible eradication (OIE 1991). The official DLD control policy for FMD incorporates such strategies as mass vaccination, livestock movement regulation and compulsory notification with mandatory local control measures in response to outbreaks (Kongthon 1991). The overall control program is primarily reliant on six-monthly mass vaccination in those parts of the country where FMD remains endemic (see also Wipit Chaisrisongkram, these proceedings).

Some aspects of the epidemiology of FMD relevant to control in Thai villages remain poorly understood (Forman et al. 1989). These include

* Queensland Department of Primary Industries, Animal Research Institute, 665 Fairfield Rd, Yeerongpilly, Queensland 4105, Australia.
† CSIRO Australian Animal Health Laboratory, PO Bag 24, Geelong, Victoria 3220, Australia.
§ Northern Veterinary Research and Diagnostic Center, Hang Chat, Lampang 52190, Thailand.

reliable estimates of annual incidence, methods of spread among villages as well as the effectiveness of control measures such as vaccination and regulation of animal movements. A project to study the epidemiology of FMD in Thai villages began in 1990 to obtain information which might assist in improving the effectiveness of the official control program. The project was based from the Northern Veterinary Diagnostic and Research Center (NVDRC) at Hang Chat in Lampang Province. This paper reports findings of a study that forms part of the overall epidemiological research project.

In Northern Thailand, FMD outbreaks remain common in the smallholder sector. It is believed that outbreaks in villages mainly result from the introduction of infected animals from local livestock markets and through spread from neighbouring villages. However, there have been no detailed epidemiological studies to evaluate the relative importance of the different potential risk factors for FMD in Thai villages.

The present study was therefore undertaken in an attempt to find out why some villages had more outbreaks of FMD than others. The study was designed to identify and quantify the importance of FMD risk factors for which intervention strategies could be found.

Materials and Methods

A cross-sectional study was undertaken in Region 5 of Northern Thailand[1] where there are approximately 5000 villages in eight provinces. A sample of 20 villages from each of Lampang, Lamphun and Chiang Mai Provinces was chosen. Criteria for enrolment into the study were willingness to cooperate, past history of participation in DLD livestock programs and physical accessibility. For seven of the villages in each province there was an additional requirement for long-term participation in an FMD vaccine efficacy study. The vaccine study is not described in this paper.

Data collection

All data were collected during 1991–92 by interviewing villagers using a questionnaire. One interviewing team collected the data for all villages using a standardised protocol. The recorded responses comprised the collective opinions of the headman, keyman and other influential farmers in the village. In Thai villages, the headman is the senior government official, while the keyman is a volunteer whose responsibility is to assist in implementing DLD programs within the village.

The number of outbreaks of FMD experienced during the previous five years from the time of interview was recorded. Data were also recorded for a total of 145 putative risk factors for having an outbreak of FMD in the village. The risk factors comprised the following broad groups: animal trading (27 factors); husbandry practices (22); current livestock inventory (21); FMD vaccination and outbreak history (29); economic priorities (13); distances and level of service by DLD officers (12); animal products (6); fomites (9); FMD reservoirs and vectors (6).

All data were entered into the microcomputer database manager, PANACEA[2] in preparation for summarisation and statistical analyses.

Statistical analysis

Analyses were undertaken using the statistical packages, STATISTIX 3.1[3] and BMDP (Version BMDP386)[4] on a microcomputer.

Two approaches were taken to classifying the 60 villages according to FMD outbreak history prior to data analysis. First, villages were divided into three groups: 0–1 (low), 2–3 (medium) and 4 or more (high) outbreaks in the previous five years. Second, to more clearly separate low from high risk villages, those with zero or one outbreaks were compared with those with four or more.

Univariate analyses were undertaken to select for statistical modelling, sets of independent variables from the original 145. The frequencies of categorical independent variables were compared among FMD frequency groups using chi-square tests. Since most of the continuous independent variables were not normally distributed, the Kruskall-Wallis nonparametric test was used to compare mean ranks. One continuous variable (VISDLD in Table 3) whose distribution clearly separated into two distinct groups was categorised prior to analysis.

Independent variables with a P value of less than 0.2 in the univariate screening were chosen for statistical modelling. Stepwise logistic regression was used to select best fitting models for the two different approaches to classifying the outcome

[1] A map showing the regional divisions for Thailand is included in the Thailand Country Paper (these proceedings).

[2] PANACEA, Pan Livestock Services Ltd, Reading, England

[3] STATISTIX 3.1, Analytical Software, St Paul, USA

[4] BMDP, Biomedical Data Programs, Los Angeles, USA

variable, frequency of FMD outbreaks in the previous five years. Adjusted odds ratios were obtained to quantify the relative importance of the different risk factors in the models.

Results

The numbers of people and livestock in the 60 study villages are shown in Table 1. The numbers of villages in each of the three FMD frequency groups with the median morbidity rates in cattle at the most recent outbreak are shown in Table 2.

Table 1. Numbers of people and livestock in the 60 study villages.

	Mean	Median	Range
People	790	619	192–3500
Families	203	168	46–800
Work cattle	17	0	0–250
Beef cattle	310	250	15–1630
Buffaloes	33	3	0–350
Pigs	168	60	0–1600

Table 2. Frequency distribution of the number of villages in FMD outbreak groups LOW (0–1 outbreaks in last 5 years), MED (2–3 outbreaks) and HIGH (4 or more outbreaks) and the median reported morbidity in cattle at the most recent outbreak.

FMD frequency group	Number of villages	Median cattle morbidity rate (%) at last outbreak
LOW	19	11.5
MED	19	20
HIGH	22	20

Univariate analysis

A total of 27 variables met the criteria for use in the logistic regression modelling. These are shown in Table 3. Not all variables shown in Table 3 were used in the logistic regression modelling. Because cattle and buffalo abortions or sales were not regarded as putative risk factors for FMD, ABRATE and TVCBSAL were not used in the logistic regression modelling. The pig-related variables VPIGPUR, PIGSG6, DISTPIG and PIGFEED were also not used in the statistical modelling. Findings from other research in the same location as the present study indicated that pigs were rarely clinically affected during outbreaks of FMD in villages and did not play a significant part in the spread of the disease (Chamnanpood et al. 1993). Finally, because only six villages imported animal manure, the variable DUNG was not used in further analysis.

Logistic regression

The best fitting models for both approaches to classifying FMD outbreak frequency are shown in Table 4. In the polychotomous logistic regression analysis, the variables which best explained the variation in FMD frequency when classified three ways were TVCBPUR, VSHAREWAT, ICASH and DISTMEAT (Model 1). The variable DISTMEAT was rejected in the final model because it did not significantly improve its goodness of fit and also because it was in a direction opposite to what made biological common sense.

In this model, the effects of the explanatory variables are assumed to be equal across the different levels of FMD frequency with the 0–1 group being the reference category. Thus, the risk of being in the next higher FMD frequency group was increased 1.6 times for each additional neighbouring village with which livestock shared water. The risk was increased 1.3 times for each extra 10 cattle or buffaloes purchased annually and villages whose most important source of cash income was not from agriculture were at 3.4 times the risk of those villages dependent on agriculture.

When all eligible variables were offered in the stepwise logistic regression analysis, difficulties were experienced with multi-colinearity among the explanatory variables. When the variable VSHAREGZ was not offered, the variables which best explained the variation in FMD frequency when classified two ways were VSHAREWAT, TVCBPUR, VILLS5KM, ICASH and IMTHSGZ. IMTHSGZ did not significantly improve the fit and so was not used in the final model. VILLS5KM and VSHAREWAT were correlated and considered to be measuring essentially the same thing, that is the degree of co-mingling which occurred with livestock from neighbouring villages. Hence, VILLS5KM was also not used in the final model.

In this final model (Model 2), the risk of being in the high FMD frequency group was increased 2.4 times for each additional village with which livestock shared water. The risk was increased 1.4 times for each additional 10 cattle or buffaloes purchased and villages whose most important source of cash was not from agriculture were at 4.3 times the risk of those dependent on agriculture. The distribution of these three risk factors among villages in the different FMD frequency groups is shown in Table 5. Because the data were not normally distributed, medians, means and ranges are shown for the two continuous variables, TVCBPUR and VSHAREWAT.

Table 3. The 27 variables associated with FMD outbreak frequency in univariate analyses (P < 0.2).

Variable name	Units[a]	Description
ABRATE[b]	N	Abortion rate in cattle and buffaloes in the previous year
AGACT2	1,0	The second most important agricultural activity is livestock or not
AHPROB[b]	1,0	The most important animal health problem related to nutrition and growth in cattle and buffaloes or not
BCATTAD[b]	N	Total number of beef cattle adults in the village
DDLD	km	Distance to the nearest DLD office
DISTMEAT[c]	km	Distance to the nearest public meat market
DISTPIG[c]	km	Distance to the nearest commercial piggery
DUNG	1,0	Animal manure imported into the village or not
ICASH	1,0	The most important source of cash is from agriculture or not
IMTHSHGZ	1,0	Livestock share grazing with other villages all year round or not
ITPORTMKT	1,0	Villagers walked their cattle and buffalo purchases back from the nearest market or not
MTHSHAREGZ	N	Number of months in the year that shared grazing with livestock from neighbouring villages occurs
PCBVACC[b]	N	The percentage of cattle and buffaloes vaccinated for FMD at the most recent vaccination visit
PIGSG6	N	Number of pigs greater than 6 months of age
ROAD	1,0	Village access by a major road or not
SHAREWAT	1,0	Livestock share a common water source with other villages or not
TOTBUFF[b]	N	Total number of buffaloes in the village
TOTWC	N	Total work cattle in the village
TRUCKLVS	N	Number of trucks used to transport livestock in the village
TVCBPUR	N/10	Total cattle and buffalo purchases by villagers in the previous year excluding those by village middlemen
TVCBSAL	N/10	Total cattle and buffalo sales by villagers in the previous year excluding those by middlemen
VILLS5KM[b]	N	Number of villages within 5 kilometres
VISDLD	1,0	Thirteen or more DLD visits to the village in the previous year compared to less than 13
VPIGPUR	N/10	Total pig purchases by villagers in the previous year excluding those by middlemen
VSHAREGZ	N	Number of neighbouring villages which share common grazing
VSHAREWAT	N	Number of neighbouring villages which share a common water source
WKCONT[b]	1,0	Cattle and buffaloes come in contact with livestock from other villages while working

[a] Codes shown for categorical variables; N:counts; km:kilometres
[b] P > 0.2 when villages classified into 3 FMD frequency groups
[c] P > 0.2 when villages classified into 2 FMD frequency groups

Table 4. Best fit logistic regression models for two different methods of classifying the dependent variable. Model 1: villages having 0–1, 2–3 and 4 or more FMD outbreaks. Model 2: villages having 0 or 1 FMD outbreaks compared with those having 4 or more (villages having 2 or 3 outbreaks excluded from this analysis).

Variable[a]	Coefficient	Standard error	Adjusted odds ratio	95% confidence interval (CI) of odds ratio Lower bound	Upper bound
MODEL 1 (P1 = 0.86[b]):					
TVCBPUR	0.271	0.126	1.3	1.0	1.7
VSHAREWAT	0.468	0.166	1.6	1.1	2.2
ICASH	1.211	0.608	3.4	1.0	11.0
CONSTANT1	−0.764	0.446	0.5	0.2	1.1
CONSTANT2	−2.650	0.586	0.07	0.02	0.2
MODEL 2 (P1 = 0.78, P2 = 0.47, P3 = 0.69[b]):					
TVCBPUR	0.309	0.180	1.4	0.9	2.0
VSHAREWAT	0.862	0.334	2.4	1.2	4.7
ICASH	1.448	0.948	4.3	0.6	29.2
CONSTANT	−2.678	0.891	0.07	0.01	0.4

[a] See Table 2 for a description of variables

[b] Probabilities: P1 — goodness of fit chi-square (G^2); P2 — Hosmer-Lemeshow chi-square; P3 — Brown chi-square

Table 5. Distribution of the risk factors best explaining the variation in the frequency of village FMD outbreaks.

	FMD frequency group (number) LOW	MEDIUM	HIGH
Villages	19	19	22
TVCBPUR:			
— median	10	15	25
— mean	12	20	66
— range	0–70	2–55	0–750
ICASH (not agriculture)	3	6	10
VSHAREWAT:			
— median	0	0	3
— mean	0.8	1.4	3
— range	0–3	0–6	0–10

Note: Descriptions of TVCBPUR, ICASH and VSHAREWAT are given in Table 3. For the variable VSHAREWAT, responses were obtained for only 18/19 villages in the medium and 20/22 in the high FMD frequency groups.

The risk of a village being in the highest frequency FMD group compared with the lowest group for different levels of the three important risk factors is shown in Figure 1 based on Model 2. The underlying risk of a village being in the high frequency group in the absence of any identifiable risk factors is 0.064 (6.4%). The risk increases to greater than 0.5 (50%) for villages purchasing 100 or more cattle or buffaloes per year regardless of the levels of the other two risk factors. Villages whose livestock share a water source with those from one or more other villages, whose main source of cash income is not from agriculture and whose annual purchases are 100 or more, face a risk in excess of 0.9 (90%) of being in the high frequency FMD group.

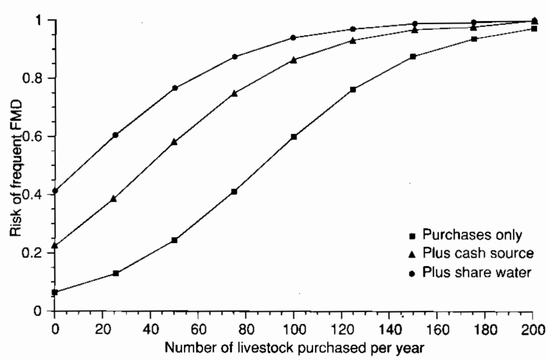

Figure 1. The risk of being in the high frequency FMD group (4 or more outbreaks in 5 years) based on the logistic regression Model 2. *Purchase only*: the change in risk with increasing annual purchases of cattle or buffaloes in the absence of other risk factors; *Plus cash source*: increased risk where the main source of village cash income was not from agriculture; *Plus share water*: increased risk where village livestock shared a water source with those from another village.

Discussion

In this study, three factors in combination were found to explain most of the variation in the frequency of FMD outbreaks in villages. This finding was consistent for the two different approaches to categorising FMD frequency. The first two factors, TVCBPUR and VSHAREWAT, reinforce the importance of livestock movement in the spread of FMD virus while the third factor, ICASH would appear to be less directly linked with FMD outbreak frequency.

Livestock movement is probably the single most important method of dissemination of FMD virus in those countries where FMD is endemic (Rweyemamu 1984; Rosenberg et al. 1980; Forman 1991; Ferris et al. 1992). In our study, the number of cattle and buffaloes purchased annually was found to be an important factor with the risk of being in a higher village FMD frequency group increasing by approximately one-third for each extra 10 animals purchased annually. This finding is consistent with the view that the virus is disseminated via the livestock marketing chain in Northern Thailand. It is possible that during outbreaks, preclinically-infected animals are sold from infected villages by owners concerned with the potential losses associated with loss of condition and the inconvenience and cost of nursing and treatment. Official DLD policy requires that only vaccinated animals are sold through livestock markets. A system of road checkpoints to ensure compliance with this policy was introduced in 1991 and, if effective, should see a reduction in the dissemination of FMD. Additional strategies which could be incorporated into an extension program for smallholders is to advocate the short-term quarantine of all cattle and buffaloes introduced into villages and to encourage a move towards self-replacing partially closed herds.

The finding that risk was increased with the number of neighbouring villages which shared a common water source for livestock indicated that spread from surrounding villages is an important source of FMD outbreaks. Village beef cattle and buffalo herds in Northern Thailand are managed on a free-range basis and co-mingling of livestock with those from neighbouring villages while watering or grazing commonly occurs. The frequency with which a village experiences outbreaks was found to be significantly associated with the level with which neighbouring villages share these common resources. It is therefore likely that simple quarantine of infected animals during outbreaks could substantially reduce the incidence of FMD by reducing spread among villages in addition to spread within the particular outbreak village. The provision of independent water supplies for different villages, among other benefits, should also reduce the frequency of FMD outbreaks.

Villages whose primary source of cash income was not from agriculture were at substantially higher risk of having FMD outbreaks. This increased risk is independent of the effects of trading and contact with surrounding villages. One possible explanation is that less attention is given to livestock husbandry in villages where many of the inhabitants are employed in nearby factories. Increasing industrialisation in Northern Thailand may thus have the secondary detrimental effect of enhancing the spread of FMD. Special attention may need to be given to these types of villages as the official FMD control program progresses.

Acknowledgments

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Epidemiological Investigations of Foot-and-Mouth Disease Outbreaks in Northern Thai Villages

Pornchai Chamnanpood,* P.C. Cleland,† F.C. Baldock§ and L.J. Gleeson†

Abstract

The results of investigations of 11 outbreaks of FMD in villages in Northern Thailand are described. The causative virus was found to be Asia 1 in seven outbreaks, Type O in two outbreaks and unknown in two outbreaks. The most probable sources of the outbreaks were found to be mingling of cattle and/or buffaloes with livestock from an infected neighbouring village (4) and recent introductions of infected cattle from a public livestock market (2) while the probable source was difficult to determine in five outbreaks. Most outbreaks lasted four weeks or less. Attack rates in cattle and buffaloes ranged from 0.28% to 50.9% but no pigs became sick during any of the outbreaks. Adult beef cattle were at higher risk of becoming a case when compared to work cattle or adult buffaloes. Beef cattle were at higher risk than buffaloes and adult cattle and buffaloes were at higher risk than calves less than one year of age. There was significant clustering of cases within households. Serological investigations indicated that most unaffected animals were probably not exposed to virus during the outbreaks. It was concluded that close contact between animals was the main method of spread and that differences in attack rates among animal classes reflected differences in animal management. It would thus appear that simple quarantine of early cases during outbreaks is likely to be effective in reducing spread within and between villages.

FOOT-and-mouth disease (FMD) is an important disease in Thailand because of its compromising effects on animal production and because it excludes the opportunity to export animal products to surrounding FMD-free countries. The smallholder beef and dairy cattle sector of the livestock industry is expanding in Thailand in response to rising demand from a more prosperous human population (Khajarern and Khajarern 1989). The recent improvements in cattle genetics, nutrition and management have highlighted the important deleterious effects that FMD has on annual production from this sector. In response, the Department of Livestock Development (DLD) within the Royal Thai Government regards the control and possible eradication of FMD (OIE 1991) as a major priority.

The main feature of the control program for FMD in Thailand is the mass vaccination of cattle and buffaloes to give at least 70% coverage in villages twice a year (Kongthon 1991). The policy to control local outbreaks involves ring vaccination together with the control of animal movement. Despite this substantial program, the disease is still endemic in the north of the country. There are many possible reasons for a considerable number of outbreaks occurring each year in the face of vaccination, including uncontrolled animal movements, vaccine handling problems, inadequate vaccination coverage and use of inappropriate serotypes in monovalent vaccines. The last problem mentioned should be overcome with the recent introduction of a trivalent vaccine incorporating serotypes O, A and Asia 1 (Kongthon 1991).

* Northern Veterinary Research and Diagnostic Center, Hang Chat, Lampang 52190, Thailand.
† CSIRO Australian Animal Health Laboratory, PO Bag 24, Geelong, Victoria 3220, Australia.
§ Queensland Department of Primary Industries, Animal Research Institute, 665 Fairfield Rd, Yeerongpilly, Queensland 4105, Australia.

The epidemiology of FMD relevant to control in Thai villages is not completely understood (Forman et al. 1989). Hence, by prospectively investigating outbreaks of the disease in villages in a systematic manner, information can be obtained which will contribute to the understanding of the epidemiology and control of FMD in the village agricultural system. A study was therefore undertaken to collect a range of information during outbreaks of FMD in villages. The purpose of undertaking the outbreak investigations was twofold. The first was to identify simple but effective measures which villagers could apply to reduce the impact of FMD when it occurs. Second, a better understanding was sought of the importance of different methods of spread and consequences of outbreaks to assist in planning future FMD control strategies.

Materials and Methods

There are approximately 5000 villages containing livestock at risk of exposure to FMD virus within Region 5 of Northern Thailand.[1] All were considered eligible for enrolment into the outbreak study. Villages were enrolled as outbreaks when notified to the laboratory and if the villagers were willing to cooperate. A suspect outbreak was a village from which one or more clinical cases of FMD were reported. An initially suspect outbreak was classified as confirmed when FMD virus was identified from tissue samples taken from one or more clinical cases.

Data collection

An outbreak was visited as soon as possible after notification. Epithelium and, if present, vesicular fluid were collected from fresh lesions of early cases and submitted to the FMD laboratory at the Northern Veterinary Research and Diagnostic Centre. The serotype was identified using an enzyme-linked immunosorbent assay (ELISA) typing method (Roeder and Le.Blanc Smith 1987) either directly on the submitted specimen or after cell culture.

Individual livestock owners were interviewed to determine the numbers and ages of beef and work cattle, buffaloes, pigs, sheep and goats. Cattle and buffaloes were classified as less than or greater than one year old while pigs were classified as less than or greater than six months. The previous FMD outbreak and vaccination history of the village were obtained through interviews of villagers and local DLD livestock officers.

[1] A map showing the regional divisions for Thailand is included in the Thailand Country Paper (these proceedings)

A sketch map of the outbreak village was made to show the distribution of village livestock, location of clusters of houses, water sources, nearby or through roads, neighbouring villages, the location of the early cases of the disease and natural barriers to transmission such as wide areas of cultivation.

The likely source of the outbreak was identified using the systematic investigation method shown in Figure 1. Most of the information was obtained by interviewing owners of index or early cases. Possible sources of infection were classified as recently infected introductions, local spread from a neighbouring village, introduced livestock products or the presence of endemic virus in the village.

The outbreak was visited once a week. Each livestock owner was interviewed to establish the species, type, number and age class of the new cases of FMD that had occurred in his current holding during the previous week. The total number of new cases in the village for that particular week was then determined. The outbreak was followed in this manner until all affected livestock had recovered and surveillance was maintained for at least one month after the recovery of the last identified case.

At the start of the outbreak, approximately 40 cattle and/or buffaloes which were not showing signs of FMD were identified by tail tag and blood samples collected. These animals were followed for the duration of the outbreak and any which developed FMD were recorded as cases. Blood was again collected from all tagged animals at the end of the outbreak. Antibody titres were measured to ascertain why some animals became cases whereas others remained free of FMD during the outbreak. In addition, the serological results were used to examine relationships between previous vaccination history and the severity of the outbreak.

Antibody titres to FMD virus types O, A and Asia 1 were measured by the serum neutralisation test (SNT) using standard methods (Golding et al. 1976). An increase in SNT titre of four-fold or more was regarded as significant and indicative of infection with FMD virus.

Statistical analyses

Stratified analyses were used to compare attack rates among species and age classes (Schlesselman 1982). Chi-square analysis was used to test for spatial clustering of cases within ownership groups. The inverse of SNT titres were log transformed prior to statistical analysis. For each serotype, mean antibody titres at the start of the outbreak were compared between cases and non-cases using Student's t-test. In addition, the titre for each animal at the

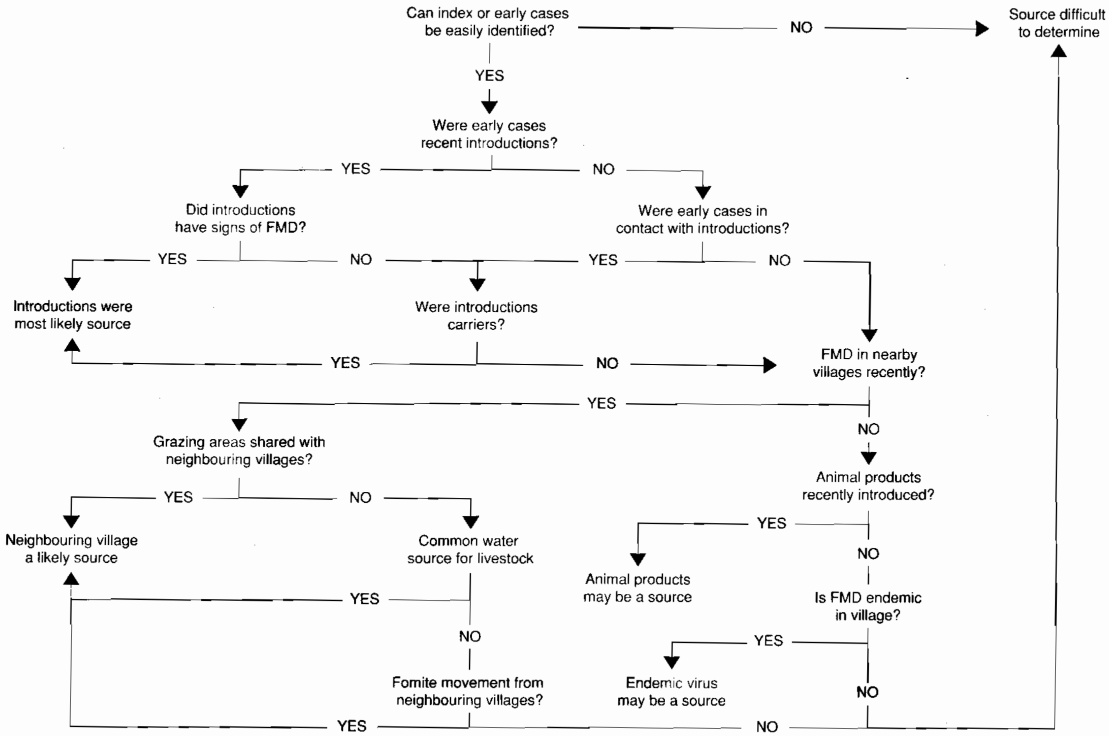

Figure 1. Strategy to determine the most likely source of FMD outbreaks in villages in Northern Thailand.

start of the outbreak was subtracted from its titre at the end and the mean change in titre compared between cases and non-cases using Student's t-test. For cases and non-cases separately, t-tests for paired data were used to ascertain whether antibody titres increased significantly. The significance level for statistical hypothesis tests was set at 0.05.

Results

The numbers of people and livestock in the 11 villages in which investigations were conducted are shown in Table 1. There were no sheep or goats in any of the villages investigated.

Causative virus and outbreak source

In seven outbreaks, Asia 1 virus was identified from index or early cases. Two outbreaks were due to type O virus and in another two outbreaks the virus type could not be identified.

Mingling of cattle and/or buffaloes with livestock from an infected neighbouring village was the most probable source in four of the outbreaks investigated. Recent introductions of infected cattle from a public livestock market was the probable source in two outbreaks. The most probable source could not be determined in five outbreaks.

Table 1. Numbers of people and livestock in the 11 FMD outbreak villages.

	Mean	Range
Families	133	30–500
People	548	135–2000
Work cattle	17	2–54
Beef cattle	458	139–1500
Buffaloes	115	2–500
Pigs	106	0–407

Outbreak description

The range in attack rates for cattle and buffaloes in the 11 outbreaks was 0.3% to 50.9%. No pigs became sick during any of the outbreaks. In three of the outbreaks, there was only minor spread over a one week period but an epidemic did not develop. The only deaths recorded were in one outbreak where three beef cattle less than one-year old died. Eight of the outbreaks lasted four weeks or less while one outbreak lasted for seven weeks and two outbreaks lasted for eight weeks or more. In six of the eight outbreaks where an epidemic developed, the number of new cases reached a peak in the first three weeks while in two outbreaks, the epidemic did not peak until the sixth and ninth week respectively.

Attack rates for cattle and buffaloes are shown in Table 2. The three villages in which an epidemic did not develop were omitted from the statistical analysis because they did not contribute any information relating risk to differences in species and age. Adult beef cattle were at 3.4 times the risk of becoming a case of FMD when compared with work cattle or adult buffaloes (P = 0.000). To compare the effects of age and species on FMD risk, a stratified analysis was conducted after excluding the work cattle since there was only one age class (adult) for this group. When adjusted for age, beef cattle were at twice the risk of buffaloes (1.61 < Mantel-Haenszel weighted relative risk (MHRR) < 2.57). When adjusted for species, adult beef cattle and buffaloes were at 1.6 times the risk of calves less than one year old (1.38 < MHRR < 1.94). There was evidence for additive interaction between age and species in determining risk of FMD. The excess relative risk for adult beef cattle was greater than the sum of the excess relative risk for each factor considered in isolation, that is being adult and being cattle (Rothman 1986).

Table 2. Attack rates for FMD for eight outbreaks with relative risks shown for all groups compared with buffaloes less than one year old which had the lowest attack rate.

Type	Number Sick	Number At risk	Attack rate	Relative risk
Buffaloes				
< one year	10	242	0.04	1.00
adults	64	890	0.07	1.74
Beef cattle				
< one year	105	946	0.11	2.69
adults	771	3218	0.24	5.80
Work cattle	10	143	0.07	1.69

There was a strong tendency towards clustering of cases within households in each of the eight outbreaks where the epidemic developed significantly beyond the index cases. Each outbreak was analysed separately using chi-square tests and the pattern observed was that most cases were derived from a relatively small number of households while remaining households had low morbidity or remained free of the disease (P < 0.01).

Outbreak serology

A total of 344 animals were identified and bled for serology at the beginning and end of outbreaks. In some instances, animals were vaccinated during the course of an outbreak. For such animals, pre-outbreak but not post-outbreak serological results were used in statistical analyses. A total of 37 identified animals became cases. The mean $\log_{10}$ SNT titres for the causative serotype for animals bled at the start and end of outbreaks are shown in Figure 2.

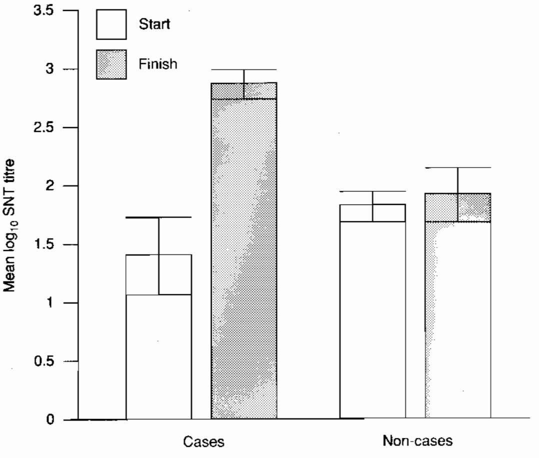

Figure 2. Mean $\log_{10}$ reciprocal SNT titres for cases and non-cases to the causative serotype at the start and at the end of outbreaks. Intervals shown are 95% confidence limits for means.

The mean $\log_{10}$ SNT titre for non-cases at the start of outbreaks was higher than that for cases but the difference was not significant (P = 0.057). The mean change in log titre from the start to the end of outbreaks was significantly greater for cases than for non-cases (P < 0.0001). Among non-cases, there was no significant change in mean log titre to the causative serotype during outbreaks. On the other hand, among cases, there was a significant increase in mean log titres (P < 0.0001).

Discussion

The individual animal risk for FMD during outbreaks was associated with both age and species with adult beef cattle being at the highest risk. It is unlikely that age and species *per se* are risk factors for FMD. It is more likely that the differences in the observed relative risks reflect differences in management of the livestock classes. Individual ownerships of working animals in villages in northern Thailand tend to consist of cattle or buffaloes but not both. Work cattle are commonly confined close to the owner's house and are often hand fed, and thus do not frequently mix with grazing beef cattle or buffaloes. The work cattle are therefore likely to be protected from exposure to circulating viruses during an outbreak, when compared to grazing beef cattle. Adult beef cattle comprise the largest single livestock group. Hence, the majority of contacts which occur between livestock from neighbouring villages when grazing or watering tend to be among adult beef cattle. The cattle and buffaloes tend to graze as loosely separate herds during the day and are housed separately at night. This system would be expected to aid transmission within a group but impede transmission between groups. Also, adult beef cattle are the largest class of animal traded. The study indicated that mingling of grazing livestock with those from an infected neighbouring village and introduction of infected animals from a market were important sources of outbreaks. Hence, it is suggested that the adult beef cattle are the most likely group to be first exposed to virus during outbreaks and that infection would tend to remain confined to this group in the management system described. The finding of clustering of cases within households also supports the hypothesis that management of animals in discrete groups aids the transmission within groups but inhibits transmission between groups.

The serological findings suggested that the main reason animals did not become cases during outbreaks was due to lack of exposure to virus rather than possessing a pre-existing immunity. There was no significant difference in mean titres between cases and non-cases at the start of the outbreaks and many of the animals which did not get sick had low titres and did not seroconvert.

Overall, the findings from the outbreak investigations suggest that close contact between animals is the main method of virus spread and that indirect methods such as by aerosol droplets and fomites (other infected items) are not as important. Virus particles in aerosols or on contaminated objects are likely to be rapidly inactivated by the intense heat and sunlight present in Northern Thailand (Forman 1991). It is suggested that an infective viral dose is much more likely to be delivered by close contact between susceptible hosts than by any other means and that indirect transmission should not be regarded as a major concern in the tropical climate in which this study was undertaken.

The findings also suggested that simple quarantine of early cases during an outbreak is likely to be effective in reducing spread within and between villages. Effective control of the disease is likely to be more dependent on control of local animal movements than on prophylactic ring vaccination in response to an outbreak. Currently, it is not possible to strictly enforce quarantine of all infected villages or to undertake a control program based on slaughter of infected stock, however isolation of early cases of the disease is a measure villagers could take independently of disease control authorities as an aid to reducing the severity of outbreaks.

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Serological Response of Village Cattle and Buffaloes in Northern Thailand to a Newly Introduced Trivalent Foot-and-Mouth Disease Vaccine

L.J. Gleeson,* M.D Robertson,* W.J. Doughty,* Chanpen Chamnanpood,† P.C. Cleland,§ Pornchai Chamnanpood† and F.C. Baldock§

Abstract

A field study of vaccination responses in village stock was carried out in a total of 21 villages in three provinces of Northern Thailand. The animals were monitored over a 19-month period during which time they received four vaccinations at the specified six-month intervals. The data was analysed by age group according to whether the animals were seropositive or seronegative in the serum neutralisation test (SNT) at the start of the program. Regardless of age, it was not until seronegative animals received two vaccinations that greater than 80% of the animals maintained a $\log_{10}$ SNT titre of 1.5 or above for a full vaccination interval. The data on serological responses showed the value of monitoring the vaccination responses of village livestock.

THREE serotypes of foot-and-mouth disease (FMD) virus (O, A and Asia 1) are endemic in Thailand. The Department of Livestock Development (DLD) is responsible for implementing a new program with a number of strategies to control FMD. A key element of the control program is six-monthly administration of locally manufactured trivalent vaccine to all livestock over six months of age.

Prior to the introduction of the trivalent vaccine in 1991 monovalent vaccines were used, mainly in ring-vaccination programs to localise outbreaks. However, no systematic studies had previously been carried out to measure the FMD vaccination response of cattle and buffaloes in the village production system in Thailand. Many authorities on FMD vaccination have stressed the importance of monitoring vaccine performance in the field (Henderson 1970). A field study of vaccination responses in village stock was carried out over an 18-month period in a total of 21 villages in three provinces in Northern Thailand from January 1991 to September 1992. The goals of the study were to evaluate the performance of the new trivalent vaccine under conditions of the village production system and to develop a basis for future monitoring of FMD vaccines in the field in Thailand.

Materials and Methods

Vaccination study

Seven villages in each of three provinces (Lampang, Lamphun and Chiang Mai) were selected for participation in the program. Animals were vaccinated on four occasions (rounds) at six-monthly intervals. A total of 40 bovidae were enrolled in each village at the beginning of the study and where possible this included an equal number of cattle and buffaloes and the animals were selected across all age groups. Serum samples were collected on the day of vaccination (bleed 1) and four weeks after each vaccination (bleed 2) for each round. These collection points were designated by round (R1, R2, R3, R4) and bleed (R1B1, R1B2, R2B1 etc.). An

* CSIRO Australian Animal Health Laboratory, PO Bag 24, Geelong, Victoria 3220, Australia.
† Northern Veterinary Research and Diagnostic Center, Hang Chat, Lampang 5200, Thailand.
§ Queensland Department of Primary Industries, Animal Research Institute, 665 Fairfield Rd, Yeerongpilly, Queensland 4105, Australia.

additional serum collection was made from a subset of villages at R2B3, three months after R2B1. Sera were separated by centrifugation and aliquots inactivated at 56°C and stored at −20°C. One batch of vaccine was used for the first three rounds and a second batch for the fourth round.

Serology

Serological responses to vaccination were measured by the serum microneutralisation test (SNT) using IBRS-2 cells (Golding et al. 1976). Sera were titrated in duplicate and titres were expressed as log to the base 10 ($\log_{10}$) of the reciprocal of the 50% serum neutralising endpoint (SN50). The lowest titre measurable was 0.8 (after addition of virus). Homologous vaccine challenge stocks and positive control sera obtained from the FMD Center, Pak Chong were used for the SNT.

Analysis

All individual animal data were recorded using the PANACEA[1] database software program (Pan Livestock Services) on a IBM compatible computer. Statistical summaries were prepared using the STATISTIX[2] software package. Data was transferred to another software program (Quattro Pro) for the graphics preparation. For the purpose of calculation of means and standard deviation of titres, titres of less than 1:8 were arbitrarily given a log SNT value of 0.6 to facilitate manipulation of data by the computer software packages. A log SNT titre of equal to or greater than ($\geqslant$) 1.2 was regarded as positive. For analysis the sample was divided into three age classes:

- *P* — equal or greater than six months; less than one year;
- *Q* — equal or greater than one year; less than two years;
- *R* — greater than two years.

Herd immunity following vaccination was assessed in two ways. A $\log_{10}$ SNT titre of $\geqslant$ 1.5 was regarded as likely to confer protection against field challenge on an individual animal basis. Age class means titres were also calculated and used to estimate the percentage of animals within the class with a 95% probability of resisting field challenge on a population basis.

Probits for protection were calculated from the equation of Pay and Hingley (1992):

$$z = e + fy$$

where:

- z is the probit of expected protection from challenge;
- e is a constant set globally at 0.26;
- f is the slope of the regression set globally at 3.76;
- y is the mean $\log_{10}$ SNT titre.

Results

Of the 21 villages initially participating in the program, one village was excluded from the study at round R3B1 because of a poor return to follow-up at R2B2, and a further two villages dropped from the study at R4B1, when the second batch of vaccine was introduced. Moreover, because the serological response pattern appeared established by R3B2, a smaller set of villages was sampled at R4B2. The data collected at R4B2 confirmed that the second vaccine maintained the herd immunity.

A total of 921 animals were enrolled at R1B1, and a progressive but not excessive decline in the total number of animals presented was experienced between R1BI and R4B1. In some villages replacement animals matched for age, sex, body condition, and vaccination history were enrolled to replace animals that were lost to the program. However, not all animals sampled at each round were tested. Most of the animals enrolled, sampled but not tested belonged to the age class *R*, and all dropped from the sample population at a later point. Data from 43 animals that were less than six months of age at R1B1 were also excluded for calculation purposes, because the official vaccination policy is to vaccinate animals six months and over. Serological data were generated for 616 animals at R1B1. Animals lost to follow-up did not introduce a bias into the results. Table 1 shows the number of animals for which serological data were generated at each point of the trial.

The percentage of animals by age class at each sample point that were regarded as likely to be protected from field challenge is shown in Figures 1, 2 and 3. For each age class the pattern is similar. The percentage of animals with titres $\geqslant$ 1.5 is lower for type A at R1B1 for all age classes and the percentage of animals with titres $\geqslant$ 1.5 is noticeably higher for type O age class *R* at R1B1. The distribution of SNT titres for each serotype, except for type O age class *R*, was initially right skewed, tended toward a normal distribution as the animals began to respond to vaccination and then became left skewed as a large percentage of the sample population began to develop substantial titres.

[1] Pan Livestock Services, Reading, UK
[2] Analytical Software, St Paul, USA

Table 1. Distribution of animals in each age class providing serological data at each sample point.

Sample point	Age class			Number of villages represented
	P[a]	Q[b]	R[c]	
Initial	170	245	418	21
R1B1[d]	138	190	288	21
R1B2	138	190	289	21
R2B1	139	190	289	21
R2B2	139	190	289	21
R2B3	60	52	99	6
R3B1	118	169	294	20
R3B2	78	113	153	12
R4B1	71	102	188	18
R4B2	44	58	78	8

[a] Age class *P* — animals at least 6 months old and not older than 1 year at R1B1
[b] Age class *Q* — animals older than 1 year but not older than 2 years at R1B1
[c] Age class *R* — animals older than 2 years at R1B1
[d] Round and bleed number

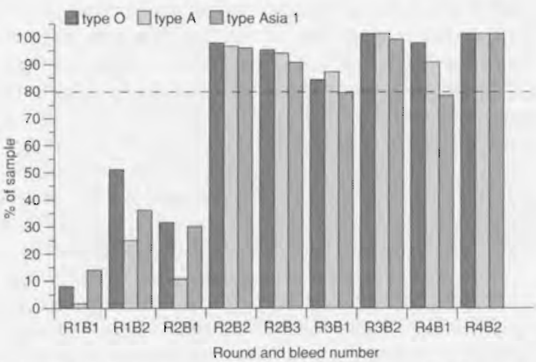

Figure 1. Percentage of animals with $\log_{10}$ SNT titres $\geqslant 1.5$ against serotypes O, A and Asia 1: Age Class P (0.5–1 year).

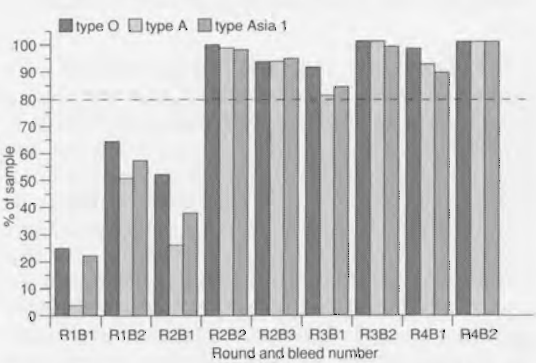

Figure 2. Percentage of animals with $\log_{10}$ SNT titres $\geqslant 1.5$ against serotypes O, A or Asia 1: Age Class Q (1–2 years).

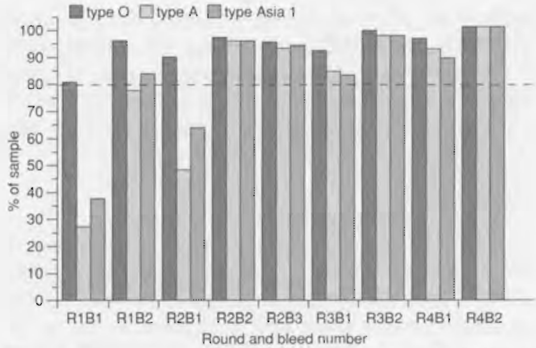

Figure 3. Percentage of animals with $\log_{10}$ SNT titres $\geqslant 1.5$ against serotypes O, A or Asia 1: Age Class R (> 2 years).

To analyse the influence of the SNT titre at R1B1 on the serological response pattern by age class, the data set was reduced to include only animals which were present at R1B1 (i.e. replacement animals were excluded). The response to vaccination was analysed separately by serotype for animals seronegative (SNT−) and seropositive (SNT+) at R1B1 to that serotype i.e. with an R1B1 SNT titre of < 1.2 and $\geqslant 1.2$ respectively. The data is shown graphically for serotype Asia 1 for each age class, because there were sufficient animals in the SNT− and SNT+ groupings for each age class. The distribution of animals in each age class in the reduced type Asia 1 set is shown in Table 2. There were insufficient animals SNT+ to type A at R1B1 in age class *P* and insufficient SNT− to type O in age class *R* to facilitate a meaningful analysis. Data for type O was included as a comparison for age classes *P* and *Q* and for type *A* for age class *R*. The plots for mean SNT titre and the percentage of animals regarded as highly likely to be protected against field challenge are shown in Figures 4 to 6.

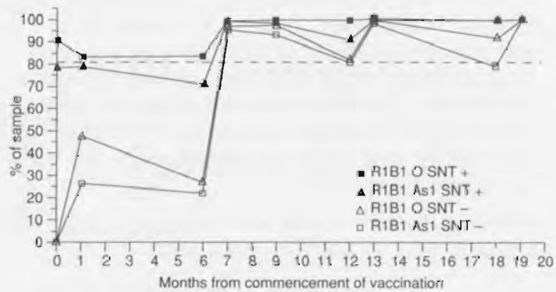

Figure 4. Vaccine responses of age class P (0.5–1 year) animals categorised by serological status at the commencement of vaccination: percentage $\log_{10}$ SNT titres $\geqslant 1.5$ against serotypes O and Asia 1.

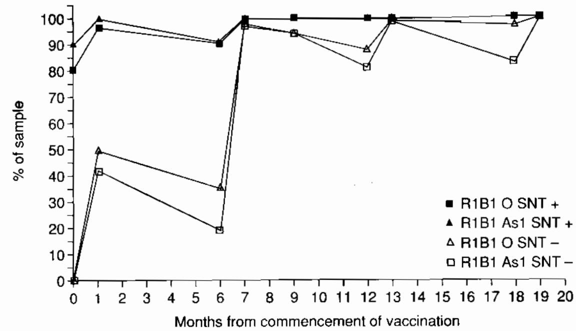

Figure 5. Vaccine responses of age class Q (1-2 years) animals categorised by serological status at the commencement of vaccination: percentage $\log_{10}$ SNT titres $\geqslant$ 1.5 against serotypes O and Asia 1.

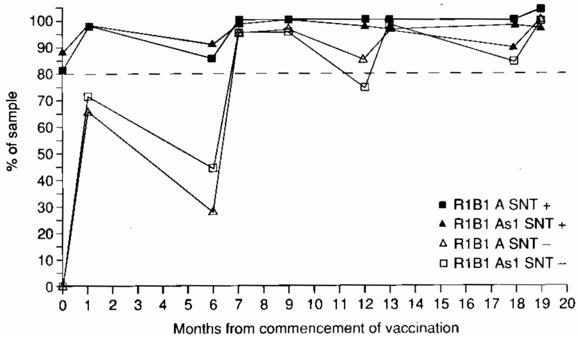

Figure 6. Vaccine responses of age class R (>2 years) animals categorised by serological status at the commencement of vaccination: percentage $\log_{10}$ SNT titres $\geqslant$ 1.5 against serotypes A and Asia 1.

Table 2. Distribution in each age class at each sample point of animals allocated to seropositive or seronegative group by Asia 1 SNT status at the commencement of the study (R1B1).

Sample point	Age class					
	P		*Q*		*R*	
	SNT+[a]	SNT−[b]	SNT+	SNT−	SNT+	SNT−
R1B1[c]	24	114	47	143	121	167
R1B2	24	113	47	143	121	167
R2B1	24	114	47	143	121	167
R2B2	24	114	47	143	121	167
R2B3	10	45	9	34	36	48
R3B1	23	86	37	118	107	150
R3B2	16	61	32	73	51	91
R4B1	11	58	30	63	64	99
R4B2	9	35	27	28	33	39

[a] Asia SNT titre at R1B1 $\geqslant$ 1.2
[b] Asia 1 SNT titre at R1B1 < 1.2
[c] Round and bleed number
Note: For definitions of age classes *P*, *Q* and *R* see Table 1.

The probit plots of the 95% likelihood of resisting field challenge for the SNT− groups are shown in Figures 7, 8 and 9. These plots are derived from the mean group titres (data not shown).

Age class *P*: vaccine responses of type O SNT+, type O SNT−, type Asia 1 SNT+ and type Asia 1 SNT− groups.

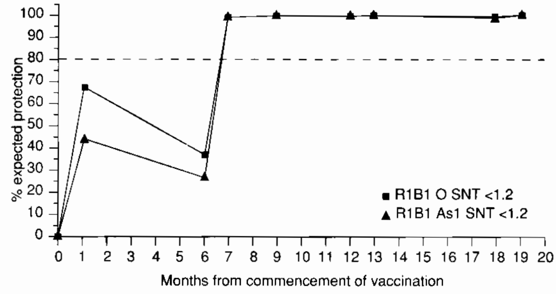

Figure 7. Expected percentage protection based on probits derived from group mean $\log_{10}$ SNT titre against serotypes O and Asia 1 for age Class P (0.5-1 year) animals seronegative at commencement of vaccination.

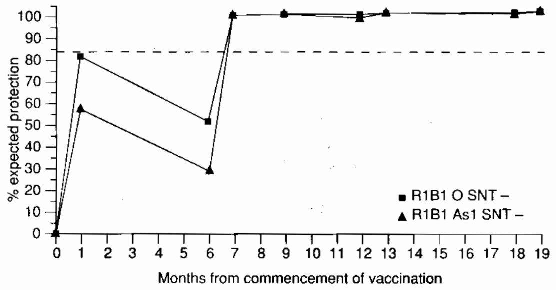

Figure 8. Expected percentage protection based on probits derived from group mean $\log_{10}$ SNT titre against serotypes O and Asia 1 for age Class Q (1-2 years) animals seronegative at commencement of vaccination.

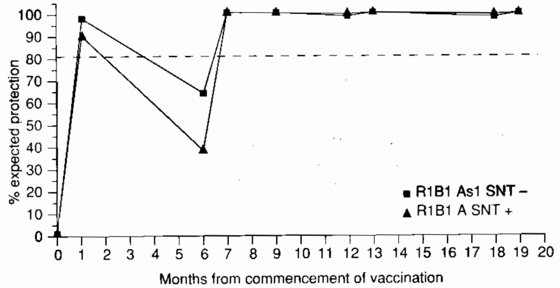

Figure 9. Expected percentage protection based on probits derived from group mean $\log_{10}$ SNT titre against serotypes A and Asia 1 for age Class R (>2 years) animals seronegative at commencement of vaccination.

After two vaccinations six months apart, more than 80% of the type Asia 1 and type O SNT− groups were regarded as protected against field challenge for subsequent vaccination intervals. It appeared that the type Asia 1 titre decayed more rapidly than the type O titre for both SNT+ and SNT− groups after the third vaccination (data not shown). The greater decay in Asia 1 titres was reflected in the substantial difference in the percentage of animals with a titre < 1.5. A chi-squared test of the number of titres < 1.5 and $\geqslant 1.5$ showed a significant difference between the two serotypes at R4B1 (chi-square, 22.1, df 1, $p < 0.0001$). At R4B2 the mean titre of all four groups of animals was similar. The mean titres of the SNT+ groups were both > 2.25 at R1B1, giving at least a probit for protection of 8.72, i.e. 100% of animals had a 95% likelihood of resisting field challenge. The percentage of animals with a 95% likelihood of resisting field challenge to both serotypes is shown for the SNT− groups in Figure 7.

Age class *Q*: vaccine responses of type O SNT+, type O SNT−, type Asia 1 SNT+ and type Asia 1 SNT− groups.

The pattern of response was similar to the age class *P* animals in all respects (see Figs 5 and 8). Using the probit equation, the percent protection in the SNT+ group reached 100% after one vaccination and did not decline, whereas there was a decline in the percent of animals protected against both type O and type Asia 1 after R1B2 for the SNT− group. The expected percent protection was 100% after two vaccinations and did not significantly decline (Fig. 8).

Age class *R*: vaccine responses of type A SNT+, type A SNT−, type Asia 1 SNT+ and type Asia 1 SNT− groups.

The percentage of R1B1 SNT− animals protected at R1B2 was greater for this age class than the other two (Fig. 6). The mean Asia 1 SNT titre for this group was similar to the other two age classes at R3B1 (data not shown), but there was an slightly greater decline in the percentage of animals likely to be protected against challenge by Asia 1 at this point. There was also an unexplained failure of the vaccine to induce 100% likely protection against Asia 1 in the SNT+ group at R3B2 and R4B2 (Fig. 6).

Discussion

The serological data obtained from village livestock vaccinated with the new trivalent vaccine demonstrated that the vaccine stimulated high levels of neutralising antibodies in serum. However in animals that were classified as not previously vaccinated or infected at R1B1, at least two vaccinations were required before the majority of animals had sustained serum antibody titres regarded as likely to indicate a protective immune status. The response to the vaccine after two doses indicated that the vaccine was very potent, with the mean titre for all serotypes > 2. There was an obvious difference in the response of the SNT+ groups compared to the SNT− groups, and after 18 months a difference was still obvious. However the smaller sample at R4B2 indicated that the mean titres of the SNT+ and SNT− groups were similar. It therefore seemed that the priming of the SNT+ groups was substantial. The study did not progress long enough to determine if the vaccine could induce an SNT antibody response against all three serotypes for a six-month period in the SNT− group the same as the SNT+ group of animals. The mean log SNT data suggested that the response to type Asia 1 was not sustained as to type O after three vaccinations. The vaccine batch in use had reached the 12-month expiry date by R3B1 and this result could have indicated some difference in the stability of that antigen. Further analysis of the antibody decay may be useful in predicting herd immunity to each serotype. Data not shown here also indicated that a primary course of two vaccinations one month apart greatly enhanced the development of herd immunity (see Cleland et al., these proceedings).

The differences in the serological profiles shown in Figures 1, 2 and 3 probably reflect that type O vaccine was the monovalent vaccine most recently used prior to the study, and that type Asia 1 was the serotype predominantly circulating in Northern Thailand around the commencement of the study. Type A vaccines were not in extensive use and outbreaks of FMD caused by type A had been relatively rare for about two years (unpublished results). However, the percentage of animals of the *R* age class considered protected against type A at R1B2 suggested a greater herd type A immunological memory for this age class.

The issue of possible exposure to wild virus during the study period was also considered. Although it might be expected that animals in some villages were likely to be exposed, examination of the titre changes for different villages over time revealed no unusual variations in titre between vaccinations. Since there was no way to reliably identify animals exposed to wild virus, no action was taken in the statistical analysis.

There was no information available from challenge work to establish the minimum titre of trivalent vaccine-induced SNT antibodies likely to induce 70% protection against the homologous viruses, and so a threshold mean log SNT titre value of 1.5 was initially selected on the basis of data available from studies in other countries (Pay and Parker 1977). Based on the pooled data of Pay and Hingley (1992), this was converted into a probable protection (probit 5.9) against field challenge of 81% of a group of animals with a mean log SNT = 1.5, while not allowing for the substantial differences likely in innate resistance to infection of native breeds, the difference between a field challenge and an experimental challenge, and antigenic differences between field viruses and vaccine viruses that evolve (see Gleeson, Doughty et al., these proceedings). Pay (1983) has stated that in order to prevent an epidemic, 70% of the population need to be protected, but to absolutely prevent an outbreak on a herd basis 95% protection is required. It is also important to note that there are significant differences in the antibody requirements for protection as time elapses after vaccination (Wittmann 1972). In the situation in Thailand it seemed that the mean SNT titre threshold of 1.5 to ascribe likely protection to 80% of animals is a reasonable goal at this early stage of the control program. While 80% protection may have been a conservative requirement to ensure herd immunity, it seemed more judicious to err on the high side than to overestimate vaccine potency and efficacy, especially as the other requirement for an even coverage over the whole population will be hard to achieve in Thailand.

The use of the equation of Pay and Hingley (1992) to calculate probits may be questioned, although their relationship was based on a large amount of good quality data. It is noted, however, that the SNT used in the case of European vaccine manufacturers was a tube test, and in this case the microneutralisation test was used. Data published from the Pan American Foot-and-Mouth Disease Center suggests that a higher SNT titre must be used to predict 70% protection when the SNT titre is determined by the microneutralisation test (Sutmoller and Viera 1980; Sutmoller et al. 1980).

The events determining protection against disease are complex and it has been suggested that the SNT titre should be regarded only as a predicting variable of the likely outcome of challenge (McCullough et al. 1988; Amadori et al. 1991). However protective immunity in cattle is generally considered closely related to the serum neutralising antibody titre present at the time of exposure to infection. It has been argued that anti-FMD antibody titres should be classified into three zones; the 'white zone' in which antibody titres are high and likely to protect; a 'black zone' in which antibody titres are low and unlikely to protect and a 'grey zone' in which titres are intermediate and interpretation with respect to protection is least reliable (McCullough et al. 1992). Differences between the minimal protective titre have been observed for different serotypes and for different strains of challenge virus (Sutmoller and Vieira 1980). In the case of evaluating a trivalent vaccine it was noted that while there is no evidence of synergy between serotypes in conventional vaccines (Black et al. 1986) there is evidence that multiple natural infections can induce heterotypic antibody responses (Hedger et al. 1982).

The results showed the value of monitoring the vaccine response in the target population, and that the contribution of the previously immune animals to the overall herd immunity was considerable. Natural immunity after infection is long lived and probably is the reason for the cyclical appearance of the serotypes observed in the livestock population in Northern Thailand. If the prevalence of infection is reduced to all three serotypes, then it will be important for the vaccination program to be sustained, or a population of animals simultaneously susceptible to all three serotypes could emerge. An epidemic involving all three serotypes would have a devastating effect on the livestock production system. This suggests that some further monitoring of herd immunity will be important as the number of animals immune due to natural exposure is reduced. It will be also important to maintain a high level of immunity to prevent outbreaks from occurring in partially immune animals, a situation that is regarded as likely to encourage the emergence of new strains antigenically divergent from the vaccine strain, and further reduce the efficacy of the vaccine.

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Antibody Responses to Foot-and-Mouth Disease Virus VIA Antigen Monitored During a Field Vaccination Trial

Chanpen Chamnanpood,* L.J. Gleeson† and M.D. Robertson†

Abstract

Sera was collected from village livestock during the vaccination trial in 21 northern Thai villages. Animals from the project database were divided into two groups. Those with $\log_{10}$ serum neutralisation test (SNT) titres of < 1.2 to all three serotypes (A, O, and Asia 1) were classified as *seronegative* and those with a higher titre to at least one were classed as *seropositive*. At the start of the trial there were no reactors among the seronegative animals and there was an increase to about 10% one month after the first vaccination. Most reactions disappeared by six months after vaccination but returned after revaccination. Vaccination with the new production batch of the same vaccine provoked a substantial reactor prevalence. The seropositive group reactor rate rose from 30% to 70% after one vaccination, and many animals were still seropositive six months after vaccination.

THE antibody response to the foot-and-mouth disease (FMD) virus non-structural protein called the virus infection-associated (VIA) antigen has been used to detect recent infections with FMD virus (McVicar and Sutmoller 1970). Although it was initially thought this antigen would prove to be a very useful diagnostic tool to discriminate immune responses induced by vaccination from those induced by infection, animals that have received multiple vaccinations respond serologically to VIA antigen present in inactivated vaccines (Dawe and Pinto 1978; Pinto and Garland 1979). The VIA agar gel diffusion test (AGDT) is still used to gather epidemiological information about virus activity in the field, although recently a specific and sensitive liquid phase blocking enzyme-linked immunosorbent assay (ELISA) has been described (Alonso et al. 1990). While VIA AGDT status is very useful in situations where vaccine is not used, the results must be interpreted with caution where vaccine is in use. Widespread application of a new trivalent vaccine produced by the Department of Livestock Development is a key strategy of a program to control and eradicate FMD in Thailand. This paper briefly describes the VIA AGDT reactor prevalence profile of a group of animals monitored during a longitudinal study of the responses of village livestock in Northern Thailand to the trivalent vaccine.

Materials and Methods

Experimental design

Animals in 21 villages (seven in each of three provinces) in Northern Thailand were ear tagged and vaccinated as previously described (see Gleeson et al., these proceedings). Sera collected at seven visits on the established vaccination response monitoring schedule were tested by AGDT and the results recorded on a computer spreadsheet database (PANACEA[1]). Data was summarised with the aid of a statistical software package (STATISTIX[2]). Histogram plots were used to depict the results of the analysis. Serum neutralisation test (SNT) titres to O, A, and Asia 1 at the commencement of the program were included in the database.

* Northern Veterinary Research and Diagnostic Center, Hang Chat, Lampang 52190, Thailand.
† CSIRO Australian Animal Health Laboratory, PO Bag 24, Geelong, Victoria 3220, Australia.

[1] Pan Livestock Services, Reading, UK
[2] Analytical software, St Paul, USA

VIA antibody assay

The VIA AGDT was carried out according to Cowan and Graves (1966) except that the agar was prepared in 0.02 M Tris, 0.15 M NaCl buffer, pH 7.6 (0.02 M Tris buffer). VIA antigen was prepared from infected cell culture supernatant fluids treated with polyethylene glycol (PEG) 6000 for production of purified 146S antigen (Doel and Baccarini 1981). DEAE cellulose (Whatman DE-52) washed and equilibrated with 0.02 M Tris buffer was added to the PEG-treated supernatant fluid (40 g per 2 litres) and gently mixed overnight at 4°C. The gel was collected in a sintered glass funnel and washed extensively with 0.02 M Tris buffer. Bound protein was then eluted in a semi-crude batch procedure by increasing the NaCl concentration in the buffer to 1 M. The eluate obtained was progressively concentrated on Amicon XM300 and YM30 membranes using a nitrogen pressurised stir cell (Morgan et al. 1978). The two concentrates were pooled, then precipitated with NH_4SO_4 to 60% saturation, and resuspended in phosphate buffered saline (PBS). Preparations were screened for VIA antigen activity by AGDT using a reference VIA antigen preparation and a reference convalescent bovine serum obtained from the Research Section, FMD Center, Pak Chong. Supplementary field test antigen was also supplied by the FMD Center and the positive control serum for the field tests was a pool of field sera that gave a reaction (3+) equivalent to the bovine reference in the test. The test was read after 48 and 72 hours incubation in a humidity chamber and the results recorded on a spreadsheet database (PANACEA). Reactions were scored from 1+ to 3+ in comparison to the positive control reaction. However for the purpose of frequency analysis of reactor prevalence all positive reactions were equally weighted.

Vaccinations

Animals were vaccinated at round 1 (R1), 6 months later at round 2 (R2), and again after a further 6 (R3) and 12 months (R4). Serum samples were collected at each vaccination round on the day of vaccination (B1) or 4 weeks later (B2) and were designated by round number and bleed number (B1 or B2). AGDTs were carried out on samples from R1B1, R1B2, R2B1, R2B2, R3B2, and R4B2. An additional collection was made on a subset of villages 3 months after the second vaccination (R2B3). The same batch of trivalent vaccine was used for the first three rounds of vaccination, and a second production batch was used for the last vaccination. Three different batches of VIA antigen were used to complete the study: one batch was used for the R1 and R2 tests, a second batch for R3 tests and a third for R4 tests.

Results

There were no reports of clinical FMD from any of the participating villages during the course of the study. During the course of the study there was a decline in animal numbers enrolled in the monitoring program and in some villages replacement animals, matched as closely as possible to those not returning, were added. Only animals present at R1B1 were included in the data set for this analysis. The remaining 644 animals were first divided across all age groups into two exclusive groups:

- 273 animals seronegative (SNT titre < 1.2) to all 3 serotypes of FMD at R1B1 (R1B1 FMD negative); and
- 371 animals seropositive (SNT titre $\geqslant 1.2$) to any one serotype of FMD at R1B1 (R1B1 FMD positive)

The changes in AGDT reactor prevalence for these two groups are shown in Figure 1. There were no VIA reactors in the FMD negative group at R1B1.

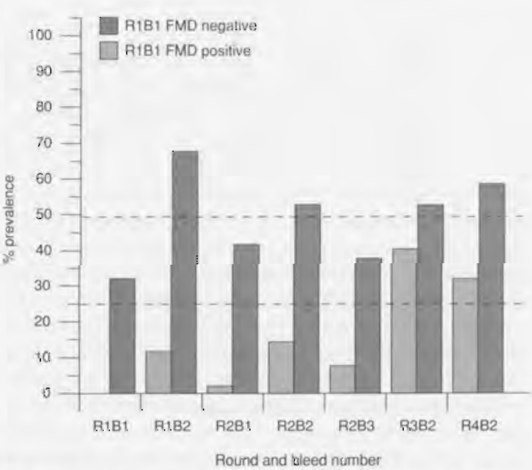

Figure 1. VIA responses during vaccination trial: prevalence (percent) of AGDT positive samples among R1B1 FMD seronegative (all SNT titres < 1.2) and seropositive (any SNT titre $\geqslant 1.2$) animals.

A further two independent divisions of the animals present at R1 was carried out. In order to assess the influence of previous vaccination with type O monovalent vaccine, a subset termed R1B1 O positive (R1B1 SNT titre O $\geqslant 1.2$) was selected using the following criteria: (omit age < 2 years);

(omit if R1B1 SNT titre O < 1.2); (omit if R1B1 SNT titre Asia 1 > O); and (omit if R1B1 SNT titre A > O). These criteria selected 129 of the 644 animals.

In order to asses the influence of recent infection on the AGDT reactor rate after vaccination, a subset termed R1B1 Asia 1 positive (R1B1 SNT titre Asia 1 > 1.35) was selected using the following criteria: (omit if R1B1 SNT titre Asia 1 < 1.35); and (omit if R1B1 SNT titre O > Asia 1 or R1B1 SNT titre A > Asia 1). These criteria selected 95 animals.

AGDT reactor prevalence in these two subgroups over the four rounds of vaccination is shown in Figure 2.

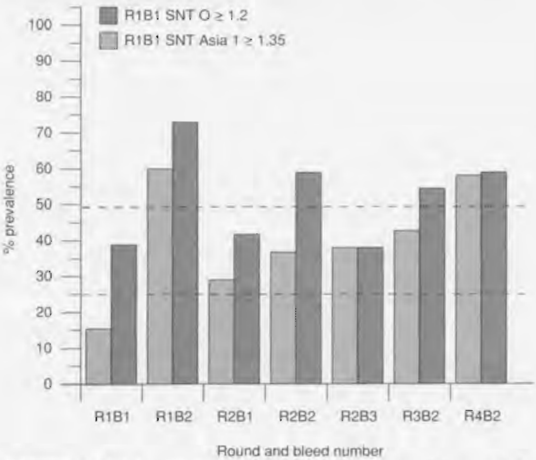

Figure 2. VIA responses during vaccination trial: prevalence (percent) of AGDT positive samples among R1B1 O positive (R1B1 only SNT titre O ⩾ 1.2) and R1B1 Asia 1 positive (R1B1 SNT titre Asia 1 ⩾ 1.35; Asia 1 > O, Asia 1 > A).

Discussion

The results indicated two major points of interest. First that there was a low prevalence of reactors induced by the first two vaccinations of animals regarded as probably not previously exposed to FMD VIA. Second, for animals with previous exposure to FMD antigens either by vaccination or infection at R1B1 (i.e. seropositive to any serotype), there was a considerable anamnestic antibody response to VIA antigen as indicated by the large increase in reactor prevalence four weeks after the first vaccination. However, after the third vaccination of the R1B1 FMD negative group, there was a substantial rise in the prevalence of AGDT reactors.

Although the type O positive group showed a substantial increase in reactor prevalence after the initial vaccination, the overall reactor prevalence for the type O positive group was lower than for the type Asia 1 positive group, suggesting that the selection criteria used had selected for animals with different previous exposure to FMD VIA. Type Asia 1 was the most prevalent cause of FMD outbreaks in Northern Thailand in the period immediately prior to the commencement of the study (unpublished project data). The reactor prevalence in the type O positive group at R4B2 increased disproportionately to the other groups suggesting that the fresh batch of vaccine provided an increased VIA stimulus to this group. It has been reported that variation in the reactor prevalence might be expected to occur from batch to batch of VIA antigen, if the VIA source in the vaccine is predominantly from the same serotype used to prepare the AGDT antigen (Ahl and Wittmann 1986).

The results show that during the current FMD control program in Thailand, in which widespread use of the trivalent vaccine is planned, results of the VIA AGDT will have to be interpreted with extreme caution. The sharp increase in reactor prevalence in the R1B1 FMD positive group occurred in the absence of FMD outbreaks in 21 villages. If the first 11% of AGDT reactors at R1B2 in the R1B1 seronegative group were due to some previous sensitisation, it would also appear that there is potential to stimulate AGDT reactors in a significant proportion (up to 20%) of animals after three vaccinations. Clearly further longitudinal investigations are required to clarify if there is any effect of vaccine batch on the VIA reactor prevalence, and to determine the duration of reactions following routine vaccination. Knowledge of expected reactor rates and decay times may increase the usefulness of the test in monitoring the effectiveness of the vaccine program in preventing subclinical infections.

Acknowledgments

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A Modelling Approach to the Investigation of Vaccination Strategies for Foot-and-Mouth Disease

P.C. Cleland,* F.C. Baldock,† L.J. Gleeson* and Pornchai Chamnanpood§

Abstract

A state-transition model of the temporal development of herd immunity to foot-and-mouth disease (FMD) in response to vaccination was constructed based on the observed dynamics of populations of cattle and buffaloes in villages in northern Thailand. Model parameters were the birth rate, age-specific mortality and selling rates as well as the vaccination rate and a number of probabilities derived from field studies and estimating vaccine efficacy and titre decay for different classes of animals. An animal was regarded as immune to FMD if its serum neutralisation titre was 1 in 32 or greater ($\log_{10}$ titre $\geqslant 1.5$). Output from the model was graphed as the change over time in the percentage of animals in a village having an immunity to FMD. For the purposes of the study, a minimum acceptable level of 80% prevalence of immune animals was assumed to be necessary to prevent spread of FMD virus. The model indicated that a simple strategy of six-monthly vaccination with an approximate 70% coverage would never achieve the minimum acceptable level of herd immunity. Increasing the coverage to 90% resulted in periods of several months where more than 80% of animals were immune alternating with periods immediately prior to revaccination where the level of herd immunity dropped below an acceptable level. A strategy which included a primary course of two inoculations one month apart for newcomers to the program combined with six-monthly revaccination of 80% of all animals produced a similar long-term effect to the simple 90% coverage but with the advantage that herd immunity levels were achieved more quickly.

FOOT-and-mouth disease (FMD) is endemic in Northern Thailand where the circulating viruses are serotypes O, A and Asia 1. The control program for the disease has been based on 6-monthly vaccination of at least 70% of all village cattle and buffaloes greater than six months of age with a trivalent vaccine, combined with movement controls, supporting zoosanitary measures and ring vaccination in response to outbreaks (Kongthon 1991). A two-year Thai–Australian research project to evaluate the serological responses of village cattle and buffaloes to the trivalent vaccine commenced in January 1991. In addition to the vaccination response studies, data were collected on the population dynamics of village cattle and buffaloes. The information from these field studies was used to construct a computer spreadsheet model to simulate the development of immunity in a 'typical' village herd in response to FMD vaccination. Of primary interest was the likely impact of present vaccination strategies in reducing FMD spread. In addition, the model was used to compare a number of alternative strategies with the view to identifying possible improvements in the way vaccine is used.

* CSIRO Australian Animal Health Laboratory, PO Bag 24, Geelong, Victoria 3220, Australia.
† Queensland Department of Primary Industries, Animal Research Institute, 665 Fairfield Rd, Yeerongpilly, Queensland 4105, Australia.
§ Northern Veterinary Research and Diagnostic Center, Hang Chat, Lampang 5200, Thailand.

Methods

Assumptions and model parameters were derived from field observations on 60 northern Thai villages.

Definitions

Herd: The aggregate of all cattle and buffaloes in a village set at a size of 250 animals.

Efficacy: The proportion of animals becoming immune to FMD infection following vaccination. Individuals with a serum neutralisation test (SNT) titre of 1 in 32 or greater were regarded as immune ($\log_{10}$ SNT $\geqslant$ 1.5).

Herd immunity: The resistance to infection of a group of animals due to the immunity of a high proportion of individuals in the group. The level of herd immunity is the proportion of immune animals in a group. When the level of herd immunity is high, there will be insufficient susceptible animals for FMD to spread and infection will die out.

Model overview

A state-transition model of a village herd, based on discrete monthly time-steps over two years was constructed incorporating age and immune states. A flow diagram is shown in Figure 1. In the model animals occupied one of three states: *susceptible*, *immune* or *removed* through death or sale. The herd was divided into age classes of six-month intervals from birth to > 8 years old. The whole herd was assumed to be susceptible at the commencement of the vaccination program and immunity developed only in response to vaccination, there being no exposure to natural challenge. Herd size was held fairly constant with time. Output from the model was graphed as the change with time in the percentage of animals in a village having an immunity to FMD.

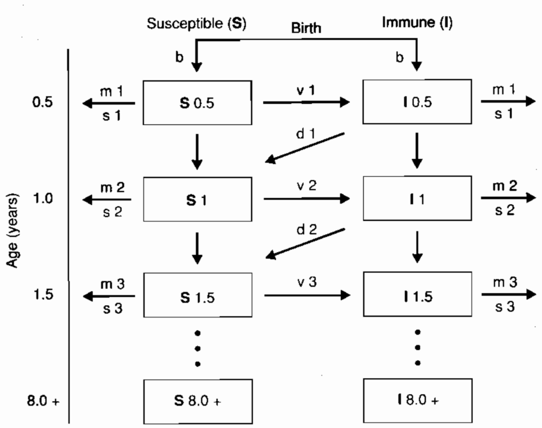

Figure 1. Flow diagram of the development of vaccination-induced immunity to FMD in a northern Thai village cattle and buffalo herd. **b:** birth rate; **m:** age-specific mortality rate; **s:** age-specific selling rate; **v:** age-specific vaccine effectiveness (combines efficacy and proportion of animals vaccinated); **d:** age-specific decay over time from immune to susceptible.

Assumptions and parameter estimation

Females comprised 75% of animals greater than three years old. Cows calved for the first time at three years of age and thereafter every second year. Calving was non-seasonal and the proportion of immune calves born in any one month was equal to the proportion of immune cows present in that month. Colostral immunity persisted for six months and calves were first vaccinated at six months of age. The probability of being vaccinated, dying or being sold was independent of FMD immune status.

Rate parameters were the vaccination rate, age specific death and selling rates, rates estimating the probability of a susceptible animal responding to vaccination and becoming immune one month later depending on the number of previous vaccinations it had received (vaccine efficacy) and rates estimating the probability of an immune animal maintaining its status from one vaccination round to the next.

Estimates of vaccine efficacy were obtained from a database of cattle and buffaloes selected from a purposive sample of 21 villages, whose serological responses to vaccination were monitored over four six-monthly vaccination rounds (R1–R4). Blood samples for serology were taken at each vaccination visit and at one month after vaccination. Antibody titres to FMD virus types O, A and Asia 1 were measured by the serum neutralisation test (SNT) using standard methods (Golding et al. 1976). A subset of animals which had $\log_{10}$ reciprocal SNT titres of less than 1.2 to all three serotypes at R1 (and therefore unlikely to have been previously vaccinated or infected with FMD virus) were selected as the base sample for estimating vaccination efficacy. These animals were subsequently classified as immune if the $\log_{10}$ reciprocal SNT titres to all serotypes were greater than or equal to 1.5. On the basis of this classification, the probabilities of individuals responding to vaccination and maintaining immunity from one vaccination round to the next were calculated. The resultant probabilities for maintaining immunity between vaccination rounds used in the models are probably overestimates if vaccination coverage is less than 100%, since these rates were derived from a database where all animals had been vaccinated at each round.

For each age class, the proportion of immune animals one month after R1 was:

(*the number of animals present*) × (*vaccination rate*) × (*vaccine efficacy for the particular age class*)

The number of animals maintaining immune status until R2 was then calculated as:

(the number of immune animals present one month after R1) × (probability of maintaining immunity until R2, taking into account losses due to deaths and sales)

To simplify the arithmetic, those animals maintaining immunity to the start of R2 were assumed to retain their immunity for an additional month, irrespective of whether they received vaccine at this round or not. Losses of immune animals as deaths and sales were also ignored during this month. The model therefore slightly overestimated the number of immune animals present at this point in time.

The susceptibles present at the start of the second vaccination round were considered in two ways since they either received vaccine at R1 or they did not. The number of immune animals present one month after R2 was calculated as:

$$(A \times B) + (C \times D) + E$$

where:

- A is the number of susceptibles present at R2 which had been vaccinated in both rounds;
- B is the probability of a susceptible animal becoming immune if previously vaccinated twice;
- C is the number of susceptibles vaccinated at R2, but not R1;
- D is the probability of a susceptible animal responding to a single vaccination;
- E is the number of immune animals present at the start of R2.

The above calculation steps were then repeated to determine the number of immune animals present at the third vaccination round, one month later, and at the fourth vaccination round and one and six months later. The number of immune animals present in intermediate months was calculated by assuming that the number of animals reverting to susceptible status doubled in each successive month.

To allow for revaccination of newcomers one month after enrolment, expected responses were derived from a field trial comparing single with dual priming vaccinations carried out in Northern Thailand. Where dual vaccination was assumed, the rate used for maintenance of immunity for age classes between their second and third vaccination rounds is probably underestimated because the interval between these vaccinations is five and not six months.

For the purposes of the study, a minimum acceptable level of 80% prevalence of immune animals was assumed to be necessary for a vaccination strategy to prevent spread of FMD virus (based on Henderson 1970).

Results

Vaccine efficacy estimates

There were 272 animals at the start of the vaccination study which had $\log_{10}$ reciprocal SNT titres of less than 1.2 to all serotypes. The same 272 animals were present one month later, when 37 were classified as immune. The probability estimate of a susceptible animal becoming immune one month after a single inoculation was therefore 37/272 or 13.6%. All of these 37 immune animals were present at the start of R2 when 11 were still classified as immune. Hence, the probability estimate of an animal maintaining immunity from the first to the second inoculation was 11/37 or 29.7%. There were 258 non-immune animals present at the start of R2. All were present one month later when 241 were classified as immune. Hence, the probability estimate of a susceptible animal becoming immune one month after a second inoculation was 241/258 or 93.4%. Of all the immune animals present one month after R2, 208 were still present at R3. A total 145 of these were classified as remaining immune, so the probability estimate of an animal maintaining immunity from the second to the third inoculation was 145/208 or 69.7%. A total of 51 non-immune animals at R3 were present one month later. Of these, 49 were classified as immune, so the probability estimate of a susceptible animal becoming immune one month after a third inoculation was 49/51 or 96%. 92 animals which had been classified as immune one month after the third vaccination round were present at R4. A total of 64 of these were still classified as immune, so the probability estimate of an animal maintaining immunity from the third to the fourth inoculation was 64/92 or 69.6%. There were only 13 non-immune animals at R4 still present one month later. All were classified as immune, so the probability estimate of a susceptible animal becoming immune one month after a fourth inoculation was 13/13 or 100%. There were no data on which to base an estimate of the probability of an animal maintaining immunity from the fourth to the fifth vaccination. We assumed that with additional exposure to the vaccine, an animal had a higher likelihood of maintaining immunity and used a probability of 0.8 in the model.

Model outputs

The simulated change in prevalence of immune animals over time is shown in Figure 2. The percentage of animals protected increased in a stepwise manner, peaking one month after a vaccination round and then declining between vaccinations. At a vaccination coverage rate of 70%, herd immunity did not exceed the threshold level of 80% protection considered necessary for effective control. At a coverage rate of 90%, herd immunity first exceeded 80% one month after the third vaccination round (month 13) and remained above this threshold for 7 of the following 11 months.

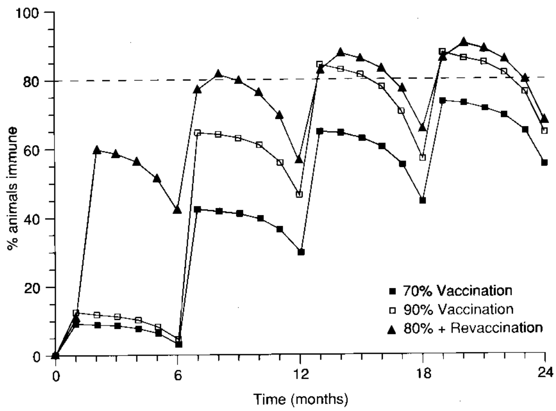

Figure 2. Model predictions of the development of herd immunity (prevalence of immune animals) in a northern Thai village for 3 different FMD vaccination strategies. It is assumed that all animals are initially fully susceptible and there is no exposure to natural infection. 70% vaccination: 70% of animals over 6 months of age vaccinated every 6 months; 90% vaccination: 90% of animals over 6 months of age vaccinated every 6 months; 80% + revaccination: newcomers receive a primary course of 2 inoculations 1 month apart with 6-monthly revaccination of 80% of all animals. The horizontal line at 80% indicates the assumed minimum desirable level of herd immunity.

When 80% of animals were vaccinated and newcomers were revaccinated one month after the initial vaccination followed by regular six-monthly boosters an acceptable level of herd immunity of 80% protection was reached by month eight and then fluctuated around this level, exceeding 80% in eight of the following 16 months but dropping to as low as 56% in month 12.

Discussion

The results from this study indicate that vaccinating 70% of village cattle and buffaloes twice a year is unlikely to produce a level of herd immunity sufficient to prevent spread of FMD virus. Reasons for the relatively low level of herd immunity resulting from this strategy include poor responses to initial vaccination, decline in titres between vaccinations and natural increases in the number of susceptibles through births. The relatively short-lived immunity induced by the trivalent FMD vaccine under study highlighted the need for vaccination to include as near to 100% of the cattle and buffaloes population within the control zone as possible.

Using an alternative approach of giving newcomers two inoculations a month apart followed by six-monthly boosters improved the rate of development and overall level of herd immunity substantially. However, even with a dual inoculation priming vaccination, it appears that coverage rates in excess of 80% would be required to maintain continuous protection against outbreaks at the village level.

The findings from the present study of a requirement for high vaccination rates to maintain an effective herd immunity in a dynamic and open population are consistent with reports for other directly transmitted viral diseases. In humans, it has been estimated that 92–96% of children must be vaccinated to eliminate measles and pertussis, 84–88% to eliminate rubella and 88–92% to eliminate mumps in Western Europe and the United States (Anderson and May 1985). The situation is similar for Rinderpest in cattle where vaccination rates of between 80% and 100% are required, depending on the level of vaccine efficacy (Rossiter and James 1989).

The FMD herd immunity model did not take into account the problem of sustaining herd immunity when the field virus is heterologous to the vaccine virus. Serological differences are frequently observed between field viruses within the same subtype group in countries where the disease is endemic. When serological differences occur between the field and vaccine virus, the herd immunity resulting from vaccination is lowered because of lowered vaccine efficacy (Brown 1992; Rweyemamu et al. 1982).

A further limitation of the model is that the probability of being vaccinated may not be independent of FMD immune status. One of the main reasons for failure of villagers in Northern Thailand to present their animals for routine FMD vaccination is due to difficulties in mustering (Cleland, unpublished data). It is likely that animals missed at a vaccination round are at higher risk of being missed subsequently. Furthermore, there currently is substantial variation in vaccination coverage among villages in Northern Thailand. Both factors would favour the maintenance of high levels of infection in the field and increase the level of challenge in villages in which animals have been well vaccinated. Effective control of FMD by vaccination therefore requires that not only must the proportion of the herd vaccinated be as high as possible, but that there is little variation in vaccination coverage between villages.

Despite the potential pitfalls implicit in the assumptions used, the modelling approach taken has provided useful insights into what vaccination strategies may be required to achieve effective control of FMD under Thai village conditions. Further field trials are required to validate model predictions. If these trials are combined with carefully planned serological monitoring, it should be possible to evaluate the ongoing effectiveness of the vaccination program and to assess the risk of FMD outbreaks in specific control zones.

Acknowledgment

We are grateful to Dr J. Harkin for his assistance in refining the computer spreadsheet program used for the model.

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CONTROL OF FOOT-AND-MOUTH DISEASE IN SOUTHEAST ASIA

One of the key objectives of the veterinary authorities of the countries meeting at this workshop is the control and eventual eradication of FMD. In this session the keynote speaker, Dr Peter Ellis addressed the very important issue of the economic benefits and costs of disease control programs and emphasised the need to employ economic evaluation in planning and implementation phases. A partial budget analysis procedure was used by Dr Ellis to illustrate how financial effects of disease and control costs can be evaluated.

A regional success story — Indonesia — was the subject of the next presentation in which Dr Herawati Setyaningsih from the Veterinary Biologics Centre at Surabaya, Indonesia presented a paper describing the strategies used to eradicate FMD from Indonesia.

In considering the issues for the regional control of FMD in Southeast Asia it is of interest to compare the situations that have occurred elsewhere in the world. To this end Dr Alex Donaldson presented a discussion of the strategies used in Europe to control and eradicate FMD and the present European Community policies to prevent and control outbreaks in the future.

In respect of the strategies for regional control of FMD Dr Masao Sasaki from the Food and Agriculture Organisation Regional Office in Bangkok discussed the important patterns of livestock movements in Southeast Asia, especially across international boundaries and stressed the importance of these movements in any regional strategy to control FMD. A regional plan for the eradication of FMD was further discussed by Dr Y. Ozawa, of the Tokyo office of the Office International des Épizooties. The proposed plan includes the formation of a *Sub-Commission for the Control of FMD in Southeast Asia.* A proposed organisational structure for this sub-commission was presented by Dr Ozawa.

The Economics of Foot-and-Mouth Disease Control

P.R. Ellis*

Abstract

Foot-and-mouth disease can cause tremendous economic loss and remains a threat to the livestock industries of many countries. Economic analysis helps to justify investment in prevention, control and eradication programs but a wide variety of information must be gathered on the characteristics and productivity of animal populations involved as well as on incidence rates and losses in different production systems. The analysis must satisfy the farmer that the cost and inconvenience he has to bear are far exceeded by benefits that he can appreciate. A partial budget analysis procedure is used to illustrate how financial effects of disease and control costs can be evaluated. Benefit-cost analysis procedures and findings are used to explain how a foot-and-mouth disease control strategy can be evaluated from the nation's point of view taking into account the changing value of money over time. Strongly positive net present values and benefit-cost ratios of 6:1 are commonly obtained. However, adjustment may have to be made to take into account national livestock development goals, market requirements and trade policies.

VERY few people concerned with livestock would disagree that foot-and-mouth disease (FMD) is still one of the most serious animal health problems. Enormous losses have been recorded, like those estimated at £250 000 000 in Britain in 1967 when a major FMD epidemic required the slaughter of thousands of highly productive animals to ensure eradication and the whole economy and trade of rural areas was disrupted. In Asia too, losses could be enormous. When preparations were being made in 1976 to launch a systematic FMD control program in India, a combined epidemiological and economic study revealed that an average of 15% of the country's livestock population was affected every year causing production losses in excess of 4000 million rupees or about £200 000 000. Fortunately improvements in the efficacy of vaccines and the efficiency of other control measures have helped countries to avoid such enormous disasters and are steadily reducing continuing losses in Latin America and Africa as well as in Asia. However, intensification of animal production systems results in increasing losses when FMD does occur and greater trade and movement of livestock and animal products are increasing the risks of spread of any infection that persists.

* Veterinary Epidemiology and Economics Research Unit, Department of Agriculture, University of Reading, PO Box 236, Reading, RG6 2AT, England.

In order to improve the efficiency of prevention, control and eradication schemes and to justify national and international support it has become essential to apply economic analysis techniques. At first sight these may appear incomprehensible to veterinarians and farmers but, in reality they involve simple and logical calculations.

The core requirement in FMD control is that benefits for the farmers should exceed all costs and inconveniences that they may have to bear. The owner of a valuable, high-producing, dairy herd does not hesitate to pay for regular vaccination or to conform to very strict sanitary regulations if the threat of FMD arises. In contrast owners of low-grade beef animals or small ruminants in extensive grazing systems, or pigs in smallholdings may be unwilling or unable to participate in an organised control scheme without subsidies and assistance.

Since FMD spreads so easily by contact, air and residues, control and eradication can only be achieved if the whole susceptible livestock population is involved in the program. Furthermore, the program must evolve systematically over a number of years as measures are extended and intensified. Governments are understandably reluctant to make necessary funding commitments unless they can be convinced that the benefits for the nation comfortably exceed the costs of government support and intervention. In addition the government needs to be confident that the total subsidy involved can be sustained over the years and that the expenditures on FMD do not rob other vital activities or plans of funds which would give the nation even greater net benefits.

For these complex reasons economic analysis has to be made from two different points of view, that of the producer and that of the nation or region concerned. Realistic results can only be obtained if realistic information has been gathered on the actual incidence and effects of FMD in the different areas and types of production system involved. Secondly, since the program is certain to extend for some years the probable changes in production systems must be evaluated. Only then can the new or more intensive control measures be specified, quantified and valued. Only then, too, can realistic projections be made about the reductions likely to occur in the number and severity of FMD outbreaks year by year which constitute the benefits that can be set against cost. To provide simple and practical illustrations of these steps which are applicable to Asia the author has drawn material from an excellent economic study made in northern Thailand by Bartholomew and Culpitt (1992) and from his own work in India (Ellis and James 1976).

Collection of Basic Information

Official records of FMD incidence vary widely in quality. The disease may be so mild where it is endemic that farmers may not recognise it and even if they do recognise it they may not bother to report cases. Effects are usually transient and insidious but often affect a large proportion of animals in the herd or flock.

Information from official records has, therefore, to be supplemented with data gathered from farms and opinions of field staff closely associated with them. Even very limited surveys can produce remarkably good results. It is important to concentrate on obtaining good quality of information from a few, well-selected farms or animal groups rather than a large volume of information of questionable reliability. Bartholomew and Culpitt (1992) were able to use epidemiological and production data from a total of 61 villages studied by Drs Baldock, Cleland and Chamnanpood and as part of the Thai–Australian FMD project (see papers included in these proceedings). In addition they conducted in-depth enquiries in four villages as to numbers of animals, ages, outputs and uses, feeding, management, frequency of FMD outbreaks and effects. Findings provided a sound basis for economic analyses in terms of the effects on two types of village in the area as described below:

> . . . A Type 1 village was characterised by relatively highly productive animals while a Type 2 village was characterised by relatively low productive animals. Differences in animal productivity related to animal type (cross-bred vs native cattle), feeding practices (use of purchased food vs non use of purchased feed), natural soil fertility etc. Also the Type 2 village had an overall higher incidence rate of foot-and-mouth disease than the Type 1 village, based on epidemiological study (Bartholomew and Culpitt 1992, p. 7).

In India this author and a series of teams spent around six weeks in different sections of the country that had been selected on an ecological basis to represent different systems of production and different aspects of the FMD problem. Each team consulted key officials and farmers' organisations but also spent a large proportion of their time visiting villages and farms. While the information in villages was unrecorded they were able to build up, through discussions with farmers and veterinary assistants, a remarkably clear picture of the effects of FMD. They could then calculate losses on which estimates of potential gains from control measures could be based for seven representative categories of milk and draft animals.

Economics from the Farmer's Point of View

The partial budget

The key aid to the financial assessment of FMD loss and the valuation of gains from control is the *partial farm budget* which calculates:

(*a*) extra income resulting from the program;
(*b*) costs no longer incurred as a result of the program;
(*c*) costs of implementing the program;
(*d*) income lost as a result of the program; and

Net gain $= a + b - c - d$.

Data and prices from the Bartholomew and Culpitt study have been used in Table 1 to construct hypothetical partial budgets for beef cattle in a fairly productive village with and without improved FMD control. Although benefits appear fairly close to those found in the study, they should not be regarded as representing the situation in any specific village situation in Thailand. The table provides a very simple illustration of the technique. It could be prepared with paper, pencil and calculator but is most useful if set up as a spreadsheet on a microcomputer. Animal numbers and production parameters are listed for the situations with and without changes in the control scheme. Control measures for each situation are listed: proportion of all animals vaccinated twice yearly increased from 70% cover (0.7) to 90% (0.9) and revaccination of all calves is introduced. Treatments for the 20% of animals currently affected each year are assumed to be reduced to zero. Prices of animals are assumed to increase because of better values at sale but unit costs of vaccination and treatment remain unchanged.

In a simple series of calculation shown in the last two columns of Table 1, changes in values of income, costs saved, extra costs incurred and revenue foregone are all shown. The net benefit in this illustration is 41 300 baht and the ratio suggests that farmers should receive 7.35 baht for each additional baht spent on the FMD control measures.

Table 1. Partial budget for FMD control in an Asian village beef herd.

PRODUCTION PARAMETERS	PRESENT	CHANGED		
Number of animals in herd				
cows	200	200		
calves	100	100		
heifers	75	75		
steers	25	25		
totals	400	400		
Sales (no.)				
steers	50	52		
cows	20	51		
CONTROL MEASURES				
proportion of herd vaccinated	0.7	0.9		
proportion of calves vaccinated	0	1		
treatments	0.2	0		
PRICES (all values in Thai baht)				
Sales				
steer	3 500	3 850		
cow	6 000	6 600		
Vaccination				
vaccine	15	15		
application	10	10		
Treatments:	50	50		
PARTIAL BUDGET			Change in value	
Income				
steers sold	175 000	200 200	25 200 (a)	
cows sold	120 000	138 600	18 600 (b)	
Costs saved				
treatments	4 000	0	4 000 (c)	
Total benefit				47 800 (a + b + c = x)
Extra costs				
feed	0	0		
vaccinations	14 000 (d)	20 500 (e)	6 500 (e–d = y)	
Revenue forgone				
none	0	0	0	
Total cost				6 500 (y)
NET BENEFIT				41 300 (x – y)
FINANCIAL BENEFIT:COST RATIO		7.35:1		

Note: Values used in this table have been obtained from Bartholomew and Culpitt (1992).

The effects of further changes can easily be examined. For example, numbers of steers sold could be further increased by two and additional hygiene and disinfection costs of 5 baht per animal could be assumed. The spreadsheet program automatically calculates a revised net benefit as 47 000 baht, costs as 8500 baht and the ratio as 6.53. Although the ratio is lower, the farmer gains an extra 5700 baht for an extra cost of 2000 baht.

Results of such analyses for FMD control among improved livestock are generally very good but for an unimproved animal the costs of regular vaccination often exceed the benefit. In the case of India in 1976 estimates were made of average losses for seven types of animals. The estimated cost of annual vaccinations with teams working to maximum efficiency was around 12 rupees. For an average native dairy animal the benefit was likely to be no more than 29.7 rupees. For the native cattle and buffaloes used for draft purposes returns at 81 and 73 rupees respectively were better but only the hire charge of 63 rupees would be obvious and still not a strong justification for a new FMD control initiative. Certainly, owners of such animals were unwilling to pay such a vaccination cost. Only for improved buffaloes and crossbred dairy cattle with potential gains at 136 rupees and 884 rupees respectively, and for crossbred draft cattle with a potential gain of 242 rupees, were results very attractive.

Other factors to be considered by the farmer

Analyses from the farmer's point of view should not be limited to average financial benefits and costs. FMD rarely attacks all animals or all herds in a population and never to the same extent. For a farmer with one or two improved animals and little or no land, a single outbreak of FMD could lead to financial disaster whereas a farmer with a dozen or more unimproved cattle may hardly notice the effects of several cases of the disease. If many draft animals are affected in a village at a critical cultivation or crop marketing time, losses could be enormous, as was seen in India, because replacements could only be hired at enormously high prices. Fortunately tractors and trucks are becoming available as alternatives. Thus the perceived importance of FMD for the farmer in some situations may be much greater than the estimated financial loss. A case could be made for counting perceived benefits rather than average benefits and regarding vaccination as an insurance cost against the disease.

With respect to costs, other considerations also apply. For example, farmers might be expected to pay for vaccine, and perhaps the costs of vaccinations as well, but can they be relied upon to have the money in hand when needed? If a year or two has elapsed since the last FMD outbreak in his area the farmer may decide to risk not vaccinating. In addition, if his animals can produce more milk or grow faster after FMD has been eliminated, is he able to grow or buy the extra feed needed to obtain these gains? If he decides to buy a crossbred dairy animal, could his wife or child carry the larger volume of milk to a collection point?

From the farmer's point of view, these and many other considerations arise whenever a significant change is proposed so an economic evaluation must also extend to social and operational factors before a policy decision is made.

The National Economic View

Planning an appropriate program

A thorough and systematic appraisal of the extent and effects of FMD and of potential control measures in the farm or village is essential for realistic planning of an effective nationwide or area-wide control program. Appropriate packages of measures can be designed for the different areas, according to the production system characteristics, and special measures can be prepared for problem areas. Activities such as vaccination can be coordinated so as to minimise costs and plans can be made for the additional infrastructure needs such as vaccine production and storage, diagnostic facilities and movement control.

Economic analysis

As at the farm and village level this is a logical procedure which helps planners to sum the different kinds of costs that would be incurred year by year as a new FMD control scheme evolves. In parallel with this the total values of benefits arising year by year can be estimated.

A framework outlining the steps required is shown in Figure 1. In this case, gains from reduced treatment and disease effects are calculated by multiplying the gains calculated for farm or village 'units' and the numbers of such units in each area introducing the control scheme. In the same way costs can be calculated by totalling those for the units involved and adding in the common costs of new infrastructures such as vaccine storage, movement control posts and coordinating centres for the scheme.

To complete the economic analysis, the current (gross) values of benefits and costs for each year are assembled as in Table 2. However, these cannot

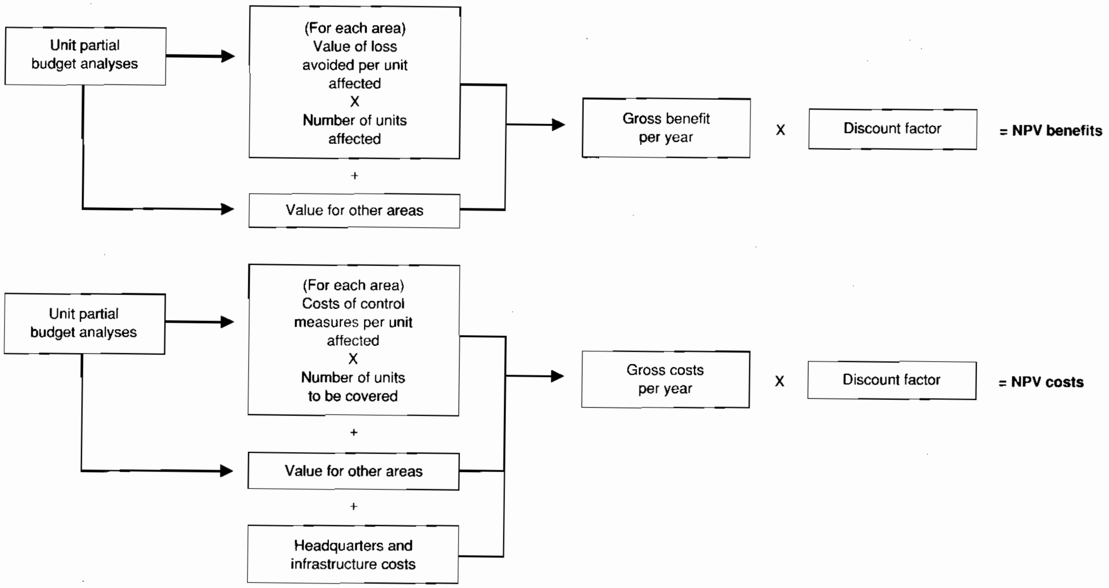

Figure 1. Economic analysis procedure for each year of a national FMD program.

simply be totalled for all the years and used to calculate the net gain and benefit-cost ratio as was done at farm level for a single year. Adjustments have to be made for the changing value of money over time because major costs of a new program usually arise in the early years whereas benefits may take some time to build up. Table 2 lists a hypothetical series of benefits and costs from FMD control which follow these patterns. The ministry of finance of each country usually specifies a discount rate, between 5% and 12%, and commonly 10%, by which both benefits and costs accruing in future years have to be reduced. As can be seen in the table with a rate of 10%, 1000 baht spent or gained in year one is reduced in value to 909 baht. In year two the reduction factor is 0.826 and goes down to as little as 0.386 in year 10. Resulting figures are net present values (NPV). Justifications for this procedure are very complex and may be studied in books such as that of Gittinger (1984) but the basic principle is that money now in hand has a greater value than that obtained or to be spent in the future.

Having made the necessary adjustments to values, benefits can then be added together for all years, costs can be added in the same way as shown in Table 2 to provide:

$$\text{NPV} = \begin{array}{l}\text{NPV of benefits} - \text{NPV of costs}\\ \text{of the program}\end{array}$$

and

$$\begin{array}{l}\text{Economic benefit-}\\ \text{cost ratio (BCR)}\end{array} = \frac{\text{NPV of benefits}}{\text{NPV of costs}}$$

Other measures of profitability such as *internal rate of return* (IRR) and *breakeven point*, are less commonly used and the reader should refer to Gittinger (1984) for details.

For the situation in northern Thailand, Bartholomew and Culpitt (1992) calculated an NPV of 179 million baht and a BCR of 11.75:1 at a 10% discount rate. They quote a ratio of 5:1 from an earlier study of FMD eradication in Thailand and a ratio of 3.15:1 estimated for FMD eradication in the Philippines. Governments consider favourably any project that gives a BCR greater than 2:1.

Sensitivity analysis

Anyone who knows the changing risks and variable effects of FMD should, at this stage, be wondering how errors in assumptions about the efficacy of control measures or in the rate of improvement in animal productivity would affect the result. To provide reassurance for policy makers, economists have developed a procedure called sensitivity analysis. If, for example, cost reduction in Table 2 were delayed by one year, the BCR would fall from 4.13:1 to 3.87:1. Again this is an easy task with a spreadsheet model.

Table 2. A hypothetical economic benefit-cost analysis (values in pounds [£] sterling)

	Benefits			Costs		
	Gross	Discount factor (10%)	Discounted value	Gross	Discount factor (10%)	Discounted value
Year 1	0	.909	0	100 000	.909	90 900
Year 2	100 000	.826	82 600	50 000	.826	41 300
Year 3	150 000	.751	112 650	50 000	.751	37 550
Year 4	200 000	.683	136 600	50 000	.683	34 150
Year 5	250 000	.621	155 250	50 000	.621	31 050
Year 6	250 000	.564	141 000	50 000	.564	28 200
Year 7	250 000	.513	128 250	40 000	.513	20 520
Year 8	300 000	.467	140 100	30 000	.467	14 010
Year 9	350 000	.424	148 400	20 000	.424	8 480
Year 10	400 000	.386	154 400	10 000	.386	3 860
Totals	2 250 000		1 199 250	450 000		310 020

Gross benefit − gross cost	=	1 800 000
NPV benefit − NPV cost	=	889 230
BC ratio (NPV benefit/NPV cost)	=	3.87

Economists may also test the possible effect of a better than expected success rate. If the market cannot absorb all the additional products, prices might fall thus offsetting increased output and further changing the NPV and BCR. Thus sensitivity analyses usually lead the analyst to present a range of BCRs and other economic measurements. In the case of South India the Ellis and James evaluation (1976) produced basic BCRs ranging from 5.2:1 to 8:1 with a high discount rate of 12%. However, India needed much more milk to substitute imports and was promoting cattle and buffalo improvement very strongly. When the effects of these changes were also taken into account the increased BCRs ranged from 7.1:1 to 11.4.1. The program was adopted and is steadily achieving the desired improvement in FMD control and productivity.

Conclusions

Over the past 20 years increasing numbers of veterinarians have come to use economic analysis in a widening range of activities. Government services use it to decide not only whether a national program is justified but also to determine which cost farmers can be expected to pay. Meanwhile, practising veterinarians have adopted partial budgeting as a means of determining the value of controlling such problems as infertility, mastitis and parasitism.

This paper is intended only to introduce the main procedures used in economic analysis of FMD control so that veterinarians, animal production specialists and economists can share a common approach. The procedures outlined can be studied in greater depth in such texts as Gittinger (1984) and Putt et al. (1987).

Experience to date indicates that well-planned FMD programs give very high economic returns. The key points to remember in making economic evaluations are that:

- data about FMD incidence and effects and about the populations to be protected or freed from the disease must be carefully selected, collected and checked for reliability;
- the attitudes of farmers must be taken into account in designing control programs, and benefits and costs for the different types of production systems must be evaluated individually by partial budgets; and,
- economic analysis of national or area schemes must be based on a realistic representation of how the complexes of different production systems in each area will respond; sensitivity analysis must be used to assess the potential impact on any proposed program of variations in FMD epidemiology, in control costs and in animal production policies.

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The Experience of Indonesia in the Control and Eradication of Foot-and-Mouth Disease

Soehadji,* Marthen Malole† and Herawati Setyaningsih§

Abstract

In 1974 the Indonesian livestock authorities divided the country into three zones with respect to foot-and-mouth disease (FMD); a *disease-free zone*; a *suspected zone*; and an *infected zone*. Strict animal movement and quarantine measures were introduced to protect the disease-free zone and routine surveillance was carried out in the suspected zone. In the infected zone a mass vaccination program was carried out using both 'crash' and 'low speed' programs. After three years of the mass vaccination programs many regions were declared free of FMD. However, in July 1983, just before the country was going to be declared free of the disease, an outbreak occurred on Java and spread over much of the island infecting 13 976 animals. Stringent control methods were brought into force including high-speed mass vaccination, movement control, stamping out and a range of other measures. The last cases of the disease occurred in December 1983 and the last vaccinations were carried out in Java in 1985. Indonesia was declared free of FMD in 1986 and vaccination and production of FMD vaccine are now prohibited.

THE first outbreak of FMD in Indonesia was reported in East Java in September 1887, and 19 years later Madura Island was infected in 1906 and 1913. Since then the disease was endemic in East Java, and spread throughout the whole Java and some islands of the country such as Sumatra (1892), Kalimantan (1906), Sulawesi (1902), Bali (1962) and West Nusa Tenggara (1911).

The distribution of the disease to other parts of Java and outside of the island was influenced by the movements of animals which related to a distribution program of breeding stock during the Dutch occupation.

Only the FMD virus type O was found in Indonesia, as identified by the World Reference Laboratory (WRL), Pirbright, United Kingdom in 1973. Many efforts to control the disease were implemented which finally culminated in the eradication of the disease and in 1986 Indonesia was declared free from FMD.

* Directorate General of Livestock Services, Ministry of Agriculture, Republic of Indonesia.
† Faculty of Veterinary Medicine, Institute of Pertanian, JI Taman Kencana No. 1, Bogor Jawa Barat, Indonesia.
§ Veterinary Biologics Centre, JI Raya Jend A. Yani 68–70, Surabaya 60231, Kotak Pos W03, Indonesia.

Eradication Campaigns

The eradication of FMD in Indonesia can be divided into five stages as described below.

1. 1887–1912

No regulation concerning FMD control was published during this time. However, the Dutch Government made many efforts to control the disease using conventional and traditional treatment of all infected animals.

2. 1912–1945

The Dutch Government promulgated the first regulation concerning animal disease control in 1912 (State Gazette 1912 No. 432 and 435) after which controlling and reporting of infectious disease became compulsory in Indonesia. The first vaccine for FMD was introduced in 1930 using the Waldmann method. Vaccination of animals in areas surrounding infected areas and stamping out of positive cases were conducted to prevent the spread of the disease.

3. 1945–1974

Indonesia became independent in 1945. During the independence war and governmental transition period, animal disease control in Indonesia was discontinued and it was suspected that in some areas FMD became endemic. From 1962 FMD control was undertaken locally and was financed from provincial government resources.

In Java and Madura FMD control was based on routine vaccination of dairy cattle and livestock at the centre of infected areas. A stamping out policy was not undertaken in the island due to socio-economic considerations.

An FMD outbreak occurred in Bali in 1963. The outbreak was controlled by restraining livestock movements in and out of the area, stamping out of infected animals and vaccination. The disease was under control in 1965 and no cases were reported thereafter. However, an outbreak occurred in 1973 because of buffaloes smuggled in from an infected area in Java.

FMD control in other islands outside Java and Bali such as Sumatra, Sulawesi and Kalimantan, were carried out by intensive vaccination surrounding infected areas, control of livestock movements and intensive surveillance activities.

4. 1974–1981

Prior to 1974 FMD control activities were conducted by local governments. The disease status was sporadic at low incidence. However, in 1974 a national program was launched by the Directorate General of Livestock Services (DGLS) to eradicate the disease. During this period the National FMD Eradication Program was assisted by the Australian Government.

To ensure the success of the eradication program, provincial governors, members of the police, the armed forces, the civil defence, women and youth organisations all fully supported the campaign.

Recognising the fact that prior to 1974, FMD cases occurred almost annually and the disease spread sporadically at low incidence in certain areas, the Government of Indonesia formulated methods and approaches for the control and eradication of FMD based on technical and economic rationales.

Based on the incidence and distribution of FMD in Indonesia in 1974, the country was categorised into three zones (see Map 1).

- a *disease-free zone* which includes East and West Nusa Tenggara, Irian Jaya, Moluccas and East Timor;
- *suspected zone* areas without any reported case for the last few years. This zone includes Kalimantan, Sumatra and Sulawesi (except South Sulawesi); and
- an *infected zone* which included Java, Bali and South Sulawesi.

Map 1. FMD distribution in Indonesia in 1973.

According to the above categories the program consisted of three different measures.

(i) *Free zone:* strict animal movement/quarantine measures. Transport of livestock from infected/suspected zone to this area was not allowed.

(ii) *Suspected zone:* surveillance in these areas was carried out routinely.

(iii) *Infected zone:* a mass vaccination campaign was conducted in two stages:
- *crash program* — mass vaccination was implemented in order to prevent reappearance of the disease in the infected areas; and
- *low speed program* — undertaken gradually but in an intensive manner and covering the areas where the disease had the potential to spread to the non-infected areas.

Basically the vaccination procedure was similar for both systems:
- vaccination was carried out annually (three times in three years) for all livestock more than three months old. Pig were vaccinated only in infected herds. In 1976, it was decided to vaccinate goats and sheep voluntarily because they had been shown experimentally to be possible disease carriers;
- vaccination coverage was at least 80% of the livestock population;
- vaccinated animals were identified by ear marking (earcut);
- there was a strict control of livestock, vehicle and feed movement to the vaccination areas; and
- intensive epidemiological surveillance was carried out continuously during the program to monitor the possible reappearance of cases.

After three years of vaccination, an epidemiological evaluation team carried out surveillance of the animal population in order to prepare the disease-free declaration.

Java

In Java, the eradication campaign was started in 1975 in the eastern part of East Java moving westward, while in West Java it was started in 1976 moving eastward. The coverage of animals vaccinated during that first campaign was 93% for cattle/buffaloes and 69% for sheep/goats.

The second and third vaccination campaign were combined into one and were successfully undertaken from 1976 to 1980. In early 1978, Madura was declared a FMD-free area while in 1981 the rest of East Java was also declared FMD free.

In Central Java the vaccination campaign started from 1976 and from 1976–81 over 2.5 million of cattle and buffaloes were vaccinated. Vaccination coverage of 80% was achieved in 1980–81. No further cases of FMD were recorded in Central Java until an outbreak in Blora erupted in 1983.

In West Java and the municipality of Yogyakarta the vaccination campaign was initiated in 1975 and extended to 1982. The coverage of animals vaccinated during the vaccination campaign in West Java and Yogyakarta was 90–98% of the livestock population.

Bali

The first year a mass vaccination campaign was undertaken was 1974 and vaccination continued until 1975. Total number of animals vaccinated were 333 397 cattle, 11 073 buffaloes and 11 051 sheep and goats. About 97% of the cattle and buffaloes in Bali were vaccinated during the first campaign.

The second campaign started in August 1975 and was completed at the end of the year. The total number of vaccinated animals in the campaign was 296 729 cattle, 10 427 buffaloes, 8 801 sheep/goats. To follow up the mass campaign in order to ensure that young and other unvaccinated animals were covered, vaccination was continued in 1976.

The third year of vaccination and associated mini-campaigns were staged from October 1976 to April 1977 representing a vaccination coverage of 94% animals. No cases of FMD were reported during 1976 at the end of the third vaccination campaign, as active surveillance was undertaken by the DGLS and the Provincial Livestock Services in selected villages. Based on the accumulated evidence, Bali was declared free from FMD early in 1978 and the island has remained free ever since. The situation was reported to the Office International des Épizooties (OIE) in Paris by the DGLS.

South Sulawesi

South Sulawesi has breeding and commercial stock resources and distributes cattle to other provinces in Indonesia. FMD was recorded in South Sulawesi in 1962 and the last case was reported in 1973. During 1973–74 about 125 000 heads of animals or 92% were vaccinated in the province.

At the end of the vaccination campaigns, an active surveillance was undertaken by the DGLS and the Provincial Livestock Services staff checking the vaccination records and undertook clinical and serological examination of animals in selected villages. Based on the result of the surveillance, South Sulawesi was proclaimed free of FMD in early 1981.

5. 1983–present time

The last reported outbreak of FMD in Java was in 1979 in Cilacap in Central Java when only one animal was affected. It was declared by the livestock authorities in 1982 that during six months until December 1981 there had been one case of FMD in the country.

However, the vaccination program was continued in Central Java until the end of 1982. By this time the provinces of West Java, Yogyakarta and Jakarta would have completed their three years of mass vaccination and these provinces would await evaluation before they would be declared free of FMD.

In July 1983, an evaluation and surveillance team which had been sent to carry out investigation on FMD in Central Java, discovered an outbreak of FMD in Blora, Central Java, at the time when the country was just about to be declared free of FMD. The outbreaks of FMD in Blora in Central Java and in Bojonegoro in East Java in July, 1983 then spread to other parts of the island (see Map 2). No cases were recorded outside Java. During the 6–7 months of the outbreak, 64 districts (Kabupaten) and 246 subdistricts (Kecamatan) were affected in the provinces of West Java, Central Java, East Java, Jakarta and Yogyakarta. The total number of livestock infected was 13 976. Of these 13 628 (97.1%) recovered, 136 (0.97%) died, 13 (0.09%) were destroyed (as part of the stamping-out program) and 199 (1.42%) were slaughtered and the meat disposed of. The latter number was exclusive of those that were slaughtered at the Jakarta Cakung Abattoir.

The above situation prompted DGLS to immediately undertake a series of measures to control the disease. The measures included:

- studies by staff of the Directorate of Animal Health (DAH) to investigate, determine and confirm the clinical nature of the disease;
- collection of the necessary specimens for analysis by the Veterinary Biologics Centre (VBC) in Surabaya and to WRL at Pirbright;
- surveillance and control measures by staff of DAH and VBC and the provincial livestock services (PLS) and district livestock services (DLS) of Central Java, particularly in those areas that were exposed to the infected source; and
- meeting of all heads of PLS in Java and those of disease investigation centres to plan the necessary strategies for the overall control and eradication of the disease.

The control measures were all planned to ensure they were undertaken in a coordinated manner together with the relevant agencies of the government and private organisations, including the provincial and district administrative and livestock services, the Research Institute for Veterinary Science, academic institutions (faculties of veterinary medicine), etc.

The Indonesian Government decided to undertake massive vaccination programs to cover the entire island of Java. To effectively undertake such a gigantic task, strategies were planned, including the establishment of a number of action units such as vaccination teams, disease diagnostic and vaccine production teams, field investigative and epidemiology teams, disease outbreak and field research and evaluation teams and a monitoring and evaluation team.

The control measures that were to be taken at the outbreaks, were as follows:

- stamping out;
- control of livestock movements and disinfection of vehicles;

Map 2. Spread of FMD after erupting in July 1983 in Blora, Central Java.

- closure of infected areas for the purpose of restraining livestock movements in and out of the area;
- control at the abattoirs including the control on slaughter and meat distribution;
- control at the quarantine stations;
- isolation and treatment of livestock and disinfection of livestock premises;
- mass vaccination;
- reporting of cases;
- surveillance; and
- extension services.

In undertaking the above FMD control program, it was stressed that there must be joint and active participation from all agencies of the governments (central, provincial and district) including the police, the military, the Information Department, the Office of the Governors, the research institutes, the veterinary faculties, the academics and the private organisations including the women, youth, farmers, community leaders, etc.

Closure of infected areas

As a control measure, 14 districts/cities and 84 subdistricts were closed to all traffic for livestock and livestock products. However, some were later reopened including the originally infected districts of Blora and Bojonegoro. The livestock checkpoints which were situated at various strategic places played a key role in the control and eradication of FMD in Java.

Vaccination

In the high-speed mass vaccination campaigns that ensued, a total of 8.1 million vaccinations were carried out representing a vaccination coverage of 96.9% of the eligible animal population of 8.3 million. The livestock vaccinated were largely cattle and buffaloes. A small number of sheep, goats and pigs were also vaccinated. Each animal was subjected to two vaccinations with an interval of 2–3 weeks. Only animals of over three months of age were vaccinated. Growing animals (cattle and buffaloes) on reaching the age of three months, were vaccinated in the second round of the campaign. As evidence of vaccinations, all animals had their ears notched.

Monitoring and evaluation

The monitoring and evaluation group undertook detailed monitoring and evaluation study of the FMD situation in the island covering 108 districts and a total of 756 villages. It was evident from the visits and the studies undertaken that there was the imperative need to reach a target of 100% vaccination coverage in the FMD control program. This need was impressed upon the official vaccinators and the community participants. The high coverage was to ensure that there was a much greater protection and immunity conferred on the livestock from FMD. As a result of these efforts, an increased coverage was achieved by the vaccination teams.

Epidemiological studies

The epidemiological studies team was of the view that the outbreaks in 1983 were the result of virus infection within the country. As part of its contribution the team established an inventory of the FMD viruses that had been prevalent in the country including that which was the causal agent in the 1983 outbreaks.

Research

The Research Institute for Veterinary Science (RIVS) and VBC had jointly undertaken studies of the efficacy of the various vaccines that had been used during the period of the mass vaccination campaigns in 1983. Comparisons were made with the vaccines, that had been used earlier, and the later campaign, i.e. O1 BFS (British field strain), O Campos, O Malaysia and O Java 83. It was found that O Java 83 was the most protective. As a result, the vaccines that were used subsequently in the campaigns were O Java 83, produced by VBC. During the six month period of the outbreak, a total of 491 specimens were received, including 123 pathological samples and 368 serum samples. These specimens were from Java, Bali, South Sulawesi, Lampung and Bengkulu. Of the 123 pathological specimens (tongue, buccal mucosa, esophagus and brain) submitted, 17 were found positive for FMD. Of the 368 serum samples, 165 were found to have low (0.45–1.0) antibody titres and 102 samples had variable antibody titres (1.0–1.8).

Control of livestock movements

The livestock checkpoints, as was stated earlier, had played an important role in the control of the spread of the FMD virus. All cattle and buffaloes passing through had to be vaccinated as evidenced by their ear notches, and had to be accompanied by the necessary health certification and movement permits.

There was increased quarantine security at the airport and seaport quarantine stations in Java. During the period of the FMD outbreaks, no animals were allowed out of Java. Animals leaving Bali and Madura, the two islands which had remained unaffected by FMD, had to undergo vaccination against FMD at their respective quarantine stations at Ketapang and Kalianget.

Animals from other parts of Java destined for the abattoir in Jakarta were subjected to tight surveillance at the collection points. The vehicles in which the animals were transported were subjected to disinfection before and after the transportation of the livestock. These animals had also to undergo FMD vaccination before they were transported.

Declaration

As result of the eradication program during 1974–1981 period, the following areas were declared as FMD-free, by the Minister of Agriculture: Bali and Madura in 1978, South Sulawesi and East Java in 1981. The last case of FMD was reported in Kebumen, Central Java in December 1983, while the last vaccination in Java against FMD was at the end of 1985. Vaccination and production of FMD vaccine in Indonesia are now prohibited. The Minister of Agriculture Decree No. 260 was promulgated in 1986 which proclaimed Java free of FMD. Since the whole country has been declared free of FMD serological and epidemiological surveillance are carried out annually.

In relation to the international and regional proclamation of the disease-free status of Indonesia, the Food and Agriculture Organisation (FAO)/Animal Production and Health Commission for Asia and the Pacific (APHCA) in Bangkok nominated Dr Osman bin Din to undertake the FAO/APHCA assignment to review the FMD status in Indonesia. In his visit to Indonesia in 1986, he undertook field visits to review and evaluate the present status of the disease. With the assistance of the Government of Indonesia, he also prepared a submission concerning a FMD surveillance program for ensuring the continued FMD-free status of the country. His concluding remarks were as follows:

- the excellent achievement of the Government of Indonesia in successfully controlling and eradicating FMD which had been prevalent for more than 100 years from the republic is worthy of emulation by any other country;
- the government had the will, commitment and the dedication to succeed in the national program of FMD control; and
- the remarkable achievement of Indonesia is perhaps unparalleled in so successfully containing the disease in so wide an area with such a large livestock population.

In 1990, the Association of South-East Asian Nations (ASEAN) FMD Study Team assigned a team which consists of representatives from ASEAN member countries and FAO/OIE to visit Indonesia in order to review the FMD status in the country. A sero-epidemiological approach was undertaken by the team and the result was that the team recommended that Indonesia should be declared free of FMD.

Control of Foot-and-Mouth Disease in Europe

A.I. Donaldson*

Abstract

The European Community (E.C.) consists of 12 member states — Belgium, Denmark, France, Germany, Greece, Holland, Italy, Luxembourg, Portugal, Ireland, Spain and the United Kingdom. The E.C. completed the arrangements for establishment of a single market on 1 January 1993, which abolished border controls and permits free movement of people and goods across frontiers within the community. This free movement includes live animals and animal products. In advance of the implementation of this decision it was recognised that the single market could only be achieved if all member states adopted common disease control policies. In the case of foot-and-mouth disease, the Council of the European Community decided that prophylactic vaccination against FMD in the E.C. should cease by December 31 1991, and, following the completion of the single market, all member states must apply stamping out and specified zoosanitary measures if outbreaks of disease occur. The background leading to these decisions is reviewed in this paper.

UNTIL 1991 the control policies for FMD applied by member states in the European Community (E.C.) were different — essentially according to whether or not prophylactic vaccination was routinely applied. In the event of outbreaks in the countries where prophylactic vaccination was used the policy was to apply total or partial stamping out (slaughter and disposal) on the infected premises and to ring vaccinate in the surrounding area. In the non-vaccinating countries total stamping out alone was the policy used. In the latter category were the United Kingdom, Ireland, Denmark and Greece; the other member states were in the former (Fig. 1).

During 1988–89 the Commission of the E.C. (CEC), recognising that the Single Market could only be successfully established if there was uniformity of disease control measures in all member states, reviewed the possible options for FMD control: non-vaccination; or pan-vaccination. The risks associated with each policy were assessed and a benefit–cost analysis applied to each strategy. Even allowing for a worst-case prediction of 13 primary outbreaks and 150 secondaries per primary over 10 years the results clearly showed that the benefits would be much greater if there was cessation of prophylactic vaccination (Report of the CEC 1989). This policy would fulfil the double aim of ensuring a high animal health status throughout the E.C. and would permit free movement of live animals and products within the Single Market. Most importantly, the cessation of vaccination would permit export of livestock and animal products, such as fresh meat and milk powder, from the entire Community to other FMD-free, non-vaccinating countries e.g. the United States, Canada, Australia, New Zealand and Japan. This would represent a considerable economic opportunity for those countries which formerly applied prophylactic vaccination against the disease.

The history of vaccination against foot-and-mouth disease in Europe has been mainly one of success. The question arises, therefore, 'why stop vaccination?' This can best be answered by reviewing the epidemiology of FMD in Europe over the last 40 or so years and highlighting the changes in disease control policy.

* Agriculture and Food Research Council, Institute for Animal Health, Pirbright Laboratory, Ash Road, Pirbright, Woking, Surrey GU24 0NF, England.

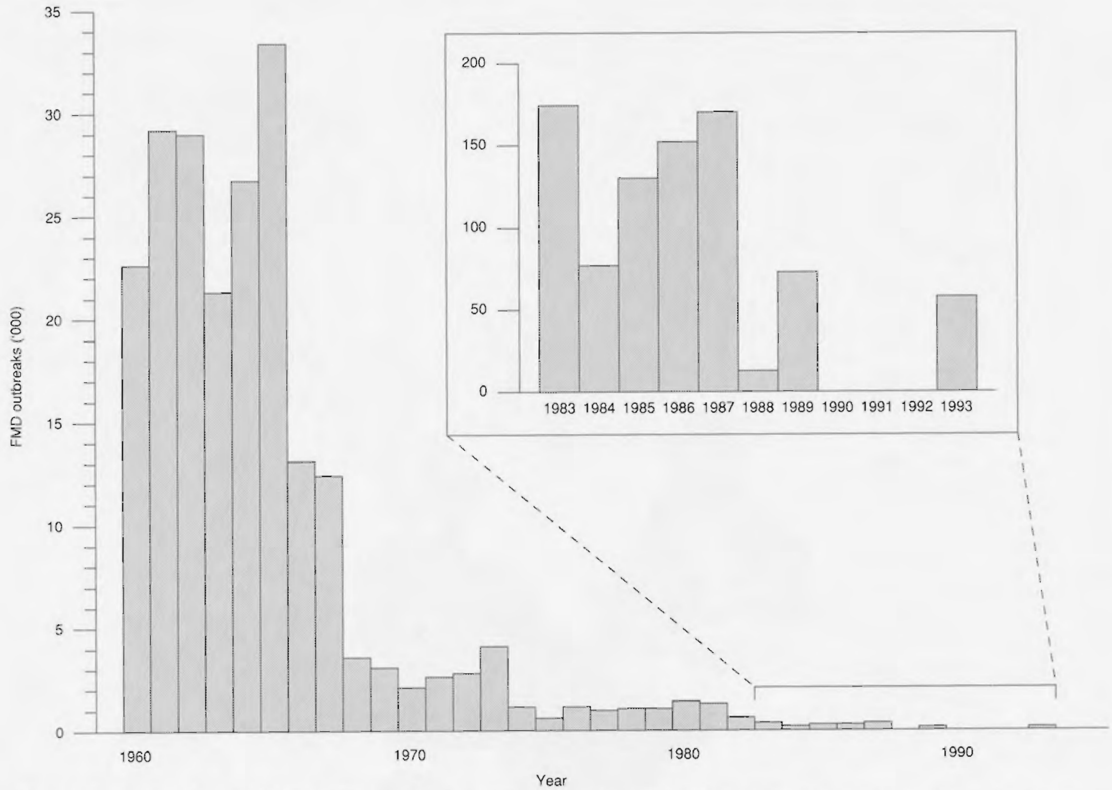

Figure 1. Outbreaks of FMD in Western Europe, 1960–93. Mass vaccination was introduced in the mid-1960s and ceased in 1990–91.

Epidemiology and FMD in Europe since the 1920s

The European livestock industry was seriously affected by FMD in the 1920s and 1930s. After the Second World War the number of outbreaks declined but in the early 1950s there was a dramatic increase — 1952 being a particularly bad year with most countries experiencing several hundreds of thousands of outbreaks.

A method of producing highly potent FMD vaccine in large quantities was developed in Holland in the late 1940s and early 1950s (Frenkel 1951). This made feasible the mass annual vaccination of cattle, a policy first adopted by Holland. Vaccination together with zoosanitary control very quickly produced a dramatic reduction in the number of outbreaks (Map 1). This success encouraged other European countries to follow suit. France began mass vaccination in 1957 and Germany in 1965. As time went by other countries soon joined in and steadily the overall number of outbreaks in Europe declined, only occasionally being interrupted by major outbreaks, for example during the 1960s and early 1970s. In the 1980s only Italy (1984–87 and 1988–89) and Portugal (1980–84) have experienced large epidemics (Table 1).

The origin of FMD outbreaks in Europe during the period 1977–87 has been investigated by a sub-group of the Scientific Veterinary Committee of the CEC. Of 34 primary outbreaks, 8 were concluded to have originated from outside the E.C., 13 were of unknown origin and the remaining 13 were attributed to origins from within the E.C. (Report of the CEC 1989). It is possible that there were other incursions of virus during this period but they failed to become established due to the immunity of challenged animals or the heat treatment of waste food. In regard to those outbreaks which originated from outside the E.C. in 1977–87, the majority were attributed to the importation of contaminated meat products. One outbreak was probably due to air-borne spread of virus from eastern Europe. In 1978 the E.C. introduced a policy requiring that beef

Map 1. The European Community showing FMD vaccination status of member countries prior to 1990–91.

imported from countries where the disease is endemic must mature (i.e. pass through *rigor mortis*) and be deboned before export. It is believed that this policy has had a very positive benefit as few outbreaks since then have been attributed to the importation of meat (Report of the CEC 1989).

The availability of newer biochemical techniques, in particular dideoxynucleotide sequencing, has permitted the detailed comparison of FMD virus strains from field outbreaks with reference strains. Using such procedures it has been possible to show that for 13 of the outbreaks originating from within the E.C. in the period 1977–87, there were two major sources: the use of vaccines which had not been fully inactivated and contained small amounts of residual infectivity; and escapes of virus from laboratories (Beck and Ströhmaier 1978).

Table 1. Outbreaks (number) of FMD in member states of the E.C., 1980–93.

Country	Most recent	1980	81	82	83	84	85	86	87	88	89	90	91	92	93
Belgium	1976	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Denmark	1983	—	—	22	1	—	—	—	—	—	—	—	—	—	—
France	1981	—	18	—	—	—	—	—	—	—	—	—	—	—	—
Germany	1988	2	—	1	—	3	—	—	2	4	—	—	—	—	—
Greece	1984	—	5	—	—	2	—	—	—	—	—	—	—	—	—
Ireland	1941	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Italy	1993	1	3	—	—	45	130	150	167	7	73	—	—	—	57
Luxembourg	1964	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Netherlands	1984	—	—	—	4	2	—	—	—	—	—	—	—	—	—
U.K.	1981	—	1	—	—	—	—	—	—	—	—	—	—	—	—
Spain	1986	5	5	1	12	—	—	1	—	—	—	—	—	—	—
Portugal	1984	584	303	—	164	22	—	—	—	—	—	—	—	—	—

— No outbreaks

Faulty vaccines have been largely attributed to the use of formalin as an inactivant. This inactivant, unless used under very stringent conditions, can give unpredictable results leading to a risk of the survival of some virus. The mechanisms of escapes from laboratories have been difficult or impossible to pin-point but are thought most likely to have been associated with procedures generating highly concentrated aerosols of virus such as the experimental infection of susceptible livestock or large-scale virus growth for vaccine production (Mowat 1989).

Therefore, while the use of vaccine has undoubtedly played a significant role in reducing FMD outbreaks on continental Europe during the last 40 or so years, a significant proportion of recent outbreaks can be attributed to vaccine or vaccine-related activities. It was this evidence which strongly influenced the decision by the CEC to recommend the use of vaccine be discontinued. Consequently, the Council of the E.C. directed that vaccination was to cease in the E.C. before the 1 January 1992. This allowed a one-year period for vaccinated animals to lose their immunity before the Single Market came into operation. However, some countries decided to stop well in advance of the deadline. Spain stopped at the end of 1990, and Belgium, Holland, Luxembourg and Germany carried out their last rounds of vaccination in the Spring of 1991. France and Italy ceased vaccinating in the Summer of 1991.

Present E.C. Policies for Control and Prevention of FMD

In the event of outbreaks in the E.C. the main disease control policy is total stamping out, i.e. slaughter and disposal of all affected and in-contact susceptible animals on the infected premises. This is supported by zoosanitary measures including disinfection and movement restrictions. A E.C. contingency fund has been established to compensate farmers in the event of outbreaks.

In addition to stamping out, emergency strategic vaccination may be undertaken in certain circumstances. In anticipation of this possibility vaccine banks will soon be established in which concentrated inactivated FMD virus antigens will be stored over liquid nitrogen. It has been decided that there will be four banks — located in France, Germany, Italy and the United Kingdom. It is intended that the equivalent of 5 million vaccine doses of each of 10 different strains will be stored.

Additional technical support is provided by a Community Co-ordination Institute for FMD Vaccines (CCI) which tests vaccines produced for use in the E.C. and in Community-supported vaccination campaigns in non-E.C. countries which export to the E.C. The CCI also evaluates vaccine innocuity and potency testing systems and trains experts in vaccine technology. The Central Veterinary Laboratory, Lelystad, Holland has been designated as the CCI.

In 1990 the Institute for Animal Health, Pirbright Laboratory, was appointed as a Community Reference Laboratory (CRL). Its main duties are to ensure liaison between national FMD laboratories in the E.C. in regard to the standards and methods of diagnosis and differential diagnosis of FMD; to receive field samples when necessary from member states and certain non-E.C. countries; to identify and characterise any isolates of FMD virus; and to build up and maintain a reference collection of FMD virus strains and specific antisera. The CRL is also responsible for the supply to national FMD laboratories of reagents for diagnosis, for providing diagnostic training, for standardising FMD diagnosis and differential diagnosis in the E.C. and for collecting and disseminating related data and information to the CEC and the member states.

The CCI and the CRL are both responsible for formulating guidelines for disease security in the respective national FMD laboratories. At present 13 laboratories are manipulating FMD virus in the E.C. Three are vaccine production plants and the remainder hold virus for diagnostic or research purposes. To lessen the risk of virus escapes those establishments manipulating virus, whether for diagnostic purposes or for vaccine production, are subjected to inspection by representatives acting on behalf of the CEC and they have to demonstrate that they comply with specified microbiological security standards.

The cessation of prophylactic FMD vaccination in the European Community has resulted in a significant reduction in the number of vaccine production plants. Both of these factors together with stricter security measures have greatly reduced the risk of 'home-grown' outbreaks within the E.C.

Importation from Third Countries

Since the completion of the Single Market all imports of live animals, meat and other animal products such as milk, hides, wool, offal, biological products and materials (including veterinary vaccines and pharmaceutical products) and feedstuffs, are only permitted through specified ports of entry located around the periphery of the E.C.

Animal importations

The importation of animals from non-E.C. countries is freely permitted if those countries apply control measures equivalent to those of the Community. The former eastern bloc countries, for example, have been accorded similar status to member states of the E.C. since they have implemented the same policies for the control of FMD — in particular cessation of vaccination. The other countries of Europe, namely the Scandinavian countries, Switzerland and Austria fall into the same category, so in regard to FMD essentially all of Europe has the same trading arrangements.

Animals from non-E.C. countries of a lower health status or where the control measures are not as stringently applied are either prohibited entry or are isolated in quarantine and tested to ensure an absence of both virus and circulating antibody.

Meat and meat products

These products are considered on an individual basis. If they originate from a non-E.C. country of equivalent FMD status to the E.C., i.e. non-vaccinating and FMD-free, entry is usually freely permitted. However, if they come from a country of lower health status either the product is prohibited or certain safeguards are required before entry is allowed.

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Patterns of National and International Livestock Movement in Southeast Asia: Implication for a Regional Foot-and-Mouth Disease Control Program

Masao Sasaki*

Abstract

The movement of livestock, in particular cattle, within and beyond international boundaries has been a long tradition in Indo-China countries. Without any effective control mechanisms for livestock movement, cattle and, to some extent, buffaloes move to the place where they can be sold at a better price. Therefore, it is extremely important to understand prevailing patterns of national and international livestock (mainly cattle) and to implement a proper control mechanism to complement programs for FMD control and eventual eradication. This paper reviews animal movement patterns in the Indo-China peninsula countries of Myanmar, Thailand, Laos, Cambodia and Vietnam. It is suggested that international cattle movement should not be banned or regarded as 'illicit'. Instead, liberalised livestock trade should be encouraged under certain conditions for the benefit of both exporting and importing countries. In this regard, effective animal quarantine systems both at the international border and along important transportation routes within a country become necessary. Bilateral agreements and closer contact between neighbouring countries at both national and local levels are essential to develop proper animal movement control systems which are convenient and practicable for livestock owners.

IN the context of any programs for FMD control and eventual eradication in Southeast Asia, it is important to have strategies to deal with animal movements within a country as well as across international boundaries. It has been a long tradition in this region that cattle and buffaloes move almost freely from one place to another sometime covering distances of more than 1000 km on foot and often crossing international borders. This is due to the economic principle that all commodities including live animals move to the point where their prices are highest, as long as there are no restrictive measures (or effective control mechanisms) to regulate this movement.

Animal Movement Patterns

Animal movement patterns of five Indo-China Peninsular countries (i.e. Myanmar, Thailand, Laos, Cambodia and Vietnam) are shown in the respective country papers included with these proceedings and in Map 1 of Ozawa (these proceedings). The information presented in this paper is based mainly on the *Report on the Second Meeting of the Coordination Group for the Control of FMD in Southeast Asia*, Bangkok in February 1993.

In Southeast Asia, animal movement involves mainly cattle, and to much less extent, buffaloes. Movement of sheep and goats, and swine also exists but their effects in terms of FMD control and eradication is much less. With the possible exception of raw hide, there is hardly any significant movement of meat and other animal products/ by-products.

Myanmar

Myanmar is divided into seven divisions, predominantly populated by Burmese, and seven states where other ethnic groups reside.

Of a total cattle population of 9.3 million in 1992, most were in five divisions and one state: Sagain Division (1.6 million), Mandalay Division (1.5),

* Food and Agriculture Organisation Regional Office, Phra Atit Road, Bangkok 10200, Thailand.

Magway Division (1.4), Bago Division (1.0), Ayeyarwaddy (Irrawaddy) Division (1.0) and Shan State (0.9). All five divisions are centrally located and these are the areas of cattle production and the origin of their migration to other divisions/states and across the international borders.

Since cattle in Myanmar are mainly raised for draft purposes (land cultivation and harvesting for rice paddy production), major cattle movement starts just before and after working seasons, i.e. twice a year; just before and after the monsoon. Major movement takes place for the purpose of slaughtering, search for better feed resources, livestock market and illicit trade beyond the international boundaries. International cattle movement is almost exclusively *out* into neighbouring countries. In spite of the fact that a large number of animals move into Thailand, and to some less extent, into Bangladesh, China and India each year, the government still regards cattle movement into the neighbours as illicit and there are no effective systems existing in the country to regulate the movement of animals.

Thailand

Thailand is divided into 4 areas (Central, Northern, Northeastern and Southern) which are further divided into 9 regions and 73 provinces. The total cattle population in 1992 was 7 million, of which 1.5 million are in Region 3 (Northeastern), 1.1 million in Region 6 (Northern), 0.9 million in Region 7 (Central) and 0.9 million in Region 4 (Northeastern). The Southern Area (Regions 8 and 9 combined) which is currently designated as an FMD-free zone, has relatively few cattle (0.7 million). The role of cattle in Thailand is rapidly shifting from provider of draft power to producer of meat, milk and other by-products. In rural areas cattle still play an important role as draft animals but rapid economic growth in recent years has resulted in more frequent movement of beef cattle from production areas (Northern and Northeastern) into consumption areas (Central). In addition, traditional movement is from the northern regions to the Southern Area and further down into Malaysian territory. Also an inflow into the country from neighbouring countries has been traditional. Each year large numbers of cattle arrive from Myanmar on a routine daily basis. In recent years movement of livestock from Laos and Cambodia, involving a large number of buffaloes, has also become more significant.

Thailand operates 20 international and 11 inland animal quarantine stations (see Thailand Country Paper in these proceedings). One of the major purposes of both international and inland quarantine stations is to prevent the spread of FMD and protect the FMD-free zone from a new incursion of FMD infection. The effectiveness of current quarantine systems need to be evaluated since the Department of Livestock Development (DLD) allocates substantial funds and personnel to maintain and operate these systems which are apparently not functioning as effectively as they should be. Petchburi/Cha-am Animal Quarantine Station was established in 1963 and is the oldest station in the country. Its main purpose has been to establish, expand and maintain the FMD-free zone in the Southern Area. Even 30 years after its establishment, the role of this station has not changed. The present policy is that only FMD-vaccinated animals (at least 21 days, but less than 6 months, since vaccination) with individual ear tags, could be allowed to pass this station southwards. At present, there is no cattle registration law (or at least no implementation of the existing law, if any) by which all cattle in the Southern Area are required to register with valid ear identification tags. Thus, there is no way to distinguish animals which are native from those illicitly brought from FMD-contaminated regions into the south. The DLD has already designated the Eastern Region (Region 2) as FMD-free. This area close to the boundary with Cambodia is becoming important mainly for swine production.

Thailand's plan to control and eventually eradicate FMD has already a long history. The DLD has been allocating substantial funds for this purpose each year including: FMD vaccine production; mass vaccination; and operation of quarantine stations and check posts. It has now been realised, however, that a successful FMD eradication campaign in Thailand requires, among other things:

- improved field veterinary services and other infrastructure;
- cattle owners and traders full understanding and cooperation;
- the Government's strong and continued commitment; and most importantly
- a coordinated approach with all the neighbouring countries concerned.

Laos

The country is land-locked and surrounded by three neighbours: China, Vietnam and Thailand. The cattle population has grown steadily in the past 10 years with the average annual growth of 7.5% (total population in 1993 of 1 million) and is distributed evenly over the country, while the buffaloes (1.2 million) are found mainly in the south (Mekong Basin). The major function of both cattle and buffaloes is to provide draft power. Meat production is still regarded as a by-product operation of much less importance than draft use. However, in recent years export earnings from cattle and buffaloes have become important with estimated earning of over US$10 million in 1992. Live cattle and buffaloes and their raw hide are exported. While bovine movement is in one direction towards Thailand, live animals, mainly cattle, come into Lao territory from China, Vietnam and Cambodia. Some cattle arrive in the Lao provinces from Vietnam and continue to move into Thailand. It has been reported that there are some mechanisms to control animal movement (quarantine stations and check posts) both at international borders and on the major inland animal trading routes but their effectiveness is to be evaluated. There is a national FMD control program whose major activity is FMD vaccination. Only 50 000 animals (out of over 2 million of bovine species) are vaccinated yearly just to reduce or confine outbreak incidences. There are no particular provinces (areas) identified yet where a future FMD-free zone will be created.

Cambodia

Cambodia has 22 provinces and according to the latest Food and Agriculture Organisation (FAO) statistics, the cattle population in Cambodia has more than doubled in the past decade (956 000 head in 1981 vs over 2.1 million in 1991) with an average annual growth rate of 8.6%. The buffalo population has also increased significantly from 0.4 million in 1981 to 0.8 million in 1991 with a growth rate of 6.7%. The provinces with the largest number of cattle are Kampong Cham (330 000), Takeo (314 000), Kampong Spoe (273 000), Kandal (248 000) and Prey Veng (182 000), all located around the capital, Phnom Penh. For buffaloes, Prey Veng has the largest population (133 000), followed by Kampong Cham (109 000) and Svay Rieng (100 000). As is the case for Thailand, Laos, and the southern part of Vietnam, most FMD outbreaks coincide with the monsoon season, during which period cattle and buffaloes are required to work as draft animals for rice paddy production. The movement of animals occurs mainly during the dry season. Internal movement of cattle is from the northeastern to the central provinces and international movement of animals, including a significant number of buffaloes, is from the central provinces to Thailand (on foot or by boat), to Vietnam and, to some extent for cattle, to Laos. The major gates for animal movement are: Poipet (Aranyaprathet in Thailand) in Banteay Meanchey Province; and Bavel in Battambang Province. Three provinces (Koh Kong, Kampong Song and Kampot) facing the Gulf of Thailand are assumed to export a significant number of live animals and some quantities of meat products by sea.

There exists a law (Decree on Sanitary Control of Animals and Animal Products) under which animal movement can be regulated inside the country as well as at the border. Due to many confronting problems, the enforcement of the law has not been practised.

Vietnam

Vietnam is divided into seven regions, three in the north and four in the south. Cattle are densely populated in two central coastal regions but relatively less in the two delta (Red River and Mekong) regions. More buffaloes are found in the north, particularly the North Mountains and Midlands Regions. The country's cattle population increased from 1.7 million in 1981 to 3.3 million in 1991 with an average annual growth rate of 7.5%. The increase in buffalo population is, on the other hand, rather nominal with an annual growth rate of 2.4% (2.3 million in 1981 vs 2.9 million in 1991).

No FMD outbreaks were reported in recent years in either the north or the central areas of Vietnam. Major outbreaks were reported in provinces in the Mekong Delta and some in the South-Central Region. In the north, cattle move into Hanoi for slaughter while some move out into China and Laos. In the south, both cattle and buffaloes move to Ho Chi Minh City for slaughter. Some cattle are also transported into Lao territory and end up in Thailand. Movement across the Cambodia–Vietnam border is in both directions depending on the price of animals at any particular time.

A reorganisation of field veterinary services was completed in 1992. The provincial subdepartment can now directly manage the district animal stations, resulting in an improved vaccination campaign, epidemiological survey and disease reporting system. There are animal check posts along the major provincial borders and those on the international border with Cambodia. However, the animal movement both within the territory and at the international border is not effectively regulated except for the emergency area where the severe FMD outbreaks are taking place.

Livestock Movement Control: Effective Animal Quarantine Practices

As already described, cattle movement in the Indo-China region traditionally involves long-distance journeys frequently crossing international boundaries. Traditionally such movement of animals was on foot and this is still practised. However, trucks are now widely used to ship animals faster over long distances. An ocean route is also of considerable importance in the case of Cambodia.

It is therefore difficult and rather impractical to try to enforce a total ban on so-called 'illicit' movement of cattle across the borders. Furthermore, it seems to be a rather out-of-date concept to call this kind of movement illicit since it has been practised for such a long time. In the long run, a more liberalised movement of cattle across the border would benefit both cattle producers in exporting countries and beef consumers in importing countries. However, at present, cattle-crossing at an international border is considered to be an illegal action in all five countries and practical strategies therefore have to be worked out under these circumstances.

Some animal quarantine stations and check posts have already been set up in all these countries. The role of such stations are to make sure that animals passing through the quarantine point cause no threat of introducing specified infection(s) in a new location. For international quarantine stations further functions are:

- to regulate the movement of animals and their products/by-products so that a possible entry of any undesirable diseases/infections can be prevented — i.e. *protecting own country*; and
- to make sure that animals and the products/by-products are free from diseases and of an acceptable standard of veterinary health for receiving countries as well as the exporting country itself — i.e. *protecting the partner country*.

In practice, however, existing animal quarantine stations/posts in the region are not functioning properly. There are many reasons for this failure of the existing quarantine systems. Poor facilities, lack of enforcement power, shortage of personnel, budget constraints and lack of cooperation by animal owners and traders are just a few of them. Probably the largest problem for animal movement control through quarantine systems, however, relates to ignorance amongst the general public, other government agencies and in some cases, the livestock department itself on why quarantine stations are needed and their responsibility/duty to enforce regulations.

Without doubt, bilateral and regional cooperation is essential and indispensable to the proper implementation of animal movement control mechanisms which are one of the most important strategies on FMD control and eradication in the region.

In this respect, it is very gratifying to learn that Laos and Thailand made a tentative agreement to establish several cattle holding sites close to the Laos side of the border where animals destined for Thailand are held and properly quarantined by both Lao and Thai veterinarians.

Conclusion

It can not be overemphasised that without proper control of animal movement within countries and across international boundaries, FMD control and eventual eradication programs will not succeed. Cattle movement from one place to another, sometimes involving the crossing of international borders, has been a long tradition and is considered as an indispensable activity in the daily life of people in the region. Thus, it may be necessary to recognise this and, instead of tightening the existing laws to ban such animal movement, it would be more practical and beneficial to encourage this movement as a legitimate livestock trade in the region.

For this purpose bilateral and regional level cooperation is essential and the following measures are required:

- field veterinary services, which include effective inland and international animal quarantine systems, need to be improved;
- the role, function and real effectiveness of all existing animal quarantine stations/check posts should be reviewed with a well defined, narrowly targeted objective of their existence. It is wasteful to pay much attention to many endemic diseases whose local distribution has not yet been well established. In most inland and international border stations, FMD would be the only disease of special concern;
- formal as well as informal contacts should be developed with neighbouring countries at both national and local levels to discuss the practical mechanisms of animal movement control;
- animal owners and traders should be given more information on FMD so that they can understand why their animals need to be quarantined; and
- government quarantine procedures (issuing animal health and moving certificates, holding animals at a station, animal inspection, etc.) should be, as long as they are technically sound, simpler, less time consuming and with a minimum cost involved so that animal owners and traders are encouraged to move their animals in a legalised way, instead of smuggling them.

Strategy Options for the Control of Foot-and-Mouth Disease in Southeast Asia

Y. Ozawa*

Abstract

The past involvement of the Office International des Épizooties (OIE) in efforts for the control of foot-and-mouth disease (FMD) in Southeast Asia is briefly described. Strategy options for the control of FMD are discussed emphasising that the most economical and effective option is to organise an internationally coordinated eradication campaign against FMD in Southeast Asia covering the countries between Myanmar and the Philippines. The outline of the OIE plan for the FMD campaign in Southeast Asia is described. The proposed plan includes the formation of a sub-commission for the control of FMD in Southeast Asia as a part of the OIE Commission for FMD and Other Epizootics. The proposed plan also includes a justification of the campaign; proposed strategies; duration of the campaign, which is divided into three phases; the organisational structure; and the proposed budget.

IN Asia, foot-and-mouth disease (FMD) has been a subject of great concern to all the countries. Since its inception in 1976, the Food and Agriculture Organisation (FAO)/Animal Production and Health Commission for Asia (APHCA) has made continuous efforts to control the disease. Several missions were fielded, and a comprehensive review of the situation and recommendations were published in 1984 (FAO/APHC 1984). There was a proposal to organise a coordinated international campaign in Asia in the APHCA region, but this did not materialise.

Although some good progress has been achieved in some island countries such as Indonesia, most of the countries in Asia which share land borders continue to suffer because of the movements of infected animals. Civil strife and wars in Indo-China, resulted in the interruption of disease control programs in this subregion for several years.

However, in recent years, as the political and economic climate has begun to improve in Indo-China, there has been a marked increase in both legal and illegal movements of animals across international borders, and the FMD situation in some of the countries in Southeast Asia has taken a turn for the worse. Under these circumstances, the OIE *Symposium on the Control of Major Livestock Diseases in Asia* was held in Pattaya, Thailand, in November 1990, and the FMD control strategy in Southeast Asia was discussed. The symposium recommended that the OIE should form a sub-commission for the control of FMD in Southeast Asia in order to promote internationally coordinated campaigns against FMD in the region.

This recommendation was approved by the OIE International Committee in 1991, and the first meeting of the *Coordinating Group for the Control of FMD in Southeast Asia* was held in Bangkok under the OIE/Japan Trust Fund Program in February 1992 with the participation of FAO.

The second meeting of the same group was in February 1993. The group consisted of Myanmar, Thailand, Malaysia, Laos, Cambodia, Vietnam and the Philippines. The participants agreed that common overall strategies for the control/eradication of FMD should be taken by these countries, and also agreed to develop national plans based on the agreed strategies.

* Office International des Épizooties, Tokyo Regional Office, East 311, 1-1-1 Minami-Aoyama, Minato-ku, Tokyo 107, Japan.

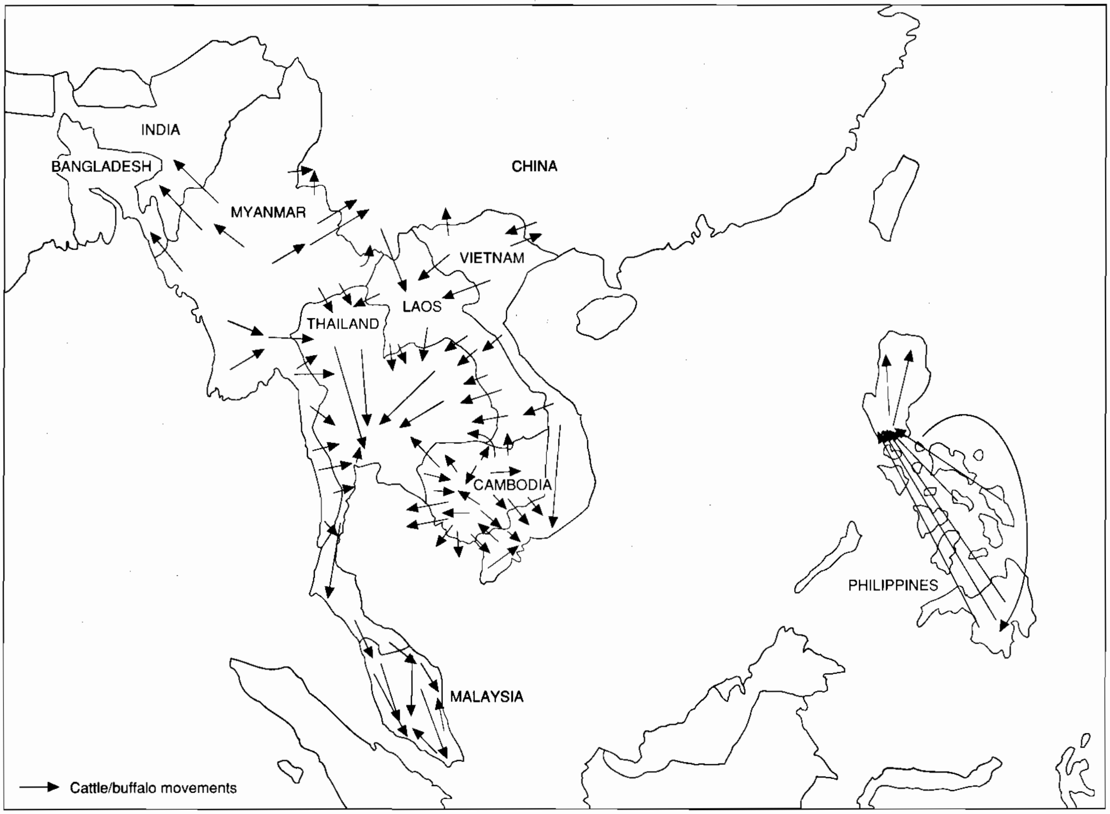
Strategy Options

There are at least three options for FMD affected countries which are discussed below.

- *Do nothing.* This option means that no special efforts are made to control FMD. If a country takes this option, FMD will spread all over the country and also to its neighbours, causing serious economic losses in all infected countries.
- *Maintain the current status.* This option means that a country has to live with the disease forever, and will have to continue to allocate high levels of funds to keep the disease under reasonable control. Annual expenses for the control or prevention of FMD will increase as trade in animals increases in the region.
- *Eradication campaign.* This option may cost more during the campaign, but in a long run the benefit-cost ratio may reach between 5:1 and 8:1 in favour of the campaign (Ellis and James 1979). It is essential that such campaigns should be internationally coordinated in order to prevent the re-entry of FMD from neighbouring countries.

From the above, it is obvious that the eradication campaign is the best choice for all the countries in Asia. The success of a national campaign depends on the efficiency of veterinary services if the country is isolated by sea or natural barriers. However, if a country shares land borders with other affected countries, the success of a national campaign depends on many other factors, such as the control of international movements of animals and their products, synchronisation of vaccination campaigns along the borders, tracing back the origin of FMD virus across the borders, the exchange of information about the FMD situation between countries. For this reason FMD control campaigns in the countries of Southeast Asia should be well coordinated if the campaigns are aiming at the eventual eradication of the disease.

It is known that FMD is endemic in Myanmar, Laos, Cambodia, Thailand, Malaysia, Vietnam and the Philippines (OIE 1993). With the exception of the Philippines, all other countries share land borders, and movements of animals crossing national borders are increasing year by year as shown in Map 1.



Map 1. Movement patterns of cattle and buffaloes in Southeast Asia (OIE 1993).

Under these circumstances, the countries between Myanmar and Vietnam should be considered as a community, and an internationally coordinated program should be developed before individually-planned national campaigns are launched. At the same time, measures to prevent the entry of FMD into the community of countries should be strengthened. The entry of susceptible animals from India, Bangladesh and China should be prohibited to avoid the introduction of FMD through those countries.

Prior to launching an FMD campaign in Southeast Asia, national and international campaign strategies within the community of countries should be developed, based on the epidemiological studies and the trade patterns of susceptible animals including illegal trade across land, river and sea borders.

There will be several strategy options for a regional campaign such as this, but it is usual that vaccination programs start in the areas that are found to be the source of infection by epidemiological studies. Then, all animals for trade should be immunised and earmarked prior to their departure. Importation of susceptible animals and their products from FMD-infected countries outside the community should be banned.

National vaccination campaigns should continue until the number of outbreaks is reduced to a few, and then a stamping-out policy with full compensation to the owners should be applied where it is feasible. When this policy cannot be applied, strict movement control of animals and ring vaccination should be carried out. Then, FMD-free zones in each country should be established and the free zone should be gradually expanded until the entire country becomes FMD-free. If a free zone is created near a national border, internationally coordinated efforts should be planned in order to expand the FMD-free zone along the border. These are just a few basic strategies to be considered, but the actual strategy to be applied in a regional campaign will be far more complicated.

OIE Plan for the Campaign against FMD in Southeast Asia

Objectives

The immediate objective of the OIE plan is to improve the standards of veterinary services in FMD-affected countries in Southeast Asia. The intermediate objectives are to improve the productivity of animals by keeping FMD under control and to increase the income of livestock producers in Myanmar, Laos, Cambodia, Thailand, Malaysia, Vietnam and the Philippines. The long-term objective is to facilitate and promote the international trade of animals and animal products by creating FMD-free regions in Southeast Asia.

Justification

In the last decade, FMD control efforts in the countries of Southeast Asia have received a great deal of attention, and individual national control programs were carried out. Funds, equivalent to several millions of dollars, have been spent annually for these programs but without much success mainly due to the fact that there were no common overall strategies and that there were no internationally coordinated programs.

Recent changes in the political and economic climate in the region encouraged the commercial sectors of many countries to pursue international market-oriented trade in livestock and its products. A sudden increase in both legal and illegal trade of animals crossing national borders resulted in the expansion of the FMD-infected areas due to the movement of infected animals.

The countries of Southeast Asia have shown during the first and the second meetings of the Coordinating Group for the Control of FMD in Southeast Asia (held in Bangkok in 1992 and 1993) that they are ready to work together with confidence, and that they are all anxious to start an internationally-coordinated campaign with a common overall strategy.

A study made in 1977 (Ellis and James 1979) in South Asia on the benefit–cost analysis of FMD control programs showed the ratio between 5:1 and 8:1 in favour of control programs. This impressive ratio is likely to be even higher in Southeast Asia where the eradication of FMD is considered feasible and permanent improvements in the production systems can be safely introduced. However, the rising costs of FMD control programs require the development of the most efficient and economical strategy through rigorous evaluations and regular benefit–cost analyses of national programs.

Strategy of the campaign

A common strategy for the control and eventual eradication of FMD in the region includes the following elements:

- establishing a regional reference laboratory and a regional coordinating unit;
- strengthening veterinary services in individual countries;
- active involvement of the private sector (e.g. farmers' unions and livestock producers and traders) in the planning and implementation of control programs;

- developing effective FMD surveillance and reporting systems;
- establishing national diagnostic capabilities for virus identification and serotyping;
- implementing mass vaccination programs as the primary method for reducing the incidence of the disease to low levels; and
- implementing other control methods for individual outbreaks, as appropriate.

These elements of the strategy were accepted by the participants of the second meeting of the Coordinating Group for the Control of FMD in Southeast Asia held in Bangkok in February 1993. In order to coordinate activities in Southeast Asia for FMD control, it is essential to establish an efficient regional reference laboratory/regional coordinating unit in Bangkok as soon as possible. Also, as a matter of urgency, each country included in the campaign should develop action plans based on the above measures. Each country should also identify the areas in which external assistance is required.

Duration of the campaign

The duration of the campaign is approximately 12 years. The campaign is divided into the following three phases:

Phase 1 (the preparation phase) — 3 to 4 years for reducing FMD outbreaks;

Phase 2 (the control phase) — 5 years for the expansion of low prevalence areas; and

Phase 3 (the eradication phase) — 3 to 4 years for the eradication and conservation of FMD-free status.

It is intended that phase 1 of the campaign begins in 1995, phase 2 in 1998 and phase 3 in 2003. The major activities of the three phases are summarised below.

Phase 1 (preparatory phase)

- Establish a regional reference laboratory and a coordinating unit.
- Strengthen both field veterinary services and laboratory services in each country.
- Collect FMD samples from each outbreak for typing.
- Investigate further the movement of animals, and develop better systems for animal health control at national borders.
- Carry out epidemiological surveillance on FMD and improve the disease reporting system.
- Improve public awareness of the importance of FMD through communication campaigns with special emphasis on disease reporting by livestock owners.
- Encourage active involvement of the private sector in the planning and implementation of control programs.
- Strengthen cold-chain systems in each country.
- Introduce earmarking systems for vaccinated animals.
- Increase FMD vaccine production capacity in the region after identification of the most suitable vaccine strains and to introduce a strict vaccine quality control system.
- Develop national and international plans for the control of FMD.

Phase 2 (FMD control phase)

- Step up communication and vaccination campaigns and to encourage the active participation of the private sector and farmers in the campaigns.
- Implement progressively stamping out in areas as epidemiologically indicated.
- Evaluate the efficacy of FMD vaccination by taking adequate numbers of serum samples.
- Strengthen the movement control of animals from infected areas or countries (only vaccinated and earmarked animals are allowed to move).
- Carry out investigation and each outbreak including strain identification and epidemiological tracing.
- Create disease-free zones including the surrounding buffer zones, and expand the zones step by step to cover entire countries.

Phase 3 (eradication and consolidation phase)

- Establish solid buffer protection zones to prevent the entry of FMD from countries not included in the campaign.
- Strengthen further the movement control of animals and animal products, and prevent the entry of FMD through sea/air ports and smuggling operations.
- Cease vaccination in areas where other preventive measures are consolidated and no outbreaks have occurred.
- Intensify clinical surveillance in these areas.
- Carry out serological surveillance of FMD in the areas where vaccination has ceased for more than two years.
- Maintain and strengthen legal and financial measures for stamping out FMD outbreaks.
- Maintain producers and public information campaigns in order to prevent the reintroduction of FMD.

- As soon as OIE requirements for FMD-free status are fulfilled by a country/zone, the country may request the OIE to verify the status before the country makes an official declaration of FMD-free status.

Over the three phases, the veterinary services must continuously be strengthened, and public awareness for the importance of animal health with special emphasis on the major epidemic disease must be improved.

Organisational structure

A proposed organisational structure is shown in Figure 1. The *OIE Sub-Commission for the Control of FMD in Southeast Asia* will be formed from delegations of the governments of Myanmar, Laos, Thailand, Malaysia, Cambodia, Vietnam and the Philippines. This sub-commission will be part of the OIE Commission for the Control of FMD and Other Epizootic Disease, and is supported by the OIE Regional Commission for Asia, the Far East, and Oceania; the OIE Central Bureau; OIE Tokyo Office; FAO Regional Office in Bangkok; the International Atomic Energy Agency (IAEA) and donor agencies. The annual meeting of the sub-commission will be held in a place decided during the previous meeting of the sub-commission.

The *Executive Committee* will consist of two of the above seven countries elected by the sub-commission, the Head of the Regional Coordination Unit and an OIE Representative. The committee will meet once a year (usually just before the annual meeting of the sub-commission).

The *Advisory Committee* is formed by the representatives of OIE, FAO, IAEA and major donor agencies. The committee will meet on an *ad hoc* basis and the chairman of the Executive Committee and the Head of the Regional Coordination Unit will be requested to take part in the meeting.

The main functions of the *Regional Coordination Unit* are:

- coordination of FMD control activities in Southeast Asia;
- coordination of FMD reporting in the region;
- coordination of epidemiological studies of FMD in the region;
- coordination of research/training activities;
- formulation of FMD control strategies in the region; and
- provision of advice to national FMD campaign coordinators.

The main functions of the *Regional Reference Laboratory* will include:

- identification and antigenic characterisation of FMD virus samples received;
- introduction of new laboratory methods for FMD virus typing and serological tests;
- provision of standard diagnostic reagents for use in the region;
- investigation of vaccine failure by laboratory tests; and
- quality control of vaccines used in the campaign as required.

In each country, a *National Coordination Unit* for the FMD campaign will be established to

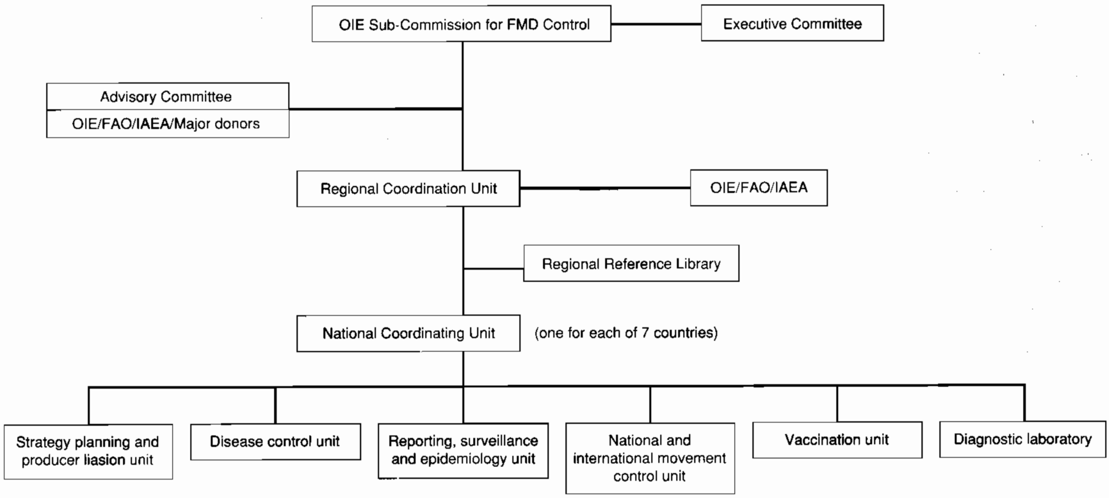


Figure 1. Proposed organisational structure for the OIE campaign against FMD in Southeast Asia.

coordinate national activities related to FMD control/eradication. The activities include:

- strategic planning of the campaign based on epidemiological studies and cost-benefit analysis;
- epidemiological investigation of FMD, and reporting the disease situation;
- execution of FMD surveillance and control programs;
- movement control of susceptible animals and their products;
- vaccination of animals, and monitoring of the efficacy of vaccines used;
- laboratory investigation of all FMD-like disease and vaccine failures;
- establishment of FMD-free zones/countries; and
- strengthening of preventive measures, etc.

Finance

Each country of the OIE sub-commission will allocate annually funds necessary for the national campaign. A separate allocation of funds (in local currency) shall be made to cover the costs such as travel expense of national coordinators to attend international meetings, travel expenses for trainees to attend international courses, travel and per diem expense of international coordinators and technical advisers during their stay in the country.

In addition to the above, assistance from international organisations such as the OIE, FAO, IAEA, United Nations Development Program, European Community, Asian Development Bank, etc, and also from bilateral aid agencies will be sought to meet the financial requirements for both national campaigns and international coordination of the campaign.

The costs of national campaigns and regional activities will be made by national officials in consultation with international advisers.

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DIAGNOSIS OF FOOT-AND-MOUTH DISEASE

The focus of this session was the diagnosis of foot-and-mouth disease (FMD) and the first speaker, Dr Ab Kongthon of the Department of Livestock Development, Thailand, described the development of diagnostic facilities in Thailand since the late 1950s when the complement fixation test was first used. Use of the enzyme-linked immunosorbent assay (ELISA) was developed in Thailand in 1986 as a result of a collaborative Thai–Australian project. Initially the reagents were obtained from the World Reference Laboratory at Pirbright , United Kingdom, but since 1987 the reagents have been produced by the FMD Center at Pak Chong in Thailand. As the virus cannot be detected in a proportion of the samples it is necessary to have the ability to isolate the virus prior to typing. Virus isolation capabilities are therefore necessary to be included in national diagnostic laboratories.

Dr Laurence Gleeson of the Australian Animal Health Laboratory described strain differentiation studies carried out as part of the Thai–Australian FMD project in Northern Thailand. The principal goals of the study were to examine the serological relationships between a large sample of recently isolated field strains and existing vaccine viruses so as to attempt to identify problems arising from continued use of established vaccine strains; determine epidemiological relationships between outbreak virus strains; and suggest candidates for vaccine selection. The results of the study illustrate the need for continued monitoring of field virus strains so as to ensure that the most appropriate vaccines are used.

To promote animal health and the spread of disease through international trade the Food and Agriculture Organisation and the Office International des Épizooties have designated reference laboratories for important infectious diseases including FMD. Dr Alex Donaldson from the World Reference Laboratory, Pirbright gave a global overview of these reference laboratories and their role at national, regional and international levels for diagnosis (serotyping), virus isolation and other technologies, epidemiological data analysis, provision of vaccine advice for prophylaxis and emergency control, training and other activities related to FMD control. The Institute of Animal Health at Pirbright, United Kingdom has been designated by the OIE/FAO as the World Reference Laboratory for FMD and the FMD Center, Pak Chong is the Regional Laboratory for Southeast Asia.

Finally, Dr Ana Maria Espinoza from the National Institute of Health in Peru described a study of FMD virus infection-associated (VIA) antibodies in Peruvian cattle and camelids (llamas, alpacas, vicuñas). The study compared the use of the standard agar gel immunodiffusion test (AGID) with the more recently developed liquid phase enzyme-linked immunosorbent assay (ELISA) and concluded that the ELISA technique is more sensitive for detecting the presence of VIA antibodies and is therefore a better test to support prevention and control programs for FMD.

Development of Laboratory Diagnosis of Foot-and-Mouth Disease in Thailand

Ab Kongthon*

Abstract

Confirmation of a clinical diagnosis of foot-and-mouth disease (FMD) is initially attempted by demonstrating the presence of the viral antigen in samples of vesicular epithelium. The complement fixation test (CFT) has been employed since 1959. The method was subsequently modified resulting in a simple, sensitive and reliable assay. Testing by the enzyme-linked immunosorbent assay (ELISA) was started in 1986 as part of a collaborative project of the Thai and Australian Governments. With a proportion of samples, viral antigen cannot be demonstrated by either CFT and/or ELISA. In these circumstances virus isolation subsequent to virus typing must be performed. Attempts to isolate the virus were carried out in suckling mice and in cell culture, e.g. BHK-21 and foetal lamb lung (FLL) cell lines or primary bovine thyroid (BTy) cells. The requirement for national diagnostic laboratories in Southeast Asia must be appreciated due to the need for virus typing capability from field samples. Key factors for consideration in the establishment of a national laboratory are facilities, methodology, equipment, staff and budget.

Laboratory Diagnosis

Complement fixation test

LABORATORY diagnosis of foot-and-mouth disease (FMD) was established in Thailand in 1959 using the complement fixation test (CFT). Reagents were locally produced and testing carried out at the FMD Center, Pak Chong. The results of the testing for 1959 to 1990 are shown in Table 1.

Enzyme-linked immunosorbent assay

The antigen trapping typing enzyme-linked immunosorbent assay (ELISA) was introduced as part of the ACIAR-sponsored Thai–Australian FMD project. This test has been used at the Northern Veterinary Research and Diagnostic Center, Hang Chat, since 1986 and has recently replaced the CF test as the routine typing test at the FMD Center, Pak Chong. The test is carried out by the indirect double antibody sandwich method. The reagents originally used were derived from the World Reference Laboratory, Pirbright, England, and supplied via the CSIRO Australian Animal Health Laboratory, Geelong, Australia, but since 1987 have been produced at the FMD Center in Pak Chong. Antisera are prepared in rabbits (for capture) and in guinea-pigs (for detection) by inoculation with purified 146S antigen of selected Thai field isolates or with reference strains. The antibody concentrations to be used in typing by ELISA were determined by titration against homologous strains. These reagents have been found to be as sensitive as the original reagents from WRL.

Virus isolation

Diagnosis of FMD can be achieved by direct detection of the virus in field samples by immunological methods (CFT and ELISA). However, with some samples it is not possible to detect virus directly in this way, because of either the poor quality of the sample or the low sensitivity of the test. In these cases virus isolation is necessary before identification of the virus type can be carried out. FMD virus isolation has been carried out in suckling mice and more recently in cell culture.

* Department of Livestock Development, Phyathai Road, Bangkok 10400, Thailand.

Table 1. Results of complement fixation testing of field samples at the FMD Center, Pak Chong, 1959–90.

Years	Total no. of samples	Virus type			
		O	A	Asia 1	Untyped
1959–80	2769				
% of samples		56.9	7.2	13.7	22.2
annual prevalence (%)		11.6–84.2	0–30.2	0–51.8	6–39.4
1981–90	1772				
% of samples		44.1	16.2	18.8	21.4
annual prevalence (%)		10–84.5	0.9–57.1	2–53.9	7–31.8

The cell cultures which have been used for virus isolation are the baby hamster kidney (BHK)-21 cell line; a foetal lamb lung (FLL) cell line derived by Japanese collaborators; and primary cultures of bovine thyroid cells (BTy). Although the most reliable method for virus isolation is inoculation into primary bovine thyroid cell cultures, primary cell cultures are complicated to prepare and maintain for routine virus isolation. The cell lines, which are comparatively simple to prepare and maintain, might therefore have an advantage over the primary cells provided that a similar sensitivity is obtained.

Various experiments have been carried out to compare the sensitivity of the different procedures used at the FMD Center. Isolation of FMD virus in BHK-21 cells was compared with the detection of antigen by the CFT. The results are summarised in Table 2. Attempts to isolate virus from samples which were not identified by the CF test were also made in suckling mice. Comparison of the results of isolation in BHK-21 cells and suckling mice are shown in Table 3.

Table 2. Comparison of isolation of FMD virus in BHK-21 cells, and the complement fixation test.

	Virus isolation	
	Positive	Negative
CF TEST		
Positive	96 (41.2%)	31 (13.3%)
Negative	50 (21.5%)	56 (24.0%)
Total	146 (62.7%)	87 (37.3%)

Table 3. Isolation of FMD virus from complement fixation negative samples in BHK-21 cells and suckling mice.

	Mouse inoculation		
	Positive	Negative	Total
BHK-21 cells			
Positive	12 (19.0%)	23 (36.5%)	35 (55.6%)
Negative	2 (3.2%)	26 (41.3%)	28 (44.4%)
Total	14 (22.2%)	49 (77.8%)	63 (100%)

In another study comparative titrations of 21 field FMD virus samples in the three different cell culture systems (BHK-21 and FLL cell lines; primary BTy cells) were made and the results of are shown in Table 4. The FLL and BTy cells did not detect virus from 2 (9.5%) and 4 (19%) samples respectively and BHK-21 cells failed to detect virus from 11 (64.7%) out of 17 samples examined. The FLL and BTy cells detected virus in the field samples readily even at the first passage whereas BHK-21 cells did not always detect virus at the first passage, and so a number of passages of the sample were required. The average $\log_{10}$ virus titre in six samples positive in BHK-21, FLL and BTy cells were 2.9, 2.9 and 4.5 respectively, while 16 samples positive to FLL and BTy cells gave average $\log_{10}$ virus titres of 2.4 and 4.1 respectively.

BHK-21 and FLL cells were further compared to determine at what passage level they initiated cytopathic effect (CPE) upon inoculation with field samples. In this study a total of 175 field samples

Table 4. Titrations of field FMD virus in BHK-21 or foetal lamb lung (FLL) cell lines and primary bovine thyroid (BTy) cell cultures.

Type	Sample	Virus titre (TCID 50/mL)		
		BHK-21	FLL	BTy
O	36/89	1.6	1.1	1.8
	38/89	UD	1.6	3.8
	49/89	3.8	3.8	5.6
	56/89	UD	1.8	UD
	68/89	UD	1.1	4.1
	71/89	4.3	4.3	6.8
	72/89	ND	3.3	6.6
	85/89	UD	1.6	3.3
	177/89	ND	3.6	5.8
A	161/87	UD	1.1	UD
	28/88	ND	1.1	3.1
	37/88	UD	UD	UD
	63/88	2.3	2.6	4.6
	5/89	1.8	3.1	2.6
	48/89	UD	UD	1.3
Asia 1	40/88	UD	1.3	3.1
	52/88	UD	1.1	1.8
	61/88	UD	1.8	UD
	431/88	UD	2.1	2.3
	432/88	3.3	3.3	5.3
	433/88	ND	3.8	5.3
Total		17	21	21
No. of UD		11	2	4

UD Undetected
ND Not tested

were submitted for FMD diagnosis and identified by CFT as types O, A and Asia 1 for 103, 38 and 24 samples, respectively. Nine samples were not type identified. All samples were simultaneously inoculated in BHK-21 and FLL cells as mentioned earlier. The passage level from which the CPE occurred was recorded and the infectious fluid was collected and the virus confirmed by CFT. The FLL cells detected virus in 170 (97.1%) out of 175 samples examined. Furthermore, 162 (92%) samples were detected in the first passage and the remaining 8 samples (4.5%) gave positive results in the second passage. The FLL cells did not detect one sample from a CFT-positive specimen, while it detected five out of nine CFT-negative samples. BHK-21 cells detected virus in 156 (89.1%) of the samples but more passages of the samples were needed compared to the FLL cells. The numbers of virus-detected samples in the first to fifth passages were 116 (66.8%), 36(14.9%), 9 (5.1%). 4 (2.3%) and 1 (0.6%), respectively. Among the 19 samples non-detected by BHK cells, 14 samples were from CFT-positive and five from CFT-negative specimens. However, four samples detected by BHK 21 cells were from CFT-negative samples.

In conclusion, the modified CFT and isolation of FMD virus in BHK-21 cells have a similar sensitivity for detecting FMD virus in diagnostic samples. BHK-21 cells are not as sensitive as FLL or BTy cells, which have a similar sensitivity. While isolation of FMD virus in primary BTy cells is regarded as the most sensitive procedure for detecting infectious FMD virus, it would seem, in our hands, that FLL cells are a suitable substitute.

Comparison of ELISA, CF Test and Virus Isolation for FMD Diagnosis

Laboratory confirmation of FMD can be achieved by CFT, ELISA, or virus isolation with subsequent typing of the virus. It has been suggested that CFT is not the method of choice because of its insensitivity and problems with anti-complementary effects. However, the sensitivity of the CFT routinely used at Pak Chong has been increased by modification of the test. The ELISA is generally regarded as more sensitive than the CFT and not influenced by anti-complementary factors in samples and so is recommended for routine FMD diagnosis by international bodies. However, in spite of its sensitivity, in this study the ELISA still failed to detect virus in some virus positive samples and so in some instances virus isolation was still required. In this work the sensitivity of the modified CFT and the ELISA (based on locally produced reagents), and the isolation of virus in FLL cells were compared in order to develop a strategy for typing diagnostic specimens.

A total of 437 field samples submitted to the laboratory from September 1988 to July 1990 for FMD diagnosis was used in the study. A summary of the results is shown in Tables 5–7. The data in Table 5 indicates that the performance of the two tests against FLL cell isolation was very similar. Table 6 indicates that the modified CFT and ELISA perform similarly when compared to each other. There also does not appear to be any particular bias in the performance of the tests in relation to the virus isolation results in FLL cells (Table 7). Running both the CFT and ELISA in conjunction can increase the percent serotyping to 68.4% overall. Isolation of virus in FLL cells increased the percent serotyping from 64% for CFT and 63% for ELISA, to 73% overall. Whether a laboratory can justify the cost of maintaining a tissue culture facility for this improvement in the number of viruses serotyped from clinical specimens will depend very much on the number of outbreaks occurring in the field and the importance attached to laboratory confirmation and serotyping of an outbreak. Experience in Thailand has shown that the probability of obtaining a positive result (on an outbreak basis) using an immunological serotyping test is greatly enhanced by increasing the number of samples submitted from the outbreak.

Table 5. Examination of tissue samples for FMD virus by CFT, ELISA and virus isolation in FLL cells.

	Virus isolation	
	Positive	Negative
CF TEST		
Positive	284	45
Negative	35	73
ELISA		
Positive	281	43
Negative	38	75

Table 6. Comparison of FMD virus detection by a modified CFT or ELISA.

	CF test		
	Positive	Negative	Total
ELISA			
Positive	303	21	324
Negative	26	87	113
Total	329	108	437

Table 7. Performance of a modified CFT and ELISA compared to virus isolation.

Test results		Virus isolation	
		Positive	Negative
CF Test	ELISA		
Positive	Positive	266	37
Positive	Negative	18	8
Negative	Positive	15	6
Negative	Negative	20	67

Establishment of a National Diagnostic Laboratory

To establish a national diagnostic laboratory key factors which have to be considered are:

- *facilities* — purpose-built laboratory, quality water supply, air conditioning, security;
- *equipment* — e.g. ELISA plate reading equipment with computer linkages, incubators, freezers;
- *staff* — trained staff with required expertise are needed and may require special training. Prospects for staff need to be good to attract suitably qualified personnel;
- *budget* — needs to be secured for facilities, equipment and staff costs.

National laboratories can obtain reagent supplies and receive training at either a regional veterinary laboratory or World Reference Laboratory. The testing procedures of national laboratories should be checked by a reference laboratory from time to time.

A Review of Strain Differentiation Studies in Thailand: Implications for Vaccination Programs

L.J. Gleeson,* W.J. Doughty,* R.A Lunt,* W. Linchongsubongkoch† and S.D. Blacksell*

Abstract

Antigenic variation among FMD viruses circulating in the field can reduce the protective capacity of vaccines. It is therefore important to monitor the relationship between field strains and vaccine strains in use. One-way serological relationships (*r* values), determined by the two-dimensional serum neutralisation test (SNT) or the liquid phase enzyme-linked immunosorbent assay (LP ELISA), are useful indicators of the protection likely to be afforded by vaccination with the reference virus. Strain differentiation studies were carried out as part of the Thai–Australian Foot-and-Mouth Disease Project to examine the relationship between a large sample of recently isolated field strains to existing vaccine strains. The results of the survey of type A isolates showed that two separate groups of type A viruses are present in Thailand. The majority of viruses were related to the historical A15 vaccine strain but there was a distinct geographical focus of viruses not A15-related but related to the A22 reference strain. These data suggested that future vaccines against type A virus in Thailand need to be evaluated against both the A15 and A22 groups of viruses. The type Asia 1 field viruses examined appeared to belong to a single group. They were not closely related to the historical vaccine strain but were related to a selected field strain. This or a similar virus appeared to be a good vaccine candidate. The type O viruses examined also appeared to belong to a single group and showed a close relationship to the vaccine strain by SNT but slightly less close by LP ELISA. The current vaccine strain appeared adequate in this case. The effect of reduced *r* values on a vaccination regime are illustrated. Results from the World Reference Laboratory for FMD, Pirbright, on viruses from different parts of Southeast Asia indicated some differences in relationships of field viruses to reference vaccine strains. As FMD control requires a regional strategy, further study of the relationships of viruses from different countries in the region by molecular techniques will provide a greater insight into the regional epidemiology of the disease.

THREE serotypes of foot-and-mouth disease (FMD) virus are endemic in Thailand, and until 1991 monovalent vaccines incorporating local strains of serotypes O, A and Asia 1 FMD viruses formed a key part of the program to control the disease. The historical strains characterised by the World Reference Laboratory (WRL), Pirbright, United Kingdom, in 1960 were O Bangkok 1960 (O/BKK/60), A Bangkok 1960 (A/BKK/60) and Asia 1 Bangkok 1960 (As1/BKK/60). The A/BKK/60 isolate was the WRL subtype A15 reference strain. The early control program also called for the establishment of a disease-free zone in the two most southern administrative regions (Regions 8 and 9, comprising 14 provinces). The monovalent vaccines, produced by the Department of Livestock Development (DLD), were used in both preventive campaigns and in controlling local outbreaks by ring vaccination. On occasion bivalent and trivalent vaccines have been imported from India or Europe to supplement local supplies. In 1991 the first trivalent vaccine produced at the new FMD vaccine production facility at Nongsarai, Pak Chong was released for field use.

In the past there have been reports of variable efficacy of type A (Kongthon et al. 1985) and type O (Ouldridge et al. 1982) vaccines in Thailand. It

* CSIRO Australian Animal Health Laboratory, PO Bag 24, Geelong 3220, Australia.
† Foot-and-Mouth Disease Center, Pak Chong, Nakhon Ratchasima 33130, Thailand.

is well recognised that antigenic variation that occurs among FMD viruses circulating in the field can affect the protective capacity of vaccines employed in control programs (Gebauer et al. 1988), and it is recommended that the relationship of field strains to vaccine strains in use is actively monitored (Kitching et al. 1988). The rationale for selection of appropriate vaccines has shifted from the approach of sub-typing of outbreak viruses to one of determining relationships to established vaccine strains (Kitching et al. 1989). Several techniques are available for determining antigenic relationships between viruses, and demonstrating differences in protein structure. More recently differences in gene sequence have been used to show relationships between viruses, and to establish epidemiological connections between outbreaks. One-way serological relationships (r values) determined by the two-dimensional serum neutralisation test (SNT) are accepted as useful indicators of the protection likely to be afforded by vaccination with the reference virus (Rweyemamu et al. 1978; Rweyemamu 1984). Similarly r values have been generated by the liquid-phase blocking enzyme-linked immunosorbent assay (LP ELISA) and provide an equivalent result to the SNT (Kitching et al. 1988; Samuel et al. 1988; Samuel et al. 1990). Reactivity of monoclonal antibodies to viral antigens in ELISA has also been used to demonstrate relationships between viruses (Samuel et al. 1991).

The principal goals of the strain differentiation studies carried out by the Thai–Australian FMD project were to examine the serological relationships between a large sample of recently isolated field strains and existing vaccine viruses by determining r values, and to examine the apparent variability among the r values of field viruses. The objectives were to identify potential problems arising from continued use of established vaccine strains; to determine any obvious epidemiological relationships between outbreak viruses; and to suggest candidates for vaccine selection. While formal epidemiological relationships between viruses were not established in this project, some conclusions about virus strain distribution were possible as a result of the findings.

Materials and Methods

Reference viruses and antisera

Reference virus standards were vaccine challenge strains maintained by the Foot-and-Mouth Disease Center, Pak Chong, Thailand. In addition a small number of field strains, referred to as field reference strains, were selected. The viruses are listed in Table 1. Antisera to reference viruses were obtained either from vaccine potency tests conducted in the course of vaccine quality control, or prepared by inoculation of rabbits with purified 146S antigens (Ferris and Donaldson 1984). Sera used in the LP ELISA as trapping or detecting antibody were prepared according to established procedures (Roeder and Le Blanc Smith, 1987).

Field viruses

Field viruses were isolated from diagnostic samples submitted to either the Northern Veterinary Research and Diagnostic Center (NVRDC), Hang Chat, Lampang or the Foot-and-Mouth Disease Center, Pak Chong mostly in the three-year period from 1986 to 1989. Ten Asia 1 field viruses were isolated from samples submitted to the NVRDC between January 1991 and January 1992. Viruses were isolated in any of primary bovine thyroid, primary or secondary bovine kidney, primary or

Table 1. Reference viruses and antisera used in FMD virus strain differentiation studies in Thailand.

Serotype	Source of reference virus	Source of homologous serum
Type A		
A BKK/60	vaccine challenge virus	bovine post challenge
A NPT/86	field reference virus	rabbit anti 146S antigen
A 179/86	field reference virus	rabbit anti 146S antigen
A SKL/73	vaccine seed virus	rabbit anti 146S antigen
Type Asia 1		
As1 BKK/60	vaccine challenge virus	bovine post vaccination/post challenge
As1 NPT/84	vaccine challenge virus	porcine post vaccination/post challenge
As1 36-2/88	field reference virus	rabbit anti 146S antigen
As1 45/88	field reference virus	rabbit anti 146S antigen
Type O		
O BKK/60	vaccine challenge virus	bovine post vaccination/post challenge
O NPT/65	vaccine challenge virus	porcine post vaccination/post challenge

secondary goat kidney, IBRS-2 or BHK-21 cells, typed by ELISA (Roeder and Le Blanc Smith 1987) or complement fixation test and then passaged in BHK-21 cells for adaptation to the SNT, or until sufficient antigen was available to apply to other tests. During the study 50 type Asia 1, 82 type A and 76 type O viruses from cattle, buffaloes and pigs were variously examined.

Experimental approach

The two-dimensional SNT was performed as previously described and *r* values determined (Rweyemamu et al. 1978; Blacksell et al. 1992). An *r* value of close to one (1.0) indicates that the field virus isolate has a close antigenic relationship with the reference virus. An *r* value significantly different from one indicated that the test system has determined an antigenic difference between the test and reference virus. The critical *r* value is the highest value of *r* which is distinguishable from one at a set probability for a given number of test replicates (Rweyemamu and Hingley 1984). All viruses were tested at least twice against the vaccine strain unless indicated. The *r* value is expressed as *r(V)*, where *V* is the virus against which the reference serum was prepared.

The LP ELISA was modified slightly from that originally described (Hamblin et al. 1986) to enable reference serum titres to be determined at several antigen input levels. In this way the test emulated the two-dimensional SNT, where the reference serum titre is determined at an interpolated 100 TCID50 virus input (Rweyemamu et al. 1978). By cross-titrating both test and control antigens and the reference serum, it was possible to interpolate LP ELISA endpoints to obtain the serum titre at equivalent test and control antigen inputs. The details of this test will be described in more detail elsewhere (Lunt et al. in press). Comparisons between viruses were expressed as an *r* value and the established criteria (Samuel et al. 1990) were used to interpret the significance of the relationship demonstrated to vaccination programs. The guidelines suggested for *r* values obtained by the LP ELISA were:

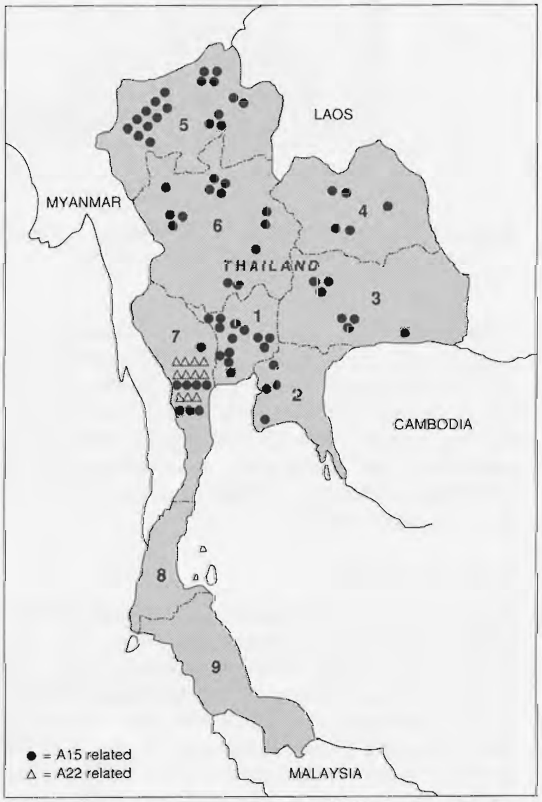
- *r* = 0–0.19 highly significant serological variation from the reference strain;
- *r* = 0.20–0.39 significant difference from the reference strain, but protection may be satisfactory if using a sufficiently potent vaccine;
- *r* = 0.40–1.0 not significantly different from the reference strain.

A unique ELISA system was devised to produce a reactivity profile of type A viruses and to determine the degree of relationship of the test virus to a panel of reference vaccine and field strains (Lunt et al. in preparation).

Results

Type A viruses

The most comprehensive study was carried out on the type A field viruses. Viruses were collected from all seven administrative regions where FMD is endemic. The geographical distribution of the isolates is shown in Map 1. The isolates were from cattle (52), buffaloes (12) pigs (16) sheep (1) and one unknown. The distribution of the *r* (A/BKK/60) values obtained with the bovine serum is shown in the frequency histogram in Figure 1. For this study the critical *r* value was 0.26, and using this criterion, 70 (85%) of the viruses were not distinguishable from the A15 reference virus A/BKK/60, and so were termed A/BKK/60 related. The mean *r* value for this group of viruses was 0.68 and the mean *r* value of the 12 viruses distinguishable from A/BKK/60 was 0.16. Of the 70 A/BKK/60-related viruses, 9 were from Region 7 and originated from outbreaks in both cattle and pigs. The 12 viruses



Map 1. Distribution of selected FMD type A isolates May 1986–January 1989.

not related to A/BKK/60 were also differentiated from A15 reference virus by the A/BKK/60 rabbit antiserum, which produced r values in the range 0.01 to 0.02 for this group. However the r values produced by the rabbit serum to the A22 vaccine challenge strain A/NPT/86 ranged from 0.37 to 1.0 with a mean of 0.7. Eleven of these isolates were from Region 7 and one from a buffalo in Region 3 in 1987. Six of these 11 isolates from Region 7 were from outbreaks in cattle and five from outbreaks in pigs. These 12 viruses were referred to as A22-related viruses.

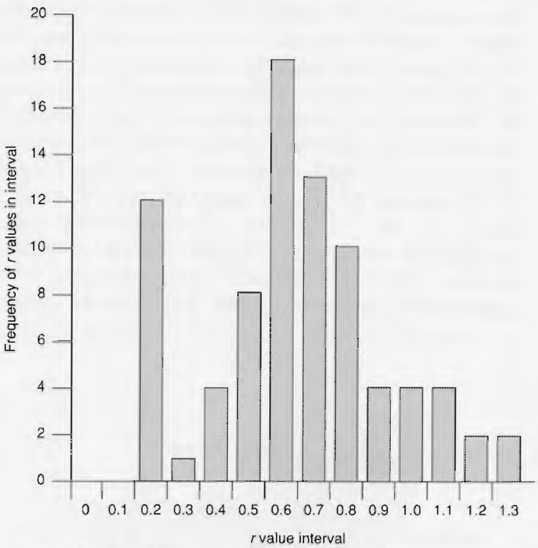
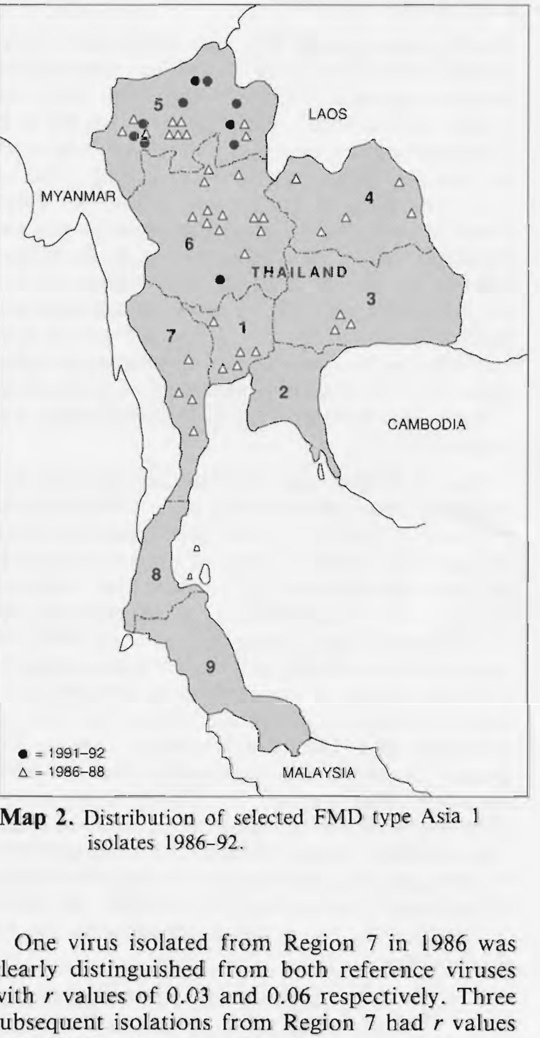


Figure 1. Thailand type A field isolates, 1986–89: distribution of r values to A BKK/60.

The 82 field viruses were independently categorised into the same A15-related and A22-related groups by the ELISA profile method, which further confirmed the above distinction of the two groups. The ELISA profile method also confirmed the serological relationship of the A22-related reference viruses to each other (Lunt et al. in preparation).

Type Asia 1 viruses

Forty Asia 1 field viruses isolated between 1986 and 1988 and a further 10 isolates from 1991 were examined by the two-dimensional SNT. The geographic distribution of the isolates in the first group is shown in Map 2. All 1991 isolates examined were obtained from submissions to the NVRDC, and were drawn from Regions 5 and 6. The critical r value for the comparison with As1/BKK/60 was 0.26 and the critical r value for the comparisons with the field reference viruses was 0.24. The frequency distributions of the r values obtained using the bovine serum to As1/BKK/60 (40 field viruses) and As1 38-2/86 (35 field viruses) from the first study are shown in Figure 2, and the histogram from a similar study of the 1991 viruses is shown in Figure 3.



Map 2. Distribution of selected FMD type Asia 1 isolates 1986–92.

One virus isolated from Region 7 in 1986 was clearly distinguished from both reference viruses with r values of 0.03 and 0.06 respectively. Three subsequent isolations from Region 7 had r values to 38-2/88 of > 0.5. The frequency histograms showed that the majority of r values to As1/BBK/60 in the low end of the range (mean r value 0.29, 50% < 0.26, whereas most viruses showed a close relationship to 38-2/88 (mean r value 0.83, with only the virus mentioned above < 0.24). The distribution of r values for the viruses isolated in 1991 was very similar to that described for the 1986–89 isolates.

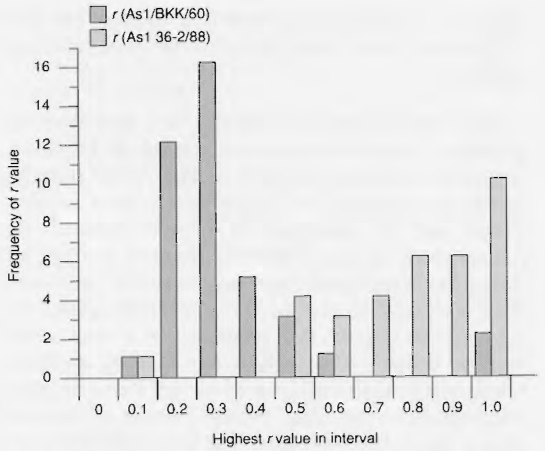


Figure 2. Thailand type Asia 1 isolates, 1986–88: *r* values to As1 BKK/60 and As1 36–2/88.

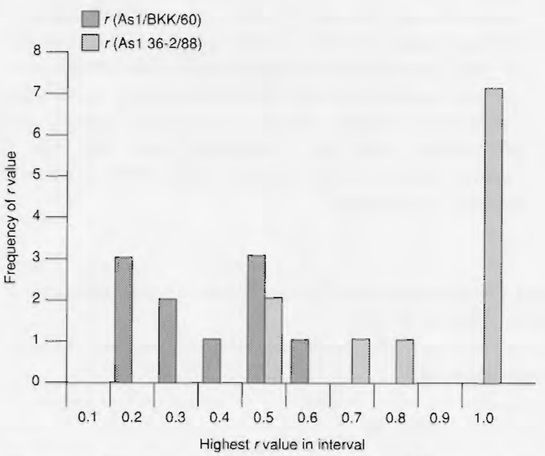


Figure 3. Thailand type Asia 1 isolates, 1991: *r* values to As1 BKK/60 and As1 36–2/88.

Type O viruses

The two-dimensional SNT was applied to viruses submitted to the NVRDC during two recent epidemics (1986–87 and 1989–90) caused by type O infections. An isolate was selected from each epidemic from five provinces in Region 5, and four provinces in Region 6. An additional isolate was obtained from two further provinces in Region 6 from the 1989–90 outbreaks. There was no discernible difference in the *r* values between outbreaks or between provinces. The mean *r* value for the 20 isolates was 0.71 and the range 0.66 to 0.80 (Blacksell et al. 1992).

Data obtained by the modified LP ELISA using the bovine serum against O/BKK/60 (56 viruses) and the porcine serum against O/NPT/65 (51 viruses) is summarised in the histogram shown in Figure 4 and the respective *r* value means are 0.45 and 0.51.

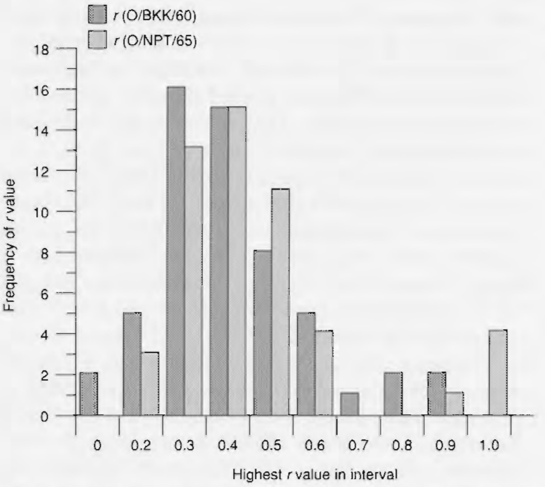


Figure 4. Thailand type O field isolates, 1986–89: *r* values to O BKK/60 and O NPT/65 determined by liquid-phase blocking ELISA.

Discussion

Type A viruses

The sample of field viruses gathered for the survey of *r* value relationships to the A15 vaccine strain was large and regarded as representative of the field situation. The majority of viruses from Regions 1 to 6 could not be distinguished from A/BKK/60 , whereas 11 of 12 viruses not related to A/BKK/60 originated from Region 7. Others regarded viruses from this area as A22 related (Kongthon et al. 1985; Lombard et al. 1987; Dubourget et al. 1991), and the results with the A/NPT/86 antiserum confirmed this view. The majority of the large piggeries in Thailand are in Region 7 or the lower part of Region 6. The A22-related vaccine strain A/NPT/84 had been established for vaccine production to control outbreaks in pigs in the mid-1980s. These A22-related viruses were isolated from both pigs and cattle from Region 7, and interestingly A15-related viruses were also isolated from both cattle and pigs in this area during the same period. The profile ELISA technique also clearly recognised the two distinct groups of viruses. Other *r* value data (Doughty et al. submitted for publication) also indicated that there was a relative antigenic uniformity among the A15-related field viruses.

The first recognised outbreak caused by an A22-related virus occurred in 1973 in southern Thailand. Outbreaks caused by A22-related viruses were not reported again until 1984, but it is not clear if A22 viruses remained endemic in the intervening period or there was a new introduction from outside Thailand. The latter seems likely as it is hard to reconcile the recent restriction in distribution, the fact that the 1973 outbreak occurred in cattle and buffaloes, and the long period between epidemics. It would also appear that there is an undefined epidemiological variable operating at present to maintain the relative localisation of the A22-related strains. It was noted that although an A22-related virus caused an outbreak in Region 3 in 1986, future isolates from the region were A15-related, so it would appear that the A22-related strain did not become established here. While there was a view that A22-related viruses had replaced A15-related viruses in Thailand, the source of samples was from the Region 7 area (Lombard et al. 1987; Ouldridge et al. 1982). More recent data obtained from the World Reference Laboratory (Table 2) supports the view that the A15 vaccine is still relevant in Thailand and also that some strains are closely related to A22. The virus TAI 5/89 originated from pigs in Region 7, whereas the virus TAI 7/89 originated from pigs in Region 5. There was no information available about the origin of the other two viruses, but TAI 2/89 is very clearly not related to the A22 reference virus.

It is clear from the findings that two separate groups of type A viruses are present in Thailand, and that the historical A15 vaccine while offering protection against the majority of field strains, would not be suitable to protect against the A22-related viruses. However there is insufficient information available from any source to determine if an A22-related vaccine would protect against the A15-related viruses. It is possible that a very potent vaccine based on a field strain sharing antigenic relationships with both groups would be efficacious. Discrepancies do exist between some serological results and protection tests. The Office International des Épizootics (OIE) has previously recommended that cross protection tests should be conducted on cattle when future outbreaks occur, in order to establish whether the vaccine in use is satisfactory. As previously noted (Lombard et al. 1987), the rate of viral mutation is greater when foot-and-mouth disease spreads among an incompletely vaccinated population than among a fully susceptible population, and so it is critical that the type A vaccine strain is able to prevent circulation of both groups of viruses.

Table 2. Vaccine strain relationships of recent type A/O/Asia 1 FMD isolates from Southeast Asia: *r* values determined at the World Reference Laboratory by liquid-phase blocking ELISA.

Virus type	Isolate	Reference antiserum				
A		A22 Iraq	BKK 60			
	TAI 2/89	< 0.1	0.75			
	TAI 4/89	0.5	1.0			
	TAI 5/89	1.0	—			
	TAI 7/89	0.33	—			
Asia 1		Ind 8/79	Shamir 3/89			
	MAY 11/92	0.1	1.0			
	MAY 15/92	0.3	0.5/1.0			
	MAY 16/92	0.35/1.0	1.0			
	MAY 17/92	0.5/1.0	1.0			
	MAY 18/92	0.5	1.0			
	VIT 1/93	0.8	0.3			
	VIT 2/93	1.0	0.4			
	VIT 3/93	1.0	0.5			
O		BFS	Manisa	Ind 53/79	BKK 60	Campos
	CAM 13/92	0.5	> 1	> 1		
	TAI 1/92	0.25	0.5/0.35	1	0.25	
	MAY 1/92	0.25/0.5	> 1			
	MAY 4/92	0.2	0.5		0.1	0.25/0.5
	MAY 5/92	0.25	0.5/1.0			0.5/1.0

Source: World Reference Laboratory, Pirbright, UK

Type Asia 1

Type Asia 1 viruses belong to one antigenic grouping, although there was one extreme *r* value outlier. This virus had not established and triggered a new epidemic, although clearly if this had happened a new vaccine would have been required to control the outbreak. It would appear from the *r* value data that a contemporary strain such as 36-2/88 was an ideal vaccine candidate. However the approach taken here illustrated the value of examining more than one field virus, because the distribution of *r* values to another field virus 45/88 fell between the BKK/60 distribution and the 36-2/88 distribution (Doughty et al. submitted for publication).

The *r* values determined at the WRL of some contemporary Asia 1 viruses indicate the potential for viruses in one part of the region to be a threat for other countries in the region. The Asia 1 virus MAY 11/92 was submitted from an outbreak in Northern Malaysia in 1992 and this virus undoubtedly originated from Thailand. The virus MAY 18/92 shows a different *r* value profile, suggesting some mutation of the virus has taken place in the field, or a new virus has been seeded into the population. Viruses submitted from Vietnam in 1993 appear to belong to a different antigenic grouping, as the *r* value profile to the two reference vaccine viruses is essentially the reverse of the MAY viruses. It is not possible to determine if the viruses emerging from Vietnam pose a threat to Thailand or vice versa, but this matter seems deserving of investigation on a regional basis, especially in relation to vaccine selection.

Type O viruses

In this study it was apparent the O serotype had shown the least antigenic change with respect to the historic vaccine strain O BKK/60. The relative stability of the neutralising epitopes of the field virus was surprising because the predominant vaccine used was a monovalent type O vaccine. Data from the LP ELISA showed a similar antigenic stability and lack of variability in the group, although the mean *r* value was lower than that found using the SNT. It has been suggested that an *r* value (LP ELISA) of less than 0.2 indicates a requirement for selection of a new vaccine strain, but that *r* values between 0.2 and 0.4 indicate antigenic differences which may affect vaccine efficacy (Samuel et al. 1990). However the findings of the project were a little at odds with more recent data from WRL. The *r* value to O/BKK/60 of virus TAI 1/92 indicated that this vaccine strain was not likely to be highly efficacious. Similar *r* value relationships applied to the MAY isolates, that undoubtedly originated from Thailand. Previous studies had shown that type O viruses from Southeast Asia were antigenically stable and an isolate from Laos was closely related to a Thai isolate (Lombard et al. 1987). Type O viruses have been the most prevalent cause of FMD outbreaks in Thailand since a typing capability was established (see A. Kongthon, these proceedings). Perhaps this indicates a particular adaptation of this serotype to the southeast Asian environment, and therefore reinforces the requirement for stringent monitoring of the circulating strains to ensure early detection of significant antigenic variants.

Significance of strain variation to vaccination programs

The significance of the *r* value of the challenge virus to a vaccination program was elegantly illustrated by Pay (1983). Figure 5 shows the impact on the estimated percentage protection when the *r* value is 0.4 compared to 1.0. Where a six-monthly vaccination program is pursued, there would be a two-month period twice yearly when the percentage of animals protected drops below the level required (70%) to prevent an outbreak from progressing. In a situation where vaccination coverage is not 100% this window would be even larger. It would appear from the graph that the As1/BKK/60 vaccine strain must be replaced with a new strain more closely related to the current field viruses, and Asia 1 isolates must be monitored to ensure that unrelated viruses from the region do not begin to circulate. It would also appear that the type O viruses have remained relatively antigenically stable, and that if a new strain is not readily adaptable to vaccine production, a potent O/BKK/60 vaccine may continue to be efficacious. The position with type A is the least straight forward because of the two serologically distinct groups of viruses present in the country. Further work is required to determine whether an A22-related vaccine strain will protect against the A15-related field viruses. It would also seem important to monitor the spread of the A22-related viruses, as further spread has potential to complicate the control program.

Control of foot-and-mouth disease is regarded as a regional problem, and this has been one motivation to conduct this workshop on FMD in Southeast Asia. While the efficacy of vaccines is a key issue for disease control authorities, the tools of genetic fingerprinting must be applied alongside more traditional procedures such as neutralisation tests and animal challenge in order to understand the regional dynamics of foot-and-mouth disease, and so increase the efficiency of control measures.

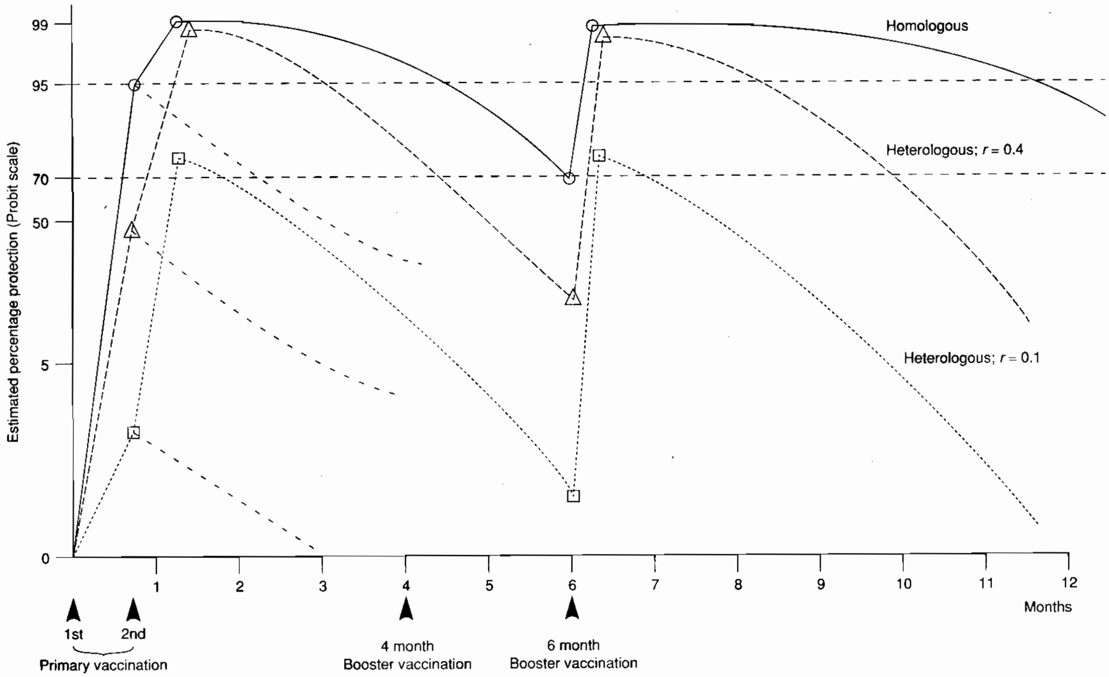


Figure 5. Estimated percentage protection values against homologous and heterologous viruses using regression estimates (Pay 1983).

These studies illustrated the need to examine a significant number of viruses from within Thailand to develop a clear picture of the antigenic variation of field viruses, and that similarly sized samples are required to obtain a representative view of the regional situation.

Acknowledgment

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Role of Reference Laboratories in Foot-and-Mouth Disease Control Programs

A.I. Donaldson*

Abstract

As part of their mission to promote animal health and prevent the spread of disease through international trade in animals and animal products, the Food and Agriculture Organisation of the United Nations (FAO) and the Office International des Épizooties (OIE) have designated reference laboratories for important infectious diseases of animals. Selection of these reference laboratories is based upon the ability of a particular centre to meet certain criteria and designation is made by the OIE and FAO International Committees. Reference laboratories have been designated in specific regions which act as the reference laboratory for the countries in that region. Regional laboratories collect and compile epidemiological data from the region with the collaboration of national veterinary services. The Foot-and-Mouth Disease Center, Pak Chong, Thailand, is the OIE/FAO Regional Laboratory for Southeast Asia. A World Reference Laboratory (at the Institute of Animal Health, Pirbright, England) has also been designated by the OIE/FAO and functions as the central reference laboratory for all FMD virus serotypes and subtypes, and diagnostic methodologies.

THE Food and Agriculture Organisation of the United Nations (FAO) and the Office International des Épizooties (OIE) have designated reference laboratories (or centres) for certain important infectious diseases of animals, as part of their mission to promote animal health and prevent the spread of disease through international trade in animals and animal products. These laboratories are expected to fulfil a range of functions at an internationally recognised standard related to the diagnosis and immunoprophylaxis of infectious diseases of animals, specifically those of greatest economic importance.

Selection and Designation of Reference Laboratories

In the case of OIE the basis for selection is as follows:

- the OIE reference laboratory must be capable of working at the international level in its designated activity;
- the facilities and staff must be capable of delivering the high quality service and international leadership in the designated activities; and
- its prospective stability in terms of personnel and funds must be assured from its own reserves.

Designation is made by the OIE International Committee based on the advice given by the OIE Standards Commission, following its appraisal of the laboratory and in consultation with appropriate experts.

Finally, the agreement of the head of the establishment where the reference laboratory is to be located is obtained after consultation with the national government. After official designation an institution is known by the official title of *OIE Reference Laboratory* which may be followed by a description of the functions to be discharged by the laboratory e.g. *'for Foot-and-Mouth Disease'*. Designation is made for a period of five years after which time the OIE Standards Commission reviews the possibility of renewing the designation. Either party has the right to withdraw from the designation at any time. Acceptance of designation implies an agreement to provide a brief report to OIE at the end of each year.

* Agriculture and Food Research Council, Institute for Animal Health, Pirbright Laboratory, Ash Road, Pirbright, Woking, Surrey GU24 0NF, U.K.

Functions of OIE Reference Laboratories for FMD

The functions and activities of regional laboratories and the World Reference Laboratory for FMD were drafted by the FMD and other Epizootics Commission in 1989 and adopted by the International Committee at the General Session of OIE in May 1989.

World Reference Laboratory

1. The World Reference Laboratory (WRL) will function as the central reference laboratory for all FMD virus serotypes and subtypes, and diagnostic methodologies.
2. The WRL must operate under high security conditions as recommended in the FAO guidelines on minimum standards.[1] The high security systems should be regularly inspected by the relevant authorities (national and regional).
3. The WRL should function as a depository for all FMD virus isolates received.
4. The WRL should promote the activities of the regional laboratories (RLs) by:
   a. arranging training courses;
   b. organising collaborative studies (comparative trials on FMD diagnosis and serology);
   c. preparing, storing and supplying samples of standardised reagents to the RLs in order that diagnostic tests performed in the different laboratories can be related to one another.
5. When requested by the RLs or veterinary services of a country, the WRL may assist in investigations. Results should be forwarded directly to the RL concerned, and also to the sender of the material (if not the RL).
6. Results should be compiled and regularly presented to the OIE and FAO.
7. The WRL should perform tests in order to provide advice about vaccines for prophylaxis and emergency control. The definitive test is the cattle challenge test. Advice can be given, based on results from indirect tests provided a correlation has been established between the indirect test and the cattle challenge test.
8. All requests for the supply of FMD virus from other laboratories should be made through official channels; viz the central veterinary service of the country must make an official approach in writing to the proposed supplier of the virus on behalf of the requesting laboratory.
9. The supply of FMD virus which is exotic to the country of the requesting laboratory should be according to OIE and FAO procedures.

[1] Set out in a revised and updated paper entitled *Security Standards for FMD Laboratories* which has been adopted by the OIE/FAO/CEC (1993).

Regional laboratories

1. The regional laboratory (RL) should act as the reference laboratory for the countries in the region. The RL should collect and compile epidemiological data from the region with the collaboration of the national veterinary services.
2. All RLs must operate under high security conditions as recommended in the FAO Guidelines on Minimum Standards (OIE/FAO/CEC 1993). The high security systems should be regularly inspected by the relevant authorities (national and regional).
3. Samples for FMD diagnosis should be received from the national veterinary services in the region.
4. If a country wishes the WRL to perform the diagnosis then samples should be sent simultaneously to both the RL and WRL.
5. If a virus isolate is suspected to be of a serotype previously exotic to the region samples should be sent to the WRL for confirmation and storage.
6. The RL should be equipped and skilled to rapidly provide an initial diagnosis (serotyping).
7. The RL should be equipped and skilled for the determination of serological responses of animals in terms of the serotypes of FMD virus in the region.
8. The RL should possess a sensitive and specific test. The serum neutralisation test (SNT — also referred to as the virus neutralisation test, VNT), the complement fixation test (CFT) and the enzyme-linked immunosorbent assay (ELISA) are all considered appropriate tests. For this purpose the RL should maintain a stock of regional serotypes of FMD virus and inactivated antigens of exotic types and the appropriate immune sera.
9. The RL should be equipped to propagate any FMD virus isolates in animal hosts and cell culture systems.
10. In the case of an uncertain diagnosis the RL should send a sample of the virus from the primary case to the WRL for confirmation and further characterisation. Ideally an aliquot of field material should be sent but if this is not possible then animal passage material, obtained from the original host species, or low cell culture passaged material is acceptable. The history of animal or cell culture passaged material should be provided.
11. Further virus characterisation should be carried out by the most up-to-date techniques, but only as a second priority.
12. The RL should participate in collaborative studies with the WRL and other regional laboratories.

13. The RL should regularly provide training courses in FMD diagnosis, epidemiology and disease control. The RL should organise collaborative studies with the national laboratories in order to standardise tests.
14. Upon request the RL should assist national laboratories by supplying reagents as required.
15. The RL should perform tests in order to provide advice about vaccines for prophylaxis and emergency control. The definitive test is the cattle challenge test. Advice can be given, based on results from indirect tests provided a correlation has been established between the indirect test and the cattle challenge test.
16. Results and epidemiological data should be compiled and presented regularly to the OIE, FAO and the WRL.
17. All requests for the supply of FMD virus from any other laboratories including the WRL should be made through official channels; viz the central veterinary authority of a country must make an official approach in writing to the proposed supplier of the virus on behalf of the requesting laboratory.
18. The supply of FMD virus which is exotic to the country of the requesting laboratory should be according to OIE and FAO procedures.

Food and Agriculture Organisation

FAO operates along very similar lines in designating its world and regional reference centres. Currently the Agriculture and Food Research Council Institute for Animal Health (IAH), Pirbright, Surrey, UK is the OIE/FAO World Reference Laboratory for FMD. The FMD Center, Pak Chong, Thailand is the OIE/FAO Regional Laboratory for FMD for Southeast Asia and the Pacific; the Botswana Vaccine Institute, Gaberone, Botswana is the OIE/FAO Regional Laboratory for FMD for southern Africa; and the Pan American FMD Center, Rio de Janeiro is the Pan American Health Organisation Laboratory for South America.

European Community Reference Laboratory

In April 1990 IAH, Pirbright was designated as a reference laboratory for the European Community (E.C.) by the Commission of the E.C. (CEC). The E.C. is composed of 12 member states — Belgium, Denmark, France, Germany, Greece, Holland, Ireland, Italy, Luxembourg, Portugal, Spain and the United Kingdom.

In agreeing to accept the designation, IAH accepted the following duties:

1. to ensure liaison between laboratories of the member states with regard to the standards and methods of diagnosis of FMD, and differential diagnosis, where necessary, in each member state by:
   a. receiving samples from member states and certain non-E.C. countries with a view to determining their identity;
   b. typing and full strain characterisation of foot-and-mouth disease virus from the samples referred to in point (a) and communicating the results of such investigations without delay to the Commission and the member state concerned;
   c. building up and maintaining an up-to-date collection of foot-and-mouth disease virus strains;
   d. building up and maintaining a collection of specific sera against foot-and-mouth disease virus strains.
2. to support the functions of national laboratories, and in particular by:
   a. storing and supplying to the national laboratories, cell lines for use in diagnosis together with virus and/or inactivated antigens standardised sera and other reference agents;
   b. organising and operating periodic comparative trials on foot-and-mouth disease diagnosis at Community level and the periodic transmission of the results of such trials to the Commission and member states;
3. to provide information and carry out further training, in particular by:
   a. gathering data and information on the disease situation and the methods of diagnosis used and differential diagnosis used and the distribution of such information to the Commission and the member states;
   b. making and implementing the necessary arrangements for further training of experts in laboratory diagnosis with a view to harmonising diagnostic techniques;
   c. organising an annual meeting where representatives of the national laboratories may review diagnostic techniques and the progress of coordination.

It was also accepted that the laboratory would operate according to recognised conditions of strict disease security as set out in the paper *Security Standards for FMD Laboratories* (OIE/FAO/CEC 1993). The laboratory also agreed to formulate and recommend disease security measures to be taken by the national laboratories in matters of FMD diagnosis in accordance with the standards adopted by the CEC.

The duties of the Community Reference Laboratory (CRL) are very similar, therefore, to those set out by the OIE for its RLs. There are, however, two important differences. Firstly, IAH, Pirbright has entered into a contractual agreement with the E.C. and, secondly, the E.C. pays for the services it requires. OIE and FAO, on the other hand, provide financial support for their RLs only on an *ad hoc* basis and except for those they do not enter into contractual agreements with their RLs.

FMD Control Programs

It is evident from the foregoing descriptions of the functions and duties of RLs that they have an important part to play in FMD control programs. In summary, in emergency situations they should provide a rapid and efficient diagnostic service. When vaccination is part of the disease control measures the RL should quickly analyse the field strain and provide advice on the most appropriate vaccine for use. Results should be speedily communicated to the headquarters of the relevant veterinary authority and to OIE and FAO. A sample of the original epithelial sample, or, if not available, a sample of low passage tissue culture harvest should be sent to the WRL for inclusion in its reference collection and, if required, detailed molecular characterisation and antigenic analysis. Personnel at the RL should be capable of providing expert advice on emergency disease control procedures.

During 'peacetime' RLs should assist national veterinary authorities in the region by advising on the most appropriate vaccines for prophylactic use and storage in vaccine banks. They should assist national veterinary authorities with the training of field personnel in the clinical diagnosis and epidemiology of FMD and other vesicular diseases. They should help in disease surveillance, in the collection of epidemiological and disease data and regularly submit results to OIE, FAO and the WRL. Field personnel should also be instructed in the procedures for sample collection and transport. These activities should complement and support those of national FMD laboratories — the overall role of the RL being one of coordination and leadership in standardisation of techniques and harmonisation of disease control policy throughout the region.

Identification of VIA Antigen Antibodies to Foot-and-Mouth Disease Virus in Peruvian Livestock

A. M. Espinoza* and E. Ameghino†

Abstract

Foot-and-mouth disease (FMD) is an economically significant disease of farm animals in Peru and its neighbouring countries with the exception of Chile. One of the principal livestock animals in Peru is the South American camelid. and the movement of this animal throughout Peruvian territory as well as import/export regulations are being studied as part of a national program for the control of FMD in Peru. Serum samples from bovine and camelid livestock from different regions of the country have been studied. The liquid phase enzyme-linked immunosorbent assay (ELISA) was compared with the standard agar gel immunodiffusion test (AGID) to identify and quantify antibodies against FMD virus infection-associated (VIA) antigen. A total of 562 cattle and 767 South American camelid sera were tested. Of these sera, 30 were from cattle from FMD-free countries; 220 from cattle and 385 from camelids collected in areas without any reported disease for the last 10 years. The other sera were from animals exposed to field outbreaks or under a systematic vaccination program. The results indicate that the ELISA is more efficient in detecting the presence of VIA antibodies and is therefore a more satisfactory test to support the prevention and control program for FMD.

FOOT-and-mouth disease (FMD) is one of the most important diseases of farm animals in Peru and the National Program for the Control of FMD is based on epidemiological characterisation of the disease in different regions of the country. Virus infection-associated (VIA) antigen of FMD virus was identified by Cowan and Graves (1966). The antigen is common for all seven serotypes of FMD, which is of considerable advantage for the use of serological assays in epidemiological surveys. Polatnick et al. (1967) established that VIA antigen is the viral RNA polymerase. McVicar and Sutmoller (1970) utilised the agar gel immunodiffusion test (AGID) to demonstrate that the presence of VIA antibodies indicative of previous FMD infection. The Pan American Foot-and-Mouth Disease Center (PAFMDC) reported the usefulness of detection of VIA antigen antibodies in animals from areas free of FMD and without a history of vaccination (PAFMDC 1980). Similarly, Pinto and Garland (1979) and Ahl and Wittman (1986) showed that cattle vaccinated with formalin or acetylethyleneimine-inactivated vaccines would occasionally react positively to the VIA antibody test. Due to the low sensitivity of the AGID tests efforts have been made to establish better assays. Villinger et al. (1989) developed an indirect enzyme-linked immunosorbent assay (ELISA) for the identification of VIA antibodies in animal sera, using bioengineered VIA antigens, but the test suffered from low specificity. More recently Alonso et al. (1990) described a liquid-phase competition indirect sandwich ELISA test of high specificity and sensitivity. In the same way Atkas et al. (1992) reported the use of a biotinylated VIA as an antigen in a single dilution liquid-phase blocking ELISA.

Since the recognition that the South American camelids (llama, alpaca, vicuña) are susceptible to FMD (Mancini 1952; Moro and Guerrero 1971; Konigshofer 1971; Lubroth et al. 1990), different studies have been carried out in order to establish their epidemiological significance in the appearance or spread of the disease.

This paper presents the results obtained with the standard AGID test and a liquid-phase competition

* National Institute of Health, Centro de Produccion de Insumos, Capac Yupanqui 1400, Lima 11, Peru.
† Faculty of Veterinary Medicine, San Marcos University, Lima, Peru.

indirect sandwich ELISA, for the detection of VIA antigen antibodies in sera from cattle and South American camelids from different epidemiological regions in Peru.

Material and Methods

Test samples

A total of 562 cattle and 767 camelids sera were examined to detect the presence of VIA antigen antibodies as follows:

- 562 cattle sera from FMD-free areas (southern Peru, Guyana, Costa Rica, United States), areas under a vaccination program (Arequipa), or naturally infected (Lima) animals;
- 385 South American camelids (alpacas) from improved single species herds of large cooperatives without reports of the disease in the last ten years (Corpacancha, Junin); and
- 382 camelids (323 alpacas, 39 llamas and 20 vicuñas) from small mixed species herds of traditional rural communities with reports of FMD in the last two years (Puno).

VIA antigen

FMD virus, strain A24 Cruzeiro–Br/55, was grown in roller culture bottles of the line cell BHK-21, and then the VIA antigen was prepared according to Alonso et al. (1990).

Antisera

Capture bovine IgG prepared from an experimental exposure to FMD virus C3 Resende–Br/55 was obtained from PAFMDC.

Detector antisera collected from guinea-pigs inoculated and hyperimmunised with infectious FMD virus O1 Campos–BR/58 was also obtained from PAFMDC.

AGID test

The AGID test was performed in disposable plastic plates as described by McVicar and Sutmoller (1970). The VIA antigen was previously titrated and the positive control sera was obtained from naturally infected animals.

ELISA procedure

The procedure was the liquid-phase indirect sandwich ELISA test described by Alonso et al. (1990) with slight modifications. All the reagents were used after titration to determine optimal concentrations. Antigen, test sera, guinea-pig antiserum and conjugate were diluted in phosphate buffered saline (PBS) containing 5% skim milk powder from FMD-free countries, 0.05% Tween-20 (PBST), and 2% normal bovine serum. ELISA plates (Immunoplate Maxisorb, Nunc) were coated overnight at 4°C with 100 μL of the appropriate dilution of bovine IgG in carbonate buffer (pH 9.6). Plates were washed three times between each step with PBS.

In a separate transfer plate, the sera to be tested were diluted appropriately and were mixed with an equal volume (50 μL) of VIA antigen and incubated for 1 hour at 37°C. Of this liquid-phase, 50 μL was transferred onto the solid phase, and the plates placed on a rotary shaker for 1 hour at 37°C. The guinea-pig antiserum and the conjugate were added successively in 50 μL volumes and incubated for 30 minutes at 37°C on a plate shaker.

The o-phenylenediamine substrate was added in 50 μL volumes. The reaction was allowed to proceed for 15 minutes at room temperature (20–25°C) and stopped by acidification (1.25 M H_2SO_4). The optical densities (OD) were read with the photometer at 492 nm. End-point titres were expressed as the dilution of sera giving 50% inhibition of the OD relative to the control.

Results

Cattle sera

The following serum samples were examined by AGID and ELISA at dilutions between 1:2 and 1:256 and the results are shown in Table 1:

- 108 positive sera from cattle between 14 days and 6 months after natural infection with FMD virus serotype O1;
- 220 'negative' cattle sera from the south of Peru where no outbreaks of FMD have been reported in the last 20 years and there has been no vaccination program for the past eight years;
- 30 'negative' sera from FMD-free countries (Guyana, Costa Rica and United States); and
- 220 cattle sera from the Arequipa area which has a systematic vaccination program.

The results showed that maximal differentiation of positive from negative sera was obtained at a dilution > 1:2. From the infected sera (108), one sera was negative in the AGID test, and in the ELISA was positive only at the dilution 1:2 (Fig. 1). From the negative sera (FMD-free countries), all of them (30) were negative in the AGID test and in the ELISA. From the sera collected in the south of the country (220), we found one positive in the AGID test and four were positive at a 1:2 dilution in the ELISA procedure.

Table 1. Identification of VIA antibodies in cattle sera of different epidemiological regions of Peru by the ELISA and AGID methods, 1991.

Origin of cattle sera	ELISA[a] (dilution)			AGID[b]		No. of sera tested
	< 1:2	1:2	> 1:8	+	–	
Naturally infected	0	01	107	107	01	108
Free countries	30	00	00	00	30	30
Area without report of FMD	216	04	00	01	219	220
Under vaccination program	20	140	44	182	22	204
						562

[a] Number of positive VIA antibody results at the dilutions shown
[b] Number of positive (+) or negative (–) test results

Table 2. Identification of VIA antibodies in South American camelid sera from different epidemiological regions of Peru, by the ELISA and AGID methods, 1991.

Origin of South American camelid sera	ELISA[a] (dilution)			AGID[b]		No. of sera tested
	< 1:2	1:2	1:4	+	–	
Single camelid herds from areas without reports of FMD	385	00	00	00	385	385
Mixed species herds from areas with reports of FMD	325	57	00	00	382	382
						767

[a] Number of positive VIA antibody results at the dilutions shown
[b] Number of positive (+) or negative (–) test results

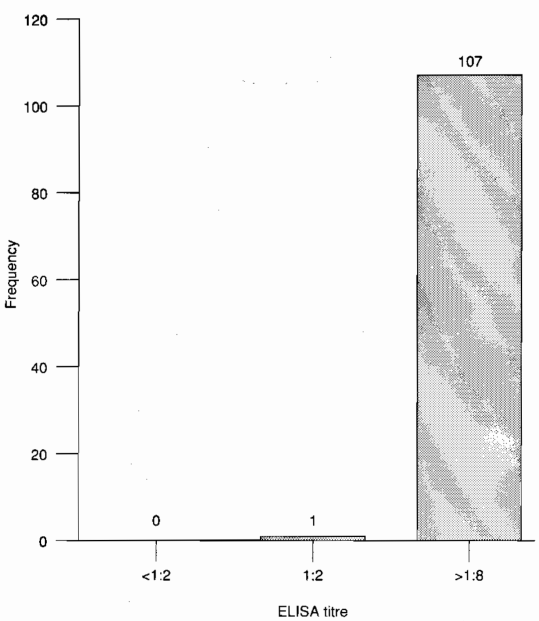

Figure 1. Identification of VIA antibodies by ELISA in sera of Peruvian cattle 14 days to 6 months after natural infection with FMD virus type O1.

From the vaccinated animals, 22 were negative and 182 were positive in the AGID test. Using the ELISA technique, however, 20 were negative, 140 had titres at the 1:2 dilution and 44 had titres higher than 1:8. The negative animals corresponded to young cattle without a history of vaccination. The other sera corresponded to revaccinated adult cattle.

Camelid sera

Three hundred and eighty five (385) sera from camelids (alpacas) from large cooperatives without any reports of FMD for the last ten years, were negative in both the AGID and ELISA procedures (Table 2). Three hundred and eighty two (382) sera from camelids from rural communities with mixed species herds and reported incidence of FMD in the last two years, were negative in the AGID test but using the ELISA method we found positive animals at a dilution 1:2 (Table 2). The positive sera corresponded to alpacas and vicuñas but not in llamas. Sera from cattle from these mixed herds were also positive in the ELISA.

Additionally, part of the sera from infected cattle were studied by the FMD-specific International Atomic Energy Agency/Food and Agriculture

Organisation ELISA kit, against serotypes O, A, C. All of the sera tested were strongly positive to type O. Also sera from camelids with VIA antibody titres up to 1:2 were tested to identify specific FMD antibodies but we did not get a positive result.

Discussion

Cattle sera

Infected animals. The results obtained in this group were as expected, with high specificity for AGID and ELISA, and higher sensitivity for the ELISA. The serum which gave a negative result in AGID and a very low titre in ELISA (see Table 1) corresponded to an animal tested after six months after infection, so it seems likely that the VIA antibodies had decreased, as reported by Lobo et al. (1976), Alonso et al. (1975) and PAFMDC (1980), who found that VIA antibody titres decrease with time after exposure.

These results agree with the cut-off reported by Alonso et al. (1990) at a dilution of 1:2 to differentiate between positive cattle sera from infected animals and negative sera from FMD-free countries.

Negative animals. All the cattle sera from FMD-free countries were negative in both the AGID and ELISA procedures. In the case of the sera from the area considered disease free in the south of the country, the detection of VIA antibodies in four (4) sera using ELISA and one using AGID, presumably corresponded to animals introduced in to this area from neighbouring regions, like Puno, where vaccination is practiced.

Vaccinated animals. The detection of VIA antibodies in vaccinated animals has been described by several workers (Pinto and Garland 1979; de Oliveira et al. 1982; Alonso et al. 1975; Ahl and Wittman 1986). The negative results obtained in the sera from young cattle indicate the absence of FMD virus activity in the area.

Camelid sera

The results obtained in the group of sera collected from an area without any reports of FMD in the last ten years, agreed with the observations on cattle from free areas, i.e. all the sera were negative in both the AGID and ELISA procedures.

The results obtained by ELISA in the group of animals from the area with reports of FMD, may indicate that the animals were in contact with the virus, especially since the vaccination of camelids is not a common practice. This is supported by the fact that cattle sera from these mixed areas, without vaccination records, also gave positive ELISA results but it is important to keep in mind that a real cut-off titre needs to be established for camelid sera.

The presence of VIA antibodies in camelid sera was detected using the AGID test in our laboratory (unpublished data) in alpacas from the department of Cusco in 1979, and no clinical lesions were observed at that time. Lubroth et al. (1990) reported the presence of VIA antibodies in one llama who developed mild lesions after contact with other llama that had been experimentally inoculated. The VIA antibodies were detected by AGID 100 days after exposure.

In our study the positive sera corresponded to alpacas and vicuñas, but not to llamas. These preliminary results confirm that future investigations need to be conducted to establish the role of the South American camelids in the epizootiology of FMD.

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INFORMATION SYSTEMS IN DISEASE CONTROL STRATEGIES

Dr Peter Ellis from the University of Reading, United Kingdom gave an overview of the characteristics of disease reporting systems, starting with some of the shortcomings and discussing progress that has been made to develop systems which meet the needs of disease reporting and collating of information at central, regional and district levels. He stressed the importance of increased participation by farmers who need to adopt recording schemes covering breeding, growth and outputs so as to understand more clearly how to adopt measures with a positive benefit-cost outcome. Local and district services should support these activities, providing advice and assistance as well as diagnostic facilities. At the regional and national levels information can be compiled to give important information on the incidence and spread of the disease and feed into specialist information sources and decision and policy-making processes.

The foot-and-mouth disease (FMD) information system in Thailand, which is coordinated through the FMD Information Center, at the Disease Control Division of the Department of Livestock Development, was described by Dr Yodyot Meephuch. The system has been set up using simple processes appropriate for a developing country and is based on the collection of disease data at local, district, regional, provincial and national levels.

An overview of geographic information system (GIS) technology and its potential use in animal health information programs in Thailand is dicussed in a paper by Dr Pramod Sharma of the University of Queensland, Australia.

Information Systems in Disease Control Programs

P.R. Ellis*

Abstract

Many national information systems, including those for foot-and-mouth disease, are overloaded and unable to produce timely and realistic reports on animal disease. An effective system provides early warning of new problems and a basis for developing herd health and productivity improvement schemes as well as disease control programs. It should also be able to provide assurance that an area is free of specified diseases. Some components of a more efficient system are being introduced including the Office International des Epizooties (OIE) system for major infectious disease reporting, some forms of on-farm or village recording, surveys and general disease surveillance. However, the complex of information required is so great that de-centralised systems have to evolve. Local services and farmers must have a system which covers all problems affecting health and productivity, to improve efficiency. District services can then provide appropriate support and generate reports required for regional and national programming. At regional level, analysis of district information will strengthen regional support and generate information for national reports and policy-making. Microcomputer programs exist to meet all these needs but must be introduced cautiously along with progressive training for everyone involved.

THE term *information system* means a network of computers to some people and to others a huge bank of data which is expected to provide the answer to any question — about disease control in this case — and often is unable to do so.

Current Roles and Problems

The main roles of an effective information system are to:

- provide early and reliable warning of new disease problems and changes in the extent and character of diseases already present;
- convert data through analytical procedures into information which, for epidemiology and control purposes, should explain why a disease is occurring and help farmers and veterinarians to decide what must be done about it;
- provide information on the way different diseases *not already present*, might spread and develop if they did gain access to the changing livestock industries of a particular country or area;
- help planners and policy makers to develop cost-effective disease prevention and control strategies;
- support the implementation and monitoring of disease control/eradication programs; and
- support health services for farms and villages.

Until recently disease information systems have been of very limited value. Veterinary services have simply collated and published periodically the distribution of outbreaks of a fixed list of major diseases, including foot-and-mouth disease (FMD), as and when reported to them. Unfortunately reports rarely gave the complete picture because of unwillingness of farmers to admit problems or inadequate coverage by veterinary services and poor communication. With respect to essential background information most countries routinely produce animal census data, market reports and trade information and they may have examples of productivity data, such as milk yields and offtakes of fat animals. However, these banks of data are often huge, confused and months, if not years, out of date. Furthermore, they are usually dispersed among several different departments or authorities so that the information generated from them cannot be integrated to give a realistic picture of how production systems, animal movements and marketing patterns are operating in a particular area.

* Veterinary Epidemiology and Economics Research Unit, Department of Agriculture, University of Reading, PO Box 236, Reading, RG6 2AT, England.

Economic data is even more difficult to obtain because, traditionally, farmers are very reluctant to tell official agencies the true extent and values of outputs. Consequently it is very difficult to make economic assessments of disease loss and control potential without the new approaches to be discussed in a later session of this workshop.

Progress

Some of the building blocks of a comprehensive animal health and disease information system are discussed below.

Routine disease reporting

Routine reporting is being strengthened. More and more countries are adopting the Office International des Épizooties (OIE) International Animal Disease Reporting System. Standard recording forms are filled out whenever an outbreak of a List A disease like FMD is discovered and on subsequent visits to the affected area. This helps the veterinary authorities to calculate incidences, measure effects of the disease and determine possible sources of infection and possible secondary spread. It is the basis for emergency actions which should contain the problem much more quickly than in the past. At the same time reports meeting international standards can be sent to the OIE and other international and regional agencies, as well as to neighbouring countries and, in return, the country receives early warning of infection nearby or in another country with which it has trade connections. Even more important is the way in which such a recording and reporting system leads to concerted control schemes by groups of countries.

Farm and local veterinary assistance records

Farm and local veterinary records are gradually being broadened and improved in Asian countries. Simple records of events on the farm can provide indications of new problems. A sudden increase in cases of lameness, for example, could be an indication that FMD has occurred although it may not have been reported. Individual farmers can be persuaded to keep a simple record of animals bought or sold and animals that were born and died. On larger holdings simple computerised schemes are being adopted. Such records can be used to compare productivity of animals when a disease problem does arise.

Targeted surveys

Surveys such as that conducted by the Thai–Australian Project (Bartholomew and Culpitt 1992) are frequently used to gather more precise information on ongoing problems and control schemes. A number of farms or villages are selected because they are believed to represent conditions in the area for which a program or a change is planned and they may be subjected to a single visit or to a series of visits to obtain details of herd productivity, uptake of FMD control measures if any and incidence rates among herds and among animals within herds. Such a survey helps to validate figures obtained from routine disease reports or to provide an index of under-reporting so that the magnitude of the problem can be more realistically estimated. Active blood sampling of animals for serological test purposes offers interesting prospects but the tests still do not appear to be able to distinguish satisfactorily between immunity from infection and that following vaccination. The collection of tissue samples from infected animals is, of course, an essential part of such a survey.

General disease surveillance

Surveillance is adding to the pool of information needed for effective programming. This is an activity which involves both field and laboratory staff in an integrated and periodic examination of the disease and the production problems being experienced by a representative range of farmers. Diagnostic specimens are collected from an agreed range of bacterial, viral, protozoal, parasitic and other diseases. These are mainly examined in regional laboratories. A regular visiting program helps the investigators to obtain a dynamic picture of the epidemiology of diseases in a region together with a dynamic picture of the productivity of herds and flocks with and without one or more of the disease conditions encountered. With such a surveillance base, more specific epidemiological studies such as case control studies, cohort studies and intervention trials can be undertaken. The objective is, of course, to help farmers solve their problems so some form of assistance has to be given to them, and evidence of benefit provided with the information that is obtained.

What does the Future Hold?

Many different agencies have begun work on the improvement of various aspects of animal disease information systems. An important landmark was a meeting in Manila (1988) on the *Improvement of Animal Disease Reporting in the Asian and Pacific Region* sponsored by the Asian Development Bank (ADB) and the OIE and attended by representatives of 22 countries (ADB/OIE 1992, Vol. 1). These agencies also sponsored follow-up visits to a large proportion of the countries of the region in 1989 in which consultants helped them to prepare development plans for their information systems. Summaries of these are contained in a separate report (ADB/OIE, 1992, Vol. 2).

There was a strong consensus on how information systems could be improved and a follow-up workshop held by OIE in Paris in 1992 reviewed progress with particular reference to information in the management of veterinary services (OIE 1992). The OIE has also set up a special bureau in Japan for the Asia and Pacific Region which is promoting further work. Meanwhile many practical achievements have been made in Southeast Asian countries with the help of a variety of aid programs.

The Structure of Information Management Systems

In the report of the country visits which followed the Manila meeting, the consultants provided a flow chart for animal health information which appears as Figure 1. It was obvious to all concerned that the existing systems were already overloaded and that improvements could only be achieved on a decentralised basis, in keeping with the trend to decentralise responsibility and authority for providing veterinary assistance.

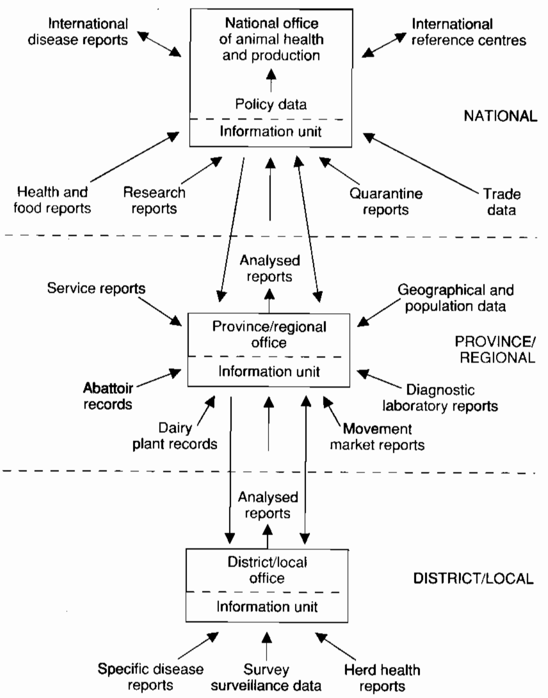

Figure 1. Flows of animal health information.

In the chart the concept of three different levels of information is indicated by grouping parts the system at three different levels: central, regional and district. Since the fundamental principle is to provide information as quickly as possible to those who supply data, it is simplest to approach the development of the system from the farm or village level upward rather than from the centre down.

District level

Farmers and farmers' organisations need to play an increasingly active part in the provision of health care for the animals and in disease control activities. To do this they need to adopt recording schemes covering breeding, growth and outputs of their animals so that they can decide when and how to adopt new measures in order to improve profitability. Change in these patterns can be linked to the effects of measures that they adopt and to the occurrence of any serious disease problems such as FMD. Obviously, such schemes require time to evolve and farmers need to be trained to use them.

Local services will have evolved to meet increasing demands for help. Such services may have to develop on a private basis by farmers' associations or cooperatives who employ their own veterinarian or assistant. It is inconceivable with world economic trends that state services will be able to attend to many farmer needs free of charge.

District service centres will find themselves moving into a support role for local services, providing advice and assistance on an increasing range of health control needs and becoming involved in issues of breeding and management. A key part of this support will have to be the strengthening of diagnostic facilities with the addition of a small laboratory.

The introduction of an appropriate information management system at the district office will be vital to the success of the whole national system. With the help of microcomputers district staff will be able to collate data on major disease incidents and build up population data banks on which epidemiological investigations can be based. They will also serve as the focal point for economic loss studies and herd and village profile studies thus generating models with which to identify and evaluate the range of day-to-day health problems requiring attention.

Southeast Asian countries have moved a long way in this direction in recent years. In Indonesia, for example, surveillance studies have been undertaken in Sumatra, West Java, Central Java and Bali. In Thailand, similar initiatives based on Khon Kaen have demonstrated, beyond doubt, the effectiveness of profile studies and, as already mentioned, there is also an excellent example of a targeted survey in the north. Malaysia and the Philippines have also taken initiatives on herd recording and improvement of diagnostic support and participants will undoubtedly be able to add further information on these and other countries.

Thus important components of farm, local and district information management systems to serve farmers while also generating better disease information are being developed.

Regional level

With the delegation of activities and information management responsibilities to the district, the regional offices will be able to provide more effective and specific support. Emergency disease control brigades can be formed to move to the affected area whenever a new crisis like FMD arises or a new impetus is to be given to existing control measures. Staff can specialise to some extent in groups of diseases and on the promotion of health and productivity schemes for individual species. At least one member of the team ought to develop the epidemiology and information management capability and assume the role of analysing data. However, all members of the team must become familiar with these capabilities and build them into each specialist support activity. In dealing with specific disease problems regional staff will promote further target surveys, profile studies and surveillance schemes to build up and update their information bank for Regional health policy-makers. Specialisation can also extend to the diagnostic laboratory whose role will be to back up certain specific programs, support district laboratories and investigate problems that cannot be covered at district level.

Each region should be able to build up an information bank on geography, climate patterns and distribution of herds and flocks to define operational zones for health control purposes. Similarly, through links with slaughter houses and markets as well as local services, it will be important for the regional office to develop stock movement maps and to use these stock-handling centres as an additional means of disease surveillance.

In fact, regional offices could become the main centres for collating, analysing and interpreting the health information which is drawn selectively from the districts. Such a dynamic approach together with rapid transfer of findings to both central and district levels will greatly enhance the efficacy of the whole information system.

National level

In principle the flow of routine disease reports to this level should be restricted only to those which require national intervention. Information generated at the regional level on a wider range of diseases and problems affecting productivity such as infertility, parasitism and nutritional deficiencies can be the subject of periodic summaries which enable headquarters veterinary officers still to publish national status reports but also to identify new needs for assistance or research.

Planning, evaluation and monitoring of nationally sponsored specific programs will be a key activity. In the flow chart presented as Figure 2 (ADB/OIE, 1992, Vol. 1) it can be seen that information must be generated at every stage of the program. In the first instance *the problem and its distribution have to be identified.* Information on the characteristics and distribution of populations of susceptible animals, movement patterns, the incidence rates of the disease and assessments of its effects have to be obtained. Only then can *control strategies* be designed realistically and *feasibility studies* carried out as will be discussed in the economic analysis section of this workshop.

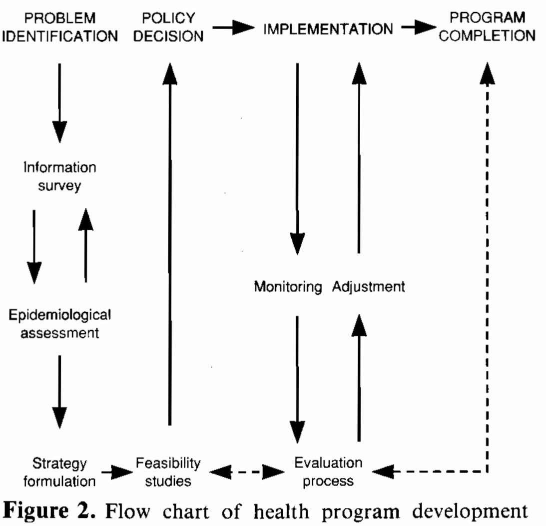

Figure 2. Flow chart of health program development pattern.

Once a *policy decision* has been made and a monitoring system is needed to generate information on the efficacy of control measures, to detect weaknesses and allow adjustments to the program to achieve greater efficiency. Finally, when the program has been completed further information will be needed for evaluation purposes. Internal links with specialist information sources such as research institutes and with agencies also involved in the livestock industries such as ministries of trade and public health can also be expected to supply relevant information. The fundamental principle must always be for the central service to have access to all necessary sources of data but to keep only the bare essentials routinely on file.

Information management unit

Such a unit will obviously become a key part of the central service providing decision-makers with summaries of routine problems and activities, early warning of new problems and changes which may contribute to them and support for any investigations that may be required.

Research and development in the applications of information technology in animal health and production are progressing at an astounding rate. New technology emerges every week and it is fair to say that microcomputer software programs are now available to do almost any data collation and analysis task that could arise. The full range from herd and village recording systems through routine disease reporting and epidemiological investigation procedures to program planning and management systems are now in general use. Attention is now being focused on models through which the risks to livestock populations from the occurrence of a new problem can be assessed. These are termed *risk models* and amongst them EpiMan, developed in New Zealand and now being developed for Europe, is probably the most advanced. It is vital, however, to proceed cautiously into computer technology, to select programs carefully and to provide adequate training for staff before this advanced capability is brought into routine use or it could soon become discredited.

Training requirement in information management

Training is probably the most urgent need. Although some people from Southeast Asia have been trained overseas the staff requirement is such that training centres must, with their assistance, be established within each country. A great deal can be achieved by short specific courses but there is a real need for an integrated program of training covering applied epidemiology and economics as well as information management and eventually to the masters degree (MSc) level.

Conclusions

It is fair to say that FMD and other epidemic disease problems and risks are motivating most governments to update their disease information systems. So much information has to be brought together that an efficient system must involve maximum decentralisation. Data generated at farm and district level should be processed as near to the source as possible so that the full advantage of feedback in herd health and in service efficiency can be achieved. Essential data for regional coordination and support services can be channelled to the Regional level and this can be integrated with that from other interested institutions and services concerned with livestock so that the specialist support and coordination roles of the regional service are strengthened. Meanwhile, at the national level the Information Management Unit will have the vital tasks of:

- receiving and relaying information very quickly in emergencies and marshalling all necessary population, disease, control resource and regulatory information that may be required;
- preparing general health status reviews through which trends and new needs can be identified;
- assembling disease, population and economic information for program planning and evaluation purposes; and,
- collecting information to facilitate re-orientation and adjustment of ongoing veterinary activities.

To do all this the unit will need to select appropriate information technology and promote progressive training for all users as well as operators of the information systems. It is important, however, to proceed cautiously, carefully and systematically into this valuable area of activity because choices are wide, costs are high and difficulties are frequent.

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An Information System Developed for Monitoring Foot-and-Mouth Disease Control in Thailand

Yodyot Meephuch*

Abstract

A foot-and-mouth disease (FMD) information system in Thailand is coordinated through the FMD Information Center, at the Disease Control Division of the Department of Livestock Development. The system has been set up using simple processes appropriate for a developing country and is based on the collection of disease data at local, district regional, provincial and national levels.

FOOT-and-mouth disease (FMD) in Thailand is ranked number one in economic importance, among notifiable animal diseases. The disease has been known to be endemic in Thailand since it was first reported in 1953. Various strategies such as strict control of animal movement, vaccination, animal quarantine, sanitary control measures, outbreak investigation, field surveillance and stamping out of sick animals, have been implemented by the Department of Livestock Development (DLD) of the Royal Thai Government, but have not been successful.

In 1991 the DLD started a new project, the Foot and Mouth Disease Prevention and Eradication Project. As part of this project an FMD Information Center was established at the Disease Control Division in order to study and evaluate the dynamics of FMD. Factors such as geographic distribution; seasonal effect on disease frequency; causes and duration of outbreaks; number of animals affected and type of viruses involved; risk areas and association between risk factors and the disease; and control measures have been monitored. The system uses a combination of routine data collection, structured prospective data collection and new data, collected specifically to improve the understanding of the problem.

Since Thailand is a developing country, we can not expect to design an information system that would be too difficult to implement on practical, technological or economic grounds. Therefore, as the starting point for the FMD data collection system basic questions were raised for consideration in order to ensure that the necessary data was collected to provide reliable and useful answers. The strengths and limitations of the available data were carefully assessed in order to make the adaptation process more effective, efficient and timely.

* Foot-and-Mouth Disease Information Center, Department of Livestock Development, Phyathai Road, Bangkok 10400, Thailand.

Local and National Needs of the FMD Information System

Local needs

- Rapid reporting of FMD outbreaks to district livestock officers (DLOs).
- Support for DLOs to take action to control the outbreak.

National needs

- Development of a disease control policy.
- Monitoring of program effectiveness.
- Budget/planning requirements.
- International reporting to the Office Internationale des Épizooties (OIE) and the Animal Health and Production Information System for ASEAN (AHPISA).

Components of the FMD Information System

The Disease Control Division (DCD) information system consists of the following components.

1. Outbreak reporting system. An outbreak reporting system is used to monitor the occurrence of the disease in the country. Information from the system is availed in the form of counts, incidence of villages affected and animal morbidity and mortality rates.

2. Structured epidemiologic investigations. Epidemiologic investigations are used to study aspects of the disease such as risk factors, effects of the disease on productivity, animal movement patterns, reliability of diagnostic testing and vaccine efficacy. This information helps develop an understanding of FMD in Thailand.

3. Monitoring/active surveillance. A monitoring program based on animal health and production profiles carried out in randomly selected villages is being developed for the whole country. At present it is underway at the Northern Veterinary Research and Diagnostic Center (NVRDC) at Hang Chat in Lampang Province. Other active surveillance activities are serological testing of livestock at border entry points and/or animal auction market.

Outbreak Reporting System

First formal outbreak report

When a disease outbreak occurs the DLO in the locality will conduct a field investigation and fills in a report form called an *EP12 form.* In the EP12, information about the location of the outbreak, number of animals affected and at risk, possible risk factors, nearest village, vaccination history, suspected sources of infection, symptoms seen, samples sent to laboratory and control actions taken are all reported. This report is sent to the provincial livestock officer (PLO) and the regional livestock officer (RLO) and finally to DLD headquarters.

Specimens and basic information of the outbreak are sent to the Foot-and-Mouth Disease Center (FMD Center) at Pak Chong, Nakhon Ratchasima Province or to NVRDC, for confirmation and typing of the virus.

Outbreak follow-up report

After sending the EP12, the DLO conducts weekly outbreak follow-up investigations and fills in another report form, the *EP13 form.* The distribution channel of this form is the same as for the EP12. The EP13 form is updated weekly during the outbreak and for 4 weeks after the outbreak is over. Information on the form includes cumulative totals of animals sick, recovered, died and at risk up to the previous week.

Monthly summary report

Information about all disease outbreaks in a district each month is collected on a *monthly summary report.* Information collected includes diagnosis, location of outbreaks, demographic data about animals affected, key dates (e.g. date of onset, date of first report), and control measures used.

Report of routine vaccination

Details about locality at village level, population of animals, number of animals vaccinated, type of vaccine used, are all filled in on an *EP14 form* by the DLO and is used to monitor the utilisation of FMD vaccine. Ultimately, this information links to outbreak reports in order to monitor the efficacy of the vaccine campaign.

Data Collection and Information Processing

EP12 database

The EP12 is a simple form of initial FMD outbreak report which indicates location of outbreak, number of animals affected, number of animals in the village, date of occurrence and so on. The form was designed for a DLO to send to provincial and thence to regional livestock officers and finally to DCD in DLD headquarters as soon as possible by fax or by phone.

Data sources. Initial FMD outbreak report (EP12), lab reports from FMD Center and NVRDC, special requests from DCD for additional information.

Reports generated. Weekly summary report.

Function. The information in the initial FMD outbreak report, EP12 report form, laboratory result form and additional information are recorded and stored using a database system for summarisation, analysis and dissemination of information to the field personnel concerned, officer-in-charge and for decision and policy makers.

Timeliness. Initial outbreak reports are entered within a few days of the information arriving at DCD and are examined, corrected and approved according to information from the EP12, laboratory results and special requests for more information.

Problems. Inadequate reporting; data analysis/ presentation needs epidemiological skill.

EP13 database

Data sources. EP13 form.

Function. This main database collects weekly update information during the outbreak and for 4 weeks after the outbreak is over. Information on the form includes cumulative totals of animals sick, recovered, died and at risk up to the previous week; similar values for the week covered by the report, and totals for the village for the outbreak.

Notes. this database can be linked and related with EP12 database.

EP14 database

Data sources. EP14 form.

Function. This database processes routine vaccination data which will ultimately be used to evaluate efficacy of vaccination program.

Structured epidemiologic investigation databases

Function. To answer questions about risk factors, vaccine efficacy, animal movement, and program feasibility.

Data sources. Information from:

- investigation and analytical studies of new outbreaks;
- outbreak reporting and efficacy monitoring of vaccination program;
- clinical trials and serum neutralisation titre test for vaccine efficacy (monitor decay in titres over time); and
- animal movement and quarantine studies.

Monitoring/active surveillance databases

Function. To record the monitoring program in randomly selected villages which include serological testing of livestock in the villages, at the border and at entry points and/or auction markets.

Data source. Information provided by monitoring of:

- randomly selected villages;
- animal movement pattern;
- monitoring completeness of outbreak reporting;
- monitor efficacy of vaccination program and outbreak reporting program;
- epidemiological data and serological data;
- imported animals; and
- animal auction market testing.

Hardware and Software used for Recording, Processing, Analysis and Presentation

Hardware

- Microcomputer (IBM compatible)
- CPU 80386
- VGA colour/monochrome display
- Hard-disk
- Dot matrix printer
- uninterrupted power supply

Software

- Databases-dBASEIII and FOXBASE+
- Analysis-EPIINFO, EPISTAT, QUATTRO PRO
- Presentation-graphics: Harvard Graphics, Freelance Quattro Pro, Windows 3.1;
- Text: Word Star, Word Perfect, Thai Word Processor

Use of Geographic Information Systems in Animal Health Information Programs

P. Sharma*

Abstract

This paper presents a brief overview of geographic information system (GIS) technology and discusses its role in an animal health information system using Thailand as a possible case study. The research proposal under consideration is the setting up of a pilot system (using the GIS package ARC/INFO) in three northern provinces of Thailand (Chiang Mai, Lamphun and Lampang).

PEOPLE often think of geography in a traditional sense of natural landscapes and built environment, and may confuse *geographical information systems* (GIS) with computer-based systems for representing physical geography and environmental factors. This thinking is far removed from the purpose of using modern information technology of GIS as a decision support aid for national disease control policies — an application discussed in this paper using Thailand as a case study. As reported by (Matthews 1990):

> Recent developments in database management strategies, computer hardware and software, and spatial modelling have provided the research community with a unique opportunity for studying questions relating to a whole series of patterns and processes . . . properly planned applications of GIS-based research which combines databases may yield knowledge that cannot be obtained in any other way . . . A GIS, together with some rigorous statistical modelling, is thus mandatory for much epidemiological research (p. 214).

Currently in Thailand — as in many other countries — traditional data recording and descriptive analysis methods (some computer-based) are used for collecting animal health information. However, such systems, even when fully computerised, suffer from a number of limitations. They offer few additional capabilities over a manual, paper-based system; have little inferential ability; lack interpolative and mapping capacity; and are extremely cumbersome when large amounts of data need to be recorded. These traditional record-keeping systems (paper or computer-based) are often characterised by late, inaccurate reports and gross under-reporting and are not well suited to providing information needed as a basis for action by animal health decision-makers.

In Thailand, livestock entry from neighbouring countries and movements within the country have an important role in the spread of FMD and other diseases. The epidemiology of these diseases has obvious spatial implications, especially where a national control program is being implemented. Epidemiology is in essence a spatial (geographical) science, in that patterns of disease spread and of control measures must be viewed over space and in relation to risk factors. In a national disease control program, disease incidence throughout a country must be monitored, and quarantines, buffer zones, vaccination programs, extension activities, etc., tailored on a spatial basis.

Modern GIS will perform the functions of a paper-based system routinely, and in addition offer a number of important analysis and reporting capabilities. Data are recorded more efficiently, with minimal duplication, ease of updating, and rapid access. Interpolation capabilities allow estimation between data points. The interrogation capability allows database layers to be combined to examine association between spatial variables, e.g. between livestock movements and disease outbreaks. Once templates have been established, livestock officers can readily generate a variety of maps indicating the

* Department of Geographical Sciences and Planning, University of Queensland, Queensland 4072, Australia.

spatial characteristics of livestock populations, disease incidence, risk factors and control effort. These maps can allow strategic targeting of veterinary services, and facilitate monitoring of progress. Additional data such as background data on estimated livestock numbers by species and type at local and provincial levels, stock movement and marketing patterns, and even specific items of demographic and socioeconomic data can all be generated. These extra data are not designed simply to complete the geographic picture of a region; they are collected as needed to allow disease risk mapping and aid formulation of control strategies.

GIS are designed to manage the information associated with the 'geography' of a problem in the broadest sense. If substantial effort is to be expended on improved observation of livestock disease incidence and herd immunity (such as new diagnostic facilities and active surveillance), then it seems logical to also improve the way in which the improved observations can be translated into useable information for tactical (outbreak) and strategic planning at a regional and national level. Access to the best possible information will certainly assist in a control program.

Modern GIS technology, in terms of software, hardware and data recording and analysis methods, is well suited to livestock disease epidemiology and is being increasingly adopted. Application areas include:

- general information systems to support surveillance, eradication and quarantine epidemiology (Hugh-Jones 1991; Arambulo and Astudillo 1991; Morris 1991; Nobre et al. 1991; Matthews 1990).
- applications focused on managing information for specific livestock diseases, e.g. for Aujesky's disease (Marsh et. al. 1991), Lyme disease (Kitron et. al. 1991), cattle diseases (Lessard et al. 1990) and bluetongue (Sutherst and Maywald 1990); and
- crisis management, e.g. of foot-and-mouth disease (Sanson et al. 1991).

The proposed animal health information system for Thailand will have several major components which will provide answers to questions such as:

- distribution of animals (by whatever attributes are regarded as important, e.g. type, age, sex);
- distribution of humans (by whatever attributes are considered to be relevant to an animal information system, e.g. occupation and degree of commuting have an impact on an animal information system if these two attributes result in different husbandry/grazing practices which in turn impact on animal health);
- distribution/delivery of current animal health services;
- distribution of current 'problem' areas (problem areas can be defined in terms of: inadequate delivery of services, such as vaccination, disease outbreaks reported, significant absence of critical data for that area);
- geographic origin of laboratory samples (of actual disease notification, routine testing etc.);
- crisis management in an epidemic (location of disease outbreak, location of vaccine, degree of risk in the surrounding area, a local map showing numbers of livestock and degree of immunity by village, i.e. a local 'risk surface'); and
- location of markets where animals are bought or sold.

From this it can be seen that with the exception of the clinical aspects of laboratory, most of the data in an animal information system have a 'geography' associated with them. As the role of a GIS is to *efficiently capture, store, update, manipulate, analyse geographically referenced information* its role in an animal health information system should be self-evident.

What is a Geographical Information System?

A GIS is an organised collection of computer hardware, software, and personnel designed to efficiently capture, store, update, manipulate and analyse geographically referenced information (any data that can be mapped). As such it is much more than 'computers' and involves a 'culture of geographic information management'.

GIS implementation (especially in large organisations) is a relatively complex process and involves a large number of institutional and technical steps. There is a need for a management methodology to help guide the planning, implementation, operational and maintenance processes; the issues are similar to those issues which are related to the management of technological change or the introduction of any new technology.

Software

The extensive capabilities of GIS software can be summarised into three broad categories which are described below.

(i) Data capture, input and conversions

Geographic data is available from a wide variety of sources including printed maps, field observations, surveys, printed reports, satellites, geographic positioning system (GPS) receivers and data loggers of various kinds. However, to be useable in a computer all data has to be in a digital form. Table 1

Table 1. Techniques for conversion of graphic data.

TECHNIQUES FOR DIGITAL CONVERSION OF GRAPHIC DATA	
Technique	Proposed project use
Encode geographic data to cells	None
Manual entry of point, lines and polygons using digitiser	Extensive use
Automated digitising-raster scanning	Not likely
Automated digitising-vector scanning (automated line followers)	None
Input from survey plans (bearings, distances) using a keyboard	None
Automatic entry at time of data capture (data loggers)	Some; if GPS[a] units are used

[a] Geopositioning system

lists the various ways in which data conversion can be effected. The use of a digitiser (an electronic tablet on which a map is placed and relevant contents 'traced') appears to be the most feasible technique for the proposed project.

Conversion of paper records and printed maps (graphic data) raises many problems and issues. The trend is toward greater capture of field observations and sensor data in digital form and with the increased use of data loggers and portable computers. For example, in the proposed project the location of villages and disease outbreaks can probably be most effectively captured by GPS units (portable units — the size of a paperback novel — which are capable of determining a geographic position in degrees of latitude and longitude anywhere on the surface of the earth).

(ii) Data manipulation, query, modelling and analysis

These operations include: (a) preprocessing operations (editing errors, joining maps, scale changes, format conversions, transformations, etc.); (b) automated mapping i.e. the broad area of conventional map drawing using computers; and, analysis and modelling functions. These 'advanced' mapping functions include four broad classes of operations ranging from the fairly simple to the more complex modelling operations: retrieval; classification and measurement functions; map overlay and buffering operations; and neighbourhood operations and connectivity analyses.

(iii) Data display and output

This concerns the ways in which the data are displayed and the results of analyses are reported to the users. Two broad types of GIS operations which involve output and presentation are: (a) automated mapping and (b) other geographic analyses and modelling. In automated mapping the output is always a map while in other analyses this need not be the case.

Hardware

Under consideration are the devices to capture, physically store, process and output data. The actual hardware that may be found at a given site will vary with the type and scale of GIS application — reflected most noticeably in the type of CPU (computer) that will be used. These range from mainframes to minicomputers for large online systems to workstations and microcomputers typically for smaller project-type, stand-alone applications.

Secondary storage devices include disks and magnetic tapes. Increasingly, CD-ROM and related optical storage technology is being used for storage of geographic data. Input devices can vary by type of operation required. A keyboard is used for text entry while digitisers and scanners are used for the entry of graphic (map) data. Increasingly, point-of-capture devices such as GPS receivers are used to collect geographic reference data. Output devices include visual display units as well as hardcopy devices such as line printers, plotters and film recorders.

However, notwithstanding the choices indicated above, a desktop (IBM compatible) computer with an Intel *i*486 CPU (or equivalent) with appropriate secondary storage, a digitiser and a plotter, would represent an acceptable minimum hardware for a workable GIS. In Australia such a system in 1993 would cost approximately $9000.

Thailand Animal Disease Information System

The proposed project is designed to develop improved disease diagnosis methods in Thailand and to incorporate these with active surveillance so as to further develop the existing disease information system (this system is at present confined to passive surveillance and to selected diseases, of which FMD is one). An additional aspect of the proposed project is the consideration of the economics of such systems. The following discussion outlines how such a system could be structured, maintained and used.

In the past, many information systems were imposed 'from above' without much consideration of what the users actually wanted. However, most information system design is now application driven which means that it is much easier to get answers from users to three critical sets of questions:

- What *outputs* or *'products'* are required of the information system for the users to accomplish their tasks?
- What *application modules* have to be developed to deliver these outputs?
- What *data* are required to support these applications?

The strength of such an approach is that as the system has been designed for the users and (in a general sense) by the users, it is more likely to be accepted and used routinely thus greatly reducing the possibility of failure.

Design considerations

Central to the design of a disease information system is a user-needs analysis and its associated data requirements specification. One of the outputs is the identification of:

- critical minimum data sets;
- desirable supplementary data; and
- 'would be nice to have data'/wish list.

Obviously the data in the first category will have to be collected regardless of the 'practicalities' because without these items the system will not have even a minimum functionality. The other data are less critical and may have to meet stricter *cost* vs *return* considerations before they are collected.

Such a system needs to be linked to livestock owners, markets and meatworks, and with the local or district veterinary office and diagnostics centre, and in turn with the provincial/regional and national offices. Data obtained from routine observations and notification requirements will need to be integrated with that from active surveillance programs.

A number of report forms will need to be designed for data input, and reports and graphics designed for decision-support and record keeping information. The other things that also have to be clearly specified in the design are: (i) initial databases; and (ii) ongoing components.

Structure of the information system

It is envisaged that the information system will initially be developed for three provinces in northern Thailand, viz. Lampang, Lamphun and Chiang Mai. It is the intention that the system will later be extended to other provinces in which livestock production is significant, and if possible to a national basis.

It is proposed that the disease information system be based on mainstream GIS technology with pcARC/INFO as the preferred software and an *i*486DX/33 type computer for hardware. (The database manager for pcARC/INFO is dBASEIV). If the application is expanded beyond the proposed project several upgrade options are available. However, an important consideration with ARC/INFO is that all data, coverages, etc. can be exported to any of the proposed upgrades. Thus, no waste is involved in 'starting small'.

The GIS will contain a number of databases although at this stage it is not clear whether the file structure will be based on livestock species or disease type (this would emerge from the user-needs study). The number of disease types would be extended progressively, full system development possibly taking several years.

The core data would be disease outbreak records, information from observations by district veterinary officers, and information generated by active surveillance. The direct 'veterinary data' will have to be backed up by other backdrop data. Such backdrop data could include: distribution of livestock in the target region; disease control infrastructure; distribution of human population in the target region; internal human migration data; location of markets; road network; administrative boundaries; and so on.

The backdrop information is particularly important as currently very little information is available on *the context* within which any sample investigations are being carried out. Also, investigators may be interested in comparing some 100% vaccinated–no outbreak villages to no vaccination–no outbreak villages, for example.

It would be impractical to collect all these data types immediately, but they could be introduced progressively. Once established, the database would need frequent updating of a range of variables, some on an incident basis, some at short intervals (e.g. monthly) and others less frequently.

Data Collection Procedures

Data on impact of livestock diseases at the local and national level will be required. Wherever possible, provincial statistics will be collated and mapped to provide the wider context within which the study area is placed. First impressions are that there is considerable published province (*changwat*) level data in Thailand; much of this is relatively recent, i.e. 1990 or later. Data availability at the district (*amphur*) level is relatively limited.

Data will be needed at the national level with respect to trade impacts of livestock disease status. These data may be available from local agencies, including the Disease Control Division and International Coordination Subdivision of the Department of Livestock Development (DLD) and from the Office of Agricultural Economics of Thailand.

The *1990 Population Census* data and the *Annual Statistical Summary* may be quite useful for background data at the provincial level. Overall, data availability for up to provincial level breakdown can be considered satisfactory in terms of project needs. Some statistics which may be useful are available by the seven regions, though not by the 70 provinces.

Detailed data will initially be collected for Lampang, Lamphun and Chiang Mai Provinces. Later in the project the remaining provinces in northeast Thailand could be included. Collection of local data on economics of livestock disease control is expected to present difficulties as the bulk of the required primary data (if not all of it) will have to be collected from Thai villages.

A two-phase primary data collection program will be needed to collect village data. The first phase (which could be conducted as a joint survey with interested parties at Chiang Mai University) will be a complete sweep of all villages in the study area to collect frame type information, i.e. establish a critical minimum profile. The second phase will represent the major data collection effort and will consist of an interview survey of a random sample of villages, supplemented by case studies of specific villages.

Data to be collected at the village level will relate to the role of livestock in village and household economies and data related to livestock systems in terms of relationships with crops, grazing/feeding management, disease control and production impacts of diseases.

Selected Research Steps

The research undertaken will, in general, reflect the conventional sequence of steps involved in developing a GIS (Anteneucci et al. 1991). However, some modifications to the sequence are dictated by the following factors: existing system, lack of GIS expertise. and the data needs of the associated subprograms.

User needs analysis

The first step will be an analysis of user needs. This will identify what the present information system does, its shortcomings, their impact and whether they can be overcome. The adoption of GIS technology frequently provides answers to a wide range of data management shortcomings. If the GIS approach is accepted then it is important to ask users what questions they expect the GIS to answer and what 'products' they expect the system to output/deliver. The product can be the answer to a query, a map on the screen or a map as a hardcopy.

Once there is some consensus on the questions/outputs, the next step is to identify the data that will be required to provide the desired answers/outputs. This will logically lead us to a further set of questions such as whether the required data exists in the right form or has to be collected, and so on. The end of this line of inquiry is the production of the functional requirements specification for the proposed system. It should be noted that important GIS design considerations related to function, data content, and system capacity depend on a clear understanding of what the users of GIS (mainly vets) need.

Included in the requirements specification is a very generalised (often graphical) view of how the system could be designed, its basic databases, and main applications. This is the conceptual design of the system and is useful because it provides a medium to long-term view whereas it is likely that only a small segment of the system can be implemented in the early stages.

Implementation plan

Implementation plans for a GIS can vary from the simple (as is the case for the proposed project) to very complex (as is the case for a nationwide GIS). However, while the plan for the proposed project is likely to be relatively simple it will have to be stated clearly at the outset as the number of individuals involved, geographic distances between them and language problems are potentially conflict generating.

The plan will provide all individuals with an understanding of their roles and responsibilities and the relationships between different tasks. In simple terms it:

- identifies and describes individual tasks;
- assigns responsibilities for each task;
- defines relationships among tasks (e.g. mapping cannot begin until boundary files have been digitised and the information to be mapped has been keyed in);
- identifies products (outputs, e.g. 6 digitised map layers); and
- establishes a schedule.

It can be seen that the implementation plan cannot be drawn up until the requirements specification is produced.

Database design

It is expected that the database design itself will be relatively simple once the requirements specification has been completed and there is general agreement on the conceptual model (and especially the application modules). At this stage it is not clear whether the final data model will reveal the need for a design which is animal-based or one that is disease-based.

Once the database design has been finalised data entry can commence. The first entry task would be to input all relevant statistics that are available (at the provincial and national level). These statistics will be the basis of initial mapping of the distribution of human and animal populations, animal diseases and so on. They will provide better information on the national patterns and also provide the context within which the study areas exist.

The next step would be to acquire and convert any relevant data that is available for the three provinces and the districts within them. These statistics will provide a profile of relevant variables within the study areas. The information detail and the map scale will increase e.g. all villages, roads etc within the three provinces will be mapped.

Computer software, hardware and user training

The project proposal is that pcARC/INFO be used for GIS software; hardware requirements will be met by any high performance (*i*486DX33) DOS-based personal computer.

Two types of user training will be required. The first is a more general GIS concepts and geographic information handling course. The purpose of this is to expose all those who will come into contact with the system to those aspects of the system that will impact on them. This type of training is vital to avoid over-expectation with regard to GIS — it does not magically cure all geographic information management problems.

The second type of training will be restricted to training in specialist aspects of GIS methodology and training in the use of selected software packages and hardware. Some specialist training in the use of hardware (e.g. use of digitisers) will be required.

Conversion of existing data

Currently it is difficult to indicate the extent of the data conversion problem. This is not surprising, as without a user needs study it is difficult to identify what data is required. Only after this step can we determine their availability and format. Once this is established, it is reasonably easy to develop a conversion plan.

Preliminary investigations have revealed that maps will be the weakest link in the data availability chain. In DLD, maps of significant parts of the target area are of early 'seventies' vintage. Also maps are generally not available at better than 1:50 000 scale. (Maps from the Census authority offer slightly better prospects). However, what can be said quite confidently is that a significant amount of conventional digitising will be involved.

System testing via a pilot study

It is conventional to do a pilot study to test components of the proposed GIS and to establish important parameters which are used in conversion and in improving system performance.

There is little need for a pilot study of the proposed system — in a sense, the proposed project itself is a pilot of a much larger system that may be developed later.

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COUNTRY PAPERS

FMD EPIDEMIOLOGY IN SOUTHERN ASIA

Speakers from 11 countries in southern Asia presented information on the foot-and-mouth disease (FMD) situation in their countries including:

- the role of livestock in the economy;
- the role of FMD as a key disease affecting livestock production and working capacity;
- the epidemiology of the disease including seasonal and geographical patterns of incidence and incidence of different virus types in outbreaks.
- the role of the veterinary services in delivering a disease control program;
- laboratory diagnosis;
- vaccines; and
- the control and eradication strategy of the country;

The purpose of these presentations was to familiarise the participants with the regional FMD situation on a country-by-country basis. The written papers included here are slightly more detailed than the oral presentations of the workshop itself and have been presented in such a way as to maximise the consistency with which the information is presented so that readers can quickly get an overview of the FMD situation in the countries covered.

Statistics

Using information supplied by the country representatives in a questionnaire, and information from the submitted papers, a page of ***Country Livestock and FMD Epidemiology Statistics*** has been prepared for each country. In this page the following abbreviations have been used:

na	to denote either *not applicable* **or** *not available* (as sometimes it was not clear from the questionnaire responses which of these categories applied).
C,B,P,S,G	cattle, buffaloes, pigs, sheep, goats

Maps

For most of the countries, where the information was available, maps are included showing geographical features of the country, livestock distribution, the main foci of FMD outbreaks, livestock markets, veterinary diagnostic laboratories, quarantine stations, livestock movement patterns and any other information relevant to a particular country. The maps are stylised and not intended to be quantitative. For further details (e.g. livestock numbers in each province/state), where available, readers should refer to the text of the individual country papers. Wherever possible consistent symbols have been used for cattle, buffaloes, pigs, livestock markets, veterinary laboratories and so on; these symbols are given as a key on each map.

Bangladesh

Nazir Ahmed* and A.F.M. Rafiqual Hasan†

BANGLADESH is a delta, of about 143 999 sq km in area with 22 155 km of rivers and 14 257 sq km of forests. The country has a low, flat and fertile alluvial soil. The major rivers (e.g. Ganges, Jamuna and Meghna) with their large number of tributaries form a complex network of navigable rivers. The country has a humid tropical climate governed by monsoons. The average rainfall is 203 cm per year (range: 117.5–637.5 cm per year). Summer temperatures vary from 23.9 to 31.1°C and in winter from 7.2 to 12.8°C. Bangladesh has a long land border with India and a portion with Myanmar. Although the country is flat in most areas there are a few small hills and hilly areas on the north and southeast parts of the country. The highest mountain peak, Kewkeradong, is 1230 metres high. During the monsoon season heavy downpours are always experienced which often cause the rivers to flood. Floodwater causes many problems for the livestock and extensive damage to crops. Bangladesh is a very densely populated country with a human population of about 109 million (1991). There are five administrative divisions with 64 districts and 464 *thana* (local administration areas).

Livestock

Of the 14 million hectares of land, 66% is arable with an annual cropping intensity of 150%. Agriculture contributes 90% of the export earning and 57% of gross domestic product (GDP). Livestock contributes about 8.7% of GDP and the total foreign exchange from livestock is about 9% per year. Pigs are not reared by farmers and only some tribal people keep pigs for their domestic use.

Livestock husbandry has been practiced mainly in the rural areas. From by-gone days the farmers have used their cattle and buffaloes principally for tilling the land, They also use the livestock for threshing of rice and transportation of agricultural produce from one place to another. Sheep and goats are raised by the farmers along with cattle and buffaloes. In recent years a proportion of farmers have started to set up mini-dairy farms using cross-bred animals. The increased use of artificial insemination services throughout the country has provided momentum for upgrading of cattle breeds. Encouraging levels of milk production have already been achieved and further increases are expected in the future.

Cattle are distributed throughout the whole country but quality cattle are mainly raised in northern and central districts. Buffaloes are mostly found in the south but are also found in some northern districts. Goats are raised mostly in the north and east of the country but are also found in other districts. Sheep are mostly raised by the farmers of Char areas (islands) where there is plenty of grazing land.

The country does not export livestock or livestock products except hides and skin.

Epidemiology

Foot-and-mouth disease (FMD) is endemic in Bangladesh and is thought to be the worst livestock disease owing to its fierce pathogenicity as well as the difficulties in controlling it. Once an outbreak starts it continues throughout the year affecting hundreds of thousands of animals.

No epidemiological study has been carried out to determine how an epidemic first breaks out in a particular area. As epidemics are related to the movement of cattle it is assumed that market places are responsible for the spread of infection. There are cattle markets in almost all districts of the country and about 23 big markets where large numbers of livestock congregate for sale. Sometimes cattle or other livestock are moved to the market on foot and animals in villages located along the sides of the roads may be easily infected. FMD is also endemic in India which has a long land border with Bangladesh. Therefore, trespassing of livestock across the border via unauthorised roads is likely to occur for sale at various markets. This is thought

* Department of Livestock Services, Krishi Khamar Sarak, Dhaka, Bangladesh.
† Livestock Research Institute, Mohakhali, Dhaka, Bangladesh.

to be one of the ways that the disease enters the country and is further magnified when natural upheavals (floods), religious festivals, or price fluctuations (domestic or international) occur.

FMD outbreaks, 1988–92

The history of FMD outbreaks in Bangladesh since 1988 is shown in the country statistics box. All four types of virus, A, O, C and Asia 1 have been identified. A, O and Asia 1 have been common but C is rare. The pathogenicity of the A, O and Asia 1 strains has always been found to be worse than the C strain which is found to be relatively benign and causes mild lesions, does not spread as fast as the other strains, and subsides naturally.

A serious outbreak of FMD occurred in 1990 which had a special significance. The virus was extremely virulent and the outbreak engulfed almost all parts of the country within just three months (March–May). It was presumed that the prime cause of the rapid spread of the virus was the very early rainfall that the country experienced that year with high humidity and gusty winds prevailing during the period of the outbreak. The virus was serotyped and found to be type O. The lesions on the affected animals were very severe causing death in an unusually high number of adult animals. Surprisingly, lesions were even found in the gastrointestinal tract at autopsy.

Seasonal incidence

A seasonal incidence of the disease is seen in Bangladesh (Fig. 1) with the highest incidence occurring in the monsoon months of March–August which also corresponds to the time of the religious festivals. A second, smaller peak sometimes occurs in November and December which is a drier time of year ('winter').

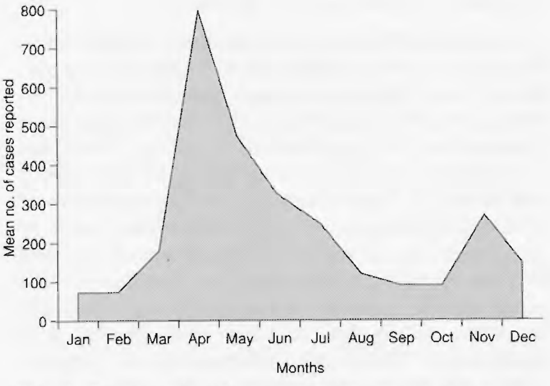


Fig. 1. Seasonal incidence of FMD (mean incidence, 1988–93).

Economic losses

Although FMD generally does not cause death to the adult animals it causes serious economic losses (25%) by livestock following infection for the following reasons:

- draft power is reduced which directly affects cultivation causing a great short-fall in agricultural output;
- in dairy cows, loss of milk, abortion, chronic mastitis etc., are common;
- milk and meat production drops drastically;
- calf mortality is very high, especially in sucking calves where it may be as high as 70%;
- beef cattle farmers also sustain a great economic loss due to weight losses;
- breeding programs are seriously jeopardised; and
- transportation of agricultural commodities from one place to another in rural areas is paralysed.

Other losses associated with FMD include the cost of setting up and maintaining facilities for serotyping; cost of the vaccine production and, in some cases, import; and personnel costs associated with control measures. Economic losses also result from disruption of international trade in livestock products; and impediments to local trade such as the marketing of village produce.

Overall, the economic loss due to FMD is very high and, although no detailed study has been carried out to calculate this loss in Bangladesh, it has been estimated that about US$15.7 million is lost every year due to the loss of milk and draft power alone (Hasan 1985). In this study death of calves, loss of meat, shortfall in agricultural output, etc. were not taken into account. If all of these factors are taken into account the loss would be much greater.

Facilities

Vaccine production

Vaccine is produced at the FMD Laboratory at Mohakhali, Dhaka. This facility was set up in 1985 with the assistance of the Asian Development Bank. Although there was provision made for the expansion of the laboratory so that an adequate amount of vaccine could be produced, this has not occurred and only 0.5 million doses per year are produced. The present scientific staff of the laboratory are as follows: one principal scientific officer; one senior scientific officer; and two scientific officers.

COUNTRY LIVESTOCK AND FMD EPIDEMIOLOGY STATISTICS

Bangladesh: 5 divisions; 64 districts; 464 *thana* (local administrative units)

LIVESTOCK STATISTICS

Animals per owner: estimated average of 2.25 beef/dairy/working cattle and/or buffaloes; 2.9 sheep/goats

Livestock	Number	Annual growth rate %	Draft use %	Meat use %	Milk production %	Estimated trade within country (million)
Cattle	22.6	0.8	40	23	49	5.5
Buffaloes	0.7	3.2	72	10	61	0.03
Pigs	na[a]	na	na	na	na	na
Sheep	0.9	8.2	na	na	na }	14.1
Goats	35.5	4.6	na	na	na }	

[a] only kept by some tribal people

International stock movements: no official trade in livestock/products except hides and skin (export)

FMD EPIDEMILOGY

Seasonal incidence: highest incidence is during the monsoon and religious festivals (March–August) — see Figure 1
Geographic frequency: none

Disease outbreaks and vaccinations

	1988	1989	1990	1991	1992	1993
Number of outbreaks	95	125	304	82	58	na
Deaths	1345	1668	5531	1078	322	na
Serotypes recorded	O,A,Asia 1	O,A,Asia 1,C[a]	O	O	O,A	O,A
Species involved	C,B,S,G	C,B,S,G	C,B,S,G	C,B,S,G	C,B	C,B
Vaccine used	O,A,Asia 1	O,A,Asia 1	O	O	O,A	na

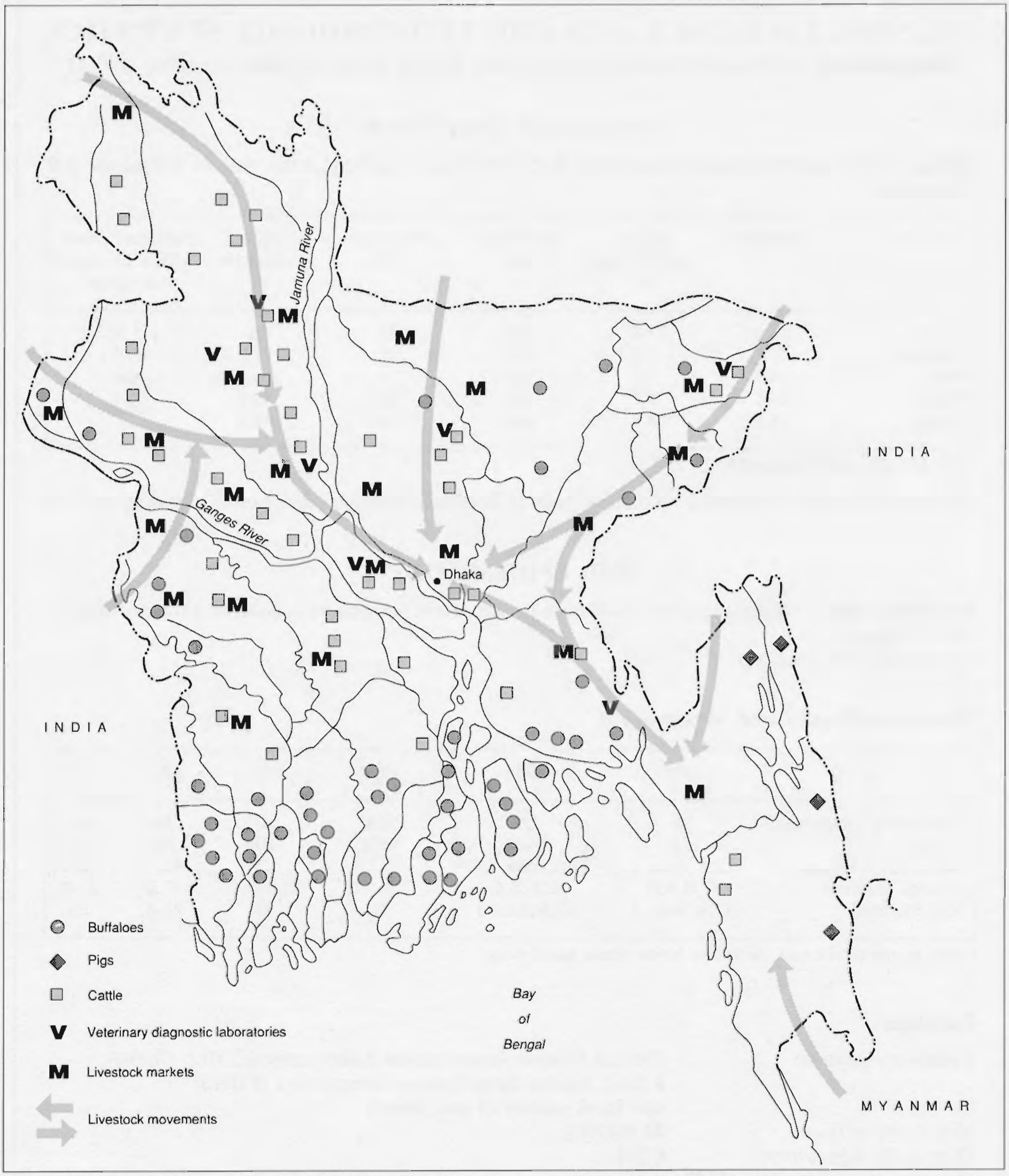
[a] Only in one district near the Indian border (India has C-virus)

Facilities

Veterinary centres: Central Disease Investigation Laboratory (CDIL; Dhaka); 8 field disease investigation laboratories (FDIL); 464 local centres (1 per *thana*)
Veterinary officers: 24 (FDIL)
Diagnostic laboratory: CDIL
Cost per diagnostic test ($US): 0.5

Vaccine

Vaccine supply: 37% — FMD Laboratory, Mohakhali, Dhaka; 63% donated
Cost per dose ($US): 0.25 (free to farmer)
Vaccine strategy: outbreak ring vaccination



Map 1. Main livestock areas, markets, diagnostic centres and livestock movement patterns in Bangladesh.

Communication system (head office to field)

A very good communication system for disease monitoring is set up in the office of the Director of Livestock Services. This system has direct contact with thana headquarters. Thana livestock officers submit monthly reports in prescribed proforma giving detailed information on diseases and other development activities. The computer system compiles all the data and prepares the monthly report in detail within a short time.

Diagnosis facilities

As already discussed, the serotyping of FMD virus is principally carried out by the Central Disease Investigation Laboratory (CDIL), Dhaka using the complement fixation test (costing about US$0.5 per test). There are eight field disease investigation laboratories (FDIL) located in different parts of the country. The officers and staff of these laboratories also collect samples to send to CDIL for serotyping of the FMD virus. There are only three veterinarians performing this role which often causes a problem when a lot of samples are sent from the field. In the last few years samples have not generally been sent to the World Reference Laboratory (WRL), Pirbright, United Kingdom, but some samples were sent in the past and the results always agreed with those obtained in the country. Serotyping obtained during outbreaks in the last 10 years are shown in Table 1.

Vaccine

The introduction of the BHK-21 cell culture line in 1970, replaced the use of primary cell culture (calf or goat kidneys) for the production of FMD vaccine and since then this cell line has been maintained in the laboratory for the production of FMD vaccine. The method of vaccine production involves cultivation of BHK-21 cell line and propagation of the virus on it. The virus is then inactivated by 0.05% formalin absorbed into aluminium hydroxide gel which contains $10^{6.5}$ to $10^{7.5}$ TCID 50. The vaccine may be mono-, bi-, or trivalent, depending on the prevalence of serotype or serotypes in the country at any given time.

The FMD Laboratory at Mohkhali is small and can only produce about 0.5 million doses of vaccine annually which is far less than the country requires in order to combat FMD. Although the laboratory has a lot of constraints, a trend for increased vaccine production has been maintained and production has increased from 100 000 doses per year when stationary (primary) culture was used to the current figure of 500 000 doses per year using roller bottle culture. Vaccine production during the last 10 years is shown in Table 2.

FMD vaccine has not been imported by the Directorate of Livestock Services (DLS). The Food and Agriculture Organization and the Bangladesh Mission (non-government organisation) donated vaccine in the wake of the unprecedented floods in 1988 that caused the death of many livestock. The French Government also donated vaccine following a severe outbreak of FMD in 1990 when the country lost about 5531 head of cattle.

With assistance from the Asian Development Bank 18 cool rooms have been set up in different district headquarters where all types of vaccines are stored. Vaccines are transported to these centres by refrigerated van. Moreover, there are refrigerators in almost all the district and thana headquarters. There is therefore no problem of maintaining the cold chain for distribution of vaccines. The cost of locally produced vaccine is about US$0.25 per dose.

Table 1. FMD virus serotypes obtained in outbreaks, 1983–92.

Year	No. of samples obtained	Serotypes obtained	
		Type	Number
1983	305	A,O,Asia 1	A = 66, O = 41, Asia 1 = 88, negative = 110
1984	152	A,O,Asia 1	A = 20, O = 12, Asia 1 = 54, negative = 66
1985	101	A,O,Asia 1	A = 16, O = 1, Asia 1 = 32, negative = 42
1986	225	A,O,Asia 1	A = 41, O = 30, Asia 1 = 76, negative = 78
1987	207	A,O,Asia 1	A = 37, O = 28, Asia 1 = 68, negative = 78
1988	212	A,O,Asia 1	A = 34, O = 26, Asia 1 = 61, negative = 91
1989	149	A,O,Asia 1,C	A = 30, O = 32, Asia 1 = 41, negative = 46
1990	376	O	O = 240, negative = 136
1991	115	O	O = 74, negative = 41
1992	91	O,A	O = 55, A = 5, negative = 31

Table 2. FMD vaccine: local production and imports, 1980-92.

Year	Doses of vaccine produced/consumed ('000)			Remarks
	Local	Foreign	Total	
1980	42	—	42	
1981	40	—	40	
1982	50	—	50	
1983	62	—	62	
1984	48	—	48	
1985	100	—	100	
1986	45	300	345	300 000 doses donated by FAO
1987	75	—	75	
1988	71	362	433	362 000 doses donated by FAO
1989	118	472	590	140 000 doses donated by Bangladesh mission; 332 000 doses donated by FAO
1990	240	590	830	590 000 doses donated by French Govt
1991	580	1100	1680	1 100 000 doses donated by French Govt
1992	580	400	980	400 000 doses donated by French Govt

— Nil

Control/Eradication

When an outbreak occurs, samples, normally vesicles off the tongue, are collected by veterinary officers in buffer solution and serotyped at CDIL. After serotyping the result is notified to the FMD vaccine production laboratory and *thana* livestock officers. The specific type of vaccine is hence supplied to the affected area and cattle around the focus of the epidemic are vaccinated in order to arrest the spread of the epidemic and confine the outbreak to a limited zone.

In addition all cattle of government and private dairy farms are vaccinated regularly. If there is enough vaccine available animals of neighbouring villages may also be vaccinated, especially along highways used as cattle movement routes, so that the epidemic can not easily spread to the interior.

This strategy has been more or less satisfactory considering the small amount of vaccine produced in Bangladesh. The vaccine is given to farmers free of cost which, due to budget constraints, is a limitation on the level of production.

Future Priorities/Constraints

As outlined above the main constraints to the control of FMD in Bangladesh are as follows:

- lack of a sophisticated laboratory for the large-scale production of vaccine. Such a laboratory should have facilities for typing and subtyping of viruses;
- existence of vast areas of common land border with neighbouring countries where FMD is endemic;
- lack of implementation of legislation for the control of animal diseases and movement of animals;
- lack of prompt and meticulous tracing of contacts, inspection and surveillance of the infected region;
- absence of quarantine camps in strategic points;
- lack of official control over slaughterhouses and cattle markets;
- lack of education/motivation of farmers through the media e.g. radio, TV, newspapers, audio-visual devices etc.

Because of the risk of FMD being introduced from neighbouring countries, regional or inter-country coordination in the control of this disease may be beneficial. A combined project with India and Myanmar in this regard may be beneficial. The advantage of adopting a regional approach would be the of sharing resources, experience and data/information and in the face of any outbreak, these countries could cooperate by supplying appropriate vaccine, technology and personnel on an emergency basis to control the spread of disease. A coordinating unit for FMD in this region could be set up to transmit information on FMD outbreaks and help neighbouring countries to adopt precautionary measures with minimum delay to avert an outbreak of this terrible disease.

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Cambodia

Sem Suan*‡ and Sen Siveth†‡

CAMBODIA is situated in Southeast Asia, between Thailand, Laos and Vietnam with the Gulf of Thailand in the southwest and has a land area of 181 035 square kilometres. The Mekong River from Tibet flows through Cambodia and Vietnam and has a major influence on the formation and the use of agricultural land due to the fluctuations in the dry and wet seasons.

The country is a vast plain field surrounding the Mekong River and Lake Tonle Sap (Great Lake). It has a tropical climate with two main seasons: the rainy season from May to October, and the dry season from November to May. The Mekong River causes Lake Tonle Sap to rise several metres during the monsoon between June and October and large areas of land are flood irrigated.

A range of mountains extends from the northwest to the north the highest of which is Oral (1833 metres). There are also some mountainous areas in the northern part of the country bordering Thailand. The nation consists of 21 provinces, including the capital Phnom Penh, and the human population was estimated as 9 million in 1992.

The Tonle Sap Basin and Mekong Lowland areas of the Central Plain consist of four main agro-ecological systems.

- The river banks or levees (*mouat tonle*) are primarily devoted to vegetables, fruit trees, and in the lower areas, to corn, sesame, and beans (grown instead of rice). The soil is relatively rich and water supply is rarely a problem owing to the high water table. The fields (*chamkar*) are usually narrow and elongated and lie perpendicular to the river bank. These areas (totalling about 500 000 hectares) are usually the most densely populated and often the most valuable, especially if they are close to markets for their products. Provinces with large areas of this type of agro-ecological system include Kandal, Kompong Cham, and Battambang.
- The lowland floodplains (*beng*), which lie between the levees and the terraces. They flood easily, depending on the height of the river during the rains. The lower parts of the lowlands are planted with flooding rice, while the high elevations are planted with rice varieties that flourish in receding waters. The soil can be fertile. These areas (estimated at 1.5 million hectares) are less densely populated but normally produce much of the rice that is consumed by the settlement on the levees. They can be found mainly in east Kandal, Kompong Chhnang, Prey Veng, and south Takeo provinces.
- The upper terraces, where mainly rain-fed agriculture is practiced (up to 200 000 hectares). The soils are often poor, apart from the rich alkaline clays of Battambang, where rice is the main crop. In addition Battambang, most of Kompong Speu Province, north Takeo, west Kandal, west Kompong Chhnang, and Pursat have this type of ecosystem.
- The Great Lake Plain surrounding Tonle Sap, which consists of flooded forest and plain. The area has rich soils on which a considerable quantity of floating and deep water rice was grown in the period prior to 1970s. It formerly covered up to 600 000 hectares but now accounts for less than 100 000 hectares.

Livestock

About 80% of the people live in the countryside and are engaged in agriculture of which rice production is the main crop. For this reason, most of the cattle and buffaloes are present in these rice-production areas. In the northeastern and southwestern provinces, the number of animals is much smaller because greater areas are covered with forest. The human populations which live in these regions practice a more primitive agriculture and animal raising is carried out in semi-wild conditions. The animals are set free in the forest in January–February and they are not attended to until May–June.

† Department of Animal Health and Production, Phnom Penh, Cambodia.
* National Veterinary Diagnostic Laboratory, Phnom Penh, Cambodia.
‡ Postal address: c/- Church World Services Cambodia, PO Box 2420, Bangkok 10500, Thailand.

In 1992 Cambodia had an estimated livestock population of 2.5 million cattle, 0.8 million buffaloes and 2.0 million pigs. The growth in animal in population is 6–7% per year. Because of many years of civil war and international boycott, the development of animal health and production services has stagnated.

Epidemiology

FMD is an endemic disease in Cambodia. It is caused by an epitheliotropic virus with a high capacity for diffusion, and this produces a high *morbidity* although the *mortality* rate is low. The major losses which this disease causes are through the inability of draft animals to work and the chronic metabolic disruption which remains in a high percentage of the affected animals. Also miscarriages and mortality in calves occur. As far as is known, in Cambodia FMD is only seen in ruminants. Pigs cannot be ruled out, however, as a very important vector for the disease.

The spread of virus depends on environmental conditions such as the uncontrolled movement of pigs and cattle, climate, the free-ranging of animals, and the high concentration of animals in the rice-producing areas. These conditions all exist in Cambodia during the months from May–December. The majority of cases develop during these months. It is also during these months that the animals have to work hardest in the rice cultivation. For this reason it is vital for the country that the cattle population is free of this disease.

In countries like Cambodia where the disease frequently occurs in the form of epidemics, there are interepidemic periods (periods without any disease manifestation) during which the cattle population shows a high level of resistance to the virus in circulation. These periods are probably interrupted when the level of resistance in the animal population decreases or new types of the virus are introduced.

FMD outbreaks, 1988–1992

The last large epidemic of FMD in Cambodia was in 1988 and affected the provinces of Banteay Meanchey, Kampot, Kandal, Kompong Cham, Kompong Chhnang, Kompong Som, Kompong Speu, Kompong Thom, Pursat, Prey Veng, Siem Riep, and Takeo, with a morbidity of 55% in the affected areas. The virus type Asia 1 (subtype India 70) was isolated.

Late in 1989, an epidemic was reported in the province of Siem Riep, which then spread into Kompong Thom, but it did not spread further into the country. Laboratory tests at that time confirmed that the FMD virus type in this case was O (subtype O1).

In 1990, a small epidemic was observed in the province of Svay Rieng, but it affected only one subdistrict which had not been reached in 1988 when the virus type Asia 1 had been isolated.

The year 1991 was the end of an interepidemic period which had lasted for two and a half years. During 1991 there were five epidemics (Table 1) from three of which samples were sent to the World Reference Laboratory (WRL) for FMD, Pirbright, United Kingdom.

The first epidemic occurred in the province of Kratie. This province had a recorded population of nearly 90 000 animals in December 1990 and its rice production is among the most important in the country. Its geographic location is epidemiologically unfavourable because it has boundaries with the provinces of Kompong Cham, Kompong Thom, Mondulkiri and Stung Treng. There were reports that the epidemic also started to appear in the province of Kompong Cham, where the situation might have become much more serious for rice production which amounted to 250 400 tonnes, the third highest production in the country. The cattle population (approximately 416 000 head) represents about 14% of the whole country population. The virus type isolated from the Kratie outbreak was Asia 1.

Table 1. Zones affected and numbers of sick and exposed animals in 1991 epidemics.

Affected zones	Sick animals	Total animals	Morbidity	Vaccinated in 1990
Kratie	60 501	86 431	69%	17%
Kompong Som	4 700	8 761	54%	34%
Kompong Speu	63 858	212 860	30%	14%
Kompong Cham	62 388	415 923	15%	23%
Battambang	?	133 330	?	23%
TOTAL		857 305	42%	22.2%

Note: This information was collected by a survey in the affected areas (the livestock department does not have good statistics).

COUNTRY LIVESTOCK AND FMD EPIDEMIOLOGY STATISTICS

Cambodia: 21 provinces (including Phnom Penh)

LIVESTOCK STATISTICS

Production unit (for animal health programs): village
Animals per owner: estimated average of 0.7 work cattle; 0.5 buffaloes; 1.3 pigs (no beef or dairy cattle)

Livestock	Number	Draft use %	Meat use %	Milk production %
Cattle	2.5	46	na	na
Buffaloes	0.8	63	na	na
Pigs	2.0	na	na	na

International stock movements: considerable movement of livestock out of Cambodia into Thailand, Vietnam and Laos. Export of animals and meat products also occurs by sea.

FMD EPIDEMIOLOGY

Seasonal incidence: most prevalent in the rainy season (May-October)
Geographic frequency: see below

Disease outbreaks and vaccinations

	1988	1989	1990	1991	1992
Serotypes recorded	Asia 1	O1	Asia 1	Asia 1	O1
Species involved	C,B	C,B	C,B	C,B	C,B
Area	Central, northwest, southeast	North-northwest	Southeast	Centre-east and southwest	Northwest
Vaccine used	O,A,Asia 1	O,A,Asia 1	O,A,Asia 1	O,A,Asia 1	O,A,Asia 1

Facilities

Veterinary centres: Department of Animal Production and Health
Veterinary officers: 6 officers; 800 field veterinary staff
Diagnostic laboratory: none (samples sent to WRL, Pirbright)
Cost per diagnostic test: free (air freight cost only)

Vaccine

Vaccine supply: imported
Cost per dose ($US): 0.6
Vaccine strategy: pre-1990 – universal vaccination
post-1990 – outbreak ring vaccination
– control zone(s) vaccination

The second epidemic, in Kompong Som, extended up to Kompong Speu. Samples were sent to WRL from these provinces. The virus type was Asia 1 with a similar subtype to the one circulating in Thailand.

In spite of the fact that the province of Kandal has a high percentage of the animals regularly vaccinated, the regions of this province bordering Kompong Speu were also affected. Fortunately, the epidemic could not penetrate further into the province due to revaccination in the disease-free zones and to other measures taken.

The province of Battambang was affected in the districts of Banon (two villages) and Battambang (one village) in November 1991. No samples were sent to WRL from these districts and hence there is little information from this outbreak.

In 1992 FMD continued to be present in an endemic form, but a number of the outbreaks reocurred. From the beginning of 1992, an outbreak developed in the province of Battambang. The first areas affected were Srok Battambang, Srok Muong Reusey and Srok Peam Ek from where it was carried to almost all of the province and also the provinces of Pursat and Banteay Meanchey. The virus was characterised in May and found to be type O (subtype O1).

The outbreaks in Pursat only affected the border areas with Battambang. The outbreaks in Banteay Meanchey reached the capital of the province. They were detected there in August 1992. In November 1992, cases were still observed in the province.

Kandal province reported a few cases of FMD in August 1992 in Srok Penhea Leu. This area is bordered by the provinces of Kompong Cham and Kompong Chhnang (see Map 1) both of which areas reported cases of FMD in 1992. To the north, Kompong Thom reported cases of FMD in many areas from February until September 1992 and, further south, Kampot reported cases in July but because of administrative problems in this province, it seems likely that there were pre-existing outbreaks.

Exact data of the morbidity of FMD is not available but in the areas visited, the figure is 20–30%. This low figure may be due to the existence of resistance against FMD in a proportion of the cattle population. The mortality is traditionally also very low in the country and reported deaths from FMD in Cambodia are very uncommon.

Origin of the 1992 epidemic

The outbreaks in Battambang began in an area very close to the area occupied by the Khmer Rouge, along the border with Thailand, but we cannot assume from which side it started. Animals constantly arrive in the province from the rest of the country and animals infected with virus O1, may have been later sold along the border with Thailand. Because this area is occupied by the Khmer Rouge it is impossible to tell if the presence of the outbreaks was caused by movement of the animals carrying the disease from one area to another, where resistance against the particular virus did not exist.

The number of animal movements in Cambodia is very high because of the large number of displaced families, the majority of whom take their most valuable possessions, cattle, with them. This situation is one of the major limitations to the control of FMD in the country.

In the last 5 years, virus types O and Asia 1 have appeared quite regularly in alternative years. There have been no reported cases of the virus type A. The number of samples sent to WRL has always been small due to internal conditions of the country which make it very difficult to collect quality samples.

Facilities

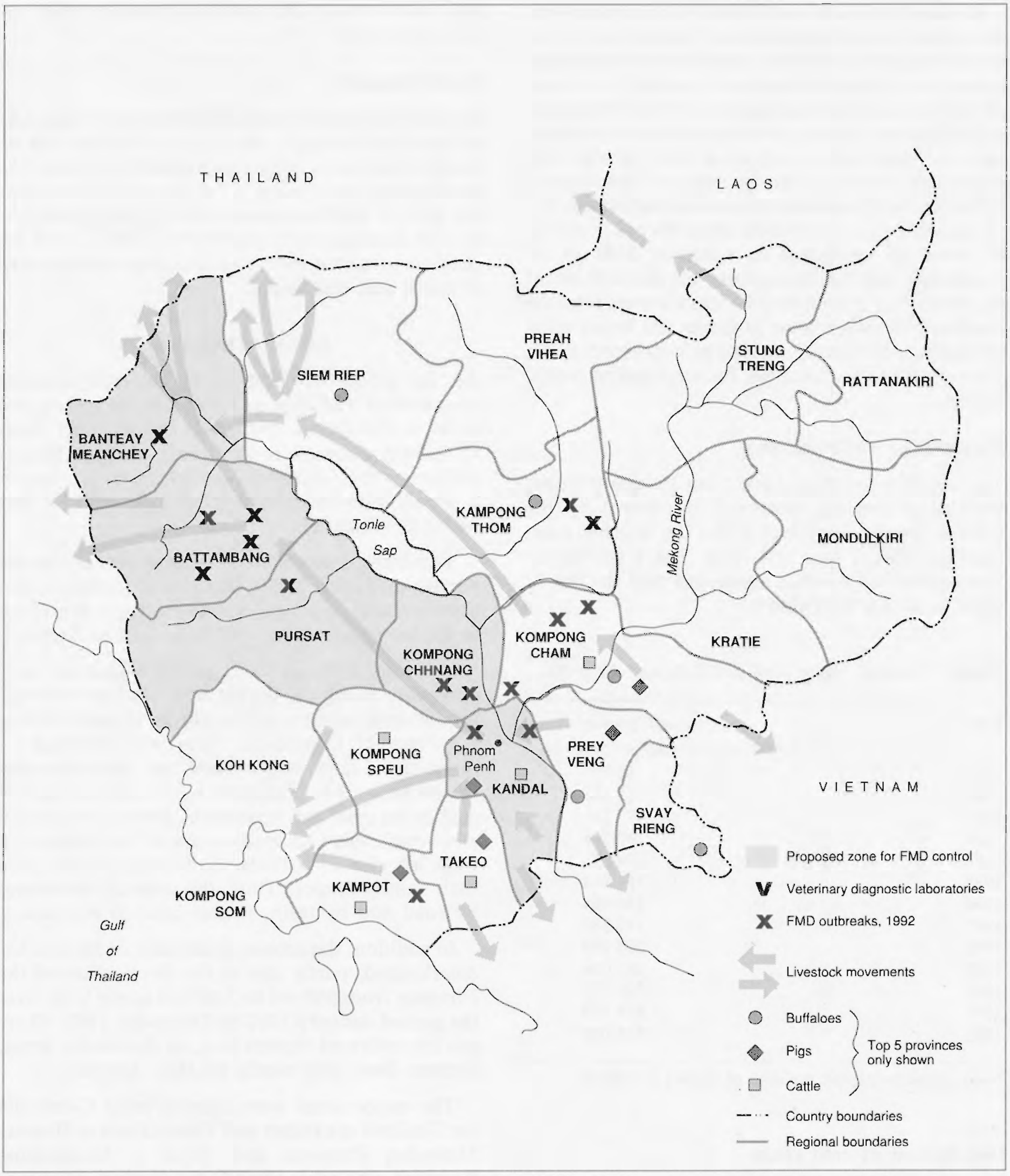
The number of field veterinary staff is about 800. Communication, starting from the subdistrict is conveyed to the district, the province and finally to the national Department of Animal Production and Health. Communication of the measures taken to restrict outbreaks of the disease follow the same route in reverse, but this is often frustrated.

It is hoped that the ELISA will be available in Cambodia in the near future enabling confirmation and typing of FMD outbreaks locally thus saving a lot of time and providing motivation for field staff to take more samples from an outbreak and to report more outbreaks.

Vaccine

The composition of the trivalent vaccine used in Cambodia against FMD is A22, O1 and Asia 1. The possibility of changing to a bivalent vaccine has been seriously considered but following the recommendations of colleagues during the last meeting of the working group of the Office International des Épizooties (OIE) in February 1991, it has been decided to continue using the trivalent vaccine.

There have been no cases observed of vaccinated animals having acquired the disease, but with the development of veterinarian activities and by maintaining the surveillance of animals, cases may be detected which could have been missed to date.



Map 1. Main livestock areas, FMD outbreaks, facilities and livestock movement patterns in Cambodia.

Because there are insufficient vaccine doses for the whole animal population, vaccination is not carried out in the affected areas but in surrounding non-affected regions in order to avoid the spread of the disease (ring vaccination). These areas consist of provinces where conditions allow the development of vaccination programs that can provide acceptable results. Initially this will result in a reduction in the *number* of animals vaccinated, but the *quality* of the vaccination program will improve. It would be inefficient to vaccinate 25% of all susceptible animals throughout the country but if the percentage is increased in specific areas then the results of the vaccination program can be expected to improve. Eventually, as long as the objective conditions permit it, the areas for vaccination would increase.

Purchase of FMD vaccines

The vaccines to be used are from Europe (Cooper Company) and are imported, purchased by the Church World Service (CWS). The vaccine types used are always type O1, A22, Asia 1 (trivalent). The number of vaccines consumed over the last 12 years is shown in Table 2.

Table 2. Vaccine doses used in Cambodia, 1980–92.

Year	No. of vaccine doses
1980	15 292
1981	115 568
1982	437 746
1983	240 224
1984	424 053
1985	351 834
1986	234 984
1987	192 388
1988	208 193
1989	285 056
1990	597 721
1991	871 100
1992	218 000

Note: Approximate cost per dose of vaccine is US$0.6.

Distribution of cold chain

The vaccines are initially stored in large refrigerators at the national department from where they can be transported by refrigerated car to provincial departments. At the provincial departments, there are refrigerators (kerosene, electric or solar power) donated by the Food and Agriculture Organization (FAO) and non-government organisations (NGOs). District veterinarians collect the vaccines from here and take them to their working areas by using ice and cold boxes.

Herd immunity

Because there is no facility for laboratory diagnosis or for virus typing in the country and the cost of transporting large numbers of samples overseas for serotyping is prohibitive, it is impossible to ascertain the level of herd immunity. With the installation of ELISA techniques by the end of 1993, it will be possible to start a survey of the levels of immunity in cattle and buffaloes.

Stock Movement

As the prices of animals in the neighbouring countries of Thailand and Vietnam are better than those in Cambodia, the movement of stock tends to be into those countries. There are also reports indicating that, in certain regions of Laos, there is a similar movement from Cambodia to Laos and hence to Thailand.

The highest numbers of animals are not in the border provinces but in the central provinces and there is therefore animal movement from the central to the border provinces, and from there to Thailand.

It is very difficult for animal movements to be controlled along the border with Thailand because only a small portion of this border is controlled by the State of Cambodia. Even with the lack of quantitative data, it is evident that the movement of the animals to Thailand has been very significant in the past, and remains so. Because of the civil war which exists in many areas in the country, a large number of families are forced to shift from their family homes. Thus, the internal movement by road and by train, is also hard to estimate.

In addition, the economic situation of farmers has deteriorated, partly due to the devaluation of the currency from 500 riel to 2400 riel to the US$, over the period January 1992 to December 1992. There are unconfirmed reports that, in the border areas, farmers have sold nearly all their animals.

The major areas were animals leave Cambodia for Thailand are Poipet and Thmar Pouk in Banteay Meanchey Province and Bavel in Battambang Province. The other areas of this latter province are heavily mined and many animals die every day because of mines.

There is no exodus of animals from Pursat Province to Thailand due to the densely forested areas along the border. The provinces of Koh Kong, Kompong Som and Kompot report a large movement of animals and meat products by sea.

The provinces of Kompot, Takeo, Prey Veng, Kompong Cham, Kratie and Ay Rieng export animals to Vietnam.

Control/Eradication Strategies

From what is known there was no vaccination campaign before 1980 indicating that the Department of Animal Health must have decided not to work actively in the control and eradication of FMD. No reports are available on the locations and numbers of outbreaks in the period before 1980.

From 1980–1992 there was active involvement by the Department of Animal Health and Development in the control of FMD by means of national vaccination program for all cattle and buffaloes. Several NGOs and, in 1991, FAO have assisted the department in supplying necessary equipment such as syringes, needles and forceps as well as cold chain equipment such as kerosene fridges, ice-boxes, motorbikes and, more recently, solar-powered fridges. Besides that there had been several training courses for farmers and vaccinators on the importance of vaccination and on the implementation of the vaccination campaign.

The result of these supporting activities was that, on average, 15–20% of the cattle and buffalo population were vaccinated. The reason that these figures were not higher was that the ongoing civil disturbances and the international boycott of Cambodia did not allow international and bilateral financial aid. In addition, infrastructure on the whole was still very poor and the inefficient structure of the department, and lack of communication with the provincial departments, prevented direct communications and reporting.

Recently there has been a shift away from mass vaccination as a control measure for FMD. At a national seminar about FMD in August 1992, another strategy for FMD control was discussed. Instead of trying to achieve overall national coverage with FMD vaccination (which has the difficulties mentioned above) all available manpower and equipment may be better used to achieve a higher percentage of animals vaccinated (80%) in the FMD-prone areas (provinces of Kandal, Pursat, Kompong Chhnang, Battambang and Banteay Meanchey); and those which are important because of animal movements.

A special FMD emergency group has also been proposed to investigate every outbreak of FMD that is reported to the department. As well as such measures at a national level, on provincial level there needs to be other strategies to improve the reporting system and to raise the awareness amongst farmers and vaccinators about the relevance and importance of FMD vaccination.

When an outbreak of FMD occurs samples from the animals clinically affected are collected in order to identify the type of the virus and determine if the vaccine employed is actually useful for the current epidemic situation in the country. Samples are still sent to WRL but we hope that, in the future, samples can be sent to Thailand, which would be much less costly.

India

C. Natarajan,* A.K. Mukhopadhayay,† G.K. Sharma§ and V.A. Srinivasan‡

INDIA is the seventh largest country in the world in terms of area and has a human population of over 870 million. It is a federal republic comprised of 25 states and 6 union territories.

The Himalayan mountains separate India from China, Russia, Afghanistan and Pakistan in the north. At the centre of the country is the Vindhya mountain region. South of this mountain range lies the Deccan plateau. The southern region of the country is a peninsula with the Arabian Sea on the west, the Bay of Bengal on the east and the Indian Ocean on the south. The northwest of the country has desert. The southeast has swampy areas bordering Bangladesh and Mynamar.

The western and eastern peninsular area is bordered by the Western and Eastern Ghats respectively. The major rivers in the country originate in the Himalayan region and the Western Ghats. The north Indian rivers flow through the vast highly fertile northern plains. The major rivers of central India originate in the Vindhya Mountains and the major rivers of southern India originate in the Western Ghats and flow east across the country and join the Bay of Bengal. The country has seven climatic zones ranging from tropical rainforest in the southwest and northeast to tropical savanna and tropical semi-arid steppe over much of the peninsular; tropical steppe and tropical desert in the northwest; humid subtropical with dry winters in the north; and a mountain climate in the far north.

* Indian Veterinary Research Institute, Hebbal, Bangalore 560 024, India.
† Indian Veterinary Research Institute, Izatnagar (UP), 243 122, India.
§ Animal Disease Research Laboratory, National Dairy Development Board, Anand 388 001, India.
‡ Indian Immunologicals, Rakshapuram, Gachibowli, Hyderabad 500 133, India.

Livestock

The main domestic animals are cattle, buffaloes, sheep and goats. The cattle serve a dual purpose of draft and dairy. The buffaloes are reared mainly for dairying and sheep and goats are mainly for meat production. No breeds of cattle and buffalo are reared exclusively for beef production and only culled animals are used for slaughter. Official information on livestock populations are only available for 1987 and are shown in Table 1. The growth pattern of livestock in India from 1951–82 is shown in Table 2.

Cattle and buffaloes

Various local breeds of cattle (Sindhi, Tharparkar, Gir, Kankreju and Ongole) are popular in the northern, western, and southern parts of India. Holstein, Friesian and Jersey breeds of cattle were introduced for cross-breeding in India 3–4 decades ago and cross-bred cattle are reared in all parts of the country. Popular breeds of buffalo are Murrah, Neeli and Surti; the home tract of these breeds are Punjab and Gujarat.

Sheep and goats

The current sheep population is 49 million and there are 37 breeds of sheep in India. Cross-breeding programs have used breeds such as Merino and Rambouillet for wool production, and Suffolk, Southdown and Corriedale for meat production

Goat rearing is popular in India and the goats are used for meat and milk production.

Pigs

Intensive pig breeding is limited to a few states in the northeastern region and is not popular in other parts of the country.

Table 1. Livestock populations in India by state, 1987 ('000).

State	Cattle	Buffaloes	Sheep	Goats	Pigs
Andhra Pradesh	12 374	8 757	6 872	4 876	724
Arunachal Pradesh	311	12	28	108	243
Assam	7 278	862	67	2 134	641
Bihar	20 841	4 872	1 520	15 032	1 053
Goa	112	40	—	18	86
Gujarat	6 240	4 502	1 559	3 585	93
Haryana	2 201	3 828	890	674	339
Himachal Pradesh	2 245	795	1 112	1 120	18
Jamnu & Kashmir	2 765	565	2 493	1 396	2
Kanataka	10 175	4 036	4 727	3 888	302
Kerala	3 424	329	30	1 581	136
Madhya Pradesh	28 549	7 351	834	7 751	601
Maharastra	16 979	4 753	2 872	9 191	334
Manipur	770	141	16	44	383
Meghalaya	587	28	15	194	280
Mizoram	50	5	1	20	82
Nagaland	203	15	1	72	314
Orissa	13 576	1 509	1 840	4 804	590
Punjab	2 832	5 577	508	537	96
Rajastam	10 922	6 344	9 933	12 577	205
Sikkim	184	3	11	98	31
Tamil Nadu	9 343	3 129	5 881	5 921	661
Tripura	828	16	3	441	89
Uhar Pradesh	26 323	18 240	2 181	11 321	2 489
West Bengal	20 311	1 164	2 312	22 695	768
Delhi	55	285	—	22	42

Source: Government of India

Table 2. Growth pattern of the Indian livestock population, 1951–82.

Species	Percentage change in population		
	1951–61	1961–72	1972–82
Cattle	+13.1	+1.5	+7.9
Buffaloes	+18.0	+12.1	+21.6
Sheep	+2.8	−0.5	+22.0
Goat	29.0	10.8	41.0
Pigs			

Source: Directorate of Economics and Statistics, Ministry of Agriculture, Govt. of India

History of Foot-and-Mouth Disease

The first systematic work on foot-and-mouth disease (FMD) was initiated at the Indian Veterinary Research Institute (IVRI), Mukteswar in 1943 for isolation, identification and typing of the FMD virus using World Reference Laboratory (WRL), Pirbright, United Kingdom, stock strains of type O, A, and C. Type O was reported to be most prevalent, followed by types A and C. With the assistance of WRL, an isolate which was different from the classical types was identified and designated as Asia 1 in 1957. Later on all four types were recorded from many parts of the country.

The Indian Council for Agricultural Research (ICAR) initiated an All India Coordinated Research Project (AICRP) on FMD virus typing in 1968 with a central laboratory at IVRI, Mukteswar and three regional laboratories at Hyderabad, Hissar and Calcutta. The objective was to isolate and identify the various types and subtypes of the virus prevalent in India using the complementation fixation test (CFT) standardised at the WRL. The scope of this project was expanded in 1972 to include 10 epidemiological units in addition to eight regional centres and two laboratories funded by the National Dairy Development Board (NDDB) at Anand and Ooty, in order to elucidate the epidemiology of the disease and to provide support to vaccine manufacturing units to incorporate the most appropriate strains of FMD virus in the vaccine. The work carried out in the above centres led to a thorough understanding of the epidemiology of the disease and a network of diagnostic laboratories capable of carrying out micro-CFT, micro-serum neutralisation tests (SNT) and enzyme-linked immunosorbent assay (ELISA) have been developed.

COUNTRY LIVESTOCK AND FMD EPIDEMIOLOGY STATISTICS

India: 25 states; 6 union territories

LIVESTOCK STATISTICS

Production unit (for animal health programs): village
Animals per owner: estimated averages — 4 dairy cattle; 2 working cattle; 2 buffaloes; 40 sheep & goats

Livestock	Number (million, 1987)	Draft use %	Meat use %	Milk production %	Estimated international movements (no. per year)[a] Entering	Leaving
Cattle	199.7	30	na	28.5	200–400	na
Buffaloes	77.0	8.6	na	47	0	na
Pigs	10.6	na	na	na	300–500	na
Sheep	45.7	na	mainly	na	na	na
Goats	110.2	na	mainly	na	na	na

[a] Regular export of live animals is minimal for breeding, mostly in Southeast Asian countries

Meat exports: 51 540 t buffalo meat and 7968 t goat/sheep meat were exported in 1987–88

FMD EPIDEMIOLOGY

Seasonal incidence: January–April; August–December
Geographic frequency: none

Disease outbreaks and vaccinations

	1988	1989	1990	1991	1992
Outbreaks (no.)	1940	790	4186	524	950
Serotypes recorded	O,A,C,Asia 1	O,A,C,Asia 1	O,A,C,Asia 1	O,A,C,Asia 1	O,A,C,Asia 1
Species involved	C,B,P,S,G	C,B,S,G	C,B	C,B,P,S,G	C,B,P,S,G
Vaccine used	O,A,C,Asia 1	O,A,C,Asia 1	O,A,C,Asia 1	O,A,C,Asia 1	O,A,C,Asia 1

Facilities

Veterinary officers: 61 National Dairy Development Board full-time veterinarians; 36 000 field veterinarians
Veterinary centres: 10
Diagnostic laboratories: Central FMD Typing Laboratory, Indian Veterinary Research Institute; FMD Control Project Laboratory, Ooty; Animal Disease Research Laboratory, Anand; Indian Immunologicals, Hyderabad
Cost per diagnostic test ($US): 1.0

Vaccine

Vaccine supply: IVRI; Indian Immunologicals; Bharatiya Agro Industries Foundation; Hoechst (no imports)
Cost per dose ($US): 0.12–0.15
Vaccine strategy: (i) control zone(s) vaccination
(ii) as requested by livestock owners

Epidemiology

During the period from 1988-92, a total of 8390 outbreaks were recorded in the country with the maximum number (4186) being in 1990. Details are shown in the country statistics. No outbreaks were reported from Andaman, and Nicobar Islands (which have been free of FMD since 1977), Chandigarh, Delhi, Dadra and Nagar Haveli during 1988–92. The states of West Bengal, Maharashtra and Karnataka reported maximum numbers of outbreaks. Wide variation in the seasonality or clustering of outbreaks with time and space (regionally), could be ascribed to seasonal and agricultural operations based on animal migration and interstate trade of livestock. Generally the clustering of outbreaks occur from January-April and August-December in almost all the states.

FMD virus type distribution, 1988–92

During the period from 1988-92 type O virus dominated the field as the preponderant virus type followed by Asia 1, A22 and C. Details of the FMD virus types identified during 1988–92 are given in the country statistics and Table 3.

Table 3. Reported isolation of FMD virus types, 1988–92.

Virus types	Year					Total
	1988	1989	1990	1991	1992	
O	587	329	709	332	666	2623
A	65	72	96	73	136	442
C	4	1	27	31	18	81
Asia 1	90	78	250	62	160	640
Total	746	480	1082	498	980	3786

Economic losses

The estimated economic loss due to FMD was 4200 million rupees per year (Ellis and James 1976) for milk and draft animals only (i.e. not including losses due to small ruminants and pigs) with more recent estimates by the AICRP of approximately 5000 million rupees per year ($US approx. 165 million).

Facilities

Typing of FMD virus is based mainly on micro-CFT and ELISA tests. All the strain differentiation studies of FMD virus are based on ELISA and two dimensional micro-SNT using bovine vaccinate sera (BVS). Adequate facilities have been developed at the Central FMD Typing Laboratory, IVRI; the FMD Control Project Laboratory, Ooty; the Animal Disease Research Laboratory, Anand; and Indian Immunologicals, Hyderabad, for strain differentiation studies. A list of the diagnostic techniques available in India is given below.

Monoclonal antibody (Mab) panels against FMD virus reference strains

Development of full facilities for hybridoma and production of monoclonal antibody against Indian reference/vaccine strains have been completed. Mab panels developed against types O, A22, and Asia 1 have been profiled against field isolates. The Mab panels against type C and virus infection associated (VIA) antigen are under characterisation.

Virus infection associated antigen and antibody

Highly purified VIA antigen was prepared for screening the population exposed to FMD and for fulfilling quarantine requirements for animals intended for export. Screening of VIA antibodies using double immunodiffusion (DID) and ELISA proved to be versatile in identifying animals exposed to FMD infection. The test results were in full agreement with the results from micro-neutralisation tests. Estimation of VIA antibodies in the vaccinated population up to an age of two years could be used effectively in screening of animals intended for slaughter for export of meat.

Development of an ELISA kit for FMD virus typing

A simple kit based on ELISA has been developed by NDDB for the field-based typing of FMD virus. The kit has proved to be efficient in typing of FMD virus and requires minimum facilities. The kit is being tested for field application.

Polymerase chain reaction and sequencing techniques

Application of new technologies for the characterisation of FMD virus have been accomplished with the generation of facilities for polymerase chain reaction (PCR) and sequencing of the genome of FMD virus at IVRI, Bangalore. Facilities for Western blot, isoelectric focusing, etc., are also available and are applied extensively (see Box 1).

Vaccine

The vaccine currently produced in India is a BEI/formalin inactivated aluminiun hydroxide gel adsorbed quadrivalent vaccine incorporating types O, A22, C and Asia 1. The vaccine is produced in BHK-21 suspension cell system using biofermentors.

Box 1. FMD Diagnostic techniques available in India

Enzyme-linked immunosorbent assay
Immunoelectro transfer blot technique (Western Blot)
Hybridoma technique for production of monoclonal antibodies
Radioimmunoassay
Nucleic acid hybridisation technique for detection of viral genomes
Polymerase chain reaction
Nucleotide sequencing
Fluorescent antibody technique
Immuno-peroxidase staining
Micro-serum neutralisation technique
Complement fixation test

The vaccine is manufactured at four vaccine plants: IVRI, Indian Immunologicals, Bharatiya Agro Industries Foundation (BAIF) and Hoechst. India has a total production capacity of about 45 million polyvalent doses of vaccine. The actual production, however, is much less, although the country is self-sufficient and there is no import of FMD vaccine.

The cost of the locally produced vaccine is approximately US$0.12–0.15 The vaccine is distributed in expanded polystyrene boxes containing cool packs to maintain the temperature between 2 and 8°C. At stocking points the vaccine is stored in refrigerators and the cool packs are stored in the deep freeze. The vaccine is taken in small insulated boxes during vaccination along with cool packs/ice.

Stock Movements

There is no regular pattern of animal movement in India. However, based on experience the Government, in consultation with the state animal husbandry departments, has developed a map showing the approximate status of animal migration. There is extensive migration of animals from west to east and from central India towards the south. These migrations depend on seasons, availability of feed, and also on various religious festivals. During the summer months the local annual cattle markets are held (about 10 000 markets per year throughout the country) and a large exchange of livestock takes place. In addition dairy animals, both cows and buffaloes, are transported from their home tracks to other places for trade and for breed improvement. Beef eating is not popular in India (except in Kerala and West Bengal) and livestock movement for slaughter is usually the culled animals to the cities.

Export of meat

In 1987–88, 51 540 tonnes of buffalo meat and 7968 tonnes of goat/sheep meat were exported (including canned meat and animal casings).

Control/Eradication Strategies

Monitoring the FMD situation in a vast country like India, with seven agro-climatic zones and having a FMD-susceptible livestock population of 419.5 million spread over an area of 3.3 million sq km is a challenging task. The population density ranges from 7–340 head per sq km. The task of monitoring reportable diseases is performed by the Department of Animal Husbandry and Dairying with the active participation of state animal husbandry/veterinary departments throughout the country. The sensory arm of the monitoring system is the field veterinary officers at the field level hospitals/dispensaries.

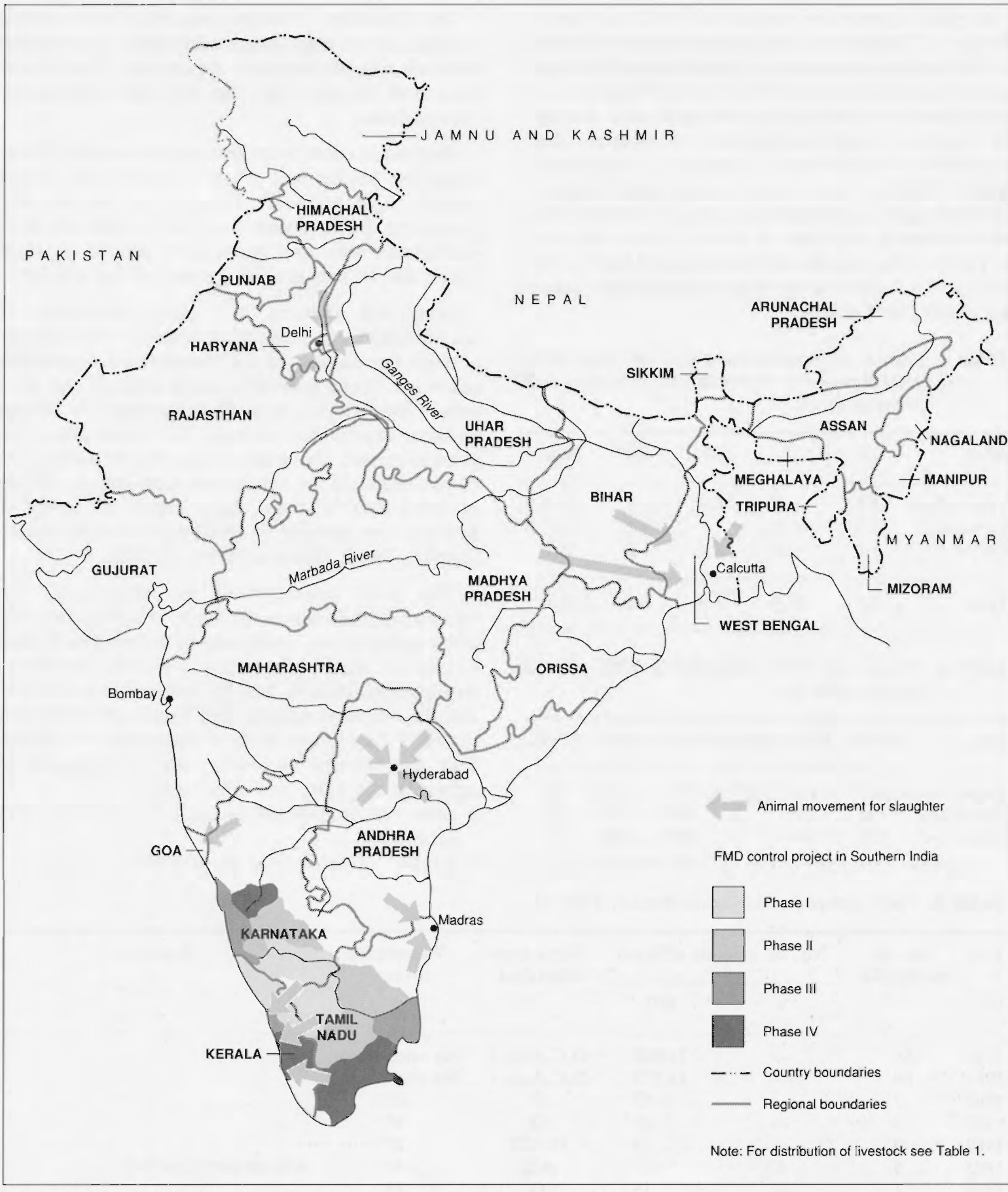
As early as the 1950s the Government of India adopted the policy of vaccinating high milk producing animals in the government farms and containing the outbreaks by vaccination of in-contacts.

The current policy for the control of FMD continues to stress selective vaccination of susceptible stock using quadrivalent cell culture vaccine. This policy is being effectively implemented in organised livestock farms owned by the government, public and private sectors. In villages, however, this can not be implemented properly because of the high cost of the vaccine; the need for repeated vaccinations; and the lack of awareness and acceptance among farmers of the benefits of vaccination. A slaughter policy cannot be adopted in India because of the socioeconomic implications.

The Indian Government has also undertaken a scheme for subsidising the cost of FMD vaccine for dairy animals. Under this scheme, the Government meets 50% of the cost of the vaccine, the State Government 25% and the livestock owner the remaining 25%.

Control program in southern India

NDDB is implementing a phased systematic control program in collaboration with the state animal husbandry department, dairy federations and milk unions in parts of three southern states of India: Tamil Nadu, Kerala and Karnataka. The strategy adopted is to ensure vaccination of all susceptible livestock and closely monitor the occurrence of outbreaks and control by ring vaccination, thus providing valuable information on field problems associated with the control of FMD, as well as some practical solutions.



Map 1. Main livestock areas, facilities and livestock movements in India.

A pilot scheme for control of FMD in Nilgiris district of Tamil Nadu was initiated by the NDDB, in 1982 with the assistance of the Overseas Development Administration (ODA), United Kingdom, to understand the problems in transport and storage of vaccine, mass vaccination of animals and regulation of movement of animals. Using funds from NDDB, state governments and farmers (through dairy cooperative unions), the scheme was later extended in phases to cover 27 more districts in Tamil Nadu, Kerala and Karnataka (Map 1). The details of vaccination carried out in different states are shown in Table 4.

Table 4. Number of vaccinations carried out in the FMD control program of southern India by state and phase (million).

State	I	II	III	IV	Total
Tamil Nadu	4.3	6.3	8.6	3.8	23.0
Karnataka	2.9	6.5	1.5	3.2	14.1
Kerala	1.9	0.6	1.1	1.5	5.1
Total	9.1	13.4	11.2	8.5	42.2

Table 5. Number of FMD outbreaks in FMD control project area.

State	87–88	88–89	89–90	90–91	91–92	92–93
Tamil Nadu	127	81	37	980	61	62
Karnataka	83	15	2	238	122	41
Kerala	218	30	7	100	164	77

The first three vaccinations of all susceptible animals except pigs were undertaken at six-month intervals free of charge to the farmer. The farmers then had to pay for the 4th and subsequent vaccinations.

Free vaccinations were continued, however, 15 km along the border and 3 km on either side of the animal migratory route, to create an immune belt protecting the enclosed susceptible animals. Ring vaccination was also undertaken around areas of outbreaks to prevent the spread of the disease.

Livestock owners are only interested in vaccinating their productive animals which leaves a large population of non-vaccinated susceptible animals. These non-vaccinated animals act as a source for virus to survive and transmit the disease to other susceptible animals. The vaccination program discussed above has helped reduce the number of outbreaks in the vaccinated area and the details of outbreaks in these three states are given in Table 5. The number of FMD outbreaks in Nilgiris district, Tamil Nadu is given in Table 6.

The field veterinarians are responsible for vaccinating the animals regularly. It is their responsibility to report the outbreaks to authorities in their respective state government animal husbandry department. NDDB has 61 veterinarians working full-time on vaccinations and disease monitoring in the field. The results of the program clearly indicate that the disease incidence can be reduced by adopting the following measures:

- mass vaccination of animals to maintain herd immunity;
- control of movement of animals;

Table 6. FMD outbreaks in Nilgiris district, 1980–92.

Year	No. of outbreaks	No. of animals affected		Virus type identified	Vaccination coverage	Remarks
		V	NV			
1980	66	—	14 000	O,C,Asia 1	No vaccination	
1981	69	—	14 972	O,C,Asia 1	No vaccination	
1982	3	—	12	O	93	
1983	3	—	16	O	91	
1984	4	—	19	O,A22	87	
1985	5	57	117	A22	88	A22 variant reported
1986	1	—	16	O	88	
1987	4	11	75	O	80	
1988	35	543	365	O	84	O variant reported
1989	6	2	23	O	65	
1990	1	—	41	O	51	Migratory animals from Karnataka
1992	25	56	275	O	78	

V = Vaccinated
NV = Non-vaccinated
— = None

Box 2. Key issues

Some of the important points relating to FMD diagnosis, epidemiology and control in India are as follows:

- application of quick, easy and inexpensive field diagnostic methods;
- development of improved and cheaper vaccine with uniform quality control;
- strengthening of infrastructure for prompt and reliable disease reporting and action for disease control;
- intensively monitored vaccinations to achieve adequate herd immunity;
- legislative and legal support for institution of measures of disease control;
- bilateral and multilateral cooperation on control at international borders;
- careful management of existing resources through appropriate linkages; and
- research support for referral services.

- ring vaccination of animals around the villages where FMD outbreaks are noticed, to prevent the spread of the disease.

The limiting factors for effective implementation of an FMD control program in India are given below:

- lack of adequate funds for vaccination. The farmers cannot afford/are not interested in the purchase of vaccine as a large population of their livestock are not highly productive. These unvaccinated animals pose a threat to high-yielding vaccinated animals.
- lack of stringent law to support and enforce vaccination and movement of animals.

Future Priorities/Constraints

The control of FMD in India is a complex problem. The major constraint relates to the existence of a large population of exotic crossbred and indigenous animals exhibiting different levels of susceptibility. Additional problems include the unrestricted movement of animals; the multiplicity of types and strains of FMD virus; the wide host range including wildlife; existence of carriers; and lack of legislative support. The type of animal farming in India is mainly small holding and a few organised herds are owned by the Government and by individuals. Control of FMD in India can be attempted only by vaccination and the current policy has already been discussed above. Some of the key issues relating to the control of FMD in India are shown in Box 2.

References

Ellis, P.R. and James A.D. 1976. An economic appraisal of the proposed new foot-and-mouth disease vaccine production plant in India. Unpublished report to UK Overseas Development Agency. Veterinary Epidemiology and Economics Research Unit, University of Reading, England.

Laos

Sommay Mekhagnomdara and Southone Vongthilath*

LAO PDR has a land area of 236 725 sq km and has land borders with Vietnam in the east, Cambodia in the south, Thailand in the west and China and Myanmar in the north. The Lao population of just four million in 17 provinces is comprised of three ethnic groups (68 minorities): Lao Loum, Lao Theung and Lao Soung which are classified according to the geographical relief and agro-ecological areas where they live. Animal production systems vary for each ethnic group and in each agro-ecological zone.

Livestock

The Lao Loum people make up about half the population and live predominantly in the lowland areas. In this area farmers practice rainfed and some irrigated rice cultivation. Animals are widely distributed in each household, averaging 2–3 buffaloes, 2–3 cattle, 2 pigs and 10–20 ducks and chickens. In general indigenous breeds of cattle, buffaloes and swine are raised. Management and feeding practices have not changed much for several decades. Grazing animals on wasteland and feeding with rice straw are common throughout the country. These animals have comparatively low productivity but are well adapted to the production environment.

Livestock production in Lao PDR is predominantly based on subsistence-level smallholders who use livestock as a supplementary and complementary resource to crop production. The distribution of livestock in Laos is shown in Table 1.

Role of livestock in agricultural development

The contributions made by livestock include protein for human consumption, draft power, capital accumulation, manure for crop production, gross domestic product and export earnings. Each of these is discussed briefly below.

Source of protein. Animals are a major source of protein in developing countries. Animal protein is important, not only in terms of quality but also with respect to quality. Products such as eggs, beef, pork, poultry and fish contain almost all the amino acids required for humans.

Draft power. According to our preliminary estimation, animals provide more than 95% of traction power in Lao PDR. Draft power not only reduces the drudgery of land preparation, but also facilitates timely planting and enables farmers to cultivate a larger land area than would be possible with only human labour.

Capital accumulation. Animals serve as a living bank of reserve capital that can be converted to cash as required. This fund can be used to cover immediate cash needs such as medical expenses; school clothes and fees; and purchase of rice when natural disasters cause crop failures.

Manure. Animal manure contributes significantly to the household production system. Manure is valued as a source of nutrients in crop production and soil improvement and in some countries it is a major source of cooking fuel.

Gross domestic product and export earnings. Livestock contributes a major share to the gross domestic product (GDP) in developing countries. In Lao PDR, livestock contributes nearly 11% to GDP which is probably an underestimate of the real contribution because intermediate products like traction power and manure are hard to estimate.

Epidemiology

Foot-and-mouth disease (FMD) is endemic in the country and causes fairly important economic losses in terms of lower productivity, loss in draft power, reduced income security and loss of export earnings. During 1991 FMD outbreaks were reported in some provinces. However, during 1992–93 there has been a considerable reduction in the number of outbreaks due to an extensive vaccination program.

* Technical Division of Veterinary Regulation, Department of Livestock and Veterinary, C/- AIDAB First Secretary, Australian Embassy, Vientiane, Laos.

Table 1. Livestock populations (1993) and vaccinations (1992) in Laos by province.

Province	Livestock numbers ('000)				No. of animals vaccinated
	Cattle	Buffaloes	Sheep and goats	Pigs	
Vientiane Prefecture	63	60	3.6	40	240
Phong Sali	12	28	0.5	36	—
Luang Nam Tha	16	22.5	11.5	57	—
Udomsai	37	59	22.4	150	500
Bokeo	18	25	8.3	92	1 000
Luang Phabang	28	60	22.4	145	—
Hua Phan	25	61	22.5	160	—
Saya Buli	38	56	3.5	81	400
Xieng Khwang	62	45	12.8	80	40
Vientiane	119.5	115	9.1	146	200
Bolikhamsai	36	49	0.5	90	8 000
Khammuan	43	95	0.6	96	4 000
Savannakhet	268	222	17.7	131	15 000
Salavan	91	70	3.7	76	10 000
Sekong	14.5	22	3.5	29	—
Champasak	133	133	0.5	123	10 000
Attafeu	5.5	44	0.7	27	—

— = None

Disease outbreaks were reported from northern (Bokeo and Oudomxay), central (Vientiane prefecture-province and Borikhamsay) and southern (Champasak) provinces during 1992. The geographical distribution of the disease is shown in Map 2.

Although disease outbreaks occurred throughout the year, they were recorded more frequently during paddy planting season.

Facilities

There are no facilities for vaccine production or typing of FMD virus in Lao PDR. However, the occurrence of 2 virus types, O and Asia 1, has been confirmed in the past by the World Reference Laboratory (WRL), Pirbright, United Kingdom. Serotyping by WRL takes 2–3 weeks.

Stock Movement

The movements of the animals in the country is shown in Map 2. Livestock production, particularly large ruminants, exceeds domestic demand and hence forms one of the main sources of foreign exchange earnings. In 1992 foreign exchange earnings for export of livestock to neighbouring countries was estimated to be about US$15.7 million. At present, the export of livestock consists mostly of live animals.

Current Control/Eradication Strategies

The currently adopted policy for the control of FMD in Lao PDR is preventative vaccination in the endemic areas using bivalent vaccine against virus types O and Asia 1 , and containment of outbreaks by vaccination of cattle and buffaloes. The movements of animals in affected areas, is also controlled. The vaccines have been procured from Bhartiyn Agro-industries Foundation (BAIF) Pune, India. The number of animals vaccinated in different provinces during 1992 is shown in Table 1.

The national animal health programs including FMD control, are planned, supervised, coordinated and monitored by central and provincial veterinary services. District livestock/veterinary services are responsible for implementing disease control programs, at village level with the help of village veterinary workers.

Problems and Constraints

There are several constraints for the control of FMD in Lao PDR, which are outlined below.

- FMD is a problem of the whole subregion.
- There are difficulties in vaccinating cattle and buffaloes kept in open range.
- Farmers are not fully aware of the importance of the vaccination.

- Livestock and veterinary services in the central government and provincial governments are not well coordinated for data collection.
- Livestock trade along the boundary has not been controlled and has increased.
- Veterinary regulation has not been effectively used and each province has its own differing veterinary regulations.
- Animal movement cannot be controlled.
- There is insufficient cold-chain equipment for storage and transport of vaccine in the field.

Map 1. Geographic features and livestock distribution in Laos.

COUNTRY LIVESTOCK AND FMD EPIDEMIOLOGY STATISTICS

Laos: 17 provinces

LIVESTOCK STATISTICS

Animals per owner: estimated average — 1-2 beef cattle; 1-2 work cattle; 2-3 buffaloes; 2-3 pigs; 0.02-0.03 sheep and goats

Livestock	No. (million)	Draft use %	Meat use %	Milk production %	Estimated livestock traded within country[a] '000/year	Estimated international movements[a] '000/year	
						Entering	Leaving[b]
Cattle	1.0	20	80	0	60	20	50
Buffaloes	1.2	90	10	0	50	10	45
Pigs	1.6	na	na	na	100	40	60
Sheep and Goats	0.14	na	na	na	na	na	na

[a] Asian Development Bank 1990
[b] Foreign exchange earnings US$15.7

FMD EPIDEMIOLOGY

Seasonal incidence: May-July; paddy planting season
Geographic frequency: more frequent in areas with low percentage of vaccination; with poorer communication/transportation; and with natural grazing land

Disease outbreaks and vaccinations

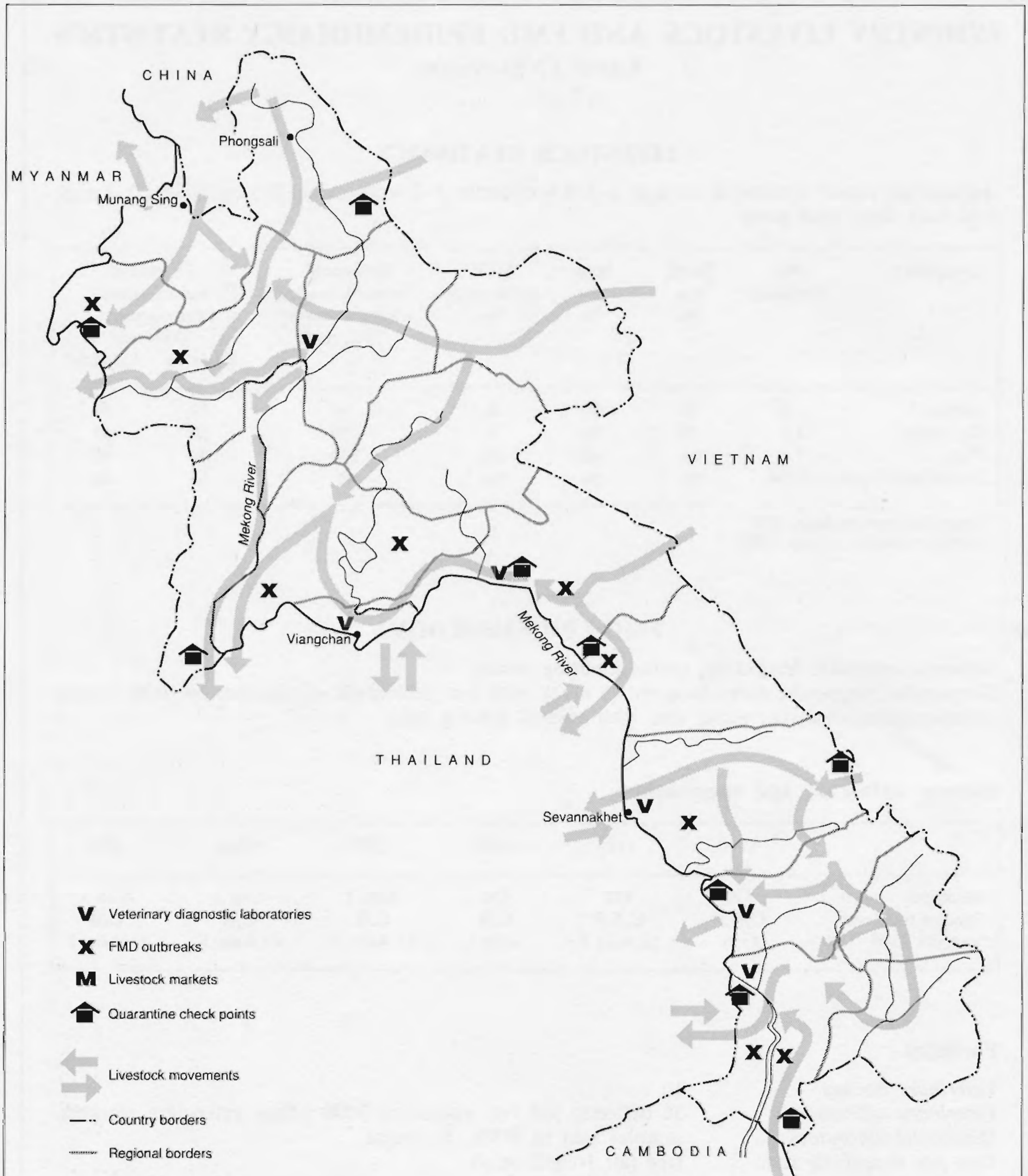
	1988	1989	1990	1991	1992	1993
Serotypes recorded	O1	O1	O1	Asia 1	Asia 1	Asia 1
Species involved	C,B,P	C,B,P	C,B	C,B	C,B	C,B
Vaccine used	O,A	O,Asia 1	Asia 1	O,Asia 1	O,Asia 1	O,Asia 1

Facilities

Veterinary centres: 10
Veterinary officers: 36 officers; 398 vet. assistants; 3000 village veterinary workers
Diagnostic laboratory: samples sent to WRL, Pirbright
Cost per diagnostic test: free (air freight only)

Vaccine

Vaccine supply: 70% from within Asia (India)
Cost per dose ($US): 2.0
Vaccine strategy: (i) outbreak ring vaccination
(ii) control zone(s) vaccination



Map 2. FMD outbreaks, facilities and livestock movement patterns in Laos.

Malaysia

Ghan Chee Hiong*

MALAYSIA shares a common border with Thailand in the north, Singapore in the south and with Indonesia and Brunei in the east. The country is divided administratively into 13 states and one federal territory (Kuala Lumpur). Eleven of the states and Kuala Lumpur form *Peninsular Malaysia* and are the subject of this paper. The other two states are Sarawak and Sabah on the island of Borneo which have never recorded foot-and-mouth disease (FMD) and are not included in this report. The border with Thailand stretches some 500 km over hilly terrain except for an 80 km eastern segment separated by the Golok River. This segment is on flat terrain, densely populated on both sides, with livestock rearing, rice cultivation and rubber production being predominant agricultural activities. This segment of the border is accessible to livestock.

* Veterinary Research Institute, Peti Surat 369, 31400 Ipoh, Malaysia.

Livestock

The susceptible livestock populations in each state of Peninsular Malaysia are shown in Table 1. Malaysia is a net exporter of poultry, eggs and swine. However, the country faces an acute shortage of slaughter cattle, sheep and goats. Consequently, about 75% of beef and 85% of mutton (lamb and goat meat) are imported.

The occurrence of FMD in Peninsular Malaysia is directly related to illegal importation of cattle from Thailand for breeding and slaughter.

History of Foot-and-Mouth Disease

Since the early seventies, Malaysia has experienced eight episodes of FMD mainly due to virus types O1 or Asia 1 (see Table 2). The year 1992 was an exceptional year in that infection due to both virus types occurred albeit in different localities along the border. In each instance, infection was detected concomitant to outbreaks in south Thailand. East Malaysia has never recorded FMD.

Table 1. Livestock populations in Peninsular Malaysia, 1991.

State[a]	Buffaloes	Cattle	Swine	Goats	Sheep
Perlis	500	10 980	100	13 520	11 030
Kedah	30 410	102 500	4 320	34 550	23 650
Penang	320	13 190	251 030	6 690	2 810
Perak	18 790	43 380	407 690	35 010	25 240
Selangor	1 480	25 590	130 740	15 430	10 640
Federal Territory (Kuala Lumpur)	30	670	—	210	—
Negeri Sembilan	10 300	37 120	607 370	24 950	33 280
Melaka	10 000	26 290	186 550	18 820	10 810
Johore	3 310	49 870	294 870	32 340	35 580
Pahang	19 190	93 060	14 180	25 070	22 020
Terengganu	16 160	72 770	—	21 490	11 010
Kelantan	17 370	162 240	2 550	60 430	48 830
Total	127 860	637 660	1 899 400	288 510	234 900

[a] Peninsular Malaysia only
— = None

Table 2. Incidence of FMD in Malaysia, 1939–93.

Year	Occurrence	Species affected	Virus type
Pre-1939	Frequent	Not specified	Unknown
1939–72	No outbreak	—	—
1973	Perlis	Cattle	A22-like
1974–77	No outbreak	—	—
1978–79	Kelantan, Kedah, Perak, Perlis, Muar abattoir (Johor)	Cattle/buffaloes	O1
1980–81	Perlis, Kedah, Penang, Perak, Shah Alam abattoir (Selangor), Pahang, Kelantan and Terengganu	Cattle/buffalo/swine[a]	O1
1982	Seberang Prai (Penang)	Cattle	O1
1983–84	No outbreak	—	—
1985	Kelantan/Terengganu	Cattle/buffaloes	Asia 1
1986	Pahang/Terengganu	Cattle/buffaloes	Asia 1
1990	Quarantine station, Padang Besar, Perlis	Cattle	Asia 1
1992–Jan 1993	(i) Kelantan	Cattle/buffaloes	O1[b]
	(ii) Perlis	Cattle/buffaloes	Asia 1[b]

[a] Penang
[b] This was the first time when 2 serotypes were recorded in the same year

Table 3. Monthly FMD disease outbreaks, January 1992–January 1993.

Month (1992)	Kelantan			Perlis		
	No. of outbreaks	No. of animals affected		No. of outbreaks	No. of animals affected	
		Cattle	Buffaloes		Cattle	Buffaloes
January–May	—	—	—	—	—	—
June	10	84	7	—	—	—
July	4 + (4)	81	2	—	—	—
August	10 + (1)	138	2	—	—	—
September	– + (3)	61	—	—	—	—
October	1	12	—	—	—	—
November	– + (2)	20	—	—	—	—
December	—	—	—	19	130	2
January 1993	2	343	—	2	18	1
Total	27 + (10)	739	11	21	148	3

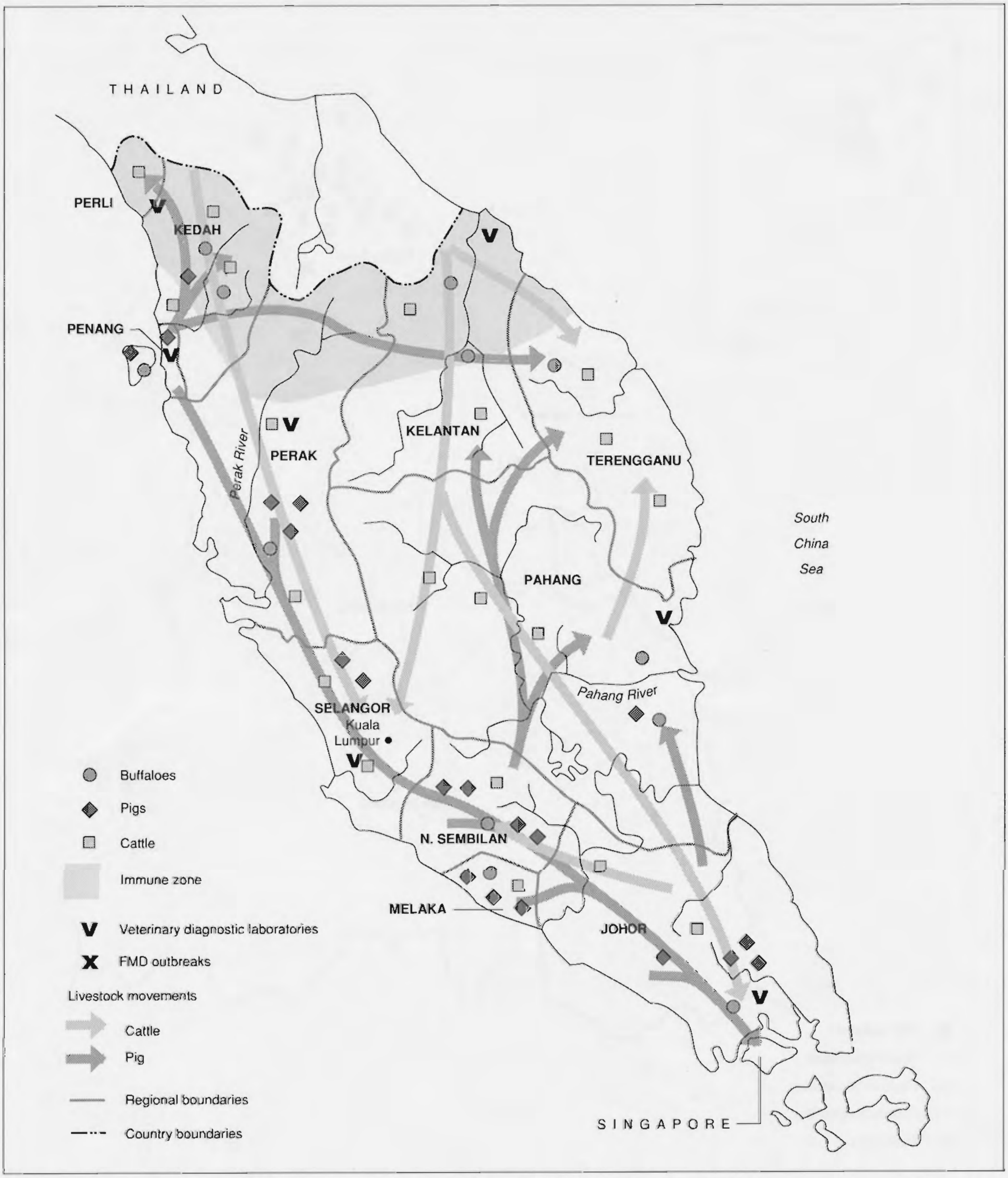
( ) Numbers in brackets are new cases in old foci
— = No outbreaks

Epidemiology

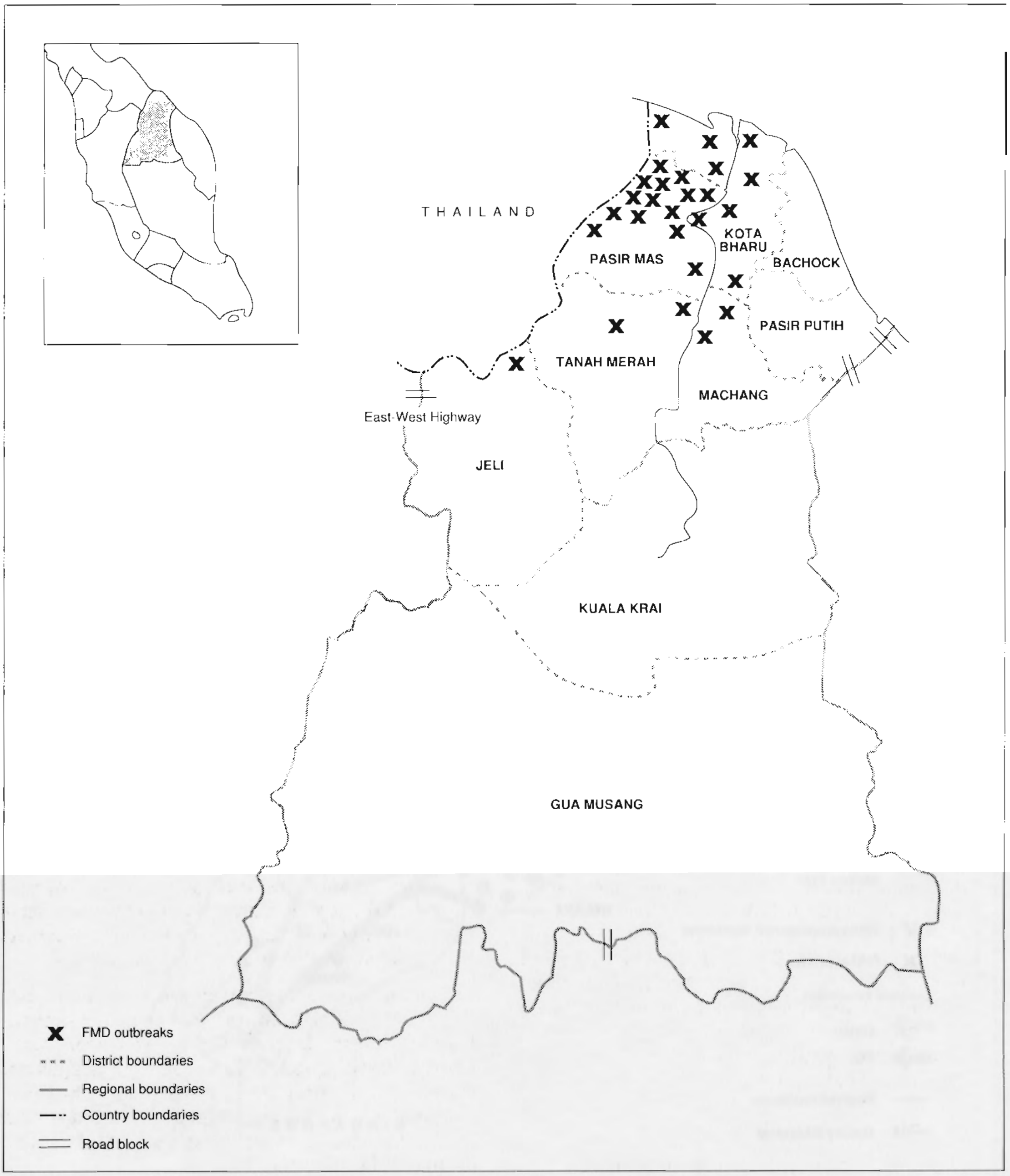
Outbreaks

No field outbreaks of FMD were recorded in Peninsular Malaysia from 1988–1991. The outbreak in 1990 was confined to the quarantine station in Padang Besar. All cattle in quarantine were destroyed. In 1992 outbreaks occurred in the states of Kelantan and Perlis which are both in the north of the country. A further suspected outbreak in Kedah was not confirmed by laboratory diagnosis (see Table 3).

Kelantan. Kelantan had been free of FMD from the time of the last outbreak in 1985 until June 9 1992 when FMD was detected in Kampong Tok Rusa in the State of Kelantan (6° 07′ N; 102° 06′ E) involving 3 head of cattle which were immediately destroyed. Another 22 head of cattle, which were then discovered to have come in contact with the 3 infected cattle, were subsequently destroyed by their owners under supervision. Despite control of livestock movement, vaccination and supervised slaughter, 24 foci were detected within a span of 184 days. These foci were located in an area of



Map 1. Distribution of FMD-susceptible livestock, FMD outbreaks, facilities and livestock movements in Peninsular Malaysia.



Map 2. The distribution of FMD foci in the state of Kelantan, 1992–93.

50 km diameter and confined within latitudes 5° 45′; 6° 14′ N and longitudes 101° 53′; 102° 17′ E. Details of these outbreaks are shown in Table 3 and Map 2.

On January 8, 1993, a fresh episode of FMD appeared to occur in the districts of Tumpat, Kota Bharu, Bachok and Pasir Putih. Mouth lesions were extremely rare but when samples were sent to the World Reference Laboratory (WRL), Pirbright, United Kingdom they were confirmed to be due to FMD virus type O1 (see Table 4).

Perlis. The second episode of FMD in 1992 was detected among smuggled animals under detention at the Chuping Anti-Smuggling Unit in the State of Perlis (6° 29′ N; 100° 15′ E) on December 5, 1992. The 4 head of cattle detained were destroyed and buried on site. Subsequent to this, 18 other foci were detected within a 10 km diameter and confined within latitudes 6° 21′; 6° 33′ N and longitudes 100 09'; 100° 15′ E. Table 3 and Map 3 provide additional information on the outbreak.

Morbidity and mortality rates

Due to the fact that most cattle and buffaloes are kept under loose systems of management, calculation of precise morbidity and mortality rates is impossible. The number of cattle and buffaloes affected on a monthly basis is indicated in Table 3 but these figures are not sufficient to calculate epidemiological parameters. In general, mortality is virtually zero and morbidity is variable depending on the status of immunity of any given population group.

Diagnosis

Samples submitted to WRL confirmed the clinical diagnosis. Virus isolates from the State of Kelantan were identified as type O1, which was antigenically related to O1 BFS (British field strain) or O1 Manissa of Turkey. The December 1992 outbreak in the State of Perlis was identified as type Asia 1 which was antigenically related to Asia 1 Shamir. The number of samples collected and results of typing are indicated in Table 4.

Origin and spread of outbreak

The outbreak which was detected in Kampong Tok Rusa (which is about 1.6 km from the Malaysia-Thai border) occurred 5 weeks after the official notification by the Department of Livestock Development, Thailand. The disease was detected at the Chuping Camp (about 12 km from the border) 3 weeks after official notification. Similar (corresponding) FMD virus types were detected on both occasions.

Table 4. FMD virus detection and serotyping, June 1992–January 1993.

State	Date of collection	No. of samples collected	Results of serotyping[a]
Kelantan	09 Jun 1992	3	O1
	15 Jun 1992	2	O1
	01 Aug 1992	2	O1
	07 Oct 1992	9 (sera)	O1
	24 Nov 1992	1	O1
	26 Jan 1993	3	O1
	27 Jan 1993	10 (sera)	O1
Kedah	15 Jun 1992	1	Negative
Perlis	05 Dec 1992	5	Asia 1
	28 Dec 1992	4	Asia 1

[a] All samples were confirmed by WRL

Thus, the origin of the disease is believed to have been through the illicit movement of cattle into Malaysia from the FMD-infected areas in Thailand. Upon introduction of the disease, internal spread was due to contact between infected and susceptible livestock in common grazing grounds; holding of cattle in illicit slaughter areas; and unauthorised interdistrict movement of cattle.

Facilities

The Department of Veterinary Services has adequate field staff located in the border states. When the need arises federal officers can be mobilised at short notice to boost personnel requirements for vaccination and other duties.

Communication systems between the affected states and the central control unit in veterinary headquarters are good. Daily reporting where necessary is by telephone and facsimile transmission.

Currently, no laboratory diagnostic facilities exist for FMD confirmation although diagnostic laboratories are located in the FMD-prone areas where initial diagnosis is based on clinical signs and history. Actual confirmation is carried out by WRL. The staff of the nearest diagnostic laboratory are trained to collect samples in the manner prescribed by the WRL laboratory.

Vaccine

In the 1992 outbreak about 42% of susceptible livestock in Kelantan, 77% in Perlis and 35% in Kedah were vaccinated. Vaccination in Perak was only carried out in areas of strategic importance along the East-West Highway (Table 5).

Table 5. FMD vaccination coverage, 1992-93.

State	District	No. of animals vaccinated		Total eligible population[a] (cattle/buffaloes)	Vaccination coverage[b] (%)
		1992 Cattle/buffaloes	Jan 1993 Cattle/buffaloes		
Kelantan	Pasir Mas	10 066	3 095	27 243	48.3
	Kota Bharu	7 143	0	22 238	32.1
	Tumpat	3 388	3 013	14 712	43.5
	Machang	8 190	0	18 305	44.7
	Tanah Merah	7 413	0	17 875	41.5
Perlis		4 582	3 913	10 980	77.4
Kedah	Kota Setar	3 544	1 176	18 314	25.8
	Padang Terap	8 855	0	17 461	50.7
	Kubang Pasu	4 210	2 211	14 613	43.9
	Pendang	2 446	0	12 569	19.5
Perak	Grik/Selama	2 482	0	15 360	16.2

[a] Based on 1991 livestock census for districts concerned
[b] For effective control of FMD at least 75% coverage is needed. Low coverage is due mainly to difficulties in obtaining sufficient vaccine

Table 6. FMD vaccines imported in 1992.

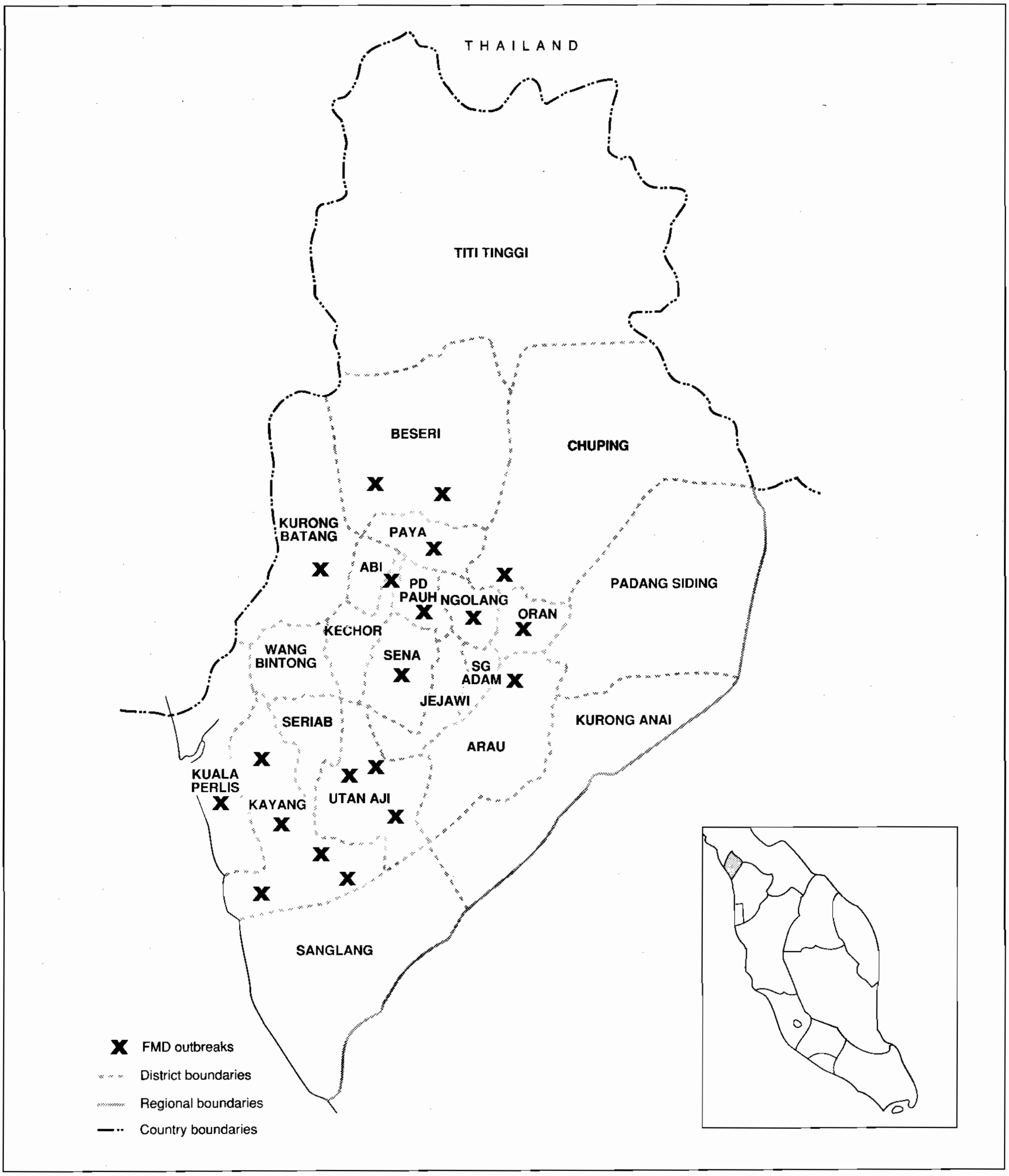
State	Vaccine type	Manufacturer[a]
Kelantan	Monovalent O1 Yala	A
	Trivalent O1, Asia 1 and A22	B
	Monovalent O1 Manissa	C
	Trivalent O1, Asia 1 and A22	D
Perlis	Monovalent O1 Yala	A
	Trivalent O1, Asia 1 and A22	D
	Trivalent O1, Asia 1 and A22	B
Kedah (no outbreak)	Monovalent O1 Yala	A
	Trivalent O1, Asia 1 and A22	D
	Trivalent O1, Asia 1 and A22	B
Perak (no outbreak)	Monovalent O1 Yala	A

[a] Information withheld to maintain confidentiality

Four types of vaccines were used in Kelantan, three preparations in Perlis and Kedah and one type in Perak, as shown in Table 6. Malaysia had to resort to multiple sources for vaccines in varying combination of serotypes because the standard emergency stock (50 000 doses from Rhone Merieux, France) was quickly depleted in early 1992 when strategic areas were vaccinated prior to the Moslem festive season when there is a large movement of live animals which are needed on foot for slaughter at the festival.

There were considerable difficulties in obtaining FMD vaccine from traditional sources in May and June 1992 due to lack of production worldwide. The problem was compounded by the fact that Malaysia is not a contributing member to any FMD vaccine bank and it was not possible to borrow from banks because of exorbitant costs. By June 1992, prices of vaccine from traditional sources had also soared to over 600% of budgeted cost based on 1991 prices.

Ineffectiveness of vaccines was suspected on many occasions, both in Kelantan and on one occasion in Perlis. Only 18 of the suspected cases in Kelantan were traceable from records. Having analysed available data as shown in Table 5, however, it was concluded that there was no unequivocal evidence of actual vaccine breakdown and that the problem was more likely to have been due to the fact that vaccination coverage was too low. The number of animals involved in the cases of suspected breakdown was also very low in relation to the total stock vaccinated and it is difficult to eliminate the possibility that vaccination is never 100% protective. For this reason, vaccines were not used for protection studies locally or sent elsewhere to clarify the problem.



Map 3. The distribution of FMD foci in the state of Perlis, 1992–93.

An investigation was also carried out into the efficiency of the cold chain under local operational conditions. There was no reason to suspect that there were weak links in this chain. Samples from suspected breakdown cases were sent to WRL and confirmed positive. Nevertheless, this is the first time in 14 years of Malaysia FMD vaccination experience, that the Department of Veterinary Services (DVS) has encountered significant numbers of suspected vaccine breakdowns.

Stock Movements

Ruminant movements occur in Malaysia for a number of reasons, whereas the movement of pigs and poultry is more structured, with an organised marketing system related to highly commercial operations.

With respect to FMD, by far the most important livestock movement is that across the northern border. Such movements are related primarily to beef cattle trade and the distances involved are determined by market forces and price differentials, supply and demand being the main factors. Demand for beef or slaughter cattle on foot for the Moslem festivals provide seasonal peaks in the intensity of movement.

Such movements essentially take place in Kelantan across the Golok River and at the western end of the Malaysia–Thai border into Perlis, onto Kedah and elsewhere in the peninsula. During the non-festive season movement is essentially into three of the border states, Perlis, Kelantan and Kedah (but not Perak). Despite the fact that the three states concerned carry the highest density of cattle and buffaloes (over 40% of the national total), movement takes place due to shortage of cattle for breeding and slaughter.

There are two means of entry for cattle and buffaloes: quarantine stations (especially Padang Besar in Perlis); and unauthorised routes. The East–West Highway along the northern border and the network of good quality roads facilitate both forms of movement.

Control of all forms of border trade is provided by combined forces of border security; police, customs and the army and where possible backed up by the enforcement units of DVS. They essentially operate along the western tip of the border in Perlis and along the Golok River. The border is virtually inaccessible in the western segment on account of border fencing, with difficult terrain in the middle segment. Of the two major quarantine stations, Padang Besar and Rantau Panjang, the former is preferred by importers due to trade forces.

Despite all attempts to curb unauthorised movement in cattle and buffaloes, it has been difficult to entirely eliminate illicit trade. Intense efforts by the DVS enforcement units to control such movement within Perlis and Kelantan has helped regulate movement and make cattle trade to points further south as safe as possible.

In addition to movement of livestock for commercial purposes, there is also a natural seasonal movement along the border in Kelantan. This occurs primarily because of grazing habits and is dictated by availability of green feed at any given period. Such movements are seen especially in Kelantan because of the narrow river that flows along much of the border and has flat terrain. There are under normal circumstances about 20 regular points at which movement can take place across the Golok River. Approximately 200 other (non-regular) options are available.

Large-scale development strategies for the sheep industry in Malaysia through integration with the rubber and oil palm plantations has placed a heavy demand for tropical breeding stock from areas north of Malaysia. Importation of sheep is exclusively through the Padang Besar Quarantine Station.

In recent years the frequency of large-scale movement to the south has been reduced due to liberal import policies for beef. In fact there is now a tendency for cattle from feedlots in the central and southern parts of Peninsular Malaysia to move as far north as Kedah.

Away from the northern border and elsewhere in the peninsula, a variety of other movements of cattle and buffaloes take place. In rice growing areas, cattle are transferred to single cropping areas during planting and harvesting seasons. Most cattle and buffaloes are kept by smallholders who practice a free-range grazing system. Common grazing grounds occur in some parts of the country and this is a significant factor in the transmission of contagious and infectious disease.

In certain parts of the country, especially in Pahang, Terengganu and in Negeri Sembilan, a free-range system of grazing is practised for most parts of the year. Mustering for mass vaccination and for slaughter is difficult under such circumstances. However, Terengganu has been successful in overcoming the problem in certain areas through construction of large permanent corrals used for a variety of purposes including pregnancy diagnosis, deworming and vaccination.

In recent years cattle rearing has been intensified in large rubber and oil palm plantations but using an unstructured form of management. The relatively

COUNTRY LIVESTOCK AND FMD EPIDEMIOLOGY STATISTICS

Malaysia: 13 states and 1 federal territory (Kuala Lumpur); Peninsular Malaysia, covered by this report, has 11 states and KL

LIVESTOCK STATISTICS

Livestock	Number (million)	Draft use %	Meat use %	Milk production %	Estimated international movements '000/year Entering	Leaving
Cattle	0.64	0	84	16	50	0
Buffaloes	0.13	0	100	0	5	0
Pigs	1.90	na	100	na	very few	1000
Sheep and goats	0.52	na	100	0	39[a]	0

[a] FAO estimation 1991

FMD EPIDEMIOLOGY

Seasonal incidence: Precedes Moslem festivals when movement of livestock is greatest.
Geographic frequency: Most prevalent in the border states.

Disease outbreaks and vaccinations

	1988	1989	1990	1991	1992	1993
Serotypes recorded	—	—	Asia 1	—	O1,Asia1	O1
Species involved	—	—	C[a]	—	C,B	C,B
Vaccine used (immune belt only)	—	O,Asia 1	O,Asia 1	O,Asia 1	O,A,Asia 1	O,A,Asia 1

— = No outbreaks
[a] Confined to quarantine station at Padang Besar

Facilities

Veterinary centres: 7 laboratories; 108 district centres
Veterinary officers: 250
Diagnostic laboratory: Samples sent to WRL; Pirbright
Cost per diagnostic test: Free (air freight cost only)

Vaccine

Vaccine supply: Imported
Cost per dose ($US): 1.40
Vaccine strategy: Since 1989 mass vaccinations carried out in the immune belt only.

wild state of the animals necessitates domestication. Cattle are moved for this purpose from Jerantut in Pahang to Kelantan, a state where farmers are skilled in domestication. Such cattle then move south for breeding or slaughter.

Based on the livestock movement patterns discussed above (Map 1), contact with FMD-infected stock usually occurs under the following circumstances:

- along variable routes of illicit trade;
- in holding areas for slaughter or breeding cattle;
- introduced through unauthorised means; and
- in common grazing grounds.

The above FMD risk situations are most likely to occur in Kelantan, Perlis and Kedah. Infection into other states can only happen when unreported or uninspected movement takes place. Spread of infection within these states from potential foci occurs when there is a low immunity of cattle and buffaloes in the vicinity.

Significantly, there are no livestock markets in Peninsular Malaysia. This reduces the possibility of inadvertent contact between infected and healthy cattle during gathering for sale and subsequent dispersal of stock.

There are currently no FMD vaccine production plants in Malaysia. All vaccines required are imported from overseas (e.g. from the United Kingdom, France, India and Thailand). The number of doses used in any particular year is usually adequate to meet the needs of establishing the immune belt in the border states. The cost of vaccine has gone up tremendously to its present price of about RM 3.50 (approximately US$1.40 per dose). Vaccine is distributed through the district veterinary offices.

Control/Eradication Strategies

A combination of slaughter and vaccination is now the adopted policy FMD control in Malaysia. An FMD immune-belt has been established stretching for about 50 km south of the Malaysia-Thai border where an intensive vaccination program is being carried out annually. This belt covers the whole of Perlis as well as the northern parts of Kedah, Perak, Kelantan and the district of Besut in Terengganu (Map 1).

Control in movement combined with a stamping-out policy was most effective in eradicating the disease in Perlis in 1973. The same policy was equally effective in the 1978 FMD outbreak in Muar, Johore and in Central Perak (essentially the district of Kinta) as well as in many affected areas of the west bank of the Kelantan River. However, many essentially social factors and prevailing concerns in Kelantan resulted in a change from shooting to slaughter by knife, which then had to be abandoned due to strong public resentment.

Since 1979, vaccination has been the major control strategy with stamping out (either by shooting or slaughter by knife) used in selected circumstances, especially in cases of animals being detained due to illicit movement from across the border and in instances where cases encountered were believed to be the first and only focus.

In essence, because of the considerable difficulties in achieving a 70–80% vaccination coverage, DVS has resorted to a combination of control measures as follows:

- restriction of movement and quarantine of animals;
- sanitation and disinfection;
- stamping out;
- mass vaccination;
- border surveillance; and
- special extension efforts.

Each of the measures presents some special challenges to be overcome. These are discussed in more detail below.

Restriction of movement

While confinement of livestock to FMD-free areas and restriction of movement are both attempted, there are difficulties encountered in determining when an animal is safe enough to be released. Usually, the inability to continually supply feed to the confined livestock or farmers' perception of safety, based on the ability of the animals to walk or to eat, ultimately determine the appropriate time of release.

Due to high demand for beef, movement of healthy animals out of the infected states is permitted after a compulsory seven-day quarantine following vaccination. Travel is only permitted direct to designated abattoirs in sealed transporters.

Roadblocks with disinfection facilities have been set up at all critical exit points and are maintained on a 24-hour basis to minimise the possibility of disseminating infection to other states.

In the 1992 outbreak, a very selective approach was taken in deciding where roadblocks should be placed. In Kelantan, only four roadblocks in key isolated routes were maintained and these were well away from infected areas (Map 2). This was because past experience shows that roadblocks close to infected zones actually encourage further illicit movement. In the areas prone to infection, livestock can move between any two trees, along any rice bund or irrigation canal. Under such circumstances, there is no strategic location at which a roadblock can be placed. For this reason no roadblocks were attempted in Perlis despite the severity of the outbreak and considerable risk to Kedah. When they have been set up these roadblocks have been supervised by staff from the adjacent FMD-free states who are highly motivated to keep FMD away.

Sanitary measures

All personnel involved in FMD control are trained in the importance of cleaning and disinfection and the potential for spreading the virus is stressed. Special sanitary precautions are undertaken for movement of livestock into and out of infected areas. These measures were all followed at the roadblocks out of Kelantan. Within infected zones, however, it was difficult to ensure that completely satisfactory disinfection was undertaken.

Vaccination

Prior to 1989 susceptible animals were vaccinated with bivalent vaccines (type O1 and Asia 1). In the event of an outbreak, ring or band vaccination was conducted followed by vaccination of animals in critical and known risk areas such as strategic trading routes.

Since 1989 Malaysia has not conducted mass vaccination except in the immune belt area and in instances where animals from disease-free areas had to be transported into the belt. In 1991, a decision was made to restrict vaccination in the immune belt to areas of strategic importance, with a view to ceasing vaccination altogether at a time considered safe. This timing was to be determined by the efficiency of control in movement of animals at latitude 12° N (Prachaub Kirikhan), this being the narrowest point of Thailand, barely 10 km wide with the adjoining area in Myanmar being virtually inaccessible.

In retrospect, it is felt that there should have been no let up in the intensity of vaccination in the immune belt adjoining a high risk area.

Conclusion and Future Priorities

Having experienced eight episodes of FMD within 20 years, there is increasing evidence that control strategies primarily involving vaccination have a limited impact for control of the disease under smallholder conditions. The answer to long-term control and eradication of FMD under such conditions lies not only in vaccination and it is now apparent that there should also be deployment of both personnel and financial resources to address other basic requirements including:

- the registration and control of all those involved in the slaughter and cattle trade;
- improving the system for issue of slaughter permits;
- development of an organised system for beef cattle production;
- expansion and improvement of enforcement activities;
- cattle registration and identification as well as a reliable database;
- logistics support; and above all
- leadership at various levels and a more effective veterinary coverage to grass root levels.

Vaccination is now perceived to be effective, in fact feasible on a massive scale, only when the above elements are in place. Regardless of this however, vaccination in critical areas along the border will remain mandatory.

The current price of FMD vaccines has become a financial burden. A regionally negotiated pricing system for vaccines from common sources will help reduce unit cost and render control efforts more cost effective.

It is difficult to expect stakeholders in the beef industry to have high commitment to FMD control as it does not have a direct impact on their economic well-being. This factor must be part of future strategy considerations.

A concerted attempt must also be made to evaluate the efficiency of quarantine stations vis-a-vis a regulated free-flow system where cattle at all points of movement can be examined, vaccinated and permitted for movement based on assessment of relative risk. There has been considerable restraint in making a bold attempt towards taking such risks but experience over the past 20 years questions the validity of this fear. It may therefore be worthwhile considering a very open system that is regulated by a different approach similar to the 'green lane' concept adopted at international airports.

Myanmar

Van Duh*

MYANMAR (the Union of Myanmar) has a total area of over 676 000 sq km and shares land borders with Bangladesh, India, China, Laos and Thailand on its western, northern and eastern frontiers. To the south it borders the Andaman Sea. The country has three distinct geographical regions: the hill regions which stretch along the land borders; the central plain which includes an extensively dry zone; and the delta areas. The mountainous areas feature three parallel chains of hills, the Rakhine Yoma, the Bago Yoma and the Shan Plateau running north to south. There are four principal rivers, the Ayeyarwaddy, the Chindwin, the Sitaung and the Salween rivers, which originate in the Himalayas to the north, flow between the ranges and discharge into the Andaman Sea.

Myanmar has a wide range of climatic conditions being tropical in the south, semi-arid in the centre and subtropical to temperate in the north. The southwesterly monsoon occurs from April to October and provides the main rainfall during the period June to October. The wet and humid monsoon season is preceded by a dry, hot summer (March–June) and followed by a cool, dry winter (October–February). Winter rains can occur in some parts of the country due to southwesterly movement of the intertropical convergence zone. There are variations to this basic pattern particularly in the north where lower latitude and greater altitude lead to cooler conditions.

Myanmar has a human population of 40.8 million (1991) giving a population density of 60 per square kilometre. Annual population growth rate is estimated at only 1.9%. Only 36% of the people are under the age of 15.

The Government of Myanmar is exercised through a system which operates at national, state or division, township, village tract and village levels. There are seven divisions and seven states. Each division and state is divided into a number of townships, which total 247. The townships are divided into village tracts each consisting of a number of villages. The seven divisions (Ayeyarwaddy, Bago, Magwe, Mandalay, Mon, Yangon and Sagaing) are occupied by generally homogenous groups who speak the Myanmar language. The seven states (of ethnic groups Arakan, Chin, Kachin, Shan, Kayah, Thanintharyi and Karen) are populated by the national races who speak their own dialects and have diverse backgrounds. The states are territorially larger than the divisions but are less populous.

In general the country is well endowed with agricultural land with about 10 million hectares now cropped. With adequate rainfall and plentiful irrigation (1.1 million hectares of irrigated land mainly by gravity diversions), Myanmar was the world's largest exporter of rice in the 1950s, peak exports reaching 3 million tonnes annually.

Agriculture is Myanmar's dominant sector, contributing 48% of gross domestic product (GDP; estimated at 138 137 million kyats in current prices for the fiscal year 1990–91) and providing 30% of exports. Cropping is the dominant subsector, generating 80% of sector output, while livestock and fish generate 15% and forestry 4%. The agricultural sector is the major source of employment for about 66% of the workforce. There are an estimated 4.3 million rural landholdings in Myanmar, of which 2.7 million (62%) are classified as small, i.e. two hectares or less. The average smallholding is estimated to be 1.07 hectares. Approximately 12% (8.7 million hectares) of the land area is cultivated, with 2.8% (1.9 million hectares) lying fallow and about 12% (8.5 million hectares) classified as cultivable wasteland.

Livestock

Although not a major contributor to national income, livestock have an important role as a source of income; protein for farming families; and draft power for crop production and transport. The most important livestock are cattle, buffaloes, sheep, goats, pigs and poultry with the most meat (47%) coming from poultry. Livestock numbers in Myanmar are shown by state in Table 1.

* Livestock Breeding and Veterinary Department, Insein, Yangoon, Union of Myanmar.

Table 1. Livestock populations in Myanmar by state/division, 1992-93.

State/division	Livestock numbers ('000)			
	Cattle	Buffaloes	Sheep and goats	Pigs
Kachin	205.0	136.2	14.3	157.0
Kayah	74.5	30.5	1.8	50.3
Kayin	228.6	52.2	25.2	85.0
Chin	62.3	20.4	21.0	119.1
Sagaing	1643.7	296.3	215.1	239.7
Taninthayi	104.4	101.1	13.2	47.6
Bago	1047.6	212.7	22.2	287.5
Magway	1419.1	63.4	352.1	183.2
Mandalay	1474.8	87.7	508.0	213.4
Mon	309.1	56.3	28.2	69.3
Rakhine	562.8	214.7	90.1	78.3
Yangon	403.1	89.4	28.1	161.5
Shan	933.2	467.1	13.8	362.4
Ayeyarwaddy	1007.0	270.6	32.9	479.5
Total	9475.3	2098.7	1366.0	2534.0

Source: Animal population census, 1992-93

Output from the livestock and fishery subsector (15% of the sector) maintained growth through the 1987-88 downturn, but then fell sharply in 1988-89 and remained low in 1989-90, with severe shortages of livestock feed and vaccines and a large drop in animal numbers.

The distribution of livestock depends on agricultural activities, availability of feed and natural feed resources, geographical and climatic conditions. The most densely populated areas for cattle are the central and upper regions of the country where agriculture is well developed and there is plentiful grazing land (see Map 1).

Buffaloes are most common in the hilly, cool regions like Shan State, Sagaing Division and Ayeyarwaddy Division which are the rainfed agricultural areas. Pig farming is commonly practised in Ayeyarwaddy and Bago Division, where by-products of rice and other crops are abundant for feed. Sheep and goats are very common in the dry central regions, Mandalay, Magwe and Sagaing Divisions.

Most livestock production occurs in the private sector and each individual farm family owns a small herd or flock of livestock or poultry. The production unit of the country can therefore be classified as small farm or individual farmholder.

Agriculture is dependent on the draft power of working cattle and buffaloes with 55% of the total population of cattle and buffaloes actively involved in the agricultural sector. A pair of draft cattle or buffaloes handles, on average, 3.1 hectares of land. In addition to draft power, cattle and buffaloes provide meat, milk and natural fertiliser which is essential for agriculture. Livestock and poultry farming is practised on a small scale by individual farmers. Private sector semi-commercial farms are commonly located in urban areas of the large cities and townships. At present large-scale commercial farms are undertaken by the state sector, but the total production of the state farms when compared with the production derived from the private sector, especially from the small-scale livestock farming, is small. The requirement of the whole country for meat, milk and eggs is largely met by private farmers.

Livestock, poultry and related products, which mostly originate from the private farmers in the rural sector are marketed either directly to the retailers or wholesalers or through agents. In some parts of the country, livestock marketing is undertaken by cooperative societies. There are well established cattle markets which are mostly run on a weekly basis in the agricultural areas. Cattle and buffaloes — intended for work and meat purposes, pigs, sheep and goats are all marketed in the cattle markets. Meat animals are carried to the nearest slaughter houses or major abattoirs by rail, ship or by motor transport.

COUNTRY LIVESTOCK AND FMD EPIDEMIOLOGY STATISTICS

Myanmar: 7 divisions; 7 states; 247 townships (each with village tracts)

LIVESTOCK STATISTICS

Production unit (for animal health programs): village
Animals per owner: estimated averages — 5 dairy/working cattle; 5 buffaloes; 4 pigs; 15 sheep and goats

Livestock	Number (million)	Draft use %	Meat production (million kg)	Milk production cattle (million kg)
Cattle	9.5	55	39.3	433
Buffaloes	2.1	55	8.6	95
Pigs	2.6	na	na	na
Sheep and goats	1.4	na	na	na

International movement/trade: movement of livestock occurs through the border areas but the volume of this trade cannot be estimated as much of it is illicit

FMD EPIDEMIOLOGY

Seasonal incidence: most prevalent during the monsoon season (June, July)
Geographic frequency: highest incidence is in Sagaing Province

Disease outbreaks and vaccinations

	1988	1989	1990	1991	1992	1993
Serotypes recorded	O,Asia 1	O,Asia 1	O	Asia 1	Asia 1	O
Species involved	C,B	C,B	C,B	C,B	C,B	C,B
Vaccine used	O	O,Asia 1	O,A,Asia 1	O,Asia 1	O,Asia 1	na

Facilities

Veterinary centres: 274 (local)
Veterinary officers: 14 state/divisional heads; 6 assistants; 258 township officers; 941 assistants at village tracts
Diagnostic laboratory: FMD Division, Livestock Breeding and Veterinary Department
Cost per diagnostic test ($US): 1.5 (18–245 tests/year)

Vaccine

Vaccine supply: 40% produced in Myanmar; 60% imported
Cost per dose ($US): 1.9 (locally produced); 0.5 (imported under FAO program)
Vaccine strategy: As requested by livestock holders

Changes to the livestock sector

A market economy system has been recently introduced by the Myanmar Government (State Law and Order Restoration Council) and in line with the new economic system, opportunities for expanding and developing the various sectors, have been opened. In the agricultural and livestock/fisheries sectors, the government is providing opportunities for crop, livestock and fish farmers to utilise the untapped land such as fallow or culturable wasteland, which have high potential for further development. In line with these new enterprises, some new legislations have been enforced or some are still under preparation. For the livestock sector, new laws for animal health and livestock development will be introduced in the near future which will contribute to the development of the livestock sector in the country.

Epidemiology

Foot-and-mouth disease (FMD) has been shown to be naturally infective for all cloven-footed species both domesticated and wild. The most susceptible species of livestock in the country are cattle, buffaloes and swine. Clinical disease has not been seen in goats. The FMD outbreak statistics for 1990–92 (by state/division) are shown in Table 2.

FMD virus typing was initiated in 1975 in the country. Three types of FMD virus, O, Asia 1 and A were serologically classified before 1978–79. But during the last decade only O and Asia 1 had been identified from the local specimens. The virus O type continuously affected cattle from 1982–90, disappeared in the two successive years and then emerged again in 1993. Asia 1 occured in 1988–89 and 1991–92 but not in 1990 or 1993.

Losses from FMD

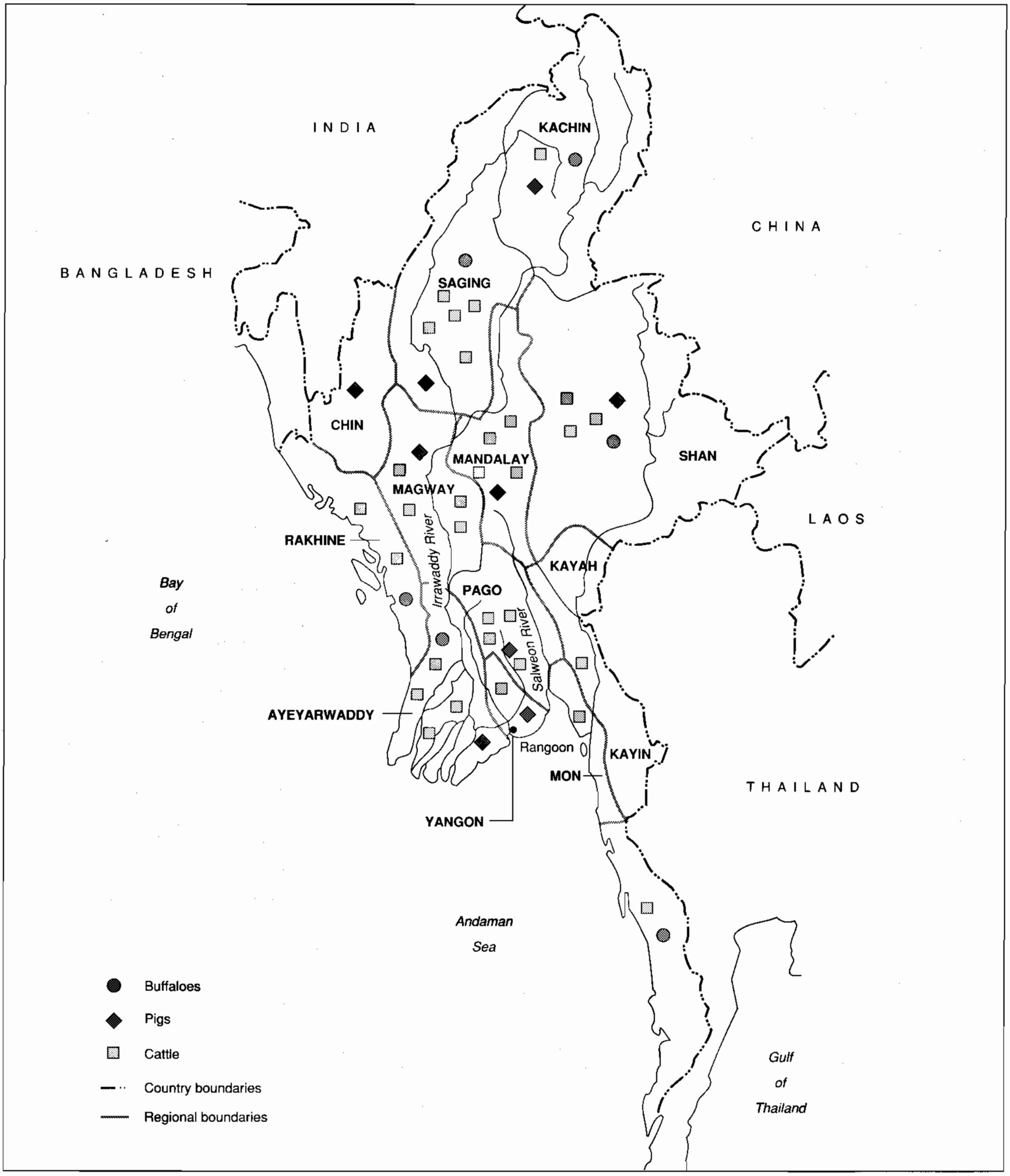
Direct loss. The economic losses caused by FMD are classified into two distinct categories, direct and indirect. The major direct losses are those sustained from reduced production of meat, milk and other products. Growth of affected animals is frequently inhibited for a long period. In dairy cattle the udder is inflamed and sometimes permanently damaged and also causes direct losses in breeding efficiency. In other cases, there are chronic joint infections and reduced fertility leading to long calving interval.

Indirect loss. Draft animals perform about 95% of all cultivation work. During cultivation seasons, FMD renders a number of difficulties to farmers by crippling draft animals when timely availability of draft power is essential for production. The acute lameness resulting from viral infection may proceed to chronic lameness as a result of secondary bacterial infection. When working animals are affected at cultivation or harvest they loose much of their working capacity, thus reducing the agricultural output.

Table 2. FMD outbreak statistics in Myanmar by state/division, 1990–92.

State/division	1990–91			1991–92		
	Outbreaks	Sick animals	Deaths	Outbreaks	Sick animals	Deaths
Kachin	—	—	—	2	1 050	—
Kayah	1	20	1	3	315	—
Kayin	—	—	—	—	—	—
Chin	3	126	—	3	86	—
Sagaing	18	11 583	109	16	6 875	16
Taninthayi	—	—	—	—	—	—
Bago	5	548	—	3	107	1
Magway	7	232	—	20	5 879	—
Mandalay	5	8 200	127	1	96	—
Mon	3	888	—	1	214	—
Rakhine	7	5 775	9	7	870	5
Yangon	1	123	2	1	96	—
Shan	6	650	8	3	4 623	—
Ayeyarwaddy	6	267	—	8	1 560	—
Total	62	28 412	256	68	21 771	22

— = None/no data



Map 1. Livestock distribution in Myanmar.

Facilities

Veterinary services

Field veterinary works are involved in the disease control and veterinary services in their assigned areas. The veterinary staff at village tract level are directly responsible for the field services, performing vaccination, treatment and extension services among the farmers. They are actively on the alert for any disease information and they must convey information on outbreaks which occur under their jurisidiction to their superior staff, local authorities and even up to the national headquarters. Depending on the severity of the outbreaks, special teams (flying squads) of staff from national headquarters or from the state/divisional level, are dispatched to the areas affected. There are 14 state and divisional veterinary heads; six assistant state/division heads who deputise for their superior heads; 258 township veterinary officers; and 941 veterinary assistants, at village tract level. The FMD Division of the Livestock Breeding and Veterinary Department (LBVD) takes responsibilities for diagnosis and identification of FMD virus specimens dispatched by veterinary staff at the outbreak area.

Diagnosis

Although four methods for identification and typing of FMD virus can be carried out in the FMD Division (LBVD), the direct complement fixation test (CFT) and neutralisation test are currently the most commonly used. Under the division are five sections involved in: (i) cell production; (ii) vaccine production; (iii) serotyping; (iv) quality control; and (v) administration. Depending on the occurrence of outbreaks, the number of virus typings range from 18–245 per year.

Vaccine

Vaccination was first undertaken in the country in 1984 with locally produced vaccines. The maximum capacity of the FMD Division for production of O type vaccine is nearly 200 000 doses and for Asia 1 vaccine is 64 000 doses.

The present production capacity cannot meet the actual requirement of the country. For this reason, vaccination is carried out on a priority basis, laying emphasis on the state farms, and the highest incidence areas. In 1989–90 FMD vaccines were received under a technical cooperation program from FAO. The cost of producing vaccine is 12.5 kyats per dose (approximately US$1.9 per dose).

Stock Movements

Being distributed widely throughout the country, livestock (cattle, buffaloes, pig, sheep and goats) move in different directions towards the areas where market demand is promising. Trade in ruminants and pigs is carried out by middle men or through cattle markets which are operated on a weekly basis in the townships of well-developed agricultural areas. Movement of livestock occurs through the border areas but the volume of this trade cannot be estimated properly because of its illicit nature. Movement of livestock for meat purpose occurs throughout the year but the marketing of working cattle and buffaloes is usually carried out just prior to the monsoon and after the harvest. Movement of cattle in search of better pasture is seen in some parts of the country.

There has been some export of livestock from the country in the past but in the near future, based on a disease-free zone which is yet to be established, the export of livestock will be sought by the country.

Current Control/Eradication Strategies

In every case of FMD, isolation of animals, notification of the disease, restriction and quarantine of infected animals as well as the proper disposal of carcasses, are compulsory. The following Acts and Rules are connected with FMD control:

- Contagious Disease of Animals (Villages) Rules 1936;
- Contagious Disease of Animals (Town) Rules 1936;
- Livestock Importation Act 1898.

FMD is a scheduled disease under the Contagious Disease of Animals (Villages) Rules 1936.

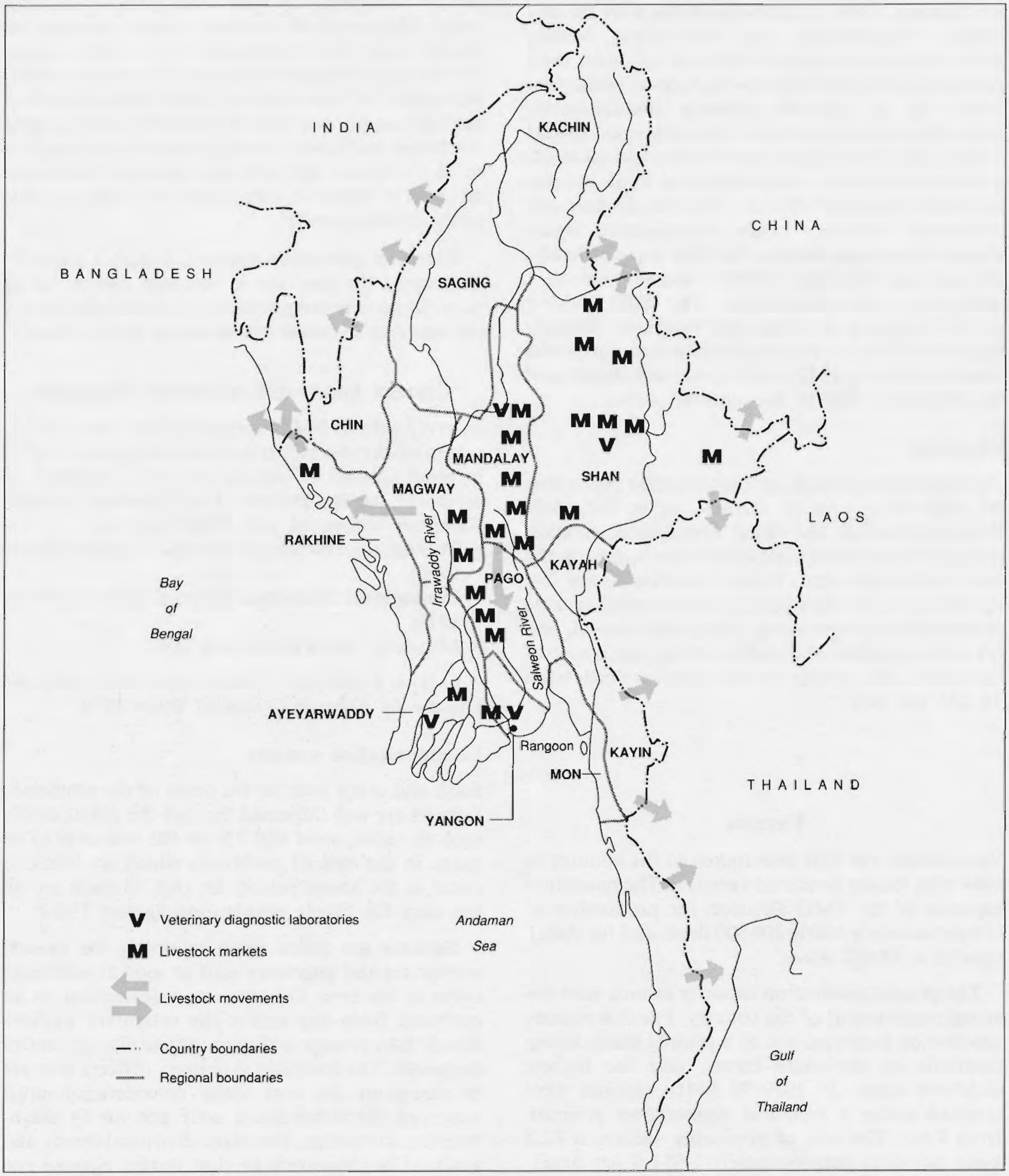
Communication systems

Each and every year, at the onset of the monsoon, farmers are well informed through the public media such as radio, news and TV on the measures to be taken in the case of outbreaks which are likely to occur in the above period. By this, farmers are on the alert for timely preparation against FMD.

Farmers are called upon to notify the nearest authorities and veterinary staff as soon as outbreaks occur in the area. On receiving information on an outbreak from any source the veterinary workers should take prompt action to initiate disease control measures. The township veterinary officers who are in charge of the area under consideration must supervise the subordinate staff and notify neighbouring townships, the state/divisional head, and national headquarters so that further actions can be coordinated. By such coordinated efforts, the outbreak can be relatively quickly brought under proper control.

Timely announcement on radio and TV, prepares farmers for notification, restriction, segregation and treatment with field chemicals/traditional medicines.

Priority for vaccination is given to the state farms, the model villages under integrated rural development activities, cooperative farms and large scale farms. An initial step is taken for the establishment of disease-free zone in an island area in Rakhine state which is naturally surrounded by sea.



Map 2. FMD outbreaks, facilities and livestock movement patterns in Myanmar.

Pakistan

Saeed Akhtar* and Mohammad Z. Haq†

PAKISTAN is one of the developing countries of Southeast Asia and has borders with India in the southeast, Afghanistan and Iran in the northwest and the Arabian Sea on the south. The area of the country is 0.8 million sq km, and is comprised of four provinces: Punjab, North-West Frontier Province (NWFP), Sind, and Baluchistan as well as northern (tribal) areas. Pakistan is divided into ten agro-ecological zones. The temperature during winter ranges from −13°C in the northern dry mountain zone to 7°C in the southern irrigated plains with corresponding mean summer temperature 30°C and 42°C respectively. The mean monthly rainfall ranges from 2–236 mm in various agro-ecological zones.

The mountainous area of Pakistan is comprised of: (i) *wet mountains* in districts of Punjab and NWFP, characterised by a series of mountainous ranges divided by wide and narrow valley plains. These mountain ranges are 1000 to 1500 metres high with forest-covered slopes; (ii) *northern dry mountains* with several peaks up to 8000 metres high, located in NWFP and tribal areas. These are extremely arid but have abundant water from the glacier-fed streams of terraced fields; (iii) *western dry mountains*, which cover parts of NWFP and Baluchistan, are characterised by barren hills of 1000 to 3000 metres altitude. Due to the steep slopes soil erosion is severe with virtually no vegetation except poor grasses.

The *southern irrigated plains* zone covers a large proportion of Punjab and Sind. Irrigation in these plains is carried out mainly through canals originating from the major rivers.

The human population of Pakistan is 84.3 million, and 70% of the population live in rural areas. The Punjab and Sind are highly populated provinces comprising 56.5 and 22.6% of the total population respectively. The NWFP (including the tribal areas) and Baluchistan have 15.7 and 5.2% of the population respectively.

Of the total area of 198.6 million acres, 26.6% is cultivated, 2.5% is under forests and 68.0% is rangeland. The overall economy of Pakistan has remained agricultural which contributes about 30% to gross domestic product (GDP). The agricultural sector employs 54% of the labour force and accounts for 75% of the total foreign exchange from exports.

Livestock

Livestock production is an integral part of the farming system and plays a significant role in the development of the agriculture sector. Livestock occupies a key position in the rural economy of the country by bringing in cash income and for improving the quality of life of the resource-poor rural population.

The annual growth in the livestock sector is about 2%. Livestock contributes about 28% of agricultural sector GDP. Trade in livestock products (leather, wool, hair, hide, skins and carpets) contributes 11% of total export valued at US$350 million. Livestock contribution in terms of traction power is equivalent to 0.3 million tractors. About 85% of livestock resources are possessed by small landholders or even landless livestock owners.

There are about 4.6 and 4.4 million production units for cattle and buffaloes respectively. The proportions of small, medium and large herds/flocks of ruminants are shown in the country statistics. About 72.4% of cattle and 91.5% of the buffalo populations of Pakistan are in Punjab and Sind. About 50% of sheep are in Baluchistan. Goat flocks are more or less uniformly distributed throughout the country.

History of Foot-and-Mouth Disease

Foot-and-mouth disease (FMD) outbreaks were reported in the Pakistan region as early as 1943 and have continued to be a frequent occurrence in the region. FMD is economically the most important viral disease of farm animals in Pakistan where it

* Animal Sciences Institute, National Agricultural Research Centre, Islamabad, Pakistan.
† Veterinary Research Institute, Lahore, Pakistan.

is endemic. No areas of the country can be considered free from the disease (Ahmad & Khan 1988) although the incidence of the disease is poorly understood in field conditions. There is no mention of virus typing in annual reports of provincial livestock departments but virus typing carried out for military dairy farms between 1954 and 1962 at the World Reference Laboratory (WRL), Pirbright, United Kingdom, showed serotypes O, A, Asia 1 and C in 13, 7, 6, 4 outbreaks respectively. No virus was recovered from 10 outbreaks (Yasin & Huq 1960; Huq 1961). From 1962 samples were collected from outbreaks in private and government herds (civil and military) from all over the country for virus typing and the Foot-and-Mouth Disease Research Centre (FMDRC) at Lahore was established. During the period of 1963–65, FMD virus serotypes O, Asia 1, A and C were recovered from 44, 36, 5 and 1 outbreaks respectively, whereas, no virus could be recovered from 23 outbreaks (Hussain et al. 1965). Since then efforts are made to collect FMD blister samples from all the outbreaks in the country for typing. The results are described in the epidemiology section of this paper.

Epidemiology

The records of disease outbreaks were obtained from FMDRC. Table 1 shows spatial distribution of four (O, A, C and Asia 1) of seven recognised serotypes of FMD virus during the last 30 years. During the last five years, however, only serotypes O and Asia 1 have been typed from a total of 257 reported outbreaks (Table 2) and most of these outbreaks occurred in Punjab, Sind and NWFP provinces.

Cattle and buffaloes were the most affected species, with only a few reports of FMD outbreaks in small ruminants (Table 3). Cattle were more severely affected than buffaloes. Mouth lesions were more pronounced in cattle and foot lesions were more severe in buffaloes. The course of FMD was shorter in buffaloes than in cattle. The exotic cattle breeds (Australian Illawarra Shorthorn, Jersey and Holstein-Friesian) and their crossbreeds with local breeds were more severely attacked by FMD than indigenous breeds (Sahiwal and Red Sindhi). Calves/heifers up to one year of age were more susceptible than adults (Sheikh 1960).

The disease is prevalent throughout the year with no major seasonal pattern (Table 3). A slight increase in the number of outbreaks occurs during January–March and May–June each year, however, possibly due to environmental stress and movements of animals during these months to local and national livestock fairs.

No national figures of economic losses due to FMD are available. However, in a 1966 study losses that occurred during an outbreak at a livestock research station were extrapolated to the national livestock population giving an estimated loss of US$34 million (Kazimi & Shah 1966). In another study (Macfarlane & James 1978) the estimated FMD-related annual losses in bovine alone were US$63 million in Pakistan.

Table 1. Spatial distribution of foot-and-mouth virus serotypes in Pakistan, 1962–92.

Province	FMD virus serotypes						
	A	O	C	Asia 1	NVD	Total	Per cent of total samples
Punjab	152	451	—	286	295	1184	85.8
NWFP	17	35	2	16	39	109	7.9
Sind	8	17	—	2	28	55	4.0
Baluchistan	1	9	—	—	20	30	2.2
Northern areas	—	—	—	—	1	1	0.1
Total	178	512	2	304	383	1379	
%	12.9	37.1	0.2	22.0	27.8		

NVD = No virus detected
— = Not detected

Table 2. Number of epidemics of foot-and-mouth disease and FMD virus serotypes in Pakistan, 1988–92.

Year	FMD virus serotypes				
	O	Asia 1	NVD	Total	Per cent of total samples
1988	45	4	33	82	31.9
1989	22	3	26	51	19.8
1990	8	—	26	34	13.2
1991	40	—	20	60	23.3
1992	19	—	11	30	11.7
Total	134	7	116	257	
%	52.1	2.7	45.1		

NVD = No virus detected
— = Not detected

Table 3. Seasonal and species-specific distribution of samples tested at the Foot-and-Mouth Disease Research Centre, Lahore, 1962–92.

Month	Livestock species					
	Buffaloes	Indigenous cattle	Exotic/crossbred cattle	Small ruminants	Total	Per cent of yearly total
January	78	33	17	6	134	9.7
February	51	58	8	7	124	8.9
March	36	34	56	7	133	9.6
April	43	22	36	—	101	7.3
May	58	38	56	5	158	11.5
June	149	44	17	9	219	15.9
July	33	16	8	3	60	4.5
August	53	45	11	1	110	8.0
September	10	21	17	—	48	3.5
October	32	32	39	17	120	8.7
November	30	9	25	—	64	4.6
December	59	11	39	—	108	7.8
Totals	632	363	329	55	1379	

— = Nil

Facilities

All diagnostic work and vaccine production is carried out at FMDRC Lahore. However, FMD research is also carried out at other institutes (Akhtar & Naeem 1985). The information about most epidemics reaches FMDRC from state livestock and military dairy farms. The staff of veterinary extension services are reluctant to report field epidemics to the respective directorates, however, and the reported number of epidemics during the last 30 years has only exceeded 100 per year on two occasions. FMDRC has the necessary tissue culture facilities for virus isolation, characterisation and typing using the compliment-fixation test (Rauf et al. 1981). The staff of FMDRC has the necessary resources in terms of logistics and an operational budget for field investigation of FMD outbreaks and for laboratory diagnosis. However, the staff of veterinary extension services, who are responsible for FMD vaccination twice a year do not get sufficient vaccine doses and face other logistical problems. Therefore, the desired level of vaccination coverage is not attained.

COUNTRY LIVESTOCK AND FMD EPIDEMIOLOGY STATISTICS

Pakistan: 4 provinces

LIVESTOCK STATISTICS

Production unit (for animal health programs): farm
Animals per owner: estimated averages — 2 beef cattle (also used for dairy and work purposes); 1 buffalo; 2 pigs; 2 sheep and goats

Livestock	Number (million)[a]	Draft use %	Meat use %	Milk production %	Estimated international movements/year[b]	
					Entering	Leaving
Cattle	17.5	30.3	53.7	16.0	0	2600[c]
Buffaloes	15.7	0.6	76.5	22.9	0	0
Sheep	23.3	na	na	na	na	na
Goats	29.9	na	na	na	na	na

[a] the annual growth rate of the livestock sector is approx. 2%
[b] Legal
[c] Mainly Sahiwa cattle for breeding programs in Malaysia and Indonesia

Herd size: cattle/buffaloes — 89% small (1-6); 11.5% medium (7-20); 0.5% large (> 21)
buffaloes — 90% small; 9.5% medium; 0.4% large
sheep/goats 87-96 small flock (1-30)

FMD EPIDEMIOLOGY

Seasonal incidence: no major seasonal pattern (see Table 3)
Geographic frequency: more frequent in Punjab, Sind and NW Frontier Provinces probably due to the larger population of susceptible animals in these provinces

Disease outbreaks and vaccinations

	1988	1989	1990	1991	1992	1993
No. of outbreaks[a]	82(33)	51(26)	34(26)	60(20)	30(11)	13(4)
Provinces involved[b]	1,2,3	1,2,3	1,2,3	1,2	1,2	1
Serotypes recorded	O,Asia 1	O,Asia 1	O	O	O	O
Species involved	C,B	C,B	C,B	C,B	C,B	C,B
Vaccine use	O,Asia 1	O,Asia 1	O,Asia 1	O,Asia 1	O,Asia 1	

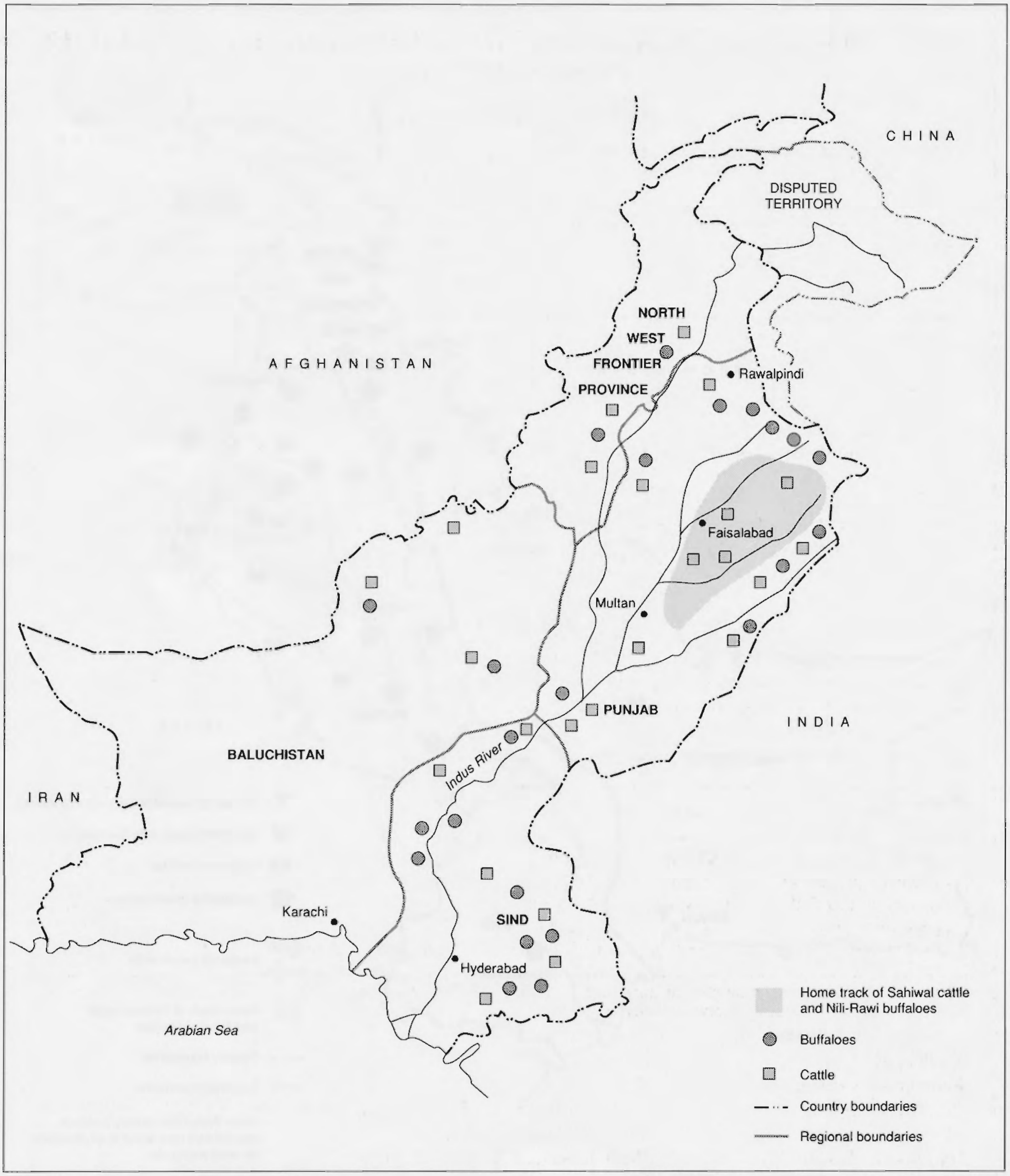
[a] Figures in brackets are the number of outbreaks for which the virus was typed
[b] 1 = Punjab; 2 = Sind; 3 = NW Frontier Province

Facilities

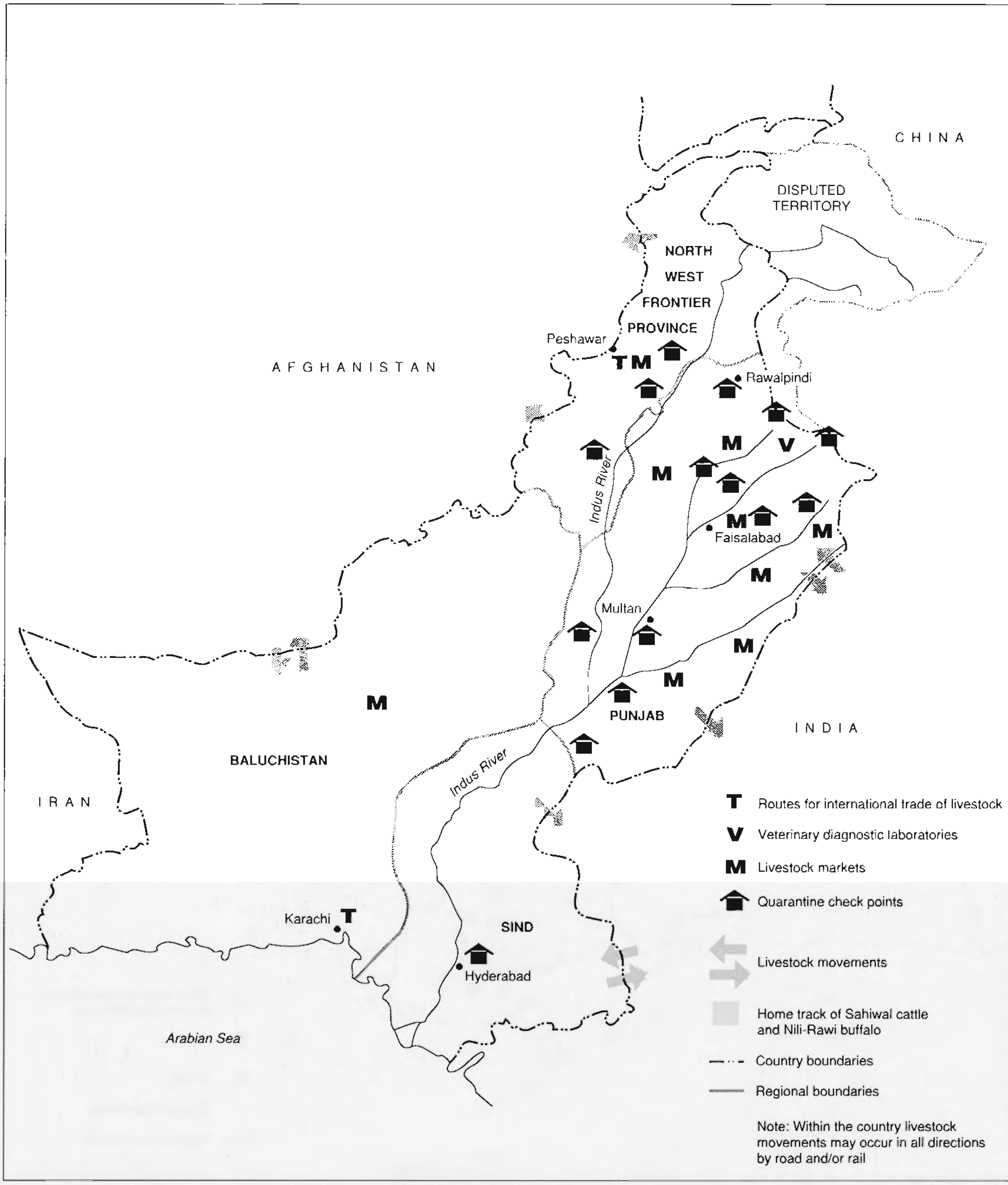
Veterinary centres: 21
Veterinary officers: staff of divisional/district laboratories and FMDRC; 4000 veterinary stock assistants
Diagnostic laboratory: FMD Research Centre, Lahore
Cost per diagnostic test ($US): 0.5

Vaccine

Vaccine supply: 100% locally produced at FMDRC, Lahore
Cost per dose ($US): 0.2
Vaccine strategy:
(i) outbreak ring vaccination
(ii) universal vaccination (only on state and military dairy farms)
(iii) As requested by livestock holders



Map 1. Main livestock areas in Pakistan.



Map 2. FMD outbreaks, facilities and livestock movement patterns in Pakistan.

Vaccine

Soon after the establishment of FMDRC, FMD vaccine production commenced initially using Belin's technique in buffalo calves (Afzal & Ilahi 1966). Later a polyvalent (serotypes A, O and Asia 1) cell culture vaccine was produced using BHK monolayer culture (Brooksby & Rogers 1957). More recently, bivalent cell culture vaccine containing O and Asia 1 serotypes is being produced. Over the last 10 years about 4.1 million doses of vaccine have been produced and distributed in the field. Presently FMDRC has the capacity to produce 0.5 million doses annually which are sold at the cost of US$0.2 per dose.

The vaccine is sold at the FMDRC and interested farmers and district authorities of veterinary extension services and managers of state-owned livestock herds, make their own arrangement to procure vaccine according to their needs. Presently, FMD vaccine is not imported from other countries.

Stock Movements

National

Livestock movement generally occurs from July to October from the interior of Punjab to Sind and NWFP. The animals transported are pregnant and/or freshly calved cattle and buffaloes to cater for milk requirements in those areas. When these animals are dried off they are either sent back or slaughtered. The small ruminants are brought to Punjab and Sind from NWFP and Baluchistan for marketing and for sacrifice during the Eid-ul-Azha festival. The transportation of livestock is carried out by trucks and rail. The district and *thesil* (local) level livestock markets (where all the species of livestock are traded) are held quite frequently.

Exports

Pakistan has exported approximately 15 000 Sahiwal cattle during the last 5 years, mainly for breeding programs in various countries including Malaysia and Indonesia. These cattle originated from the home tract of this breed in Punjab. Other breeds of livestock have only rarely been exported.

Control/Eradication Strategies

Before the establishment of FMDRC in 1962, vaccine was not available for immunisation of livestock. When an epidemic occurred control measures were enforced including restriction of the movement of animals and animal products, isolation of infected animals and disinfection of contaminated premises. When an FMD outbreak occurred in any locality, all cattle fairs were banned in surrounding areas. In some indigenous herds aphthisation was practiced but it was not safe in imported and crossbred herds (Qureshi & Anwar 1972).

With the start of FMD vaccine production in 1962, the sanitary control measures were supplemented with immunisation procedures. Initially vaccination was confined to government or private commercial farms and valuable imported (exotic) and crossbred stock. Furthermore, ring vaccination is now carried out around epidemic areas to prevent the spread of disease. The veterinary extension services at district level implement a program of prophylactic vaccination based on the known pattern of disease occurrence and livestock movements. This is an expensive procedure because the fast waning vaccinal immunity warrants immunisation twice a year in February and October (Veterinary Research Institute 1980). Furthermore, far fewer vaccine doses are produced in the country each year than are actually needed. Therefore, 99% of the total susceptible population still remains unvaccinated (Raja 1990). The socioeconomic factors affecting the immunisation program are described elsewhere in this paper.

Currently, vaccination at state farms and of valuable livestock is carried out. Once an epidemic occurs, hygienic measures are undertaken to minimise the severity of the disease and to restrict the spread of infection. When disease appears in a particular locality, all cattle fairs are banned in that area and ring vaccination is carried out to prevent the spread of infection. Mass vaccination is carried out by about 4000 veterinary stock assistants stationed at veterinary centres, dispensaries and mobile camps supervised by veterinary officers in the country. The vaccination program is hampered by a number of socioeconomic factors including shortage of vaccine, cost of vaccine, small livestock holdings, logistic problems of vaccinators, farmers ignorance about affects of FMD on livestock, productivity etc.

The information gathered by staff of FMDRC during field and laboratory investigations of FMD outbreaks is used to direct vaccine production and to identify the foci of infection. Staff of veterinary extension services are alerted and a rigorous vaccination program run in that area.

Currently, there is no official program for monitoring the effectiveness of vaccination. The reports on FMD outbreaks are sent by veterinary officers — who are always reluctant to report — and are passively received at the provincial directorate of veterinary extension services who then contact FMDRC to seek their help for field investigation, sample collection and laboratory diagnosis.

Future Priorities

Animal production is a major part of the agricultural economy of the country. Therefore, the immediate effect of FMD and the rapidity of its spread has stimulated growing concern among veterinary services. Recently, the FMDRC has been given substantial financial support to enhance vaccine production so that a recommended level of 80% vaccination coverage of susceptible cattle and buffalo (Henderson 1970) can be achieved. Furthermore, the Government has started to issue licenses to the private sector for the import of vaccine from other countries such as Turkey and the United Kingdom. Efforts are underway to streamline the distribution and storage of vaccine. The policy of mandatory notification of FMD outbreaks will be further reinforced.

Improvements are being made in the efficiency of veterinary services and district level diagnostic laboratories are being equipped and staffed with qualified diagnosticians.

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Philippines

Yvonne G. Vinas* and Bemes G. Mondia†

THE PHILIPPINES is an archipelago made up of approximately 7107 islands and islets. This geographical subdivision is grouped into three major islands namely: Luzon, Visayas and Mindanao. The human population is currently estimated to be 65 million. There are 13 political subdivisions, Regions 1 to 12 and the Cordillera Autonomous Region (CAR) in the north. The regions are further divided into 78 provinces.

The Philippines has an area of about 300 000 sq km and is bounded on the north by Taiwan; on the east by the Pacific Ocean; on the west by the China Sea and on the south by the Celebes Sea. It has several major mountain ranges and volcanoes, including the Mayon Volcano in Albay and the Taal Volcano in Batangas. The Philippines has two distinct seasons — the wet and dry.

The Philippines is basically an agricultural country highly dependent on crop production, livestock and fisheries/marine production. Rice is produced as a staple crop while corn is cultivated primarily for use as animal feed. Livestock production shares equal importance, not only for its food value, but also for draft purposes. The current animal populations of each region are shown in Table 1.

History of Foot-and-Mouth Disease

Foot-and-mouth disease (FMD) was first reported to have occurred in the Philippines on June 30, 1902 as a result of the importation of beef cattle from Hong Kong to Manila. Within the same period, four shipments of animals coming from Thailand and possibly other countries were infected.

The first major outbreak of FMD in the country occurred in Sorsogon and Bukidnon in 1920 and after this the disease became widespread in the Philippines. Sporadic cases were observed in Luzon Province. Samples taken from affected bovine and swine in Luzon in 1959, 1966, 1972 and 1975 were sent to the World Reference Laboratory (WRL), Pirbright, United Kingdom, and were identified as serotype O subtype 1.

Serotype A subtype 2 was also identified from samples submitted in 1975 as a result of another outbreak in Central Luzon, Central Visayas and Cotabato.

In February 1976, serotype C subtype 3 was first isolated from provincial cases in Central Visayas. Since that time all three serotypes have been alternatively diagnosed in outbreaks occurring from province to province.

In 1984–1986, the disease was again reported to have occurred in Luzon mainland, with a few sporadic cases in Masbate and South Cotabato in 1986–88.

Epidemiology

No major outbreak of FMD was reported from 1989–92 except for some sporadic cases in Regions 1 to 5 and CAR in Luzon (see Table 2).

Table 3 summarises the results of the typing of 303 samples submitted by the different regions in 1989–1991 as compiled at the National Animal Disease Diagnostic Laboratory (NADDL), Bureau of Animal Industry. Of the 303 FMD-positive samples, 7% were type A, 57% were type O and 34% were type C.

Origin and spread of outbreak

The outbreak in Albay was a result of an illegal shipment of pigs from Rasario, Batangas. The affected animals were immediately slaughtered and vaccination of susceptible animals was undertaken in a 10 kilometre radius to prevent spread of the disease.

* Department of Agriculture, Region IV, 4th Floor, ATI Building, Diliman, Quezon City, Philippines.
† Regional Quarantine Officer, Veterinary Quarantine Service, Port of Cagayan de Oro City, Region X, Philippines.

Table 1. Animal distribution and livestock markets in the Philippines by regions (1993).

Regions	Main islands	Cattle	Carabao[a]	Pigs	Goats	Livestock markets (no.)
CAR	North Luzon	60 479	91 014	202 113	21 847	1
1	Northwest Luzon	209 692	156 677	482 604	211 931	11
2	Northeast Luzon	77 179	206 586	454 021	42 766	5
3	Central Luzon	135 743	228 224	1 024 788	122 394	4
4	Central Luzon (incl. Manila)/ Mindoro/Palawan	185 371	165 528	1 140 151	136 972	16
5	South Luzon/Masbate	103 658	240 351	568 849	87 919	7
6	Panay	124 152	278 449	581 588	272 213	26
7	Negros/Cebu/Bohol	217 653	144 017	750 265	352 346	17
8	Samar/Leyte	26 025	158 339	574 210	56 912	8
9	West Mindanao/Jolo/Basilan/ Tawitawi	83 561	161 180	439 050	201 967	5
10	North Mindanao	210 322	147 091	589 967	201 630	7
11	East Mindanao	127 473	239 739	820 828	268 587	6
12	Southwest Mindanao	97 458	262 554	393 163	261 973	7
Total		1 658 766	2 479 749	8 021 897	2 239 457	120

[a] Water buffaloes

Table 2. Incidence of FMD based on field reports 1989–92.

Region	No. of animals affected			
	1989	1990	1991	1992
CAR	0	0	22	0
1	37	0	64	0
2	0	0	0	0
3	100	173	29	0
4	464	608	12	0
5	0	23	0	0
Total	601	804	127	0

Table 3. FMD serotype results (by ELISA and CFT), 1989–91.

Region/Provinces	Serotype		
	O	A	C
Regon 2			
Isabela			+
Region 3			
Balacan	+	+	+
Region 4			
Batangas		+	+
Metro Manila	+	+	+
Region 5			
Albay		+	
Camarines Sur		+	

Source: National Animal Disease Diagnostic Laboratory, 1989–91

Samples collected and tested revealed serotype C. The outbreak in a cargo ship with 54 pigs for shipment to South Cotabato was contained by not allowing unloading of the pigs and immediate destruction of the animals on board. The virus infection may have been contracted from Manila by the shipment.

Facilities

The disease situation is continuously monitored through field officers or through coordination with the agencies involved in animal movement. Any suspected cases are immediately reported for investigation and follow-up. Laboratory capabilities are being strengthened and improved to facilitate immediate identification of prevailing serotypes.

The Department of Agriculture maintains 13 regional offices and 78 field offices in the country with an estimated livestock personnel of approximately 1000 who are responsible for monitoring the FMD situation in the Philippines. Communication may be through radios, telegrams, telephones, verbal report, written reports or any other forms of communication available in a particular area.

The Department of Agriculture, Bureau of Animal Industry maintains a Foot-and-Mouth Disease Laboratory Unit in the NADDL located in Diliman, Quezon City. It is presently staffed with 3 highly trained veterinarians who conduct the testing and research of FMD in the country. Diagnosis of FMD is conducted using ELISA and complement fixation tests (CFT).

COUNTRY LIVESTOCK AND FMD EPIDEMIOLOGY STATISTICS

Philippines: 13 regions (1 to 12 + Cordillera Autonomous Region); 78 provinces

LIVESTOCK STATISTICS

Animals per owner: estimated averages — 2 beef cattle (also used for dairy and work purposes); 1 buffalo; 2 pigs; 2 sheep and goats

Livestock	Number (million)	Draft use %	Meat use %	Milk production %	Estimated international movements ('000 per year) Entering	Leaving
Cattle	1.7	2	95	5	2–3	0
Buffaloes	2.5	50	40	10	0	0
Pigs	8.0	na	90	na	10	0
Sheep and goats	2.2	na	90	10	1	0

FMD EPIDEMIOLOGY

Seasonal incidence: most outbreaks occur during the rainy season and late summer
Geographic frequency: most prevalent around Luzon

Disease outbreaks and vaccinations

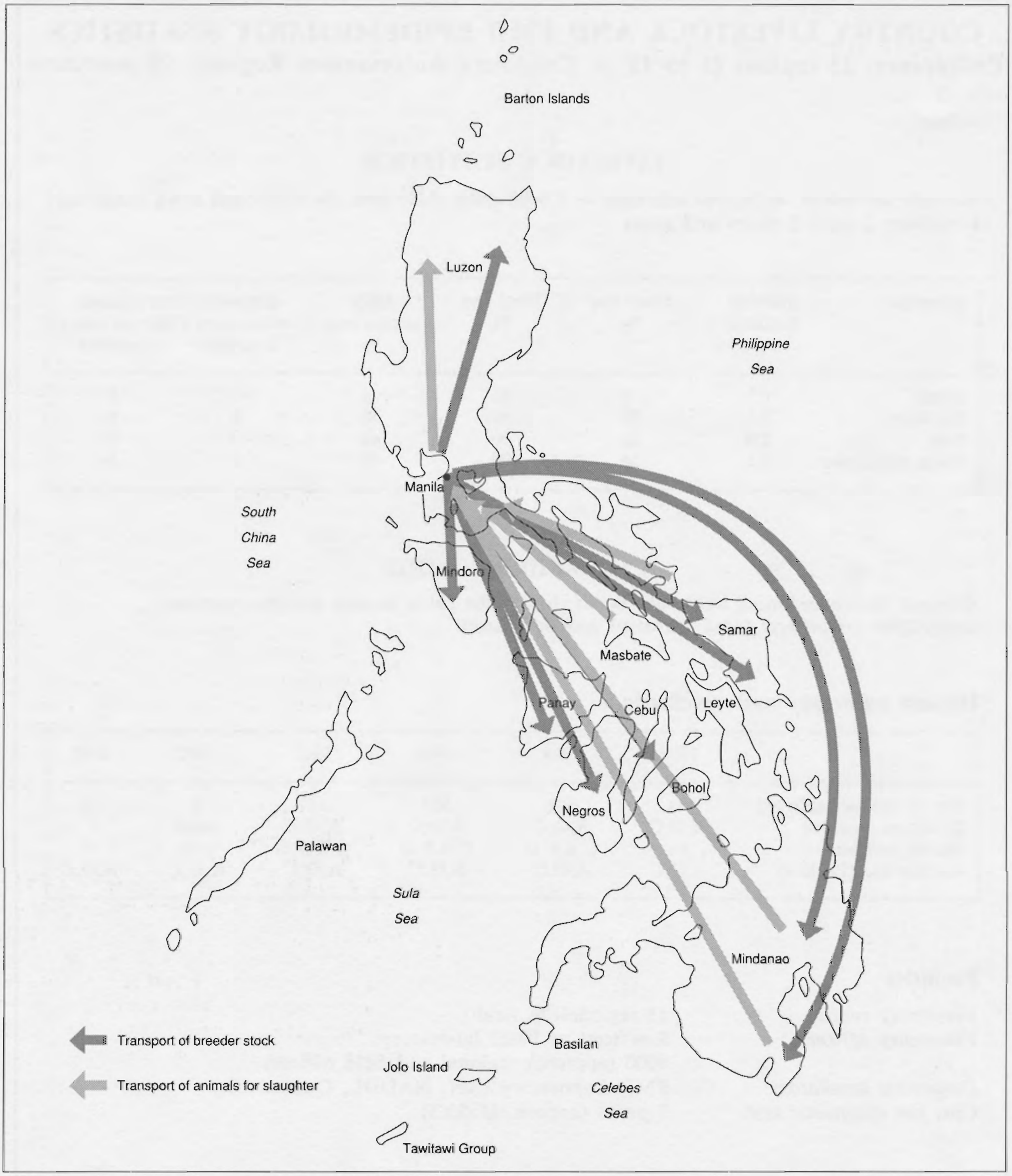
	1988	1989	1990	1991	1992	1993
No. of animals affected	na	601	804	127	0	na
Serotypes recorded	A,O,C	A,O,C	A,O,C	A,O,C	none	C
Species involved	na	C,B,P,G	C,B,P,G	C,B,P,G	none	P
Vaccine use (Table 4)	A,O,C	A,O,C	A,O,C	A,O,C	A,O,C	A,O,C

Facilities

Veterinary centres: 13 regional/78 field
Veterinary officers: 3 officers at FMD laboratory; 1000 (approx.) regional and field officers
Diagnostic laboratory: FMD Laboratory Unit, NADDL, Quezon City
Cost per diagnostic test: 7 pesos (approx. US$0.5)

Vaccine

Vaccine supply: imported
Cost per dose ($US): 1.8 (1992)
Vaccine strategy:
(i) ring vaccination
(ii) declaration of infected areas under quarantine
(iii) restriction of animal movement, especially for FMD-free zone



Map 1. Livestock movements in the Philippines.

Vaccine

The country does not have the capability to produce its own FMD vaccine. Instead, FMD vaccine is normally imported from other countries. Table 4 shows the number of doses and value of imported vaccines from 1988–93 and Table 5 shows the distribution of vaccines to FMD affected regions.

Table 4. FMD vaccine importation by year 1988–93.

Year	No. of doses	Type	Value (US$)
1988	950 050	Trivalent	306 052
1989	754 778	Trivalent	249 339
1990	1 748 000	Trivalent	573 265
1991	913 790	Trivalent	406 217
1992	270 250	Trivalent	146 288
1993 Jan–June	474 980	Trivalent	266 992

Table 5. FMD vaccine distribution (doses), 1988–92.

Regions	1988	1989	1990	1991	1992
CAR			21 500	26 600	
1	66 829	16 420	510 450	77 200	
2	7 240		248 000	16 380	
3	123 750	104 670	1 099 550	106 320	25 508
4	149 229	12 030	727 750	256 080	17 000
5	123 651	20 000	50 890	23 350	
11		98 220	98 000	16 100	2 500
Total	470 699	251 340	2 756 140	522 030	45 008

Stock Movements

Scattered all over the country are 120 strategically located livestock markets which enables continuous trading and movement of animals intended for breeding or slaughter purposes (see Table 1). Map 1 shows the major routes of animal movement in the country. The focal point of trading is in Pampanga where animals basically intended for slaughter or breeding purposes are moved/transported inwards or outwards depending on the requirement of each province. There is no movement of live animals outside the country.

There is an imposed restriction on the movement of susceptible animals into the recognised FMD-free areas. Regular serological testing is conducted in the FMD-free zone for monitoring purposes. On a limited and case-to-base basis, shipment of breeders into these areas are allowed after undergoing close observation, serological testing and isolation of animals. To maintain a negative status, only animals not vaccinated against FMD are allowed into the FMD-free zones.

For other transport/animal movement activities, licenses and permits are regularly issued to breeders or traders that transport livestock. These permits are routinely issued by veterinary quarantine officers to effect interprovincial movement.

FMD-Free Status

As discussed above, no major outbreak has been recorded since 1989 except for a few sporadic cases reported in fifteen provinces in Luzon. This development in the disease situation warranted application for FMD-free status of some specific areas in the country. So far, ASEAN has recognised the FMD-free status of Northern Mindanao (Region 10), Southern Mindanao (Region 9), the island of Batanes in Region 2 and the island of Palawan in Region 4.

At present the whole of Mindanao island has been declared by the Bureau of Animal Industry, with approval by the Department of Agriculture, as FMD-free. Three regions of the Visayas, namely: Regions 6, 7 and 8 have also been recommended to be FMD-free as well as the two remaining regions of Mindanao, Regions 11 and 12. Evaluation by ASEAN representatives and FAO has been conducted and the Bureau of Animal Industry is only waiting for the result of serological examination from Pirbright before formal declaration will be made, possibly in the early part of 1994.

Sri Lanka

Susima N. Kodituwakku*

SRI LANKA is an island located in the Indian Ocean with an area of 65 610 sq km and a human population of 17 million. It has a central mountainous region surrounded by narrow plains which widen in the northern half of the island. The country has 3 major climatic zones. The *dry zone* occupies two-thirds of the island comprising the northern half and eastern parts; the *hill country wet zone* and *lowland wet zone* occupying the southwestern quadrant. The country is divided into 9 provinces and 25 administrative districts.

Livestock

Approximately 39% of the land is available for livestock production. Livestock farming activity in Sri Lanka is integrated with agriculture, especially in the dry zone for paddy farming and hill country for tea plantations. There are over 0.6 million family holdings owning livestock. The contribution of livestock to family income varies from 30–60%. In 1992, the livestock contributed to 5.6% of agricultural products and 1.2% of gross domestic product (GDP), the main contributor being the dairy subsector.

The North-Western Province has a very dense cattle and buffalo population amounting to 22.2% and 21.5% of the national total, respectively (Table 1). Nearly 90% of the national population of pigs are in the western coastal belt of the country and are reared by small and medium-scale farmers.

Indigenous and crossbred Indian cattle are mainly reared in the dry zone and in an intermediate agricultural zone called the coconut triangle.

The pure and crossbred European cattle are reared in the hill country wet zone. The purebred temperate breeds are kept in small-holdings and are managed under limited grazing systems. Animals are tethered by day and housed at night.

* Gannoruwa, Peradeniya, Veterinary Research Institute, Sri Lanka.

Table 1. Distribution of cattle and buffalo population ('000), 1993.

Province	Cattle	Buffaloes
Central (C)	167.2 (8.8)	81 (8.1)
East (E)	231.8 (12.2)	169 (16.9)
North (N)	313.5 (16.5)	33 (3.3)
North-Central (NC)	220.4 (11.6)	199 (19.9)
North-West (NW)	421.8 (22.2)	215 (21.5)
Sabaragamuwa (Sab)	74.1 (3.9)	70 (7.0)
South (S)	167.2 (8.8)	114 (11.4)
Uva (U)	161.1 (8.5)	37 (3.7)
West (W)	136.8 (7.2)	82 (8.2)
	1.9 million	1.0 million

Note: Figures in brackets are per cent of national total.

In the dry zone, large herds of cattle and buffaloes collectively graze on natural pastures and river beds. Some animals may be confined at night. These animals provide the main source of draft power.

History of Foot-and-Mouth Disease

Foot-and-mouth disease (FMD) in cattle was recognised in Sri Lanka far back in 1869, but the first official record was made only in 1902. Although the disease has been declared a notifiable disease, the serious economic effects were felt only after crossbreeding programs with exotic breeds were implemented.

An island-wide epidemic in 1962 resulted in FMD control program with assistance from the FAO to set up a diagnostic laboratory. The serotypes O and C have been recorded in the country. Type O was recorded in 1962 while type C was first recorded in 1970 through cattle imported from India, causing disease in the northwestern part of the country.

Records of disease outbreaks since 1902 indicate that the disease assumes epidemic proportions in 4–6 years. Available figures of prevalence of FMD in the various provinces indicate greatest incidence of disease in the Eastern Province and it is also accepted that island-wide epidemic originated in the eastern parts of the country where domesticated animals are in close contact with wildlife.

In 1977–82 and 1987–88, clinical disease was recorded in all domestic ruminants including goats and sheep and also in pigs.

Epidemiology

Outbreaks of FMD have been recorded in cattle and buffaloes every year from 1988–1992 (Table 2). These outbreaks have been due to type O virus. Type C was last recorded in 1984.

Table 2. FMD cases, 1988–1992.

Year	No. of cases	Deaths	Provinces[a]
1988	6448	175	C, E, N, NW, Sab, S, N, NC, Sab
1989	313	1	E, N, NC, Sab
1990	176	06	E, N, NC, NW
1991	1879	59	NC, NW, S, U, W
1992	1110	62	C, U
1993	1 outbreak		C

[a] See Table 1 for Province abbreviations

There is variation in susceptibility of the various bovine species to the disease. The exotic European breeds and their local crosses show severe clinical signs. Calf mortality among these breeds is reported to be 2–3%. The clinical picture in the indigenous bovine appear to be variable; lesions may be mild or severe.

The disease is endemic in localised areas of the country and two foci of infection have been identified (Map 1). In the map the island is divided into: an endemic zone; a buffer zone; and a disease-free zone. The endemic zone is the area from which the disease originated. The buffer zone is the area surrounding the endemic area to a breadth of 32–48 km to which the disease can infiltrate by the uncontrolled movement of animals. The disease-free area is the rest of the island.

FMD outbreaks tend to occur during the North-east Monsoon between December and February. This coincides with the return of livestock from seasonal grazing areas in the jungles of the southeastern region where the disease is endemic. The cattle and buffalo population in this region is in small units with much local movement in a 16–24 km radius.

Economic importance of FMD

FMD is regarded as important for cattle and buffaloes (but not so much for pigs, sheep or goats) because of the loss of daft power, decline in milk production and restrictions on the movement of animals.

Facilities

The Department of Animal Production and Health provides a field veterinary service through 137 dispensaries manned by 143 veterinarians and 559 livestock development inspectors. Disease investigation service is further strengthened by six regional investigation centres located at Central, Eastern, Northern, North-Central, North-Western and Southern Provinces.

An outbreak of disease in the field is generally brought to the notice of the veterinarian by the farmer or supporting staff. The veterinarian carries out preliminary investigations and seeks the assistance of the diagnostic laboratory for confirmation.

A FMD diagnostic facility is available at the Veterinary Investigation Centre located in the Central Province. Samples are received at this laboratory for diagnosis mainly from field veterinarians. The approximate cost is US$1 per diagnostic test which is borne by the Government. The ELISA test is been used for serotyping of FMD virus. The assistance of the World Reference Laboratory (WRL), Pirbright, United Kingdom is also sometimes sought. The particulars of samples received for diagnosis of FMD from 1982–92 is given in Table 3.

Table 3. Results of serotyping of FMD virus.

Year	No. of samples				Province[a]
	Received	Positive for FMD virus	Type O	Type C	
1982	29	11	11	Nil	E, NC, S
1983	11	8	7	1	C, NC
1984	47	37	30	7	C, E, NC, NW, U
1985	10	6	6	Nil	E, NC
1986	20	9	9	Nil	NC
1987	127	58	58	Nil	C, E, NC, Sab, U, W
1988	47	26	26	Nil	C, NW, S
1989	14	4	4	Nil	E, N, NW
1990	2	1	1	Nil	E
1991	19	14	13	Nil	NCP, NW, S, U, W
1992	35	25	25	Nil	C, U

[a] See Table 1 for Province abbreviations

COUNTRY LIVESTOCK AND FMD EPIDEMIOLOGY STATISTICS

Sri Lanka: 9 provinces

LIVESTOCK STATISTICS

Production unit (for animal health programs): farm
Animals per owner: estimated averages — 1.4 dairy cattle; 4.5 working cattle; 1.7 buffaloes; 2.2 pigs; 1.8 sheep/goats

Livestock	Number million	Draft use %	Meat use %	Milk production (million head)
Cattle	1.9	na	na	0.5
Buffaloes	1.0	na	na	0.2
Pigs	0.1	na	na	na
Sheep and goats	0.5	na	na	na

International movement: minimal

FMD EPIDEMIOLOGY

Seasonal incidence: most outbreaks occur during the Northeast Monsoon (December–February)
Geographic frequency: endemic zone is in the east of the island with two main foci of infection (see Map 1)

Disease outbreaks and vaccinations

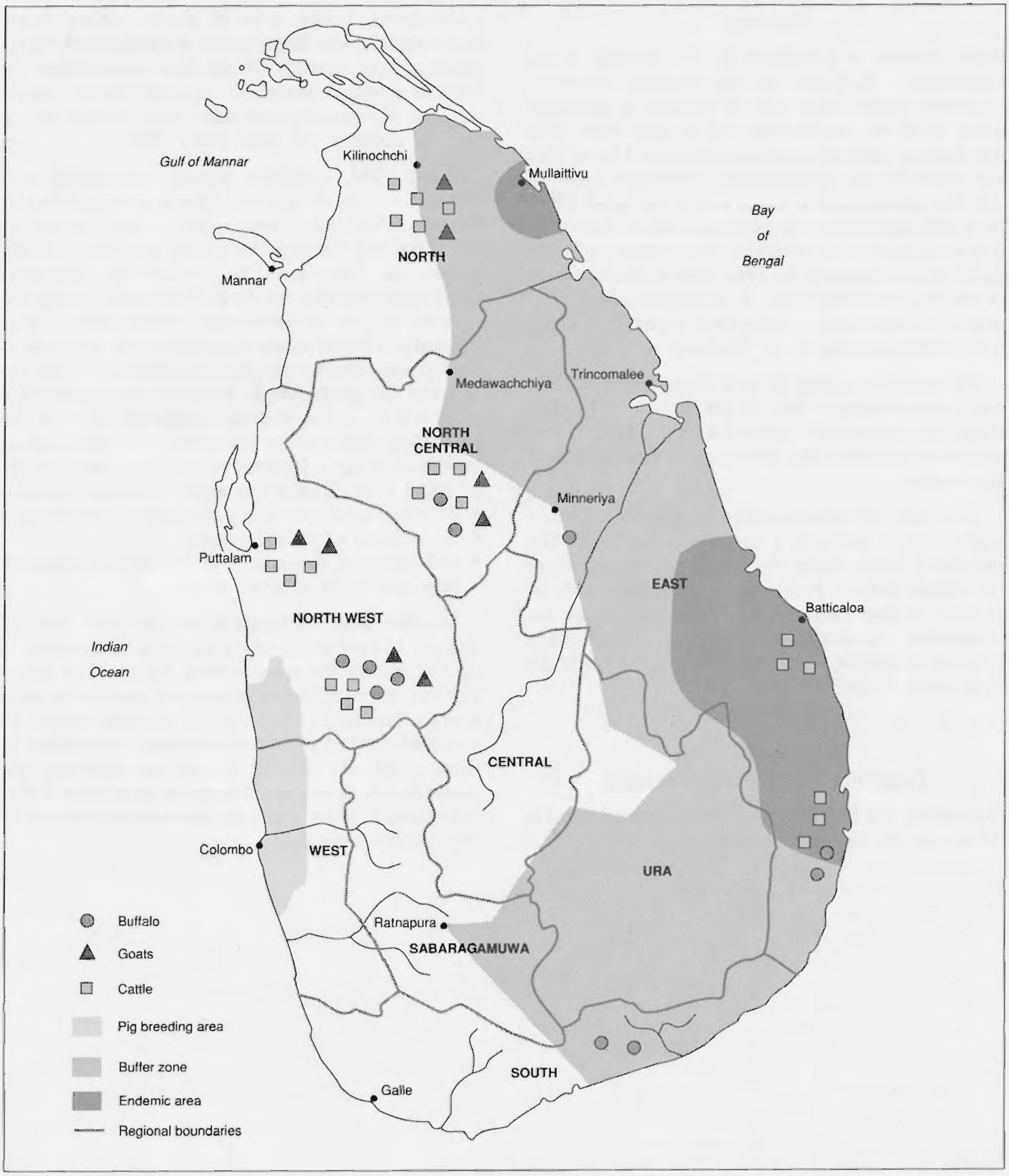
	1988	1989	1990	1991	1992	1993
Serotypes recorded	O	O	O	O	O	O
Species involved	C,B,G	C,B	C,B	C,B	C,B	C
Vaccine used	O	O	O	O	O	na

Facilities

Veterinary centres: 6 regional investigation centres; 137 field veterinary dispensaries
Veterinary officers: 143 veterinarians; 559 livestock development inspectors
Diagnostic laboratory: Veterinary Investigation Centre, Central Province
Cost per diagnostic test ($US): 1.0

Vaccine

Vaccine supply: 100% of vaccine prepared at the Animal Virus Laboratory, Polgolla, Central Province
Cost per dose ($US): 0.16 (local monovalent vaccine); 0.33 (imported)
Vaccine strategy: (i) outbreak ring vaccination
(ii) control zone(s) vaccination
(iii) as requested by livestock owners



Map 1. Main livestock areas and FMD endemic and buffer zones in Sri Lanka.

Vaccine

FMD vaccine is produced at the Animal Virus Laboratory, Polgolla in the Central Province. Currently monovalent type O vaccine is produced using BHK-21 suspension cell system with BEI inactivation and saponin as a adjuvant. Use of BEI and saponin was introduced in 1990 and prior to this formalin was used as an inactivant since 1964. Sri Lanka has to supplement local production with imported vaccine to meet the requirements of field vaccination programs. In 1992, 50 000 doses of type O vaccine was imported. A consignment of 5000 doses of monovalent vaccine was received as a gift from the Government of Thailand.

The production cost of local monovalent vaccine was approximately US$0.16 per dose in 1992. The imported vaccine cost approximately US$0.33. The vaccine is supplied free of charge to farmers by the government.

The FMD vaccine produced at the Animal Virus Laboratory is stored at a central vaccine bank. The vaccine is issued from this bank to the provinces for disease control programs. A limited quantity of vaccine is also been stored in the provinces for emergency vaccinations. The field veterinarians involved in disease control programs ensure that the cold chain is maintained.

Control/Eradication Strategies

The policy for FMD control which was adopted in 1964 was the vaccination of high quality stock in government farms and in places where stock improvement was in progress. Animals were vaccinated at four months of age and revaccinated six months later, followed by annual booster vaccinations. No vaccinations have been carried out in the hill country wet zone since 1980.

From 1984, extensive annual vaccination was adopted within the endemic (parts of Northern and Eastern Provinces) and buffer zones (parts of Northern and Eastern Provinces) and buffer zones (parts of Northern, North-Central, Eastern, Sabaragamuwa and Southern Provinces) during the months of July to September. From 1993, a supplementary vaccination was adopted in addition to the annual vaccinations during February to March, to cover the young stock. Routine vaccinations are confined to cattle and buffaloes but due to the prevailing situation in the north and east, vaccination coverage is limited. A slaughter policy is not adopted in Sri Lanka but other measures include:

- detection and laboratory diagnosis of the disease
- declaration of affected area
- restriction of movement of susceptible livestock into and from affected areas

Vaccine and vaccination is provided free of charge. In case of an outbreak, ring vaccination is carried out in the surrounding disease-free areas. For routine vaccination in endemic and buffer zone areas, a satisfactory vaccination coverage cannot be achieved due to ethnic disturbances prevailing in these areas. At present we are investigating the possibility of developing a program to achieve FMD-free status in areas which are accessible for extensive vaccination coverage.

Thailand

Wantanee Hanyanum, Kamol Awaiyawanon, Rapeepong Wongdee and Pinai Musikul*

THAILAND covers an area of 513 115 sq km with an approximate human population of 62 000 000. The country borders with Myanmar in the north and northwest, Laos in the northeast, Cambodia in the northeast and east and with Malaysia in the south. The total length of the borders is approximately 4500 km. The country is administratively divided into four areas (Central, Northern, Northeastern and Southern) which are further divided into nine regions.

History of Foot-and-Mouth Disease

Foot-and-mouth disease (FMD) has been endemic in Thailand for more than 40 years. Type A15 was first reported in 1953 and type Asia 1 and O were subsequently identified in 1954 and 1957 (Punya-Upapat 1986). These three types of FMD virus are presently endemic throughout the country except for the south which has been announced free of the disease.

Epidemiology

Susceptible animals

The immune status of the animal is the most important host-related factor in FMD epidemiology (Mann and Sellers 1990). Sufficient herd immunity, either acquired by exposure to the virus or by vaccination, results in decreased virus circulation. Insufficient FMD vaccine, improper vaccine handling, a poor vaccination program and the health status of the animals can all result in insufficient immunity which facilitates the spread of virus in the herd.

* Department of Livestock Development, Phyathai Road, Bangkok 10400, Thailand.

Virus

FMD virus is disseminated from infected animals in lesion exudates, secretions, excretions, and in the droplets of the exhaled air (Mann and Sellers 1990). The virus remains infectious for extended periods in most livestock products and on several inanimate objects (Cottral 1969). Transmission occurs by direct or indirect contact with infected animals or their excretions, secretions or tissues. Aerosol transmission can result in a rapid spread of infection (Sellers and Forman 1973).

After recovery from FMD, a chronic persistent infection may occur in the posterior pharyngeal areas with a low detectable level of virus for up to 6 months (Graves 1979). These animals are of concern as potential sources of virus for new outbreaks.

Animal husbandry

Herd size and density are important factors in the spread of the disease due to close contact between animals. They can also induce stresses or affect the nutritional status of the animals resulting in an increase in susceptibility to infections. When the density of animal populations is higher there is a larger risk of disease spread. The number and distribution of livestock populations in Thailand in 1992 are shown in Table 1.

Due to the high density of cattle and buffaloes in Region 3 and 4 and cattle in Region 5 and 6, most of the FMD outbreaks were reported in these regions. FMD in swine was prevalent in Region 7 where the populations of pigs is very high. As the people in the southern regions prefer growing rubber or mining which offer higher incomes and are less time consuming than raising livestock, the population of livestock animals is much lower in this part of the country and as a result Regions 8 and 9 have been announced free of the disease since 1956 and Region 2 since 1989.

COUNTRY LIVESTOCK AND FMD EPIDEMIOLOGY STATISTICS

Thailand: 4 areas; 9 regions

LIVESTOCK STATISTICS

Livestock	Number (million)	Draft use %	Meat use %	Milk production (kg/day)	Estimated international movements/year Entering	Leaving
Cattle	7.12	85.7	11.2	719 120	9092	2519
Buffaloes	4.73	93.2	6.8	na	5367	771
Pigs	8.19	na	67.1	na	1244	40
Sheep	0.18	na	na	na	na	10326
Goats	0.16	na	na	na	na	na

FMD EPIDEMIOLOGY

Seasonal incidence: none
Geographic frequency: most outbreaks occur in Central, North and Northeast Areas

Disease outbreaks and vaccinations

	1988	1989	1990	1991	1992	1993
Serotypes recorded	O,A,Asia 1	O,A,Asia 1	O,A,Asia 1	O,A,Asia 1	O,A,Asia 1	O,A,Asia 1
Species involved	C,B,P	C,B,P	C,B,P	C,B,P	C,B,P	C,B,P
Vaccine used	O,A,Asia 1	O,A,Asia 1	O,A,Asia 1	O,A,Asia 1	O,A,Asia 1	O,A,Asia 1

Facilities

Veterinary centres (research and diagnostic laboratories): Northern VRDC (Veterinary Research and Diagnostic Center), Hang Chat; Foot-and-Mouth Disease Center (FMDC), Pak Chong; Northeastern VRDC, Khon Kaen; Southern VRDC, Nakhon Srithammarat; National Animal Health and Production Institute (NAHPI), Bangkok[a]

Cost per diagnostic test ($US): ELISA — 6; CFT — 4; tissue culture — 14

[a] Now the National Institute for Animal Health (NIAH)

Vaccine

Vaccine supply: FMDC, Pak Chong

Cost per dose ($US): monovalent — 0.26; bivalent — 0.40; trivalent — 0.60

Vaccine strategy: (i) mass vaccination of cattle and buffaloes, twice yearly;
(ii) ring vaccination within 15 km around infected area, using monovalent or trivalent vaccine if FMD virus type is not specified.

Table 1. Livestock population in Thailand, 1992.

Region	Cattle	Buffaloes	Goats	Sheep	Pigs
1	764 010	93 973	14 389	42 486	566 053
2	261 626	161 483	2 161	4 623	1 316 131
3	1 490 829	2 205 586	3 651	1 516	1 015 975
4	965 903	1 587 092	876	750	578 258
5	734 068	330 374	8 411	1 821	838 308
6	1 144 431	202 601	14 234	25 866	677 218
7	986 584	54 634	10 327	51 985	2 444 618
8	248 322	64 152	22 941	1 987	406 913
9	523 169	28 376	82 211	45 195	349 929
Total	7 118 942	4 728 271	159 201	176 229	8 193 403

Source: Division of Planning and Statistics, Department of Livestock Development

Stock Movements

Although most of the borders are natural boundaries such as mountain ranges, rivers and coast lines, there are some passes which offer relatively free movement of livestock. FMD in cattle has been prevalent in provinces along the border, such as Chiang Rai, which is probably due to smuggling of animals across the border.

As mentioned previously, raising livestock is not the main occupation in the south. However, a number of livestock are needed in the south for local consumption and the south is therefore a tempting place for livestock traders as the prices tend to be much higher. As a result, the direction of animal transportation within Thailand are mostly from the north and northeast to the south. Region 1 and 7 which are the central part of Thailand are the transit points for animals gathering before going south.

Owing to the economic growth, road networks in Thailand have been extended further to almost all villages making the transportation more convenient. This change promotes the spread of several diseases and is one of the difficulties in controlling FMD.

Control/Eradication Strategies

Control measures for FMD have been implemented since 1956 based on the *Animal Epidemic Act 1956*. The Foot-and-Mouth Disease Center was established for diagnostic purposes in 1956 at Pak Chong, Nakhon Ratchasima Province. In 1960 the FMD Vaccine Production Center was built at Nongsari, Pak Chong. FMD diagnosis is also carried out at the Northern Veternary Research and Diagnostic Center (NVRDC) at Hang Chat in Lampang Province.

Five main activities of the FMD control strategy currently used are:

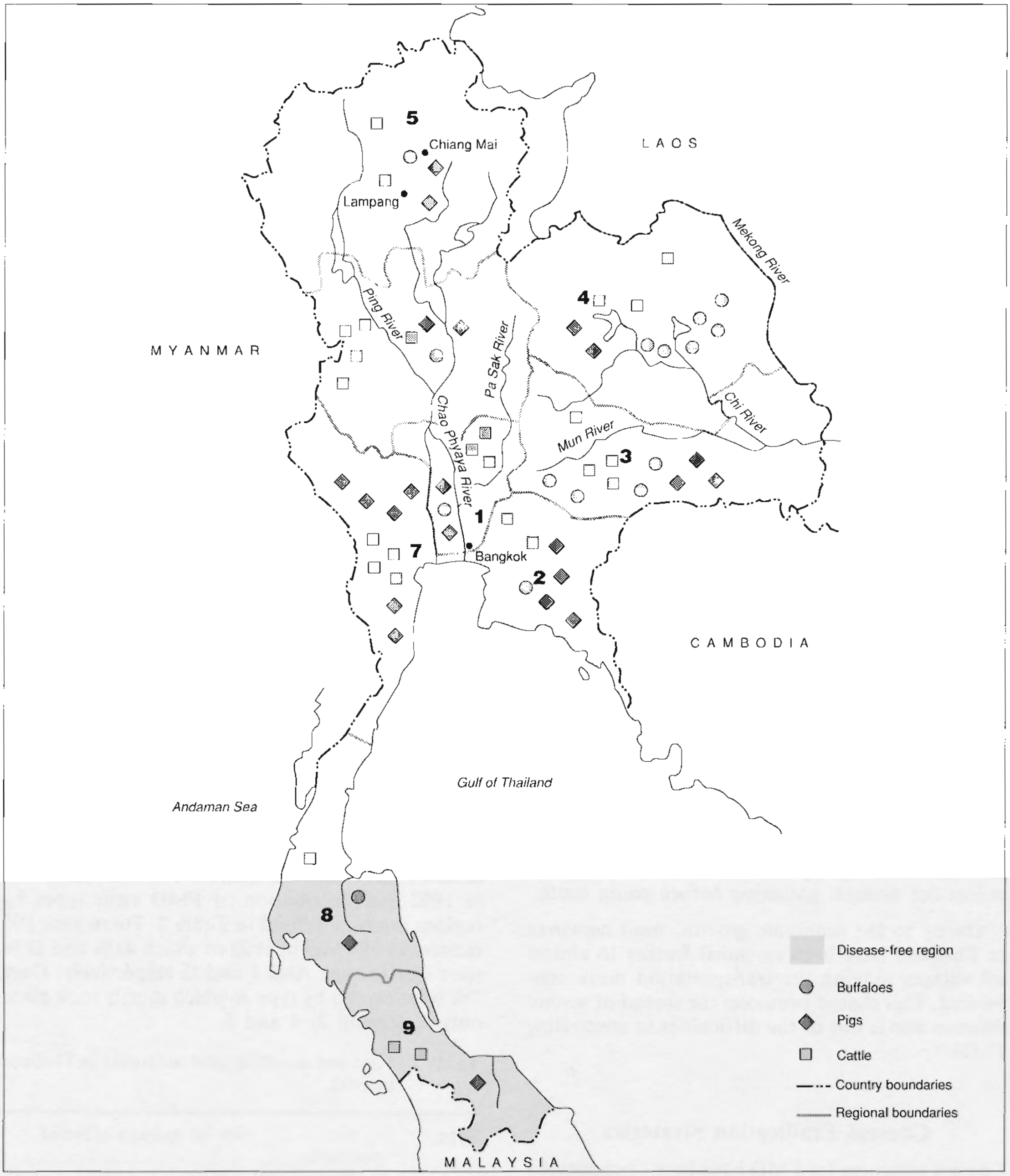
- mass vaccination program;
- FMD information system;
- control of animal movement;
- stamping out; and
- public relations with the goal of eradicating FMD from Thailand by the year 2000.

Recently a new vaccine factory has been established at Pak Chong to produce enough trivalent FMD vaccines for the mass vaccination program. In addition, new diagnostic techniques have been introduced to increase the efficiency of FMD diagnosis. The Foot-and-Mouth Disease Information Center was established at the Division of Disease Control, for the collection and analysis of FMD outbreak data. According to this information centre the number of FMD outbreaks in 1992 and distribution of FMD virus types by regions are summarised in Table 2. There were 196 outbreaks of FMD in 1992 of which 45% and 28% were due to type Asia 1 and O respectively. Only 7% were caused by type A which mostly took place only in Region 3, 4 and 5.

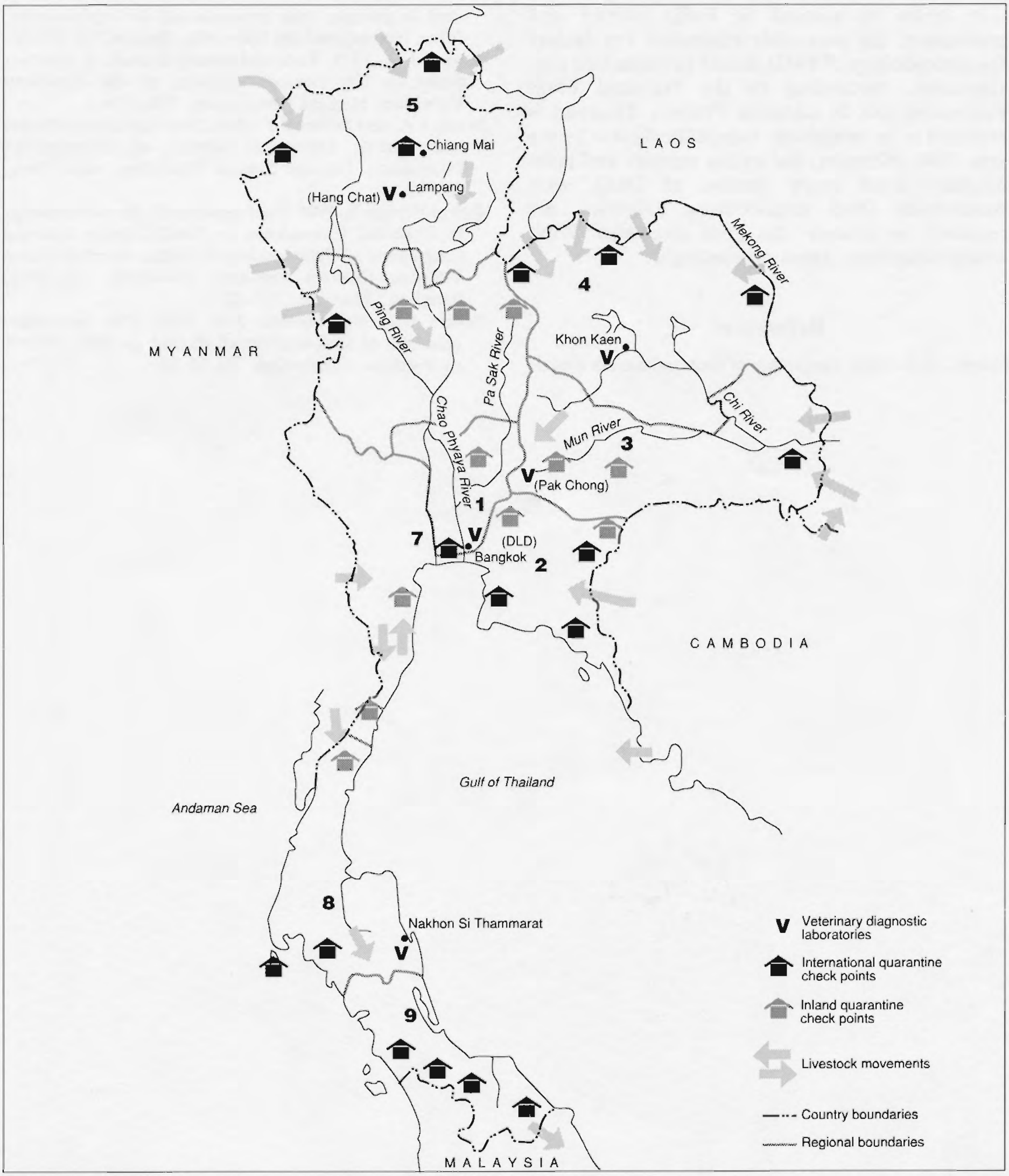
Table 2. Foot-and-mouth disease outbreaks in Thailand in 1992.

Type	No. outbreaks	No. of animals affected		
		Cattle	Buffaloes	Pigs
O	54	16 599	7 044	185 685
A	14	5 527	1 476	—
Asia 1	89	30 340	9 854	21 676
Unknown[a]	39	31 207	4 369	25 491

[a] Old lesions; virus difficult to isolate or sample was too small
Source: FMD Information Center, Division of Disease Control, Department of Livestock Development



Map 1. Main livestock areas and FMD disease-free regions in Thailand.



Map 2. FMD outbreaks, facilities and livestock movement patterns in Thailand.

In order to succeed in FMD control and eradication, the previously mentioned key factors for epidemiology of FMD should be taken into consideration. According to the National FMD Prevention and Eradication Project, Thailand is expected to be completely free of the disease by the year 2000. However, the strong support and commitment from every section of DLD, with cooperation from neighbouring countries, are required to achieve the goal (see also Wipit Chaisrisongkram, these proceedings).

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Vietnam

Nguyen Xuan Phuc*

VIETNAM has experienced a decreasing number of outbreaks of foot-and-mouth disease (FMD) and of infected animals in recent years. In 1975 the disease was very common in the south with 60 outbreaks and 17 300 animals infected. From 1978–83 about 500 000 doses of FMD vaccine (types A, O and C) were imported into Vietnam every year from the former Soviet Union without charge. Vaccination campaigns were launched by the Department of Veterinary Services, with the aim of controlling the old outbreaks, at key points along the main routes of animal movement and in areas along the border between Cambodia and Vietnam. As a result the number of outbreaks was considerably reduced with only a few outbreaks of the disease recorded every year in villages along the border provinces such as Tay Ninh, An Giang and Thuan Hai.

In 1969 samples were sent to the World Reference Laboratory, Pirbright, United Kingdom for typing and the results showed serotype O. In 1984 samples were typed by Merieux Company and type O virus was also identified. In 1990 the Laboratory of the Centre for Veterinary Diagnosis, Ho Chi Minh City checked samples collected from the outbreak in Thuan Hai Province. Serotype O was again found, but in 1992 serotype Asia 1 was also detected from samples of another outbreak. Cattle and buffaloes are both equally susceptible to the disease and pigs and goats are sometimes also infected.

The source of infection has been reported as coming from Cambodia. In general, outbreaks start in villages located along the border and then spread to other villages inland. The morbidity is extremely high covering all herds of animals in an area within several days. The mortality is low, however, except in young animals.

FMD causes great economic losses to farmers, including cost of treatment, feeding animals during the sickness and reductions in draught power. Slaughterhouses in the infected area have been closed up until now.

The policy of the Department of Animal Health for controlling FMD in Vietnam includes:

- improvement of the disease-reporting system so that new cases of the disease are reported as soon as possible;
- ring vaccination;
- isolation and treatment of sick animals; and
- strict control of animal movement.

A National FMD Control and Eradication program has been set up. However, assistance from international organisations is required in areas such as funding, disease information, organisation of ring vaccination, setting up of check points to control animal movement, provision of equipment and facilities for laboratory typing.

* Department of Agriculture, Ministry of Agriculture and Food Industry, Hanoi, Vietnam.

COUNTRY LIVESTOCK AND FMD EPIDEMIOLOGY STATISTICS

Vietnam: 3 provinces

LIVESTOCK STATISTICS

Animals per owner: Estimated averages — 4–5 beef cattle; 2–3 dairy cattle; 1–2 working cattle; 1–4 buffaloes; 2–5 pigs; 10–15 sheep/goats

Type	Number (million)	Draft use %	Meat use %	Milk production %
Cattle	3.1	40	50	10
Buffaloes	2.8	68	31	1
Pigs	12.5	na	na	na
Sheep and goats	0.3	na	na	na

International stock movement: see map

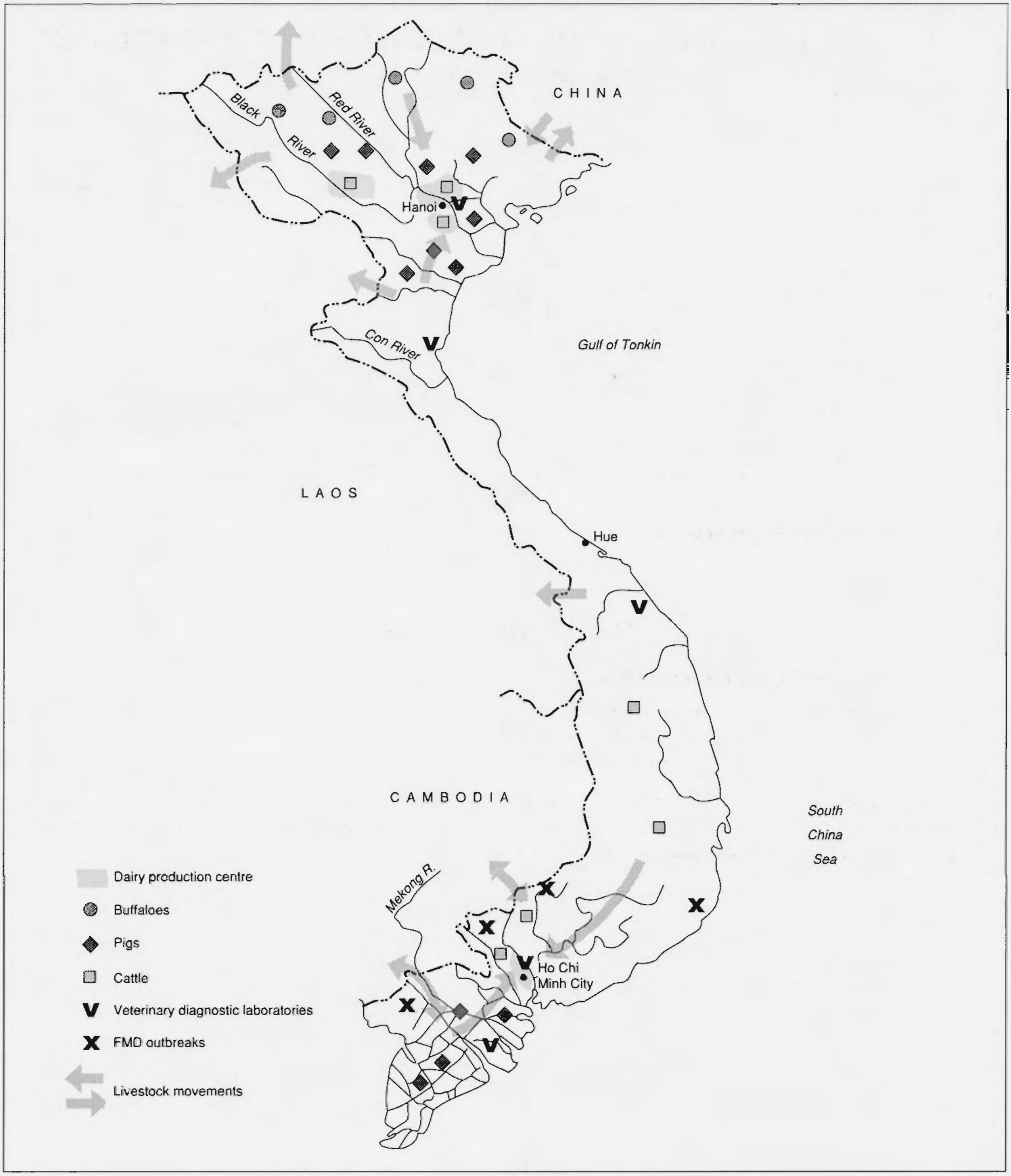
FMD EPIDEMIOLOGY

Disease outbreaks and vaccinations

	1988	1989	1990	1991	1992	1993
Serotypes recorded	O	O	O	O	Asia 1	Asia 1
Species involved	C,B,P,G	C,B,P,G	C,B,P,G	C,B,P,G	C,B,P,G	C,B,P,G
Vaccine use	polyvalent	polyvalent	polyvalent	polyvalent	polyvalent	polyvalent

Vaccine

Vaccine supply: Imported
Cost per dose ($US): 1.2 (1992)
Vaccine strategy: ring vaccination



Map 1. Main livestock areas, FMD outbreaks, facilities and livestock movement patterns in Vietnam.

RECOMMENDATIONS

The final session of the workshop consisted of group discussions and formulation by the conference participants of recommendations for an improved control program for foot-and-mouth disease in Southeast Asia. The recommendations cover the following aspects of FMD control:

- economic and extension activities;
- vaccination program;
- laboratory diagnosis to support a national and regional FMD control program;
- epidemiological and data management for control and eradication; and
- strategies and regulations for regional and national FMD control.

Recommendations of Foot-and-Mouth Disease Workshop

Recommendations on economic and extension activities

Economic activities

1. Benefits and costs from FMD control and eradication vary from area to area of each country according to differences in agricultural and livestock production systems. Assessments should therefore be based on aggregation of valued effects obtained from representative villages and farms in each area or region.
2. Assessments of loss should include the loss of draft animal power, milk, abortion, infertility and mortality, as well as the treatment costs. Such assessments can be made with partial budgets on models which can show cumulative losses in productivity and income over time. Totals can be expected to vary over time according to species and farming systems involved and the epidemiological characteristics of the FMD outbreak.
3. Costs of additional measures to be borne by villages and farmers should be calculated on the same series of representative units. That is, the costs associated with isolation facilities, handling, disinfection and compensation, if appropriate, should be included.
4. Social issues such as the value of animals as a reserve capital or as an indication of status should be estimated and included in a control and eradication campaign, particularly for the poorer smallholders and landless of the community.
5. The aggregate potential benefits can be obtained for each disease control area by using epidemiological evidence to estimate numbers of villages and farms expected to be infected in the operational area with and without selected combinations of control and eradication measures. Anticipated trends in the herd and flock characteristics have to be considered.
6. Potential costs can be summed for each control area on the basis of total farms and animals that have to receive attention. Grouped veterinary costs such as quarantine, vaccine storage, etc. have to be added for each area.
7. Social benefit–cost analyses should be used to:
   - adjust individual item values by 'shadow pricing' to reflect the national interest in such factors as export potential, rural employment and development policies;
   - adjust for the cumulative benefits and costs by 'discounting' according to national practice to reflect the changing value of money over time from the national perspective;
   - allow for public health and nutritional benefits; and
   - the most appropriate method of expressing results should be utilised, such as economic rate of return as well as benefit–cost ratios.

Extension activities

1. Extension activities are essential for a successful completion of strategies.
2. Extension strategies should:
   - be based on human, social and animal welfare as well as economic return to the community and nation; and
   - use all available resources including the media, police, and existing rural and administrative structures.
3. Communications of process and problems, at both the national and village level, of progress and resolution of problems is essential, as benefits from FMD eradication will exceed costs to the nation and farmer in the long term.

Recommendations for a successful vaccination program

1. A safe and potent vaccine with at least 3 PD_{50} (protective dose for 50% of animals) per dose should be used in order to protect animals against FMD viruses which are circulating in the area. Primary inactivates should be mandatory and have a shelf-life of at least one year when stored correctly. FMD vaccines must include only those serotypes recorded in the region.

2. Primary immunisation should consist of two vaccinations one month apart at a minimum age of six months. Vaccination campaigns should only be planned in areas where a high proportion of animals can be realistically vaccinated. A minimum level of 75% of animals vaccinated is desirable.

3. Neighbouring countries should coordinate vaccination campaigns in zones adjacent to national borders.

4. The development of a regional vaccine bank should be encouraged under the authority of a regional FMD coordination unit. Active surveillance of vaccine efficiency should be encouraged. A vaccine failure should be thoroughly investigated with the assistance of a neutral body.

5. The advantage of better adjuvants such as oil should be studied. The possibility of a combined FMD/haemorrhagic septicaemia vaccine should be examined. Future funding of vaccine production and purchases should be discussed at the regional level in conjunction with international organisations.

It was noted that there was strong endorsement of the second meeting of the Office International des Épizooties/Food and Agriculture Organization (OIE/FAO) Co-ordinating Group for Control of FMD in Southeast Asia which stressed the need of a successful vaccine control and eradication program.

Recommendations for laboratory diagnosis to support a national and regional FMD control program

1. National and regional laboratories must be disease secure and operate according to OIE/FAO guidelines.
2. Government authorities should establish a contingency fund to pay for transport of samples to the regional, national and World Reference Laboratory.
3. Research should be undertaken to improve and standardise virus infection-associated (VIA) antibody detection to differentiate infected from vaccinated animals.
4. National laboratories should be encouraged and assisted to develop a tissue culture capability for the isolation of FMD virus.
5. It would be desirable for the regional laboratory to be able to analyse FMD strains by molecular techniques.
6. The essential components of a national diagnostic laboratory are:
   - ability to diagnose FMD and serotype by ELISA techniques;
   - capacity to detect and quantify antibody to FMD virus for evaluation of vaccine, sero-surveillance and animal import/export testing by ELISA;
   - ability to train field staff in safe sample collection and transport of specimens; and
   - facility to rapidly communicate results to the national central veterinary authority in the country.
7. The essential components of a regional FMD laboratory are:
   - ability to type FMD virus by ELISA techniques;
   - capacity to test and quantify antibody to FMD virus by ELISA tests;
   - tissue culture capacity to isolate FMD viruses;
   - ability to antigenically characterise FMD virus strains for vaccine production;
   - capability to produce and supply diagnostic reagents to national FMD laboratories;
   - ability to undertake external quality assurance assessments of diagnosis at the national level;
   - facilities to collect and hold reference strains of FMD virus from countries in the region;
   - ability to diagnose exotic strains of FMD virus to the region by use of inactivated reagents; and
   - to conduct training programs for national laboratories.

Recommendations for the epidemiological and data management for FMD control and eradication

1. It is essential to determine the basic needs, framework of data collection and analysis on a national scale relevant to national and regional strategies. Data collected needs to be in a standardised form for both national and regional analysis, particularly data sheets and computer files.
2. Information needs to be exchanged with the agreement of the appropriate authorities directly among the FMD epidemiologists in each country.

3. FMD vaccination needs to be monitored to ensure correct protection and coverage levels and for serological monitoring for effectiveness. Forward and backward tracing from outbreaks needs to be determined, as well as location, name of owner, geocode, dates of first and subsequent case, number of animals at risk, species, livestock movements and suspected source of infection. Specimens submitted to the national and regional laboratories should have the following information: collection date, identification and address of animals, results of any testing and description of specimen or origin of isolate.
4. Economic implications need to be evaluated by analysis of sub-samples of outbreaks and examining the direct and indirect losses plus costs of control measures.
5. Coordination of epidemiological investigations needs to reflect national and international requirements. Regional epidemiological studies need to be coordinated by a central regional coordination unit. While cooperation and collaboration on regional FMD control does occur, a mechanism or process is required to harness national goodwill for the overall benefit of the region.

Recommendations on the strategies and regulations for regional and national FMD control

1. National governments should have an agreed policy on information flow, decision making and implementation of FMD control strategies. Each country and/or province should have an animal disease control law or regulation which is practicable and includes FMD. It may be necessary to review or amend existing laws or regulations. All should include obligatory FMD reporting.
2. In the early stage of a control program, animal registration may not be necessary. As control programs become more successful, governments should be encouraged to develop practical animal registration procedures. Abattoirs must be licensed and ante- and post-mortem inspection at abattoirs should be compulsory to avoid dissemination of infectious material. Animal health authorities, veterinarians and livestock officers need to have authority to inspect livestock products and markets.
3. Vaccination programs should be phased in and as soon as possible compulsory vaccination should be offered free of charge to farmers. Vaccinated animals should be individually identified and recorded following vaccination. Owners should be provided with health/vaccination certificates for livestock movement.
4. A compulsory quarantine zone must be implemented immediately around a FMD outbreak. The OIE recommendation of a quarantine zone of 10 km radius is supported.
5. The final stages of an eradication campaign will require a stamping out policy, which will require a legal basis for compensation. This will require careful consideration and agreement by all involved and the allocation of funds for compensation. To conclude the campaign when stamping out is practised, regulations for safe disposal of infected animals and disinfection will be necessary.

International perspective

1. There is a need to establish a regional reference laboratory and a regional coordination unit for FMD in Southeast Asia.
2. As the host country of the proposed regional reference laboratory, Thailand should make legal and biological security arrangements to accept FMD samples from the Southeast Asian region. Agreement should be negotiated by the member countries regarding submission of samples to a regional reference laboratory.
3. Bilateral and multilateral regulations should be encouraged to legalise the movement of livestock and livestock products, and for rapid exchange of disease control information.
4. Veterinary services and national diagnostic capabilities need to be strengthened and reliable standardised FMD surveillance and disease reporting systems developed on a national and regional basis. Implementation of mass vaccination programs with free vaccination should be an early aim, followed up by monitoring and evaluation of vaccine effectiveness.
5. Additional control methods for specific FMD outbreaks should be designed and implemented with a move towards effective livestock movement control, particularly around focal national and zonal outbreaks.
6. There is a need for an integrated and coordinated approach by governments, the private sector and communities within countries with the development of FMD eradication strategies including elimination of animals in final focuses with full compensation for owners.

Participants

Australia

Dr John Copland
Research Project Co-ordinator
ACIAR
3rd Floor, Drake Centre
10 Moore Street
Canberra ACT 2601

Dr K Murray
CSIRO
Aust Animal Health Lab
PO Bag 24
Geelong
Vic 3220

Mr Neil Tweddle
Head of Foreign Disease Unit
Livestock and Pastoral Division
GPO Box 858
ACT 2601

Dr H Westbury
CSIRO
Aust Animal Health Lab
PO Bag 24
Geelong
Vic 3220

Dr Janet Salisbury
Communications ACIAR
3rd Floor Drake Centre
10 Moore Street
Canberra ACT 2601

Dr Bill Geering
Director Animal & Plant Health Branch
Bureau of Resource Sciences
DPIE
PO Box E11
Queen Victoria Terrace
ACT 2600

Dr L Gleeson
CSIRO
Aust Animal Health Lab
PO Bag 24
Geelong
Vic 3220

Dr C Tisdell
Depart of Economics
Uni of Queensland
St Lucia
Qld 4067

Dr C Baldock
Animal Research Institute
Locked Mail Bag No.4
Moorooka QLD 4105

Dr Pramod Sharma
University of Queensland
St. Lucia
Qld. 4072

Dr S Harrison
Depart of Economics
Uni of Queensland
St Lucia Qld 4067

Austria

Dr Martyn Jeggo
Animal Health and Production Unit
Joint FAO/IAEA Division
FAO
Wagramerstrasse 5
PO Box 100
A-1400 Vienna, Austria

Bangladesh

Dr Nazir Ahmed
Director Livestock Services
Krishi Khamar Sarak
Dhaka
Bangladesh

Dr A.F.M. Rafiqual Hasan
Principal Scientific Officer
Foot and Mouth Disease
Livestock Research Institute
Mohakhali
Dhaka
Bangladesh

France

Dr Lombard
Rhone Merieux
28 Avenue Tony Barnier
BP 7133
08348 Lyon CEOEX 07
France

Cambodia

Mr Som Soon
Deputy Director of Animal Health and Production
Ministry of Agriculture
c/- Ms K Bourke
Australian Embassy
Phnom Penh
Cambodia

Mr Son Siveth
Head of Diagnostic Lab
Ministry of Agriculture
c/- Ms K Bourke
Australian Embassy
Phnom Penh
Cambodia

Mr Kong Reatrey
Chief of Animal Health
Pursat Province
c/- Ms K Bourke
Australia Embassy
Phnom Penh
Cambodia

Dean Sam Saron
c/-Ms K Bourke
Australian Embassy
Phnom Penh
Cambodia

Dr Sen Sovann
Church World Service
CWS-Cambodia
GPO Box 2420
Bangkok 10501
Thailand

Dr C Bartels
Church World Service
CWS-Cambodia
GPO Box 2420
Bangkok 10501
Thailand

Dr Son Saan
AFSC/Cambodia
C/- INDOSWISS
GPO Box 2420
Bangkok 10501
Thailand

M Lee Bun Kun
Church World Service
CWS-Cambodia
GPO Box 2420
Bangkok 10501
Thailand

Mr Nget Sotheara
Church World Service
CWS-Cambodia
GPO Box 2420
Bangkok 10501
Thailand

Ms Kate O'Sullivan
Church World Service
CWS-Cambodia
GPO Box 2420
Bangkok 10501
Thailand

Dr M Maclean
AFSC/Cambodia
C/- Indoswiss
GPO Box 2420
Bangkok 10501
Thailand

India

Dr V A Srinivasan
Deputy General Manager
Indian Immunologicals
Rakshapuram
Gachibowli
Hyderabad 50013
India

Dr G K Sharma
Scientist 3
Animal Disease Research Laboratory
National Dairy Development Board
Anand 388 001 Gujarat
India

Dr A K Mukhopadhyay
Project Coordinator
Modular Laboratory Building
Indian Veterinary Research Institute
Izatnagar 243122
Bareilly (U.P.)
India

Dr C Natarajan
Joint Director, Cum Officer in Charge
Indian Veterinary Research Institute
Campus

Indonesia

Dr H Setyaningsih
Laboratory Scientist
Pusat Veterinarian Farma
JI Raya Jend A. Yani 65-70
Surabaya 60231 Kotak Pos W03
Indonesia

Mr Ron Rakiman
ACIAR Country Manager
Australian Embassy
Jl Rasuna Said Kav 15-16
Kuningan
Jakarta
Selatan, Indonesia

Dr M Malole
Co-ordinator FMD Team
Faculty of Veterinary Medicine
Institute of Pertanian Bogor
JI Taman Kencana No.1
Bogor Jawa Barat
Indonesia

Japan

Dr Y. Ozawa
OIE Regional Representative
East 311, 11-1-1 Minamiaoyama
Minato-Ku
Tokyo 107
Japan

Malaysia

Dr Gan Chee Hiong
Director
Veterinary Research Institute
Ipoh
Malaysia

Dr Muhammad Safaruddin Dawan
Veterinary Officer
Diagnosis and Epidemiology
Kuala Lumpur
Malaysia

Pakistan

Dr Saeed Akhtar
Senior Scientific Officer
(Epidemiology)
Animal Sciences Institute
National Agricultural Research Centre
Park Road, Islamabad 4550
Pakistan

Peru

Mrs Ana Maria Espinoza
Instituto Nacional de Salud
Centro de Produccion de Insumos
Capac Yupanqui 1400
Lima 11
Peru

Philippines

Yvonne G. Vinas
Chief of Regulatory Division
Department of Agriculture
Region IV, Quezon City
Metro Manila
Philippines

Dr Bemes Mondia
Chief of Veterinary Quarantine Services
Department of Agriculture
Region X, Cagayan de Oro City
Philippines

Sri Lanka

Dr Susima Kodituwakku
Head Virology Division
Veterinary Research Institute
Gannoruwa
Peradeniya
Sri Lanka

Dr S S Balachandran
Dept of Animal Production and Health
Getambe
Paradeniya
Sri Lanka

Thailand

Mr John McCarthy
Australian Ambassador
Austalian Embassy
37 South Sathorn Road
Bangkok 10120
Thailand

Dr Pornchai Chamnanpood
Chief
Epidemiology Section
Northern Regional Veterinary Research and Diagnostic Center
Hang Chat, Lampang, 52190
Thailand

Dr Sasaki
Regional Animal Health Officer
FAO Regional Office
Phra Atit Road
Bangkok 10200
Thailand

Assoc. Prof. Dr Maliwan Choontanom
Department of Pathology,
Microbiology Unit
Faculty of Veterinary Medicine
Kasetsart University
Bangkok 10900
Thailand

Dr Wipit Chaisrisengkram
Deputy Director
Department of Livestock Development
Phyathai Road
Bangkok 10400
Thailand

Dr Ab Kongthon
Senior Veterinary Expert on Biologics
Division of Biologics
Department of Livestock Development
Phyathai Road
Bangkok 10400
Thailand

Dr Banchong Apiwatanakorn
Immunology Section
NAHPI
Kaset Klang, Bang Khen
Bangkok 10900
Thailand

Dr Wantanee Hanyanun
Division of Disease Control
Department of Livestock Development
Phyathai Road
Bangkok 10400
Thailand

Prof. Dr. Cherdchai Rattanasetankul
Dean
Faculty of Veterinary Medicine
Khon Kaen University
Khon Kaen 40001
Thailand

Dr Inthira Kramomthong
Bacteriology Section
NAHPI
Kaset Klang, Bang Khen
Bangkok 10900
Thailand

Dr Siltham Wara-asawapati
Chief
Epidemiology Section
NE Regional Veterinary Research and Diagnostic Center
Tha Pra, Khon Kaen 40260
Thailand

Dr Yodyot Meephuech
FMD Information Center
Department of Livestock Development
Phyathai Road
Bangkok 10400
Thailand

Dr Namba
Research Section FMD Centre
Pak Chong
Nakornartchasima 30130
Thailand

Dr Kumagai
JICA Team Leader
National Animal & Production Institute
Kasetsart University
Bang Khaen
Bangkok 10900
Thailand

Ms Chiraporn Sunpakit
ACIAR Manager
Australian Embassy
37 South Sathorn Road
Bangkok 10120
Thailand

Assoc. Prof. Dr Songkam Leungthongkam
Dean
Faculty of Veterinary Science
Chulalongkorn University
Henri Dunont Road
Bangkok 10330
Thailand

Dr Ubol Srisomboon
Director Division of Veterinary Research
Department of Livestock Development
Phyathai Road
Bangkok 10400
Thailand

Dr Suneejitt Kongthon
Director Veterinary Biologics Control Center
Division of Veterinary Biologics
Pak Chong Nakornrachasima 30330
Thailand

Dr Somchai Srihakim
Director
NE Regional Veterinary Research and Diagnostic Center
Tha Pra, Khon Kaen 40260
Thailand

Dr Chaowana Mekamol (retired)
Department of Livestock Development
Phyathai Road
Bangkok 10400
Thailand

Dr Wipit Chaisrisongkram
Deputy Director General
Department of Livestock Development
Phyathai Road
Bangkok 10400
Thailand

Dr Nimit Triwanatham
Director
Southern Regional Research and Diagnostic Center
Tung Song, Nakorn Srithammarat 80110
Thailand

Dr Rapeepong Wongdee
Director
Division of Disease Control
Department of Livestock Development
Phyathai Road
Bangkok 10400
Thailand

Dr Prateep Pemayothin
Chief
Epidemiology Section
NAHPI
Kaset Klang, Bang Khen
Bangkok 10900
Thailand

Dr Aree Supcharoen
Virology Section
NAHPI
Kaset Klang, Bang Khen
Bangkok 10900
Thailand

Dr Sanong Srinanthapan
Chief
Epidemiology Section
Southern Regional Veterinary Research and Diagnostic Center
Tung Song, Nakorn Srithammarat 80110
Thailand

Dr Somachai Kamolsiripichaiporn
Division of Veterinary Biologics
Pak Chong, Nakornratchasima
30330 Thailand

Dr Buddhachard Srisopar
Chief
Virology Section
NE Regional Veterinary Research and Diagnostic Center
Tha Pra, Khon Kaen 40260
Thailand

Dr Chanpen Chamnanpood
Chief Virology Section
Northern Regional Veterinary Research and Diagnostic Center
Hang Chat, Lampang 52190
Thailand

Dr Nopporn Saratapan
Chairman
Working Committee of National Livestock Information Center
NAHPI
Kaset Klang, Bang Khen
Bangkok 10900
Thailand

Dr Wilai Linchongsubongkot
Division of Veterinary Biologics
Pak Chong, Nakornratchasima
30330 Thailand

Dr Pinai Musikul
Division of Disease Control
Department of Livestock Development
Phyathai Road
Bangkok 10400
Thailand

Dr Laddawan Rattananakorn
Division of Disease Control
Department of Livestock Development
Phyathai Road
Bangkok 10400
Thailand

Dr Wimolporn Thitisak
International Coordination
Department of Livestock Development
Phyathai Road
Bangkok 10400
Thailand

Dr Sawat Srisithiyanon
Director
2nd Regional Livestock Office
Chacherngsao 24000
Thailand

Dr Suchinta Tangchaitrong
Director
3rd Regional Livestock Office
Nakornratchasima 30000
Thailand

Dr Udom Bhodi
Director
4th Regional Livestock Office
Udornthani 41000
Thailand

Dr Kamol Awaiwanon
Director
5th Regional Livestock Office
Chiengmai 50000
Thailand

Dr Supachai Samutrapaoraya
Director
6th Regional Livestock Office
Pittsanulok 65000
Thailand

Dr Wises Prasert
Director
8th Regional Livestock Office
Surat Thani 84000
Thailand

Dr Samor Tawe-wigarn
9th Regional Livestock Office
Songkla 90000
Thailand

Dr Phothawat Ratanachot
Chief
Chiengmai Provincial Livestock Office
Chiengmai 50000
Thailand

Dr Weerawong Komomena
Chief
Lampang Provincial Livestock Office
Lampang 52000
Thailand

Dr Prawat Ratanapumma
Chief
Mae Hong Sorn Provincial Livestock Office
Mae Hong Sorn 58000
Thailand

Dr Sakchai Sribunsue
Chief
Chiengrai Provincial Livestock Office
Chiengrai 57000
Thailand

Dr Prawat Prapapanya
Chief
Lamphuni Provincial Livestock Office
Lamphun 51000
Thailand

Dr Nisit Tangtrakarnpong
Chief
Pittsanulok Provincial Livestock Office
Pittsanulok 65000
Thailand

Dr Chan Petch-aksorn
Chief
Nakorn Sawan Provincial Livestock Office
Nakorn Sawan 60000
Thailand

Dr Ittipol Chaichanapoonpol
Chief
Parasitology Section
Northern Regional Veterinary Research and Diagnostic Center
Hang Chat, Lampang 52190
Thailand

Dr Chaiwat Withurakool
Northern Veterinary Research & Diagnostic Center
Hangchat
Lampang 52190
Thailand

Dr Pensri Teerawat
Northern Veterinary Research & Diagnostic Center
Hangchat
Lampang 52190
Thailand

Dr Narongchai Nakarangkul
Northern Veterinary Research & Diagnostic Center
Hangchat
Lampang 52190
Thailand

Dr Arun Numtoom
Northern Veterinary Research & Diagnostic Center
Hangchat
Lampang 52190
Thailand

Dr Somkid Teepatimakorn
Northern Veterinary Research & Diagnostic Center
Hangchat
Lampang 52190
Thailand

Dr Sutas Taimtanom
Northern Veterinary Research & Diagnostic Center
Hangchat
Lampang 52190
Thailand

Dr Ekkart Klung-awut
Northern Veterinary Research & Diagnostic Center
Hangchat
Lampang 52190
Thailand

Dr Watcharapol Chotiyaputta
Disease Control Division
Department of Livestock Development
Bangkok 10400
Thailand

Dr Yodyot Meephuch
Disease Control Division
Department of Livestock Development
Bangkok 10400
Thailand

United Kingdom

Dr Peter Ellis
VEERU
Department of Agriculture
Earley Gate
PO Box 236
Reading RG6 2AT
United Kingdom

Dr Alex Donaldson
Institute for Animal Health
Pirbright Laboratory
Ash Road, Pirbright
Working GU 24 ONF
United Kingdom

Union of Myanmar

Dr Aye Thein
Staff Veterinary Officer
Myanmar Livestock Breeding and Veterinary Department
Insein, Yangoon
Union of Myanmar

Vientiane

Dr Saly Sihalath
Deputy Director General Technical Section of DLV
C/- Ian Millar
AIDAB First Secretary
Australian Embassy
Vientiane

Dr Singkham Phonvisay
Director General of DLV
C/- Ian Miller
AIDAB First Secretary
Australian Embassy
PO Box 292
Vientiane

Dr Sounthone Vongthilath
Department of Livestock and Veterinary
Vientiane Laos
C/- Ian Millar
AIDAB First Secretary
Australian Embassy
Vientiane

Dr Sommay Mekhagnomdara
Director of Technical Division of Veterinary of DLV
C/- Ian Millar
AIDAB First Secretary
Australian Embassy
Vientiane

Vietnam

Dr Bui Quy Huy
Chief of Bureau for Epidemiology
Staff Member of National FMD Control Program
Department of Animal Health
Ministry of Agriculture and Food Industry
Phuongmai Dongdo
Hanoi Vietnam

Dr Nguyen Xuan Phuc
Department of Animal Health
Ministry of Agriculture and Food
Phuongmai Dongdo
Hanoi Vietnam

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