IMPROVED METHODS FOR THE DIAGNOSIS AND CONTROL OF BLUETONGUE IN SMALL RUMINANTS IN ASIA AND THE EPIDEMIOLOGY AND CONTROL OF BOVINE EPHEMERAL FEVER IN CHINA

ACIAR Projects AS1/1984/055, AS2/1990/011 and AS2/1993/001

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August 2003

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ACIAR Impact Assessment Series No. 23

ISBN 1 86320 395 8

Editing and design by Clarus Design, Canberra

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Summary

Bovine ephemeral fever (BEF) has been recorded in China since 1950, with morbidity reaching 40% during epidemics. Accordingly, the disease has been given high priority by Chinese authorities, as the development of cattle and buffalo industries is a major objective of the government. Similarly, the promotion of animal-based industries and the potential impact of bluetongue disease on small ruminants resulted in this condition being the subject of intensive research in southern China, particularly in Yunnan province.

These diseases cause direct economic losses, firstly because of animal mortality and morbidity during outbreaks, and secondly because trade in valuable breeding stock is curtailed by costly laboratory testing for the presence of diseases. China has strict quarantine testing requirements relating to bluetongue. These impede the movement of animals from place to place.

Despite the impact of BEF and bluetongue in China, little was known about disease epidemiology, potential for vaccine management and risks of introduction.

As a result of this need for more information, A$3.1 million was invested in ACIAR-supported research designed to better understand these diseases and develop a vaccine-based approach to their control. Information generated from the projects has led to the development of a successful and widely used vaccine for BEF. Also, no cases of bluetongue have been reported since 1997 when bluetongue project work ended. Furthermore, it is possible that Chinese import-testing requirements for live animals could be rationalised in the longer term, in part as an outcome of research undertaken in the projects, the results of which led to a better understanding of these diseases.

Based on levels of disease prevalence reported at the beginning of the projects, ACIAR BEF and bluetongue research investments are forecast to generate a net present value of A$4.6 million. It is estimated that Chinese cattle producers will capture approximately 90% of these benefits. Benefits to Australian exporters could be significantly larger in the longer term, but are uncertain given the political nature of trade regulations, and hence have not been included in the analysis. A benefit–cost ratio of 2.3:1 was estimated for the projects; that is, for each dollar invested, 2.3 dollars of project benefits will be generated.

In addition to possible direct cost savings to Australian animal exporters and animal productivity benefits for Chinese livestock producers, several non-economic benefits have been realised. These include a valuable enhancement of the body of scientific knowledge about these important animal diseases, and the organisation of international symposia to disseminate project findings.

1 Introduction

Bluetongue and bovine ephemeral fever (BEF) are vector-borne viral diseases transmitted to cattle, buffalo, sheep and goats by biting insects. During outbreaks of BEF in China, morbidity has been as high as 40% and mortality up to 5% (Wenbin 1993). Draught cattle have a prolonged convalescence, disrupting the farming system, and milk losses occur in animals that recover from the disease. Clinical signs of bluetongue are typically observed only in sheep, and vary depending on the virus strain and the type of livestock. Sheep mortality can be very high in affected animals, and animals that survive the disease produce less meat and wool. In addition to direct production losses, the presence of these diseases restricts trade in breeding animals. Such restrictions retard the injection of genetically improved livestock into China’s animal industries and impose high testing costs on those wishing to export animals to China.

Outbreaks of bluetongue were first documented in China during the late 1970s, while BEF had been recorded since 1950. Major outbreaks had occurred in a number of provinces, with Zhejiang, Liaoning, Shandong and Guangdong being the provinces where the BEF was most often observed (Wenbin 1993). Despite the economic impact of these diseases, very little was known about disease epidemiology, potential for management using vaccines, and risks of introduction and transmission.

Considerable BEF research expertise was centred at the then CSIRO Division of Tropical Animal Production (now CSIRO Livestock Industries) in Australia, and bluetongue expertise was located at the NSW Department of Agriculture. To develop serological tests to better understand disease epidemiology and pathogenesis, a series of research projects was commenced in the mid 1980s. The overarching aim of the investment in the ACIAR projects was to reduce the impact of the two diseases. The series of projects included:

- Epidemiology of bovine ephemeral fever in China (AS1/1984/055)
- Improved methods for the diagnosis and control of bluetongue in small ruminants in Asia (AS2/1990/011)
- Studies of the epidemiology and control of bluetongue in China (AS2/1993/001).

In total, A$3.1 million (nominal terms) was invested in the ACIAR-supported projects in Asia and Australia across the life of the projects. As a result, diagnostic tools were adopted in regional laboratories, a killed BEF vaccine has been developed and animal exportation requirements for Australian livestock destined for China might be rationalised in the future. Since completion of the bluetongue projects there have been no recorded cases of the disease in China. Similarly for BEF, there have been no major epidemics in China since the end of the ACIAR-financed research.

The killed BEF vaccine, to the development of which the ACIAR research contributed, is administered to approximately 100,000 cattle per year in China, leading to reduced disease incidence and increased animal productivity. The killed BEF vaccine differs from the live vaccine used in Australia (and used on a small scale in China before the projects) in that the virus is inactivated and cannot replicate. Such a vaccine is more straightforward to administer and does not have the cold storage and handling problems associated with live vaccines.

The economic benefits to China from BEF vaccine development, and possible benefits to Australian exporters from reduced export testing costs, are quantified in this benefit–cost assessment. The killed BEF vaccine was commercialised in the mid-1990s and, to date, benefits to only Chinese cattle producers have been realised. Potential benefits to Australian exporters from changes to export testing have yet to be captured.

2 The ACIAR projects and their outputs

The three projects evaluated in this report began in the 1986 financial year, as project AS1/1984/055, Epidemiology of ephemeral fever in China. The outputs of this and the following projects are described in this section.

2.1 Epidemiology of bovine ephemeral fever in China (AS1/1984/055)

This project involved collaboration between the CSIRO Division of Tropical Animal Production and the Harbin Veterinary Research Institute (HVRI) in China. HVRI is one of the leading veterinary research institutes in China and this project was its first with a foreign country. The research, which began in October 1985, had the following objectives:

- develop a highly specific serological test capable of distinguishing antibodies generated by BEF and related viruses
- employ the monoclonal antibody as an antigenic probe
- investigate BEF disease in buffalo
- monitor BEF infection by serum surveys and sentinel herds.

The project termination report indicates that the basic technologies for virology, serology and some biochemical techniques were established at HVRI through the combination of visits and collaboration associated with the project. The neutralisation tests for BEF were used to establish surveys of disease presence in China. Additionally, a serum bank, a sentinel herd system to study disease epidemiology and computer systems were established at the institute. A blocking enzyme-linked immunosorbent assay (ELISA) test based on monoclonal antibodies was developed and implemented at HVRI. This test is a highly specific and sensitive test for diagnosing BEF.

An experiment was conducted in Guangdong province by scientists of both countries to investigate the pathogenicity of BEF in buffalo. The virus caused reactions in buffalo similar to those in cattle, but milder. The test highlighted the need to use buffalo strains of the virus.

Insect collecting demonstrated that the vectors of the disease existed as far north as Harbin.

Research on the chemistry of the virus revealed that the Beijing strain contained at least four proteins and was similar to Australian isolates.

This research laid the foundations for improving and developing killed BEF vaccines in China. Based on the results of the project, specifically the development of diagnostic methods for BEF serum and of improved cell culture techniques, HVRI prepared a BEF killed vaccine. This vaccine is now used by many intensive cattle enterprises in China. The monetary benefits of this are quantified in the economic evaluation section. Before the ACIAR project, a live vaccine imported from Australia and one developed in China were used on a small scale. These vaccines were shown to confer low levels of immunity or to have detrimental side effects (Wenbin et al. 1993), and were not widely adopted by Chinese livestock producers.

2.2 Improved methods for the diagnosis and control of bluetongue in small ruminants in Asia (AS2/1990/011)

During the early 1990s, Malaysian authorities sought to increase the national sheep flock from 80,000 to 1–2 million head by the end of the century. Sheep were seen as a valuable component of integrated plantation production systems, acting as a source of revenue, increasing rural sector employment, reducing the need for herbicide, enhancing soil fertility and helping to manage biomass in plantations. Sheep from Australia were a possible source of breeding stock for the build-up in sheep numbers. However, the presence of bluetongue constrained the development of the Malaysian sheep industry.

Australian veterinarians were experienced in dealing with bluetongue, and this led to the implementation of project AS2/1000/011 in January 1991, with the aim of better managing the disease. The project involved collaboration between the Australian Government's Bureau of Rural Resources, the Queensland Department of Primary Industries and the Veterinary Research Institute, Ipoh, Malaysia. Key objectives of the project included:

- introduction of virus isolation and serological research and investigation of techniques using Australian and field materials (blood and serum) of known history and cell cultures
- using the techniques and cell cultures established within the first objective to examine Malaysian materials
- identifying and characterising isolates recovered in phase two
- framing and initiating research projects to investigate the ecology and control of bluetongue in Malaysia.

The external review of the ACIAR project indicated that the primary project objectives were met. The Veterinary Research Institute at Ipoh now has agar gel immunodiffusion, ELISA, cell culture, micro neutralisation, plaque reduction and polymerase chain reaction (PCR) tests for the detection of both viruses and antibodies. Bluetongue viruses were isolated from experimental herds, and bluetongue testing was introduced as a routine procedure at the laboratory. In addition to training staff in Malaysia, an international training workshop was held at which personnel from India, Thailand, China, Indonesia and the Philippines were taught with bluetongue diagnostic techniques.

Limited serological studies were conducted, while isolations and reports of clinical disease provided some evidence of disease seasonality. The shortness of the project prevented comprehensive vector studies. Following the research, the institute at Ipoh was able to undertake ecological studies, during which disease management recommendations could be synthesised. The project review report noted that Malaysian authorities had reduced the incidence of the disease by curtailing importation of susceptible sheep from Australia and New Zealand. The replacement imports, mainly from Thailand, appear to be less susceptible to bluetongue. Since this project has been completed, the Malaysian national flock has not grown as expected. Consequently, any economic benefits derived from the improved control of the disease are likely to be small, and any possible benefits associated with bluetongue management in that country are not included.

2.3 Studies of the epidemiology and control of bluetongue in China (AS2/1993/001)

Bluetongue was first detected in China in 1979, at a sheep-breeding farm in northern Yunnan province. Since then, the disease has been recorded in several other provinces and its control was given high priority in Chinese national planning. Australian scientists had been investigating bluetongue since 1977, and considerable expertise existed in the NSW Department of Agriculture and at CSIRO. At the request of the Chinese Government, a delegation from the Yunnan Animal Husbandry Bureau visited Australia in 1991, with the aim of developing a project to better manage the disease. Following this visit, ACIAR supported a project that aimed to:

- understand the epidemiology and pathogenicity of bluetongue virus in China
- improve laboratory capabilities for the diagnosis of bluetongue virus infection in China and Australia by mutual technology transfer
- develop ELISA tests that are bluetongue and serotype specific
- gain recognition of the new Yunnan Tropical and Subtropical Animal Virus Disease Laboratory as a reference centre for bluetongue
- isolate and characterise viruses from outbreaks of suspected bluetongue in sheep and from sentinel cattle
- examine serum samples from sentinel animals for the occurrence of antibodies to bluetongue viruses and for the determination of serotypes.

To develop disease-control programs, the epidemiology and pathogenesis of a disease needs to be understood. The development of laboratory capability, along with diagnostic tool (ELISA) introduction, underpins the implementation of a rational disease-management program. A sensitive c-ELISA test for detecting bluetongue antibody positive animals, and an efficient virus isolation protocol, were developed within this project. The protocol is based on chicken embryo inoculations, but employs the antigen detection ELISA to confirm presence of bluetongue. This procedure increases the efficiency of bluetongue isolation manyfold and speeds up accurate diagnosis.

The project had a large training component in general laboratory and sentinel herd establishment practices. The review team appointed by ACIAR to determine if the project had met its stated objectives was very impressed with the level of training achieved. The scientific methodology for sentinel herds is based on the strategy used in Australia. Systems for virus and serum storage and recording, suitability of serum samples for testing, organised result recording, and maintenance of laboratory and reagent supplies were implemented, along with new, general laboratory practices. Even during 1996, when large numbers of samples were tested serologically and a large number of viruses was isolated, technical and scientific scrutiny were maintained. The development of diagnostic capability helps identify bluetongue outbreaks and the types of serotypes involved. As such, the information is used to direct vaccination campaigns and reduces the risk of an outbreak of the disease. Bluetongue vaccination has been undertaken for some time in China. Diagnostic research undertaken as part of this project will help to better manage the disease. Early vaccine development in China was based on limited knowledge of disease serology. As a result of the project, and identification of serotypes, the number of vaccines used to control bluetongue was reduced. Since project completion no cases of bluetongue have been reported in China.

Tests and procedures developed within the ACIAR projects also have benefits for Australia. The bluetongue testing required of ruminants for export to China is expensive and restricts the trade in a potentially large market for ruminant livestock. The demonstration of skills by Australian scientists, identification of disease types in China and development of rapid diagnostic tests for this disease could reduce the costs of animal quarantine and testing, with possible future rationalisation of Chinese import requirements.

3 Realised and potential project outcomes

Cattle numbers in China have grown from 74 million head in 1988 to 106 million in 2002 (FAO 2003). Likewise, the sheep flock has grown over this period, although growth slowed in the 1990s when wool prices fell. Some of the growth in livestock numbers has resulted from the importation of high-performance exotic breeds from countries such as Australia. These animals are particularly susceptible to diseases such as bluetongue and BEF, and can suffer severe production loss if infected.

The Chinese authorities are committed to expanding livestock production, and have financed the development of the capacity to handle animal diseases across the country. This development included the establishment of the Yunnan Tropical and Sub-tropical Animal Virus Diseases Laboratory. The realisation of improved diagnostic capability within ACIAR-financed BEF and bluetongue projects has reduced the number of outbreaks of these diseases. The benefits of this outcome are described in this section, firstly by reviewing livestock production in China and then by outlining the nature of the bluetongue and BEF disease problems.

3.1 Ruminant production in China

Cattle are raised in farmland and pastoral areas in China. Within farmland areas, cattle are commonly raised in association with cropping enterprises and are used for draught or traction purposes. Extensive pastoral systems are found in the western parts of the country, and some of the cattle in this region are raised by nomads. Of the 29 provinces in China, approximately 6 contain areas where cattle are grazed (Tuan 1987). Beef production has increased following the rapid increase in national herd size. It should be noted that beef production has increased at a rate considerably higher than the annual percentage increase in the national herd size. This indicates that production per head is increasing as a result of the adoption of higher performing livestock (genotypes) and the adoption of more intensive management practices.

The Chinese Government has actively promoted dairy development. Tuan (1987) reported that, in Heilongjiang province, authorities provided 0.1 ha of fodder land and some concentrates with each additional cow raised. ADB (1994) reported that in provinces such as Hunan, private dairy herds usually comprise about five cows. Poor nutrition has been cited as a major constraint on milk yield. In the past, most dairies were state-operated, and many of the buildings were run by collectives near urban centres.

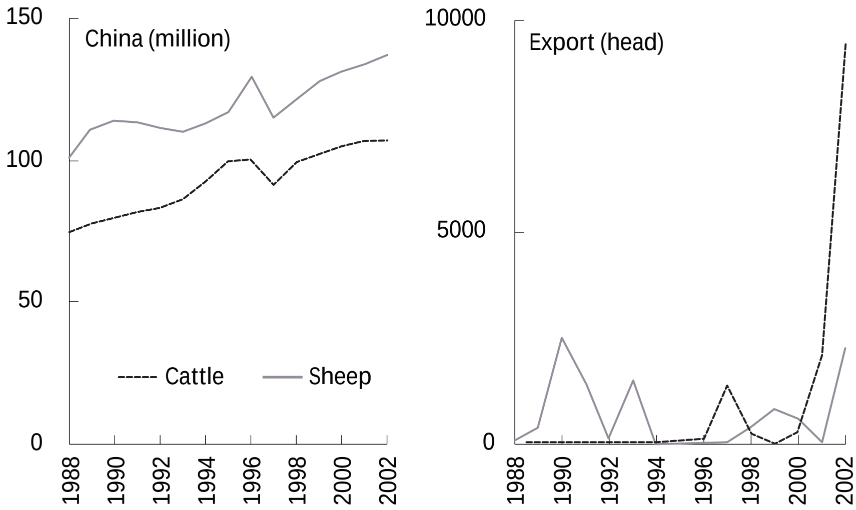

Figure 1. Chinese livestock population and Australian exports to China (1998–2002). Sources: FAO (2003); ABARE (2003).

Considerable progress has been made in improving the performance of the local yellow breeds through selection and breeding as dairy cattle, and by breeding dual-purpose animals. Dairy cattle were estimated to constitute 3.5% of the national herd in 1998 (USDA 1998). There are large numbers of dairy cattle in the provinces of Nei Monggol, Xinjiang and Heilongjiang.

The national sheep flock has also increased over the past 14 years. FAO (2003) statistics indicate that the flock increased from 103 million in 1988 to 137 million in 2002. Growth in flock numbers slowed during the mid 1990s, in response to low international wool prices. Woolmark (2000) indicated that China’s fine-wool sheep numbers fell by 30% between 1996 and 2000. In the two key sheep regions—Xinjiang and Inner Mongolia—fine sheep numbers declined because growers shifted from fine wool production into more profitable meat production. During 2000, there were about 28 million sheep in Xinjiang, of which 8 million were fine wool sheep. These sheep produce approximately 65,000 t (greasy weight) of wool per annum. A new, fine-wool flock was being developed in 2000 and was expected to produce 800 t of 12–14 µm (micron) wool from 200,000 sheep within 5 years (Woolmark 2000). To develop the fine wool flocks, exotic breeds, such as those in Australia, have been imported.

3.2 Australian live animal exports

LiveCorp (2003) reports that the live animal export industry generated A$1.03 billion in revenue during 2002. Live cattle exports represent the most important component of the trade, with nearly a million head, valued at A$613 million, being exported annually. Live sheep exports were valued at A$414.3 million for the 6.1 million head exported. The Middle East and North Africa accounted for approximately 60% of the total livestock trade.

Indonesia is Australia’s most substantial customer for exported cattle, importing 428,486 head, valued at A$256.7 million, in 2002. This country accounts for almost half of the total market. Egypt and the Philippines are the second most important countries, with Egypt taking 149,771 head, or 15.3% of the market, and the Philippines 113,263 head. Malaysia imported 90,646 head or 9.3% of the total market. Saudi Arabia is a relatively new market for Australian live cattle, taking 54,354 head in 2002. China is also a new market for Australian live cattle, importing 9372 head in 2002.

Saudi Arabia is Australia’s largest market for live sheep, importing 1.89 million head worth A$128.6 million and representing a third (30.8%) of total live sheep exports in 2002. Kuwait is the second largest market (25.5% of total live sheep exports) taking 1.57 million head worth A$100.9 million. The United Arab Emirates is the fourth largest market for live sheep, taking 446,421 head worth A$29.7 million (LiveCorp 2003). China is a very small market for live sheep exports.

3.3 The bluetongue problem

Bluetongue is an insect-borne viral disease, of sheep primarily. It is very rare in cattle. It is also known as sore muzzle, pseudo foot-and-mouth disease and muzzle disease. Bluetongue disease is caused by orbiviruses in the family Reoviridae. These viruses occur throughout the world. Mosquito species such as *Culicoides variipennis*, *C. imicola*, and *C. brevitaris* are the primary vectors of the disease, which is common in tropical, subtropical, and temperate climates.

While virus transmission is predominately by mosquitoes, some experimental studies have demonstrated that ticks might also be vectors. Its transmission in semen is not considered to be significant (Stott 1998). The virus is present throughout Africa, the Middle East, India, China, the United States, Mexico and southern Europe. Bluetongue virus infection, without clinical disease, is present in Southeast Asia, Papua New Guinea, northern South America and northern Australia (Stott 1998). Several types of the bluetongue virus are present in Australia, but natural bluetongue disease has occurred only twice, in small outbreaks in the Northern Territory.

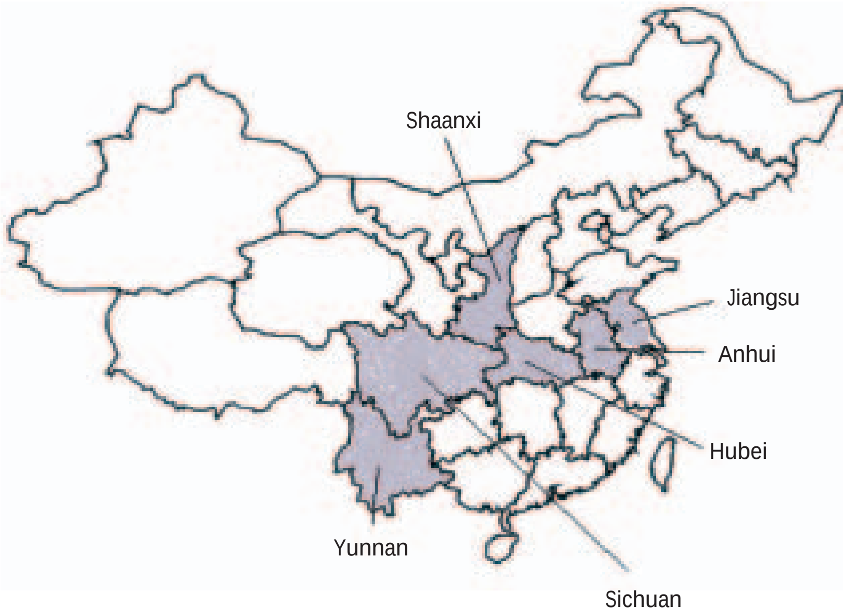

Figure 2. Outbreaks of bluetongue disease in sheep in China (1979–1997). Source: N. Zhang (pers. comm.)

The disease was first reported in China in 1979, at a sheep breeding farm in northern Yunnan. Since this initial recording, outbreaks have been observed in Hubei, Anhui, Sichuan, Jiangsu and Shanxi. While the virus has been isolated in Inner Mongolia and Xinjiang, there have been no clinical outbreaks there. Not all strains of bluetongue that infect sheep cause clinical disease. In some flocks, no clinical symptoms are apparent, whereas in other flocks infected by the same virus up to 30% of animals may develop signs of disease. Stott (1998) describes the disease as being characterised by fever, widespread haemorrhages of the oral and nasal tissue, salivation and nasal discharge. Lameness due to swelling of the hoofs, and loss of condition due to reduced feed consumption, may also be symptoms of this disease. Table 1 gives the numbers of clinical cases of bluetongue associated with each outbreak in China.

Morbidity from bluetongue can reach 100% (Stott 1998). Infected animals may recover within periods of a few days to a fortnight. Nevertheless, even in the cases where the sheep recovers from the disease, high fever may have resulted in a reduction in the strength of wool produced. The strength of wool is particularly important in the early stages of wool processing, as weaker wool can break during spinning. Hence, farmers could face a price penalty for tender wool as a direct result of their animals contracting the disease. In cattle, the symptoms of bluetongue infection are usually subclinical.

Table 1. Numbers of cases of bluetongue disease occurring during outbreaks in various provinces of China between 1979 and 1997.

	Year of outbreak					
	1979–80	1984–89	1987–89	1988–89	1990–91	1993–97
Province	Yunnan	Hubei	Anhui	Sichuan	Jiangsu	Shanxi
Cases	430	1837	6	406	130	4

Sources: St George and Kegao (1996); N. Zhang (pers. comm.)

Bluetongue virus is typically managed by vaccination. A modified-live (attenuated) virus vaccine has typically been used. Because of the large number of bluetongue serotypes and cross-protection between serotypes, vaccination has variable efficacy. The serotypes incorporated into the vaccine must be the same as those causing infection in the field (Stott 1998). Vaccination of pregnant ewes can sometimes cause abortion.

Development of rapid ELISA diagnostics as part of the ACIAR project will help authorities in China better match live vaccines with field strains, and the potential for outbreaks will be reduced. As a result of the widespread vaccination campaign in the country, no outbreaks of bluetongue have been recorded in China since 1997. During the period of widespread outbreaks — typically on government breeding stations — many exotic sheep were being imported to improve the national flock. With a fall in the world wool price, this activity declined. Consequently, fewer exotic animals were being exposed to, or transmitting, the virus, and the number of cases declined. With a return to higher wool prices, the demand for exotic sheep will likely return and the potential for disease outbreaks will increase. Enhanced diagnostic capacity will help to manage the disease.

3.4 The bovine ephemeral fever problem

Bovine ephemeral fever is a non-contagious insect-borne viral disease of cattle and water buffaloes. It is also known as three-day sickness, bovine epizootic fever, three-day stiff sickness and dragon boat disease. The disease was first reported in South Africa in 1906 and is present throughout Africa, southern Asia, southern and central China, southern

Japan, Southeast Asia and Australia. There have been no reports of BEF in Europe or the Americas (St George 1998).

The distribution of BEF in China is shown in Figure 3. It is evident that major epidemics have been reported in Guangdong province of southern China, Zhejiang and Shandong provinces of central China, and Liaoning province in northern China. Clinical cases of the disease have been reported in several other provinces marked on the figure. Years in which major epidemics have occurred are listed in Table 2.

Figure 3. Outbreaks of bovine ephemeral fever in China, 1955–1991. Darker shaded areas indicate provinces where major epidemics have occurred. Source: ACIAR Project AS1/1984/055 termination report.

St George (1998) notes that clinical signs of infection by BEF include accelerated heart and respiratory rates, anorexia, nasal and ocular discharges, salivation, muscle twitching stiffness and/or lameness. In some cases, animals may not be able to rise and they lose reflexes. The majority of cases, especially those in young cattle, are mild to moderate, and recovery is apparent after a few days. Lactating cows, bulls and fat steers suffer the most severe reaction to infection (St George 1998). Complications are possible in a minority of cases. These may include death, paralysis, temporary infertility and abortion. Milk production is reduced in infected animals, typically resulting in a 10–15% loss of production (Theodoridis et al. 1973; Davis et al. 1975).

The disease is responsive to anti-inflammatory drugs. Infected animals respond favourably to calcium borogluconate. Following infection, most animals are immune to subsequent challenge. With this immune response in mind, vaccines have been produced in South Africa, Japan and Australia. These vaccines afford protection against laboratory challenge, but field efficacy is variable. A killed vaccine has been developed in China and is thought to afford good protection. The vaccine was elaborated following the development of a diagnostic method and cell culture procedure as part of the ACIAR projects. It is used by many intensive cattle enterprises. The economic benefits of the introduction and use of this vaccine in China are quantified in Section 4.

Table 2. Years of major bovine ephemeral fever epidemics in various provinces of China

Province			
Dalian, Liaoning	Hangzhou, Zhejiang	Jinan, Shandong	Guangzhou, Guangdong
1983	1955, 1958, 1965, 1871, 1983, 1987, 1988	1955, 1958, 1966, 1970, 1976, 1983, 1987	1955, 1962, 1966, 1971, 1972, 1976, 1977, 1978, 1979, 1983, 1985, 1987, 1988

Source: ACIAR Project AS1/1984/055 termination report.

3.5 Benefits associated with improved animal disease management

Development of improved diagnostic capacity has improved both bluetongue and BEF management. To recapitulate: in the case of BEF, a killed vaccine has been developed and adopted in intensive cattle production enterprises throughout China. In the case of bluetongue, the development of diagnostic tools has facilitated more accurate disease surveillance and diagnosis, leading to improved matching of vaccines to field strains of the disease. No cases of bluetongue have been recorded in China since the end of the projects. Additionally, the isolation of new strains of BEF virus in China has allowed banking of variants that will permit rapid development of new vaccine strains should the virus change due to genetic drift.

To date, most project benefits have been captured by livestock producers in China. The economic benefits are calculated in the next section. However, before quantifying these benefits using benefit–cost analysis, the benefits to the poorest people are discussed using the ACIAR poverty-reduction framework. As part of this framework, the criteria used to assess the poverty reducing affects of a specific project include (Pearce 2002):

- improvement of poor producer incomes

- provision of benefits for rural and urban consumers through reduced food prices
- provision of health benefits
- provision of environmental benefits that improve sustainability of income generation and enhance quality of life
- promotion of pro-poor policies and institutional change
- empowerment of poor people particularly women and children
- reduction in the impact of unforeseen events.

Possibly the greatest poverty benefit from the development of diagnostic tools and vaccines is in terms of reducing unforeseen events, with measures to reduce the incidence of major disease epidemics bringing major benefits. During outbreaks of BEF in Guangdong province of southern China, Zhejiang and Shandong provinces of central China and Liaoning province in northern China, large numbers of animals suffered mortality and other production losses — such as the inability to perform traction (Wenbin 1993). Enhanced animal health and reduced disease incidence will moderate fluctuations in farm incomes.

4 Benefit–cost analysis of the projects

As noted earlier, most project benefits have been captured by livestock producers in China, because BEF vaccines partly developed as a result of ACIAR-supported research have been commercialised in that country, and because of the reduced incidence of bluetongue in sheep. The economic value of these benefits is calculated, along with possible benefits to Australian exporters through a reduction in the requirements for testing animals destined for export to China. This section gives: first, the evaluation framework; second, an outline of the project costs; and third, the assumptions behind the economic analysis. Finally, the results of the benefit–cost and sensitivity analyses are presented.

4.1 Evaluation framework

Benefits and costs are discounted using a 5% discount rate for project benefits that have already been realised and for a 30-year projection. Net present value (NPV) and benefit–cost ratio (BCR) investment criteria are also presented for each scenario. A BCR greater than one and a positive NPV indicate that project benefits are greater than project costs.

4.2 Project costs

The costs associated with project activities in China, Malaysia and Australia are presented in Table 3. The total costs of these activities were approximately A$3.1 million in nominal terms. ACIAR financial support over the period amounted to A$1.5 million. In the benefit–cost analysis that follows, these costs are translated into 2001 dollar terms using adjustment factors for inflation.

Table 3. Annual costs of the research on bluetongue disease and bovine ephemeral fever.

Year	ACIAR project costs (A$ nominal)	Other project costs (A$ nominal)	Total project costs (A$ nominal)
1986	115,139	42,670	157,809
1987	102,446	41,020	143,466
1988	80,280	48,870	129,150
1989	297,865	90,000	387,865
1990	0	0	0
1991	6,088	0	6,088
1992	24,120	0	24,120
1993	0	0	0
1994	211,259	319,000	530,259
1995	222,685	558,500	781,185
1996	245,865	425,004	670,869
1997	157,952	142,500	300,452
Total (million)	1.5	1.7	3.1

4.3 Key assumptions

In this section, the assumptions underpinning the calculation of project benefits are provided. Key economic impacts that are quantified include the additional costs of BEF vaccination, benefits associated with reduced incidence of BEF in dairy herds, benefits attributable to reduced incidence of bluetongue in sheep, and potential benefits to Australian exporters from reduced animal testing and quarantine costs. As the growth that was expected in the Malaysian small ruminant flock has not occurred, any possible benefits associated with improved bluetongue management in that country are not included.

Costs of BEF vaccination

Research conducted as part of the projects with the Harbin Veterinary Research Institute led to the development of a killed vaccine for BEF that is now widely used in China. Currently, around 100,000 animals are vaccinated per year, primarily in the dairy cattle sector. The vaccine costs about A$2 per dose and is thought to be effective. The cost of vaccination is included in Table 4, along with vaccination adoption assumptions. It is assumed that the vaccine was launched in 1995, and that it took 5 years for the vaccine to reach the current, maximum level of adoption.

Table 4. Summary of assumptions made in the economic analysis of the results of bluetongue and bovine ephemeral disease (BEF) research in China.

Parameter	Value	Source
Vaccination costs	Approx. A$0.25m per annum	Consultant estimate based on data provided by scientists at the Harbin Veterinary Research Institute. An estimated 100,000 animals are vaccinated each year. Calves receive multiple doses, and adult cattle get annual booster vaccinations.
Year BEF vaccine was commercialised	1995	Consultant estimate based on consultation with scientists at the Harbin Veterinary Research Institute.
Years to maximum adoption of BEF vaccine	5	Consultant estimate based on consultation with scientists at the Harbin Veterinary Research Institute.
Reduced number of (in milk) dairy cattle BEF cases	3000 per year	Consultant estimate based on vaccination coverage rates outlined by scientists at the Harbin Veterinary Research Institute and BEF prevalence outlined by Wenbin (1993). Dairy cows are highly susceptible to BEF.
Average farm-gate price for milk	A$0.40 per kg	Consultant estimate derived from CDIC (2003)
Average milk production per cow per year	4000 kg	Consultant estimate derived from Tuan (1987). Assumes high producing animals would receive vaccine.
Lost milk production per BEF infected case	600	10–15% taken from Theodoridis et al. (1973) and Davis et al. (1975).
Reduced number of bluetongue cases in sheep	200 per year	Consultant estimate based on outbreaks levels reported in St George and Kegao (1996)
Cost of replacing sheep	A$50 per head	Consultant estimate
Live animals exported to China	20,000 per year	Consultant estimate. Difficult to determine longer term market volume as Australian Bureau of Statistics figures show a rapid increase in trade over the last few years.
Cost saving from changed regulations	A$10 per head	Consultant estimate based on the number of bluetongue tests that have to be performed being reduced by one and the diagnostic test costs in NSW (NSW Agriculture 2003).
Probability of regulations being changed in 2005	40%	Consultant estimate

The level of BEF killed-vaccine adoption could increase in the future, if there is another major outbreak of BEF. The recent increases in the size of the dairy herd, and corresponding build-up of high-value cattle that are susceptible to the disease, could result in increased demand for the BEF vaccine. Given, however, that there has not been a major outbreak since the end of the ACIAR projects in the early 1990s, it is difficult to predict if and when such demand might appear. In the absence of precise information about BEF epidemiology and consequent demand, current levels of adoption are projected across the evaluation time frame.

Reduced incidence of BEF in dairy cattle

The dairy industry in China has been growing, and infection of dairy cattle by BEF causes considerable economic loss. Field work conducted within the ACIAR projects found considerable losses due to the disease at milk factory farms. Given the high losses suffered by animals affected by BEF, it is assumed that dairy farms are the principal purchasers of the vaccine. During the period of acute infection, animals suffer fever, and milk production is reduced by 600 kg per year per infected animal (Theodoridis et al. 1973; Davis et al. 1975). It is estimated that the BEF vaccine developed as part of the ACIAR-supported projects would result in 3000 fewer cases of BEF across China than would have occurred without the research.

Reduced incidence of bluetongue in sheep

Within China most outbreaks have been observed on government sheep-breeding farms and have involved exotic breeds imported to increase the productivity of the flock. Activity associated with exotic importation was at its height during the late 1980s when world wool prices were high and sheep raising was profitable. At this time, many sheep were being imported into China and bluetongue outbreaks were evident. In response to outbreaks, the Chinese authorities implemented widespread vaccination, and infected stock were slaughtered. During the peak of the disease, 1837 cases were reported at Hubei during 1984–89, while 406 were reported in Sichuan. With a return to higher wool prices, it is likely that exotic sheep will again be imported and bluetongue diagnostic capacity developed as part of the ACIAR projects will help to identify the serotypes of the virus involved in the outbreaks, so enhancing the targeting of any vaccination. Given there has been no bluetongue outbreak since the end of the ACIAR projects, it is assumed that an average of 200 cases per year will be avoided as a result of the diagnostic capacity development financed by ACIAR.

Reduced costs of animal exports

China has very stringent import requirements, and several tests involving bluetongue have to be performed before animals will be accepted for importation. Research into the types of serotypes found in China and Australia will help to rationalise the number of tests required by Australian exporters before shipment. It is assumed that testing requirements will be reduced by one bluetongue test per live animal destined for China as a result of research confirming the presence of certain serotypes in China. Consequently, the exporter will save A$10 per head (the approximate cost of a diagnostic test by NSW Agriculture (NSW Agriculture 2003)). Currently, Australian exports of live cattle to China are growing exponentially. For the purposes of the analysis, it is assumed that, on average, the export of live cattle will total 20,000 head per year from 2005–2015 (market growth evident in Figure 1) and that there is a 40% chance of Chinese import regulations being modified from 2005 onwards. Given the political nature of trade regulations, the probability of testing being modified is estimated to be relatively low.

4.4 Results

The NPV of enhanced animal disease control and diagnostic capability to China producers and Australian exporters is forecast to be $A4.6 million (expressed in 2001 dollar terms). The corresponding BCR is estimated to be 2.3:1 and the internal rate of return 13%. A BCR of this magnitude suggests that, for each dollar allocated to the projects, 2.3 dollars of project benefits will be generated. The flow of annual costs and benefits across the 30-year evaluation period is given in Table 5 and Figure 4.

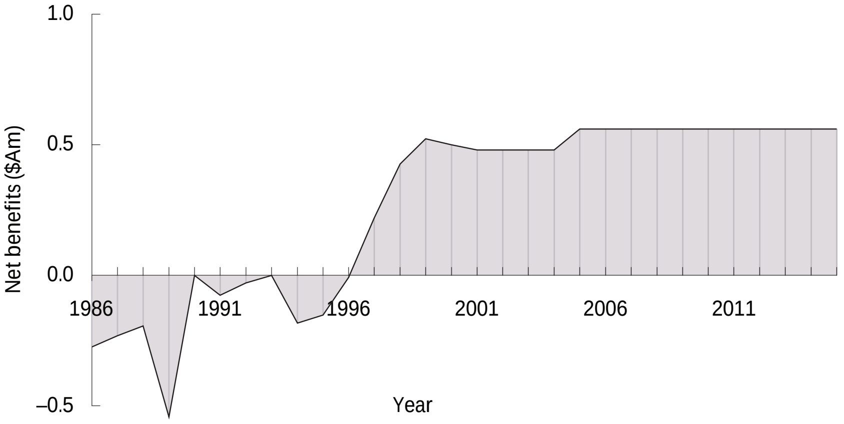

Figure 4. Flow of bluetongue disease and bovine ephemeral fever project net benefits through time.

Table 5. Benefit–cost analysis of research projects on bluetongue disease and bovine ephemeral fever.

Period		Benefits					Research	Totals	
Year no.	Year	China control costs (A$nom)	China farmer benefit (A$nom)	Aust export benefit (A$nom)	Adjust factor	Gross benefits (A$)	Total costs (A$2001)	Net benefits (A$2001)	Net present value (A$2001)
1	1986	0.00	0.00	0.00	1.74	0.00	0.27	–0.27	–0.57
2	1987	0.00	0.00	0.00	1.61	0.00	0.23	–0.23	–0.46
3	1988	0.00	0.00	0.00	1.50	0.00	0.19	–0.19	–0.37
4	1989	0.00	0.00	0.00	1.40	0.00	0.54	–0.54	–0.98
5	1990	0.00	0.00	0.00	1.30	0.00	0.00	0.00	0.00
6	1991	0.00	0.00	0.00	1.26	0.00	0.08	–0.08	–0.12
7	1992	0.00	0.00	0.00	1.25	0.00	0.03	–0.03	–0.05
8	1993	0.00	0.00	0.00	1.23	0.00	0.00	0.00	0.00
9	1994	0.00	0.00	0.00	1.20	0.00	0.18	–0.18	–0.26
10	1995	0.05	0.15	0.00	1.15	0.11	0.26	–0.15	–0.20
11	1996	0.10	0.29	0.00	1.12	0.22	0.22	–0.01	–0.01
12	1997	0.15	0.44	0.00	1.11	0.32	0.10	0.22	0.27
13	1998	0.20	0.58	0.00	1.11	0.43	0.00	0.43	0.49
14	1999	0.25	0.73	0.00	1.09	0.52	0.00	0.52	0.58
15	2000	0.25	0.73	0.00	1.04	0.50	0.00	0.50	0.52
16	2001	0.25	0.73	0.00	1.00	0.48	0.00	0.48	0.48
17	2002	0.25	0.73	0.00	1.00	0.48	0.00	0.48	0.46
18	2003	0.25	0.73	0.00	1.00	0.48	0.00	0.48	0.44
19	2004	0.25	0.73	0.00	1.00	0.48	0.00	0.48	0.41
20	2005	0.25	0.73	0.08	1.00	0.56	0.00	0.56	0.46
21	2006	0.25	0.73	0.08	1.00	0.56	0.00	0.56	0.44
22	2007	0.25	0.73	0.08	1.00	0.56	0.00	0.56	0.42
23	2008	0.25	0.73	0.08	1.00	0.56	0.00	0.56	0.40
24	2009	0.25	0.73	0.08	1.00	0.56	0.00	0.56	0.38
25	2010	0.25	0.73	0.08	1.00	0.56	0.00	0.56	0.36
26	2011	0.25	0.73	0.08	1.00	0.56	0.00	0.56	0.34
27	2012	0.25	0.73	0.08	1.00	0.56	0.00	0.56	0.33
28	2013	0.25	0.73	0.08	1.00	0.56	0.00	0.56	0.31
29	2014	0.25	0.73	0.08	1.00	0.56	0.00	0.56	0.30
30	2015	0.25	0.73	0.08	1.00	0.56	0.00	0.56	0.28
Total		4.75	13.87	0.88		10.17	2.12	8.06	4.64

Table 6 gives the present values of project benefits to Australia and China for benefits realised to date and projected forward. If only benefits to date are accounted for, then the ACIAR animal disease projects are calculated to generate a present value of benefits of A$3.3 million, all of which are captured by Chinese producers. In contrast, if possible benefits to Chinese producers and Australian exporters are incorporated in the projection, then a present value of benefits of A$8.2 million would accrue to the projects. It is estimated that Chinese producers will capture approximately 90% of the total present value of projected benefits.

Table 6. Present value of benefits (A$m) of bluetongue disease and bovine ephemeral fever research projects.

Source of benefits	Present value of benefits to China (A$m)	Present value of benefits to Australia (A$m)
Total benefits (to 2003)	3.3	0.0
Total benefits (projected forward)	7.6	0.6

4.5 Sensitivity analysis

A number of estimates have been included in the analysis in relation to the impact of enhanced diagnostic capability and vaccine development in China and Australia. These estimates have been made using the best available information, but are uncertain. Sensitivity analysis is undertaken in this section to determine which parameters have a significant impact upon the estimated economic returns of the projects.

4.5.1 Discount rate

A 5% discount rate was included in the analysis for baseline economic return calculations. The magnitude of this parameter may vary for different investors. Table 7 outlines the sensitivity of NPV and BCRs to the discount rate applied.

Table 7. Sensitivity of bluetongue disease and bovine ephemeral fever research investment criteria to discount rate.

Benefits (forward projection)	Discount rate		
	0%	5%	10%
Net present value (A$ million)	8.1	4.6	1.2
Benefit–cost ratio	4.8:1	2.3:1	1.2:1

Higher BCRs and NPVs are calculated at lower discount rates. The difference between NPVs at 0 and 5% discount rates for the projection is calculated to be A$3.5 million.

4.5.2 *Reduced live animal export costs*

The rationalisation of Chinese animal testing and quarantine import requirements is a potential benefit of the projects. At present, these requirements are very stringent and impose a substantial cost on animal exporters. If these costs were reduced, exporters would reap significant benefits. Nevertheless, there is a degree of uncertainty about the value of any cost savings, as import regulations are currently being negotiated. The sensitivity of investment criteria to export cost savings is provided in Table 8. It is evident that a 10% further increase in the cost saving would generate an addition A$0.1 million in net present value.

Table 8. Sensitivity of animal disease research investment criteria to export cost saving.

Benefits	Cases		
	(<10%)	Base (A$10 head)	(>10%)
Net present value (A$ million)	4.6	4.6	4.7
Benefit–cost ratio	2.29:1	2.31:1	2.33:1

5 Conclusions

Enhanced bluetongue disease diagnostic capability has been established in China, and a killed BEF vaccine has been developed as a result of research conducted within ACIAR-supported projects. These developments have led to reduced incidence of the insect-borne bluetongue and BEF viruses. Such a reduction increases animal productivity in China through reduced mortality and increased production of milk and meat. The potential for introducing genetically superior livestock into the national Chinese flock is also enhanced through the development of capacity to manage these diseases, which affect exotic breeds in particular.

In addition, China has stringent import requirements for livestock. Diagnostic capacity and epidemiological research conducted within the projects have identified the serotypes of the viruses present in China and Australia. This information is likely to lead to rationalisation of Chinese import requirements. If this occurs, the profitability of animal exporting is likely to increase, and the costs of exotic animal purchases by Chinese livestock producers and merchants to fall. The estimated NPV of the returns to Australia and China from the ACIAR-supported projects on BEF and bluetongue is A$4.6 million and the corresponding BCR 2.3:1.

6 Acknowledgments

The author thanks the following people for information provided during consultations:

- Mr C. Brittenden, ACIAR Country Manager, China
- Dr Z. Fuzhong, Yunnan Tropical and Sub-tropical Animal Virus Diseases Laboratory, Yunnan
- Dr Juan-Duan, Senior Research Fellow, Harbin Veterinary Research Institute
- Ms T. Gleeson, Australian Bureau of Agricultural and Resource Economics, Canberra
- Mr D. Inall, LiveCorp, Australia
- Dr P. Kirkland, NSW Agriculture
- Professor J. Longworth, University of Queensland, Australia
- Dr T. St George (former leader of BEF project)
- Ms W. Xiaomei, Division Director, Scientific Research, Harbin Veterinary Research Institute
- Dr N. Zhang, Director, Yunnan Tropical and Sub-tropical Animal Virus Diseases Laboratory, Yunnan
- Mr G. Wang, ACIAR Assistant Country Manager, China (help with data collection)
- Dr Li Zhihua, Yunnan Tropical and Sub-tropical Animal Virus Diseases Laboratory, Yunnan

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No.	Author(s) and year of publication	Title	ACIAR project numbers
1	Centre for International Economics (1998)	Control of Newcastle disease in village chickens	8334, 8717 and 93/222
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13	Chudleigh, P. (1999)	Breeding and quality analysis of rapeseed	CS1/1984/069 and CS1/1988/039
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16	Ross McLeod (2001)	Control of footrot in small ruminants of Nepal	AS2/1991/017 and AS2/1996/021
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