THE IMPACT OF THE INTERNATIONAL LIVESTOCK RESEARCH INSTITUTE

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5 Veterinary Epidemiology at ILRAD and ILRI, 1987–2018

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Executive Summary

The problem

The effectiveness of detecting and controlling animal diseases is dependent on a solid understanding of their dynamics and impacts through scientifically sound qualitative and quantitative methods by trained personnel. Veterinary epidemiology is the systematic characterization and explanation of patterns of animal diseases and the use of this information in the resolution of animal and human health problems. This discipline exploits an increasing inventory of tools for effective data gathering, assembly and analysis, modelling and reporting, all targeted at decision making by producers, governments and international development agencies. Furthermore, the integration of epidemiology with agricultural economics and other social sciences provides a uniquely effective tool for evaluating disease as a constraint to broader development agendas, for assessing the absolute and relative economic importance of diseases, and for evaluating the costs and benefits of alternative intervention options, at different levels ranging from farm to national to global. Furthermore, veterinary epidemiological and economic impact sciences are key components in a number of the global grand challenges relating to disease control, climate change and food security.

ILRI's role in the global context

The International Livestock Research Institute (ILRI) and its predecessor, the International Laboratory for Research on Animal Diseases (ILRAD), have played an important international role in identifying and developing epidemiological tools for the investigation and resolution of animal health constraints to livestock production. When the group was formed in 1987, it was charged with addressing the two diseases considered the priority in Africa, namely East Coast fever (ECF) and trypanosomiasis, to support the development of vaccines against these two diseases, which was the mandate of ILRAD.

Following the transition from ILRAD to ILRI, the institution has been a leader in exploring new epidemiological approaches, and in widening the disciplinary spectrum of epidemiological investigations. However, arguably most important

of all, ILRI has played a facilitating role in collaborating with countries, institutions and organizations in Africa, Asia and Latin America to respond to requests for both short- and long-term partnerships and support at international, regional, national and local levels, and in extensive capacity building in epidemiological tools, techniques and approaches.

Initially, ILRAD and ILRI focused almost exclusively on the dynamics and impact of tick-borne pathogens of livestock in Africa, but during the 1990s, the geographical focus, disciplinary make-up and range of tools used broadened substantially, tackling multiple diseases in Africa, Asia and Latin America and building capacity in epidemiological and economic impact assessment techniques.

For a period of 15 years (1987–2002) ILRAD/ILRI's epidemiology and socio-economic impact assessment capacity was assembled in one team serving a range of institutional and externally commissioned needs and was recognized internationally for its focus of health issues affecting development and poverty reduction. Through a major study of animal health research priorities commissioned by UK Department for International Development (DFID), the team made a substantial contribution to the design of ILRI's new strategy, which emerged in 2002, and to the poverty-focused agendas of other organizations such as the Food and Agriculture Organization of the United Nations (FAO) and the Wellcome Trust.

Impact of ILRI's research

Veterinary epidemiological and economic impact sciences at ILRAD and ILRI have left a valuable legacy of publications in peer-reviewed journals, strategic reports and policy documents, as well as methodologies and approaches that have been applied in virtually all corners of the world, and many trained epidemiologists now serving different institutional needs in Africa, Asia, Latin America, Europe and Australia.

The range of diseases subject to epidemiological and economics research has been wide, and included the viral infections rinderpest, foot-and-mouth disease (FMD), Rift Valley fever (RVF) and highly pathogenic avian influenza (HPAI), and the context of impact assessments has been applied to trade, livelihoods and poverty reduction. ILRI has worked with a multitude of partners around the world and has contributed substantially to research and development networking in many areas of animal health, including tick-borne diseases, rabies, and the fundamental tools of epidemiology and socio-economic impacts.

Scientific impacts

The group brought the science of structured epidemiological analysis to the institute in methodological terms (particularly in observational field studies), and also expanded the disciplinary contributions to include social, economic and environmental considerations in the analysis of disease impacts, and the impacts of disease control interventions.

Economic impact assessment

Most of the earlier economic impact assessments carried out by ILRAD and ILRI were disease specific, such as on ECF, rinderpest and FMD, and built on evidence derived from underlying epidemiological data. Economic impact assessments gained increasing momentum as ILRI's mandate broadened. The epidemiology group concluded that no longer should studies of the economics of diseases of production animals be limited to animal scientists seeking the collaboration of agricultural economists to affix prices to estimated productivity losses, and the new discipline of animal health economics emerged in which the quality of economic evaluations depended on integrating the products of good epidemiological studies into economic frameworks.

In 1998, the World Organisation for Animal Health (Office International des Epizooties, or OIE) approached ILRI to compile and edit a special edition of the OIE *Scientific and Technical Review on Animal Health Economics*, which comprised nine chapters on various topics such as the demands of economic impact knowledge, and seven case study chapters addressing specific diseases and different scenarios affecting the validity of the economic studies.

Developmental impacts

While we cannot ascribe higher productivity to ILRI's veterinary epidemiology research per se, the research has increased our understanding of infection dynamics, which has influenced disease control and the role of interventions in different settings.

Capacity development

Over the years, epidemiology has gone through both administrative and locality changes, seen as a unified entity for 15 years, and later under the new ILRI strategy it was fragmented and diminished. However, during the 15-year period from 1987 to 2002, the institution had supported approximately 15 MSc students and 37 PhD students with approximately 50 scientists predominantly from African countries. In addition, there have been several postdoctoral fellows who have been trained. As most of the epidemiology is conducted under a specific disease, it is difficult to determine how many more have been trained to date.

Partnerships

ILRI has worked with a multitude of partners around the world and contributed substantially to research and development networking in many areas of animal health, including tick-borne diseases, rabies and the fundamental tools of epidemiology and socio-economic impacts. In 2007, the Participatory Epidemiology Network for Animal and Public Health (PENAPH) was developed to connect groups and individuals who apply participatory epidemiology in controlling emerging and existing diseases.

Impacts on human resources capacity in veterinary epidemiology

During the 15-year period from 1987 to 2002 a substantial number of MSc and PhD students were trained through incorporation into ILRI's research activities; these were predominantly from African countries.

Impacts on national animal health departments and services

The epidemiology group provided a role model of investigative problem solving, which was picked up, copied and adopted by some institutions in African countries.

Impacts on animal health constraints in developing countries

ILRI's epidemiology research has made substantial contributions to our understanding and control of ECF and trypanosomiasis in Africa, to the preparedness and responses to RVF in eastern Africa, to a greater understanding of the economic impact of rinderpest in Africa and of FMD in Africa, Asia and Latin America, and to regional understanding of the drivers of rabies control. More recently, epidemiology research at ILRI has contributed substantially to our understanding of food safety risks in formal and informal markets and to the dynamics and risks of zoonotic diseases. The research has also contributed to the global understanding of the importance of these and other diseases to African livestock systems and to the particular animal health constraints facing the poorer sectors of Africa's livestock-engaged communities.

Impacts on ILRI's research and strategy

During the days of ILRAD, the epidemiology and socio-economic programme had little or no impact on ILRAD's research and strategy; rather, it was seen as providing evidence justifying the existence of the laboratory-based vaccine research for the two target haemoparasitic diseases. Nevertheless, after ILRI's birth in 1995, the programme played an important role in providing impact assessment services, which progressively enhanced the engagement of the institution with different national, regional and donor clients. This situation changed dramatically in 2002 following the publication of the DFID-commissioned study on animal research priorities for poverty reduction. The matrix of three 'pathways out of poverty' provided the framework of the new institutional thematic structure, not just for animal health research but also for ILRI's entire programme.

Introduction

Veterinary epidemiology is the systematic characterization and explanation of patterns of animal diseases and, importantly, the use of this information in the resolution of animal and human health problems. It is a subject that exploits an increasing inventory of tools for effective data gathering, assembly and analysis, targeted at decision making in the field of animal disease control and sustainable livestock enterprise development. The integration of epidemiology with agricultural economics and other social sciences provides a uniquely effective tool for evaluating disease as a constraint to broader development agendas, for assessing the absolute and relative economic importance of diseases, and for evaluating the costs and benefits of alternative intervention options, at different levels ranging from farm to national to global. ILRI and its predecessor, ILRAD, have played an important international role in exploiting epidemiological tools for the investigation and resolution of animal health constraints to livestock production and poverty reduction in many regions of the developing world. Furthermore, ILRI has been a leader in exploring new epidemiological approaches, and in widening the disciplinary spectrum of epidemiological investigations. However, arguably most important of all, ILRI has played a facilitating role in collaborating with countries, institutions and organizations in Africa, Asia and Latin America in response to requests for both short- and long-term partnership and support at international, regional, national and local levels, and in extensive capacity building in epidemiological tools, techniques and approaches.

The introduction of veterinary epidemiology and economics at ILRAD

The fundamental belief at the creation of ILRAD in 1974 was that vaccines against ECF and trypanosomiasis were the mandate of ILRAD. The evidence available to answer these questions at the time was derived almost entirely from African veterinary services and diagnostic laboratories, which had, for the previous 60 or so years, been servicing livestock production enterprises of the colonial powers. There were little if any economic data to quantify the impacts of these diseases, even in commercial systems, and the potential returns from vaccines.

ILRAD alone among the international agricultural research centres of CGIAR had a unique mandate to carry out basic research and as such undertook very little of the technology transfer functions. Pressure progressively increased from partners to quantify the impacts of these two diseases on African agriculture in order to better justify the scientific investment in the study of these two diseases.

Thus, it was some 13 years after the establishment of ILRAD that veterinary epidemiology was introduced into the institute. The Rockefeller Foundation initially for 3 years (and subsequently extended for a further 2 years) supported what became the Epidemiology and Socioeconomics Programme. The group was joined in 1992 by an ecologist to explore the environmental impacts of trypanosomiasis control (Reid *et al.*, 1995). The team expanded in the late 1990s to include another staff epidemiologist and two postdoctoral epidemiologists.

The group rapidly laid out a work plan, beginning with the establishment of databases on African production systems at risk from the two diseases and on methodologies for determining their impact. This challenge led to the realization that disease incidence and prevalence data in Africa were scarce and unreliable, notably on the structure and ownership of the livestock populations at risk. The need for structured quantitative epidemiology capacity emerged, which led to a sustained programme of data assembly, digital data documentation and assembly, the development of modelling techniques and, of course, the gathering of field data.

Field studies in Kenya

The first field site of diverse ecosystems and disease impacts was in Kilifi District on the Kenyan coast. A collaborative programme between the International Livestock Centre for Africa (ILCA) and the Kenya Agricultural Research Institute (KARI) was established in 1988 at KARI's Mtwapa Regional Research Centre, near Mombasa.

The smallholder dairy group was setting up a broad study on the constraints to smallholder milk production in the coastal lowlands of Kenya and how extension services covering the areas of feed and health could be improved. Specifically, the study estimated the demand for milk and dairy products, identified technical and policy constraints on production in mixed smallholder farming systems, evaluated dairy cattle breed resources, estimated disease risk to dairy cattle and tested disease control methods, and developed feeding systems appropriate to smallholder dairy production systems.

The ILRAD epidemiology team provided support to the studies on the epidemiology and impact of ECF in the form of design and analysis of studies led by KARI staff. The challenge was a total lack of data on ECF occurrence, and so a series of cross-sectional studies was set up. Key was understanding the link between infection prevalence, as measured by antibodies to *Theileria parva* in an indirect fluorescent antibody test, and disease incidence. ILRAD's entry into this research area was at a time when infection prevalence, as measured by antibody prevalence, had not been correlated with disease incidence, and, where prevalence studies had been undertaken, they had often been reported on the basis of administrative boundaries such as the FAO's 1975 study in Kenya (Kariuki, 1988).

In 1983, the *Farm Management Handbook of Kenya* was published (Jaetzold and Schmidt, 1983), which provided a unique landscape synthesis of Kenya's agricultural environment, aggregating a number of variables into a kaleidoscope of colours representing the suitability for different crops and agricultural enterprises. With the knowledge that the epidemiology and impacts of ECF were highly dependent on environmental suitability for the main vector tick, *Rhipicephalus appendiculatus* (the brown ear tick), the zone boundaries provided a new and useful sampling frame that had previously been unexploited.

A series of studies was set up in coastal Kenya to determine the prevalence and incidence of ECF and the other tick-borne infections such as anaplasmosis and babesiosis, and to evaluate the role of immunization against ECF using the infection-and-treatment method (ITM). The studies provided an initial quantitative assessment of antibody prevalence to the spectrum of tick-borne disease parasites in order to assess the epidemiological status of these infections in both indigenous Zebu cattle kept, and in improved dairy cattle in three different agroecological zones (AEZs) (Deem *et al.*, 1993; Maloo *et al.*, 2001a,b,c).

The coast work provided an opportunity to engage at the front line with national partners and to explore impact study design; it also illustrated the need to disaggregate factors affecting ECF epidemiology and impact. However, as the coastal systems were not fully representative of the intensifying livestock systems in the temperate highland areas of eastern Africa, additional studies were set up. The first was in Uasin Gishu, where larger-scale dairy and beef production was rapidly being replaced by small-scale commercial dairy enterprises (Mukhebi *et al.*, 1992a). This work coincided with the introduction of the discipline of human nutrition into the impact equation (Curry *et al.*, 1996).

In 1992, the focus of the ECF epidemiology studies moved to the central highlands of Kenya, first to Kiambu District, with a 1-year study of the dynamics of theileriosis (O'Callaghan *et al.*, 1998). This was followed in 1994 by investigations in the neighbouring Muranga District, which hosted a range of livestock production systems in diverse AEZs. There were five distinct AEZs within Muranga District, giving the opportunity to investigate the influence of a range of climate, livestock breeds and farming practice variables on ECF dynamics. The work started with a cross-sectional serological study on 750 smallholder dairy farms in Muranga District, selected in a stratified random sample (Gitau *et al.*, 1997), which showed the markedly different prevalences of *T. parva* infection across AEZs. The area was typical of the highland areas of eastern Africa in which the process of smallholder dairy intensification was gaining momentum. The investigation continued with a study that related prevalence with incidence, case morbidity and case mortality (Gitau *et al.*, 1999), and with a study of how these infections affected weight gain in calves (Gitau *et al.*, 2001). The work concluded with a synthesis of the implications of the research on disease risk and on the potential role of vaccination against ECF (Gitau *et al.*, 2000).

The synthesis concluded that ECF risk is low in predominately zero-grazing areas. Thus, tick control or future vaccination programmes will probably only be used by very risk-averse farmers who wish to protect their highly valuable cows from the low risk of ECF mortality. In contrast, for open grazing systems, particularly in the lower-elevation upper-midland 4 (UM4) zone, the risk of ECF is much greater and probably much more variable. In this system, there will be much more substantial direct impact of ECF control programmes. In areas where ECF control will be through vaccination, irrespective of the grazing management system, there will be a greater likelihood of the development of endemic stability. Increased vaccination coverage to enhance the development of herd immunity, combined with modification of acaricide control strategies to allow sufficient challenge, seemed to offer the best prospect for establishing endemic stability. It was quite clear from these studies that attention needs to be paid to the variation in ECF risk, both spatially (as ECF risk changes over relatively short geographical distances) and temporally (seasonally), to develop optimal combinations of control measures for ECF under different ecological and grazing situations.

It was in 1997 that the ECF epidemiology work expanded into other parts of Kenya, following the submission of a research proposal to the International Fund for Agricultural Development (IFAD). The revised proposal strengthened the epidemiology and impact assessment components and placed them in an *ex ante* context. Vaccine efficacy trials were limited to two sites in Kenya, while the impact assessment broadened into new areas. The impact assessment studies included an evaluation of mechanisms for optimal delivery, adoption and impact of the p67 vaccine (p67 is the major surface protein of *T. parva* sporozoites), determining the impact of a recombinant vaccine on a series of productivity and economic indicators in smallholder dairy systems. The project also included key laboratory studies to support the field studies and disease-modelling work (Ochanda *et al.*, 1998).

Table 5.1 outlines the various studies undertaken in Kenya, illustrating the differences in impacts by region, AEZ and grazing management.

There were a wide variety of products emerging from the IFAD study, ranging from Technical Advisory Notes such as 'Assessing farmer preferences for the provision of livestock health services' to international presentations (Leneman *et al.*, 2000; Kiara *et al.*, 2000, 2003; Ndung'u *et al.*, 2000, 2003; Wanyangu *et al.*, 2000; Di Giulio *et al.*, 2003, Karimi *et al.*, 2003; O'Callaghan *et al.*, 2003; Diaz *et al.*, 2003) to peer-reviewed papers in scientific journals.

In a review article of the ECF work (Perry and Young, 1995), it was postulated that the degree of mortality and production losses from *T. parva* infections were dependent on four key factors, which all exert their influence as a gradient (or cline) of effects:

- The ecological cline, in which the climatic suitability for the tick vector varies with rainfall and altitude; the ecological cline gradient can be affected by differences in vegetation cover.
- The host genetic cline, in which purebred taurine cattle bred under tick-free conditions are highly susceptible to disease, and taurine cattle bred in tick-borne infection endemic areas and some Zebu breeds (such as Boran) bred in tick-free conditions are moderately susceptible, but Zebu cattle bred in tick-borne infection endemic areas are of low susceptibility to disease.
- The feeding management cline, which controls the exposure of hosts to the ecological conditions; this can range from no influence, where cattle are herded on natural pasture, to complete influence, where cattle are kept on concrete and fed on cultivated forage grasses, as in the smallholder zero-grazing units of eastern Africa.
- The tick control cline, where tick control ranges from highly effective, regular application through to no tick control at all.

Tick-borne disease dynamics in eastern and southern Africa

At the start of these intense epidemiological investigations in Kenya, a regional meeting on tick-borne diseases was held in Lilongwe, Malawi, in 1988 (Dolan, 1989), which provided

Table 5.1. ECF risks by region, AEZ and grazing management.

Study	O'Callaghan (1998)		Gitau (1998)		Maloo (1993)	
Incidence rate type	Calves (<1 year of age); incidence density		Calves (≤6 months of age); cumulative incidence		Calves (<1 year of age); incidence density	
Grazing management	Zero grazing	Pasture	Zero grazing	Pasture	Zero grazing	Pasture
Number of animals (*n*)	93	108	134	91	38	50
ECF morbidity rate (%)	5.5	10.9	11.8	49	36.4	68.8
ECF mortality rate (%)	0	2.2	1.7	20.6	20.8	49.7
Case-fatality proportion (%)	0	25	28.6	38.1	57.1	72.2
Seroconversion rate (%)	41.4	56.5	58.4	74	0	0
Morbidity proportion (%)	13.3	7.7	12.2	36.1	0	0

an opportunity for sharing of information and understanding on theileriosis throughout the eastern and southern African regions, and where it became apparent that there were significant differences in the disease epidemiology between the eastern and southern regions. The Lilongwe meeting led to a textbook on theileriosis, *The Epidemiology of Theileriosis in Africa* (Norval *et al.*, 1992b). The book was published by Academic Press, with ILRAD supporting the time contributions of the three authors and the preparation of camera-ready copy, and the book became the reference point for all those working on control of the disease. This book remains the only textbook on theileriosis, a product of ILRAD's epidemiology team of substantial impact.

The disease called ECF was said to have been eradicated in southern Africa as a result of an intensive dipping programme, with the last case occurring in Swaziland in 1960. Nevertheless, *T. parva* infections persist, but with the official eradication declared, the names of theileriosis and corridor disease have been used to describe disease outbreaks. This curious confrontation of science and officialdom of disease and parasite nomenclature was reviewed in an article entitled 'The naming game: the changing fortunes of East Coast fever and *Theileria parva*' (Perry and Young, 1993). It is encouraging how these studies have led to our current understanding of theileriosis epidemiology, as illustrated by a recent review by Gachohi *et al.* (2012).

The heartwater studies in Zimbabwe

Through funding from the US Agency for International Development (USAID), a 5-year project on the epidemiology and impact of another important tick-borne disease of livestock in Africa, heartwater (also known as ehrlichiosis; caused by *Ehrlichia ruminantium* infection, formerly *Cowdria ruminantium*) was initiated in 1994[1]. This work subsequently received ILRI's award (and ILRI's nomination for the CGIAR Chairman's Award) for Scientific Partnership, 2000.

The collaborative research in epidemiology and economics between the Veterinary Research Laboratory (VRL) in Harare, the Heartwater Research Project of the Southern African Development Community (SADC), the Universities of Florida (USA) and Warwick (UK), and ILRI determined and quantified the infection dynamics of heartwater in the major production systems and AEZs of Zimbabwe, the economic impact of the disease, and the technical and economic viability of different control interventions, with particular emphasis on the role of inactivated vaccines. The project outputs were as follows:

- Distributions of tick vectors in Zimbabwe were defined and documented. A national survey of 3000 collections determined that *Amblyomma hebraeum* is the dominant tick in the south and that it had spread into central and eastern areas of the high veld. The survey also found that *Amblyomma variegatum* is present mainly in the north-west but that it is also found in central and eastern parts of the high veld, with some overlap of the two species (Norval *et al.*, 1994; Peter *et al.*, 1998, 1999).
- Spread of heartwater was documented and quantified, and factors affecting the spread were determined. *A. hebraeum* had spread far north due largely to movement of cattle (and some wildlife) to the high veld. A gradual reduction in acaricide use, particularly in the communal lands, contributed to the expanding distribution of this tick (Norval *et al.*, 1992a).
- Infection dynamics in the tick vector and mammalian hosts were determined and quantified. Endemic stability, in which population immunity develops, was found to be widespread but not present where acaricides were used intensively to interrupt natural infection. These results suggest that use of inactivated vaccines in many circumstances will allow a reduction in acaricide use with a transition to endemic stability and subsequent natural infection boosting the vaccinal immunity.
- The impact of endemic stability, and carrier infections, on sheep productivity was determined. Studies in sheep revealed that creating endemic stability artificially with vaccines does not harm the health and reproductive performance of breeding ewes or the growth and milk consumption of their lambs (Martinez *et al.*, 1999a,b).

- Infection dynamics models were developed using data generated by the research. A mathematical model of the infection dynamics of the heartwater pathogen, *E. ruminantium*, showed that endemic stability is due principally to the protection of calves and lambs against disease by innate or maternally derived factors (O'Callaghan *et al.*, 1998).
- Economics of livestock production in heartwater areas was determined. Both large- and small-scale livestock production could be increased significantly with more, and more cost-effective, heartwater control methods (Perry *et al.*, 1998; Chamboko *et al.*, 1999).
- The economic impact of heartwater, and of future vaccine use, was determined. The annual total direct losses in Zimbabwe (acaricide costs, milk losses, treatment costs) from heartwater were estimated to be US$5.6 million. A new inactivated vaccine was predicted to have a benefit:cost ratio of 2.4:1 in the communal sectors and 7.6:1 in the commercial sectors (Mukhebi *et al.*, 1999).
- The efficacy of future vaccine use was evaluated in epidemiological models. The timing of vaccination and frequency of revaccination were shown to have greater effects on population protection than vaccine efficacy. In the face of an epidemic, the frequency of administration is critical to a vaccine's success. Vaccines of relatively low efficacy (about 50%) can significantly reduce livestock morbidity and mortality if administered with appropriate frequency (O'Callaghan *et al.*, 1999).
- The economic impact of the disease and of its control through vaccines was evaluated and quantified in the countries of the SADC region. In total, 31 million cattle and 28 million small ruminants were found to be at risk of heartwater in the nine SADC countries affected: Angola, Botswana, Malawi, Mozambique, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe. The total annual losses were estimated at US$47.6 million, of which 61% were production losses and 39% control costs. New inactivated heartwater vaccines could yield benefit:cost ratios of up to 4.4:1, particularly in commercial and emerging market-orientated systems of the region (Minjauw *et al.*, 1998, 2000).

The successes of this collaborative project were considerable, with all objectives met and all findings published within a period of 5 years. The results of the project have given scientists a sound understanding of the factors influencing the distribution of tick vectors, and the infection dynamics and impacts of the disease in different AEZs and production systems, and predictions of the technical and economic impacts of control with a new generation of inactivated vaccines now emerging. The results generated have strong implications for heartwater control in other countries of Africa. Design and modelling features of the study have been used in studies of other tick-borne livestock diseases.

Apart from its technical achievements, the project boosted scientific capacity, particularly in Zimbabwe, through postgraduate training for national scientists. Project members produced 23 papers in peer-reviewed journals, 15 of which were authored by VRL scientists. Project staff produced another 36 publications, including 22 presentations at scientific meetings and ten articles in the project newsletter.

Economic impact assessments of tick-borne diseases

The first opportunity to undertake an economic impact assessment came in the late 1980s with the ILRAD/KARI partnership on the Kenya coast, where an immunization trial was being carried out using ITM to control ECF. Adrian Mukhebi showed greater profitability in immunized cattle compared with unimmunized, through lower mortality and higher weight gains (Mukhebi *et al.*, 1989). This was a solid first piece of evidence, although it was compiled on a state-run Agricultural Development Corporation beef ranch. The authors commented that 'these results and the recommendation apply to one immunization trial on one farm which was under an atypical management system for the region'.

Building on the potential for ITM, Mukhebi *et al.* (1990) then dissected the complicated vaccine preparation process and calculated the costs of establishing a vaccine production facility (at a hypothetical site in Kenya but using a methodology generic to other countries).

These initial forays into the economics of ECF and its control led to an Africa-wide assessment, presenting the estimated total costs of ECF in affected countries in 1989 as US$168 million (Mukhebi *et al.*, 1992b). The authors calculated benefit:cost ratios for the control of ECF through vaccination of between 8.9 and 16.8, depending on the intensity of post-vaccination acaricide use. The authors warned that 'the input values and hence results presented in this paper are dependent upon sparse and inadequate data and are largely illustrative of the methodology and data needs. Nevertheless, they provide an estimated magnitude of the economic losses attributed to theileriosis, and the economics of its control by the infection and treatment method in the infected region'.

A series of further economic studies of ECF was undertaken by PhD student Hezron Nyangito, who, in a partnership with the Department of Agricultural Economics at Texas A&M University, used a whole-farm simulation model to estimate the financial and economic pay-offs from the use of ITM vaccination, drawing on data collected from Uasin Gishu, Kenya (Nyangito *et al.*, 1994, 1995, 1996).

The study by Mukhebi *et al.* (1999) provided one of the first attempts to truly integrate epidemiology and economics models to predict future economic impacts of different control scenarios under a set of epidemiological scenarios.

Tick and tick-borne disease distribution modelling

The need to understand the geographical scale of impact of both ECF and trypanosomiasis very quickly led into the area of modelling, primarily of the vectors but also to a degree of the disease itself. In the absence of high-quality field data on *R. appendiculatus* distribution, the group first sought data on the key drivers of climate and vegetation, and in late 1987 and early 1988, a contract was drawn up between ILRAD and the Global Resource Information Database (GRID) group led by Harvey Croze at the United Nations Environment Programme (UNEP) in Nairobi. This group was using geographical information systems (GIS) for various African continent-wide assessments, running the software ARC/INFO from the Environmental Systems Research Institute (ESRI). A memorandum of understanding was set up between ILRAD and UNEP, and two UNEP scientists contributed data assembly and analysis time over the following 18 months, before the epidemiology and socio-economics group at ILRAD obtained core funds to establish its own GIS capacity, led by Russ Kruska. Research in the late 1980s and early 1990s centred on vector-borne disease distribution and impact studies; the group also contributed to the establishment in 1992 of the UNEP/CGIAR partnership on the development of digital datasets for research on a wide range of topics including natural resources, ecology, environment and socio-economic factors.

Efforts to model the potential distribution of *R. appendiculatus* were assisted by two key inputs. The first was the database on tick field samplings assembled by Jane Walker. The second was a climate matching model, Climex, developed by Robert Sutherst, with parameters for the conditions favoured by the brown ear tick (among others). Instead of the model being run on climate data for any given location, it was run for the whole of Africa, in each of the 25 km^2 pixel cells of an interpolated climate surface for the continent. The results plotted the potential distribution of *R. appendiculatus* (Lessard *et al.*, 1990; Perry *et al.*, 1990, 1991), but when compared with the database of Jane Walker and others of where the tick had been recorded, the potential distribution exceeded the historical records, suggesting that Climex did not tell the whole story. This finding stimulated interest in other predictive modelling approaches to estimate tick distribution (Randolph, 1993), in which much closer attention was paid to the climatic requirements of all three instars of the tick, which eventually led to a more biologically sound spatial prediction platform (Randolph and Rogers, 1997).

In a follow-up case study of predicting outbreaks of theileriosis in Zimbabwe using multiple climatic variables (Duchateau *et al.*, 1997), the methodology for assessing distribution drivers using climate databases was addressed. The database was considered to suffer from collinearity, because most climatic variables share qualities with (or are influenced by) other variables in the database. Fitting logistic regression models to disease occurrence with highly correlated independent variables can lead to misleading conclusions if the true biological meaning is not clearly understood. This case study used the analysis of principal components to reduce large numbers of variables to smaller sets of variables that more efficiently describe the important features of the database.

An important early stage in the impact assessment process had been to determine more accurately the distribution of diseases and their vectors. This had four major impacts:

1. It enhanced the understanding of disease vector distributions, and factors affecting these, such as climate and vegetation.
2. It enhanced the understanding of the role of GIS in predicting disease and vector distributions, and the need for appropriate high-resolution georeferenced databases, including the use of satellite-derived imagery.
3. It allowed exploration of new methods for improving the predictive capacity of distribution models (illustrated by Duchateau *et al.*, 1997).
4. It alerted Ethiopia, where *R. appendiculatus* had never been recorded, to the climatic suitability of the survival of this vector in certain parts of the country (Norval *et al.*, 1991). This stimulated the Ethiopian government to revise its policy on importation of live cattle from Kenya. A new study confirming the susceptibility of Ethiopia to ECF has since been published (Leta *et al.*, 2013), repeating the warnings made by ILRAD in 1991.

Modelling the infection dynamics of vector-borne diseases

Soon after the observational studies on ECF on the Kenya coast had started, it was felt that there was a need to develop a mathematical model (Anderson and May, 1992) of *T. parva* infection dynamics that could contribute to our understanding of disease impacts and offer a framework to test the effect of interventions, such as vaccination. This started a 15-year collaboration on infection dynamics of tick-borne infections with Graham Medley, which eventually moved from theileriosis to *E. ruminantium* infection (heartwater). This launched a wider exploration of modelling in impact assessment, and ILRAD, in collaboration with FAO, organized a modelling workshop in Nairobi in November 1992 to explore the approaches being made by different research groups (Perry and Hansen, 1994).

The collaboration with Imperial College London, and subsequently the University of Warwick (where Graham Medley moved), led to the first attempt to develop a quantitative framework of the infection dynamics of theileriosis (Medley *et al.*, 1993). It was able to demonstrate how infection was maintained in cattle populations and quantified the important role of carrier animals. With the progressive understanding emerging from field studies in different regions, the model was updated and reported by O'Callaghan *et al.* (2003).

The principles behind this first model were then applied to heartwater, and a quantitative framework was produced that demonstrated for the first time the concept of endemic stability (O'Callaghan *et al.*, 1998). The approach went on to explore the effects of vaccination against heartwater (O'Callaghan *et al.*, 1999).

The various observational field studies and the supportive modelling initiatives raised many issues, particularly the mechanism for establishment of endemic stability to both theileriosis and heartwater, and the implication of different interventions, particularly tick control, on the development and maintenance of endemic stability. This led to an extrapolation of the findings to other diseases, including malaria, warning that certain interventions might interrupt endemic stability and lead to outbreaks of disease (Coleman *et al.*, 2001). This *Lancet* publication won the ILRI's award (and nomination for the CGIAR Chairman's Award) for the Outstanding Scientific Article of 2002.

Impacts of Trypanosomiasis and its Control

Economic impact of trypanosomiasis

The focus of impact assessment remained largely on tick-borne pathogens until 1997. In the early 1990s, the epidemiology group adapted a model that had been used for theileriosis impact assessment to quantify the impacts of trypanosomiasis and its control in Cameroon, Gambia, Côte d'Ivoire and Zimbabwe. The model estimated the proportion of the national herd at risk of the disease and the annual economic cost of the disease and produced a breakdown of the costs into production losses and input costs. Work based on this model was reported in Shaw (1992), in Mukhebi *et al.* (1993) and in the later review of Shaw (2009).

Subsequently an *ex ante* model of a potential trypanosomiasis vaccine (Kristjanson *et al.*, 1999) indicated that the potential benefits of improved trypanosomiasis control, in terms of meat and milk productivity alone, were US$700 million per year in Africa. The disease cost to livestock producers and consumers was an estimated US$1340 million annually, without including indirect livestock benefits such as manure and traction. Given an adoption period of 12 years, a maximum adoption rate of 30%, a discount rate of 5%, and a 30% probability of the research being successful within 10 years, the net present value of the vaccine research is estimated to be at least US$288 million, with an internal rate of return of 33%, and a benefit:cost ratio of 34:1.

While praising the estimated returns to trypanosomiasis control, the critics were uncomfortable with these returns being attributed exclusively to the effects of a vaccine. The predicted reduction of trypanosomiasis could in fact be achieved by several different interventions, including some for which technologies were already available. It could also be an evaluation of more effective deployment of tsetse traps, or of genetically engineered livestock resistance to the effects of trypanosomiasis or of effective chemotherapy; the productivity impacts may be similar. What will differ will be the probability of success, the cost of the research/implementation, the time to achieving that success, and the adoption rates. This is important, because there are those who believe that a vaccine will be out of our reach for a long time to come, and while the evaluation demonstrated probable benefits from trypanosomiasis control, it was not specific to a vaccine as the way to achieve this. Notably, 15 years on from this study, there is still no vaccine on the horizon, whereas the results were based on one being available 9 years ago.

The epidemiology of resistance to trypanocides

In the late 1990s, ILRI began research on the epidemiology and impact of trypanosomiasis in several African countries. Field work was undertaken in Uganda, Kenya, Tanzania and Zambia (in collaboration with the national agricultural research system and the University of Glasgow) and Burkina Faso (in collaboration with the Centre International de Recherche-Développement sur l'Elevage en zone Subhumide (CIRDES) and the Free University of Berlin (FUB). Highlights of this work included the following:

- Support from the Bundesministerium für wirtschaftliche Zusammenarbeit (BMZ) for several phases of an ILRI/CIRDES/FUB project on the epidemiology of trypanocide resistance in West Africa (see Chapter 3, this volume);
- Collaboration on trypanocide resistance in eastern Africa (Kenya, Tanzania and Zambia);
- Epidemiology studies of drug resistance in Mukono County, Uganda.
- Support for drug resistance studies undertaken by the Kenya Trypanosomiasis Research Institute (KETRI) in collaboration with Glasgow University.

These studies resulted in a series of multi-author and multi-institutional publications (e.g. Gall *et al.*, 2004; Knoppe *et al.*, 2006).

The development of a modelling technique for evaluating control options

An area of emphasis was the development of models to understand factors influencing the transmission dynamics of trypanosomiasis and assessing and predicting the impact of control strategies. The objective of this research was to determine whether transition models, as proposed by Diggle *et al.* (2002), could be applied. This modelling approach offered two major advantages over standard methods. The first is that risk factor associations can be assessed simultaneously for both new (incident) infections and recurrent infections after chemotherapy. The second is that such statistical methods can allow monthly rather than weekly or fortnightly sampling intervals in the field. This latter feature is crucial logistically and would allow the analysis of data from a much wider variety of sampling sites, as monthly sampling is commonly employed. The use of transition models allowed the distinction to be made between key factors influencing both the incidence and persistence of trypanosome infections in cattle in the Ghibe Valley, Ethiopia, over a 12-year period from 1986 to 1998 (Schukken *et al.*, 2004). With an observed average prevalence, based on microscopic examination, of approximately 50%, Ghibe ranked as an area of severe trypanosomiasis impact relative to other tsetse-infested areas in Africa (Snow and Rawlings, 1999). The real benefit of using a transition model to investigate infection dynamics of trypanosomes in cattle is its ability to assess both the incidence and persistence of infections. This was particularly useful because the main factor influencing changes in incidence, namely tsetse control, differed from the factor most likely to be responsible for increased duration of infection, namely resistance to commonly used trypanocidal drugs. Age and the number of previous infections also influenced incidence and duration of infection, raising interesting hypotheses for further investigation (e.g. potential of selection of trypanotolerance in local Ethiopian breeds).

Sustainable trypanosomiasis control in Uganda

The ILRI epidemiology group began work exploring the historical resurgence of human African trypanosomiasis (HAT; also known as sleeping sickness) in Uganda (Fèvre *et al.*, 2001; Welburn *et al.*, 2001) and went on to explore different potential control options using modelling techniques (McDermott and Coleman, 2001).

HAT remains an important disease in Uganda, and cattle are its main reservoir. This project assessed the role of cattle in human disease and how control of cattle trypanosomiasis can be used to reduce the public health burden of *T. brucei rhodesiense* HAT. Activities included: (i) development of tests to differentiate human-infective and -non-infective *T. brucei* spp.; (ii) studies into cattle movement in new outbreaks of HAT; and (iii) studies to evaluate factors that influence HAT risk, burden and under-reporting.

Sustainable trypanosomiasis control in the Ghibe Valley of Ethiopia

The initial modelling work of ILCA's research in the Ghibe Valley of Ethiopia moved on into an environmental impact study, supported by the International Atomic Energy Agency (IAEA), who were at the time exploring the potential role of the sterile insect technique to eradicate trypanosomiasis. While there was general scepticism over the widespread use of this technique, there was at the time substantial political support for wider tsetse eradication under the Programme against African Trypanosomiasis (PAAT) programme. This work also built on previous collaborative ILCA/ILRAD studies of environmental impact of long-term trypanosomiasis control in the Ghibe Valley, including impacts on bird species richness (Wilson *et al.*, 1997).

Spatial modelling of tsetse distributions

Underlying several studies on trypanosomiasis were studies on predicting the distribution of tsetse species. The GIS capacity set up in the late 1980s was subsequently applied to support studies on the impact of trypanosomiasis control (Perry *et al.*, 1994) and later exploited by Robin Reid, who went on to explore various aspects of the environmental impacts of tsetse control (Reid *et al.*, 2000) before moving into broader ecosystems research at ILRI.

The leaders in the use of statistical methods and spatial climate and vegetation databases were David Rogers and colleagues at the University of Oxford (e.g. Rogers *et al.*, 1996; Wint and Rogers, 2000). However, with the greater engagement of ILRI in predicting the effects of climate change on the length of the growing period and the implications this had on livestock production systems, an assessment of the potential for changing tsetse distributions was considered (McDermott *et al.*, 2001). Subsequent research has included work on the economic impact of trypanosomiasis (Robinson *et al.*, 2014a).

Preventing and containing trypanocide resistance in the cotton zone of West Africa

In April 2012, a final report on 'Preventing and containing trypanocide resistance in the cotton zone of West Africa' was issued, which was one of a series of projects exploring drug resistance in trypanosomiasis control. Previous work had focused on methods to evaluate resistance to trypanocides in north-east Guinea, southern Mali (Affognon *et al.*, 2009; Talaki *et al.*, 2009) and south-west Burkina Faso (Der *et al.*, 2011), and on testing integrated control strategies to reduce the risk of new drug resistance. In the final phase of the project, the project continued to evaluate resistance and raise awareness and capacity to address the problem across much of the rest of the zone and to scale up the prevention strategies developed earlier. Appropriate strategies were also being developed for containing – and, if possible, reversing – resistance in the pockets previously characterized, and a specific study was undertaken to assess the impact of the trypanocide resistance research efforts to date.

This series of projects has generated an important body of evidence for improving the sustainability of trypanosomiasis control in West Africa and elsewhere in sub-Saharan Africa (McDermott *et al.*, 2003; Clausen *et al.*, 2010). The final project focused on four main outputs, with capacity strengthening in the region as a cross-cutting objective. First, national research teams generated evidence that trypanocide resistance occurs in several locations across the cotton zone of West Africa, and the partnership has provided national services improved tools for detecting and monitoring it. Through collaboration with the Institute of Tropical Medicine (Antwerp), progress was made in developing markers for identifying resistance in trypanosomes (Delespaux *et al.*, 2010); this is expected to provide even more rapid and increasingly accurate diagnostics for detecting and monitoring drug resistance.

Second, informational aids, decision tools and media messages targeting farmers and animal health service providers to reduce the risk of resistance were further developed (Grace *et al.*, 2008, 2009). There is a better understanding of how farmers access information about animal health care and of the most important actors in national-level information networks that communicate such information. A third set of activities demonstrated the effectiveness of integrated control strategies for containing trypanocide resistance in a location once it has established. In such situations, the public sector is probably required to implement tsetse control interventions and strategic treatment of cattle to suppress trypanosome populations. Actions improving cattle health status, such as helminth control, may also help further suppress surviving trypanosomes. Longer-term research is needed to confirm the subsequent dynamics of resistant trypanosome populations if trypanosomes re-establish.

Finally, a preliminary assessment of the potential impact of the investments made to date in research on trypanocide resistance indicates that adequate returns will be achieved to justify the investment (Affognon *et al.*, 2010).

Research findings and outputs from the project have been taken up by continuing efforts in the region to improve control of trypanosomiasis, notably by a network to monitor drug resistance (RESCAO: Réseau d'épidémiosurveillance de la résistance aux trypanocides et aux acaricides en Afrique de l'Ouest), the FAO PAAT and a 5-year, €3.1 million project involving the principal German partners and CIRDES to extend the project approach and findings to new countries (Togo, Ethiopia and Mozambique).

Rabies Research: A Networking and Capacity-building Role in Africa

ILRAD had no mandate in rabies research, but, beginning in the early 1990s, joined the Southern and Eastern Rabies Group (SEARG). Its first contribution was an overview paper on the epidemiology of rabies in Africa (Perry, 1992). As part of the capacity-building function of the epidemiology and socio-economics programme, partnership with the rabies control groups in Kenya and neighbouring countries was established, including the supervision of Philip Kitala in his PhD research on rabies in the Machakos District of Kenya, and a series of papers emerged (Kitala *et al.*, 2000, 2001, 2002). Other strategic contributions emerged from ILRAD and ILRI (Bingham *et al.*, 1993, 1995; Perry, 1993, 1995; Perry and Wandeler, 1993). In addition, the epidemiology team was called in to evaluate the controversy surrounding the role of rabies and rabies vaccination in the demise of the African wild dog packs in the Aitong region of Kenya's Maasai Mara (Macdonald *et al.*, 1992).

The impacts of the engagement with rabies were substantial, and mostly centred on the building of a rabies epidemiology and control network through SEARG, in capacity building on rabies epidemiology, diagnosis and control throughout the eastern and southern African region, and in highlighting priority research needs. Furthermore, ILRI's work contributed to some of the principles of dog rabies control, such as the need to understand the vaccination coverage required to prevent rabies (Coleman and Dye, 1996), the need for a sound understanding of population ecology (in this case, dog ecology) in order to target vaccination initiatives (Perry, 1993) and the need to exploit community engagement in rabies vaccination campaigns (Perry *et al.*, 1995).

The Economic Impacts of Rinderpest Control

Rinderpest has had a devastating effect on the livestock industries of Africa since its introduction to the continent in the late 19th century. In its classical form, it was responsible for high levels of mortality and its mere presence constrained trade in livestock. During the 1960s, the first coordinated international control programme was put in place, known as the Joint Project (JP) 15. Although largely successful, rinderpest returned in a major epidemic throughout much of the continent after JP15 concluded in the late 1970s. As a result, the Pan-African Rinderpest Control (PARC) programme was initiated under the auspices of the African Union–Interafrican Bureau for Animal Resources (AU-IBAR) funded by the European Union (EU) and national governments to control and ultimately eradicate rinderpest from Africa. A decade after the campaign started in 1986, increasing donor concern about its impact, coupled with an increasing public and private demand for information on the benefits and costs of rinderpest control, prompted the call for an economic impact assessment of the campaign.

Despite Africa being the last bastion of rinderpest before its global eradication in 2011, ILRAD did not become involved in research into its control, although following its eradication, ILRI did exploit the participatory epidemiology and surveillance tools used in the final phases of the campaign during its research into HPAI in Indonesia. Just before the merger of ILCA and ILRAD in 1995, the EU, which at the time was making large investments in rinderpest eradication through the AU-IBAR, approached both institutions. The PARC programme had been planning for some time to undertake an economic evaluation of the rinderpest control programme. However, the funds made available by the EU were not considered sufficient to employ an independent economist. As a result, the task was offered in 1994 to both ILRAD and ILCA, on the supposition that they could supplement the limited funds with their institutional capacities in agricultural economics. ILRAD, with its historical focus on vector-borne haemoparasitic diseases, turned the offer down, while ILCA accepted it. The two institutions were then amalgamated, and ILRI was born, and the newly created Systems Analysis and Impact Assessment Group (SA/IA, the successor to the Epidemiology and Socioeconomics Programme) 'inherited' the project. This provided a new opportunity for ILRI to work with AU-IBAR, and two agricultural economists were recruited under the leadership and supervision of the SA/IA group.

The study indicated that, for a sample of ten sub-Saharan African countries, the rinderpest campaign was implemented in a cost-effective manner, with average per livestock unit costs appearing within the narrow range of US$0.30–0.66 (Tambi *et al.*, 1999). Benefit–cost analysis revealed that the benefits of the campaign in each of the ten countries covered the value of the investment. The estimated average return over the ten countries of US$1.98 for each US dollar invested in the campaign indicated that rinderpest control in Africa has been economically profitable. The net present value of US$32 million indicates that the rinderpest campaign has been a wise public investment decision.

The work by ILRI scientists demonstrated further that rinderpest control has also improved the well-being of livestock farmers in sub-Saharan Africa, as well as that of consumers of livestock products. Analysis of the distribution of welfare gains from rinderpest control between producers and consumers revealed that producers derived the greater share (80%) of the US$64 million in net value of production losses avoided due to rinderpest control in the ten countries, while consumers derived approximately 20% in net benefits from increased supplies leading to lower prices (Roeder and Rich, 2009).

Applying Economic Impact Assessment Tools to Foot-and-mouth Disease Control

With the formation of ILRI, the new institution embarked on the development of an appropriate research role in what was a new sphere of influence for the organization, and an Asia Action Group was established to plan strategic engagement. For the epidemiology group, the first contact with the new region was a strategic attendance at the Federation of Asian Veterinary Associations (FAVA) Conference in Cairns, Australia, 24–28 August 1997, where a series of meetings was held with those attending. The representatives of the Australian Centre for International Agricultural Research (ACIAR; John Copland), and the OIE (Yoshihiro Ozawa) facilitated a discussion with multiple partners on how ILRI could provide added value to ongoing initiatives within the Asian region.

For ILRI to make an effective move into Asia in animal health research, it was considered that it should exploit the generic research capacity it had developed in epidemiology and economic impact, rather than its traditional disease focus of vector-borne haemoparasites of ruminants, as these were not considered to be a high priority in the region. In addition, it was considered that the first phase of ILRI's involvement in the region should be to better define constraints to livestock production and trade, and ways of alleviating these. To this end, it was suggested that enhancing the regional animal disease surveillance and monitoring programme, the Animal and Plant Health Information System for Asia (APHISA), in the field of epidemiological and economic impact assessment would be the most appropriate entry point. ILRI was invited to undertake an initial case study on the impact of FMD in the region, and the impact of alternative FMD control strategies. This provided an opportunity to enhance impact assessment capacity in the region, initiate longer-term disease control priority evaluations and provide immediate support to the newly created OIE-coordinated FMD control and eradication programme that had been set up. The OIE operation was funded by the Australian, Swiss and Japanese governments, with the Swiss Government offering to provide the ILRI portion of the funding.

A regional FMD coordination unit was set up, based in Bangkok, Thailand, led by Laurie Gleason, and an advisory committee was established, on which Brian Perry of ILRI was invited to sit. The first meeting was held in Bangkok on 1 March 1998. This set the scene for the first of the FMD economic impact studies, which focused on Thailand within a South-east Asia regional context. Thai epidemiologist Wantanee Kalpravidh was assigned to the study, and agricultural economics support was provided by Suzan Horst of Wageningen University, the Netherlands. The World Reference Laboratory for FMD (WRL-FMD) in Pirbright, UK, provided the FMD-specific technical support. Later in 1998, after he was recruited to ILRI's epidemiology and impact assessment group, Tom Randolph took over the economic impact analysis components of the initiative.

The first product of this work was presented at the annual meeting of the South-east Asia Foot-and-Mouth Disease (SEAFMD) group, under the auspices of OIE, in Phnom Penh, Cambodia, in February 1999, and emerged as a peer-reviewed publication later the same year (Perry and Randolph, 1999). This group provided a cost–benefit analysis of different FMD control scenarios and different emerging trading opportunities that would result from greater FMD control.

ILRI work on FMD in the Philippines had a significant impact. Randolph *et al.* (2002) developed scenarios, based on the plans and timetable of the Government of the Philippines, and more optimistic and pessimistic assumptions, each discussed in detail with national stakeholders. It also had an additional component, which was an analysis of the distribution of the benefits. It illustrated that, while the FMD control programme was funded entirely from public sector government coffers, in eradication scenarios the major beneficiaries would be the private sector pig producers, traders and marketers; the commercial swine sector was estimated to capture 84% of the benefits generated by the public investment in eradication, versus 4% by backyard swine producers.

ILRI later undertook a collaborative study on FMD on smallholder agricultural enterprises in southern Laos (Perry *et al.*, 2002a). This demonstrated the widespread impacts the disease had on multiple species and enterprises in the smallholder systems of southern Laos and has been often cited as evidence of the disruption to the livelihoods of smallholders globally.

The southern Africa FMD economic impact study

The results of a benefit–cost analysis showed that FMD control would benefit the economy of Zimbabwe (Perry *et al.*, 2003). First, in a comparison between the Baseline Scenario and the pessimistic FMD Control Scenario 3 (in which disinvestments in FMD control by 50% and resultant loss of beef export markets was predicted), it was shown that for every US$1 that Zimbabwe disinvests in the FMD control programme, a further US$5 would be lost by the country. No transboundary effects were taken into account, and the losses calculated were incurred by Zimbabwe alone. However, the association of the outbreak of FMD in south-eastern Botswana in March 2002 (after over 30 years of freedom from the disease) with the outbreaks in western Zimbabwe suggested that the costs to the region as a whole of Zimbabwe's disinvestments could be much greater.

Second, the results showed that if Zimbabwe were to invest further in the fences and the veterinary service infrastructures required to create a much larger and much more secure export zone that was internationally recognized as FMD free by the OIE, there would be returns of approximately US$1.5 for every US$1 invested. As in the disinvestment scenario, this does not incorporate benefits to the region as a whole through greater disease security for FMD control, nor does it include the other benefits that would result from an enhanced national veterinary service. This analysis did not consider whether Zimbabwe would be able to maintain the capacity, in terms of quantity and quality of beef, to supply the export market on a sustainable basis.

Importantly, the distributions of the costs and benefits turned out to be highly skewed. Expenditures from FMD control are borne almost entirely by the public sector, but when losses from trade bans resulting from FMD outbreaks are included, private sector costs are dominant. The majority of impacts of FMD and the benefits from its control are related to the ability to trade internationally, and so most of the benefits accrue to the commercial sector, comprising cattle production, beef processing, and related input industries and services. The Social Accounting Matrix/Computable General Equilibrium (SAM/CGE) modelling indicates that approximately 16% of the increased value of economic activity resulting from trade is eventually transferred as income to low-income households in both rural and urban areas.

The direct impacts on the poor of FMD, and of measures established to control it, are very limited. FMD has not been a problem in communal areas where the majority of the poor live, and its effects on indigenous cattle are considerably less than on commercially orientated herds. Furthermore, despite the fact that about 75% of poor households own or have access to cattle, over 60% of these households own fewer than five animals. Most of these households use cattle for wealth storing and other livelihood functions such as traction, and do not have the herd size capacity to engage actively in commercial cattle marketing. As such, only about 2% of households are engaged in regular marketing of cattle.

This study provided one of the most extensive analyses of FMD impacts carried out, applying new methods such as the SAM/CGE modelling to a most complex subject. Randolph *et al.* (2005) explored further the highly skewed equity impacts emerging from this study.

Economic impacts of FMD in Peru, Colombia and India

In 1995, the Joint FAO/IAEA Division of the IAEA requested ILRI support for an economic assessment of FMD control. An economic impact assessment plan emerged (Romero *et al.*, 2001). Unlike the South-east Asia partnerships, these Andean initiatives did not result in completed benefit–cost analyses; rather, the impacts of these studies in the region were in the field of networking, training, capacity building, awareness raising and methodology development.

Economic impacts of FMD control in endemic settings in low- and middle-income countries

In April 2006, Brian Perry approached the Wellcome Trust and the EU for support for an international workshop on the research needs for better FMD control in endemic settings of many low- and middle-income countries. This was approved, and the Global Roadmap for Improving the Tools to Control Foot-and-Mouth Disease in Endemic Settings was duly held in Agra, India, in late November 2006 (Perry and Sones, 2007b) and the Global Roadmap was launched in April 2007.

The Global Foot-and-Mouth Disease Research Alliance (GFRA)

ILRI developed a proposal for a GFRA with five research pillars:

1. A detailed understanding of the host immune responses to FMD virus.
2. Development of a new generation of inexpensive and thermostable vaccines that meet the requirements of both endemic and epidemic FMD control and management.
3. A full understanding of the factors that permit the development of virus carrier animals, the risk that they pose and options for managing them.
4. The identification of antiviral compounds to inhibit virus replication and rapidly reduce virus release.
5. Quantitative predictions of the performance of the new technologies developed in different settings through the use of epidemiological and economics models.

The leadership of each pillar was assigned to different institutions, with ILRI taking on this latter pillar. The US$70 million proposal was launched as a Strategic Global Research Partnership for the Control of FMD in April 2004.

The proposal was received with enthusiasm on the scientific side, but participants urged the development of a business plan. This was duly commissioned and in June 2005 representatives of the partnership set out to visit key donors (DFID and the Department for Environment, Food & Rural Affairs (DEFRA) in the UK; the EU; the Canadian International Development Agency (CIDA) in Canada; and various partners in the USA).

Considering the different contexts of FMD control in the developed and developing world, GFRA revised its approach to adopt two complementary programmes. Programme 1 was targeted at the FMD vaccine and diagnostic needs of FMD-free countries, and their trading opportunities, while Programme 2 focused on the needs of endemic settings, principally in developing countries. At this point, ILRI assumed the leadership of Programme 2, and initiated contact with potential research sponsors and development agencies. Programme 1 was assigned to the four participating research laboratories in the USA, the UK, Canada and Australia, funded through national bodies supporting each laboratory. The outcome would be a better set of tools to manage the risk to the four countries currently posed by FMD in endemic areas. This would focus on improved vaccines and diagnostics and the further development of antivirals.

Program 2 was designed to focus on developing better tools for use in endemic areas with the overall aim of a gradual reduction of the disease in endemic areas. It was recognized that targeted research would be needed to develop specific tools for Programme 2 and that this work could occur both inside and outside of the current GFRA partner institutes. It was foreseen that, for Programme 2, much still needed to be done in the area of epidemiology and impact assessment, and that ILRI would take the lead in this, and that it would be a core component of funding under Programme 2.

However, ILRI management was not at the time supportive of ILRI's engagement with GFRA, in part because it was considered that FMD did not rank highly enough in the health constraints facing smallholder producers.

Rift Valley Fever

Research into RVF at ILRI commenced with an evaluation of the impacts of the 2006/2007 outbreak that occurred in eastern Africa. This work was commissioned by USAID and FAO, and focused primarily on the north-eastern region of Kenya, thought to be the epicentre of the epidemic in Kenya. The outbreak occurred between December 2006 and March 2007 and affected more than 700 people; approximately 150 human fatalities occurred throughout the country. It was believed that people suffering severe clinical disease had close contact with infected livestock.

The impact assessment was implemented by a team of epidemiologists, economists and social scientists. A memorandum of understanding was established with Kenya's Department of Veterinary Services (DVS), enabling the DVS to participate in the project as a key partner. This work was later extended to the Arusha region of Tanzania with additional support from FAO. Surveys conducted in both sites utilized participatory epidemiological tools and the data collected were synthesized and published (Jost *et al.*, 2010). The key observations made were that there were major weaknesses in preparedness and the response to the outbreak, and that pastoralists noticed RVF-compatible events long before official notifications were made by the government. At the same time, economic impact assessments were conducted by Karl Rich and Francis Wanyoike (Rich and Wanyoike, 2010). This demonstrated that the disease induced substantial production losses, employment losses and reductions in operating capital among various value chain actors including producers, livestock traders, animal transporters, and slaughterhouse and butchery operators. It was estimated that the outbreak cost the Kenyan economy US$32 million.

These findings fuelled discussions on the need for improved warning systems and a structured contingency plan for managing the disease. More importantly, timelines developed with local communities showing events that preceded the outbreak were transformed into a decision support tool (Consultative Group for RVF Decision Support, 2010). This is considered a major contribution by ILRI and FAO to RVF contingency planning given that this tool has now been incorporated into the Ministry of Livestock's Contingency Plan for RVF. More work still needs to be done, however, to develop a harmonized contingency plan that unites the public health and veterinary sectors in line with the One Health paradigm.

Economic impact assessment of control options and calculation of disability-adjusted life years (DALYs)

The outputs of the impact study supported the formulation of a new study to assess the cost-effectiveness of RVF control options from a multidisciplinary perspective. This work also aimed to estimate economic costs of RVF in people using DALYs. The estimates generated suggest that the 2006/2007 outbreak caused a total of 3974 DALYs, or 1.5 DALYs per 1000 population. Provisional results further show that strategies to enhance mass vaccination of cattle and camels over a sustained 2-year period would greatly reduce DALYs. It also showed that integrating vector control measures, for instance through the application of larvicides, would yield even better results, although the practicability of implementing such interventions through institutional collaboration has not been fully resolved.

RVF risk maps for eastern Africa

ILRI epidemiologists have developed risk maps for the eastern Africa region that can be used together with the decision support tool to enhance targeting and evaluation of RVF interventions. This work builds on previous studies done by the National Aeronautics and Space Administration (NASA) and other research institutions such as the Centers for Disease Control and Prevention (CDC). Two methods that have been applied for this analysis are: (i) ecological niche modelling based on the Genetic Algorithm for Rule-set Prediction (GARP); and (ii) a logistic regression model, followed by mapping predicted probabilities on a spatial landscape. Both models use historical data on RVF outbreaks from the 2006/2007 outbreak. Statistical analyses demonstrate that RVF risk is significantly associated with exceptionally high rainfall, low altitude, clay soils and high normalized difference vegetation indices. Such maps could also be used to enhance our understanding of ecological niches for the virus, particularly if the existing hotspots can be classified based on their abilities to support disease persistence. More importantly, these maps are being integrated with socio-economic variables to determine areas that are most vulnerable to the disease given their livelihood patterns, capacities to access public health services and literacy levels.

Land-use change and RVF infection and disease dynamics

With increasing awareness of the impacts of RVF epidemics, there is a growing interest in determining processes that cause RVF occurrence and transmission, as well as those that promote its persistence during inter-epidemic periods. ILRI is currently leading a project in Kenya that seeks to understand RVF drivers from a multidisciplinary perspective. The project is founded on the premise that intact ecosystems can regulate disease epidemics, and that factors that disrupt ecosystem structure and function, such as climate, land use and demographic changes, contribute to disease emergence and spillovers. The project involves local partners such as the Kenya Medical Research Institute (KEMRI), DVS, University of Nairobi and Ministry of Health.

Preliminary observations indicate that there is a great potential for endemic transmission of RVF in irrigated areas established in arid and semi-arid zones, as poorly managed drainage systems and watersheds provide ideal conditions for the development of primary and secondary vectors of RVF. Observations also show that areas that are RVF endemic tend to be vulnerable to other infectious/zoonotic diseases, malnutrition or insecurity, presenting multiple challenges to the implementation of sustainable RVF control strategies.

Epidemiology of Gastrointestinal Parasites

ILRI published a field and laboratory handbook on the epidemiology and diagnosis of gastrointestinal parasites entitled *The Epidemiology, Diagnosis and Control of Gastro-Intestinal Parasites of Ruminants in Africa* (Hansen and Perry, 1990). A second edition, *The Epidemiology, Diagnosis and Control of Helminth Parasites of Ruminants*, was published several years later (Hansen and Perry, 1994).

Priorities in Animal Health Research for Poverty Reduction

In 2000, ILRI began work on animal health and poverty reduction involving scientists and opinion leaders in Africa, Asia, Europe and North America. This eventually delivered one of the highest-impact products of ILRI's epidemiology group (Perry *et al.*, 2002b). The Inter-Agency Donor Group (IADG) had just been born, as part of a process to bring greater coordination among its membership in the funding of livestock research. As part of this process, it sought to better define the research options and priorities, and DFID proposed that these be placed in the context of poverty reduction. This required first defining poverty and the association with livestock, and then quantifying the association, a process that continues (Robinson *et al.*, 2014b).

There were seven major components to the study (Perry *et al.*, 2002b). The first was to describe and quantify the distribution and extent of poverty in South-east Asia, South Asia and sub-Saharan Africa, and to determine the association of poverty with different agricultural production systems that involve livestock. These two tasks were accomplished in a companion study commissioned by DFID (Thornton *et al.*, 2002), which developed maps to quantify populations of poor livestock keepers and to predict how they would change over the next five decades. The results provided data on the number of poor (people on less than US$1 per day) in each of the major livestock production systems of the world. These figures served as a weighting factor in determining the importance of different livestock diseases to the poor.

The second component was to determine the priority species to the poor in each region and production system. This was undertaken by a literature review and through stakeholder workshops in West Africa, eastern, central and southern Africa, South Asia and South-east Asia.

The third component was to quantify the disease constraints by species. Diseases and syndromes considered to negatively affect the livelihoods, productivity outputs and marketing of livestock products by the poor were identified in a set of stakeholder workshops. The socioeconomic (primarily production losses and control costs incurred by the poor), zoonotic (for those diseases transmissible from animals to humans) and national impacts (a combination of marketing impacts on the poor with public sector expenditures on disease control) were identified and scored.

Published literature on the impact of livestock diseases and of their control in the target regions was scrutinized and synthesized by commissioned reviews. Research opportunities to alleviate these constraints were then identified. First, research needs were identified from the end users' perspectives by participants in several regional workshops. Second, research opportunities were identified from the upstream perspective by international experts specializing in different diseases. In addition to identifying relevant research opportunities, the experts were asked to estimate the cost, time frame, probability of success and available capacity to undertake such research. To ensure that issues other than technology generation were addressed, additional reviews of research opportunities for the better delivery of animal health services were commissioned. A specific review of the role of research into the genetics of resistance to disease was also commissioned.

The next step was to score the disease impacts (Shaw *et al.*, 2003), synthesize the disease impacts on the poor with the research needed to reduce them and identify priority research opportunities. A conceptual framework matrix was developed to classify different types of disease-specific research: (i) transferring knowledge and available tools; (ii) developing improved tools and strategies that were better delivered; and (iii) developing new tools and approaches by the contribution the research product will make to poverty reduction (by securing the assets of the poor; reducing the constraints to intensification or improving marketing opportunities).

This study has had a lasting impact on research priorities for development and is still the most cited reference in this context. In addition, it set the stage for measuring the association between poverty and livestock, and for applying greater emphasis to the impacts that research in animal health have on the processes of poverty reduction, rather than simply on national agricultural development. The methodology has been further developed (Perry and Grace, 2009).

The Wellcome Trust Epidemiology Initiatives

In January 2002, the DFID-commissioned study entitled 'Investing in Animal Health Research to Alleviate Poverty' was published (Perry *et al.*, 2002b). As described above, this had been commissioned by IADG on pro-poor livestock research and development, of which the Wellcome Trust was a member, and had been represented by Catherine Davies. The ILRI epidemiology group was again approached by the Trust, and following discussions in London, the group submitted a pre-proposal for a Wellcome Centre for Strategic Veterinary Epidemiology based at ILRI in Nairobi. After deliberations by the Trust, the proposal was not accepted for funding, but it did reopen the door to dialogue. Strongly influenced by the report by Perry *et al.* (2002b), in July 2002 the Trust announced a new funding programme entitled 'Animal Health in the Developing World', under which it set aside £25 million over a period of 5 years to fund researchers to develop methods of predicting and controlling outbreaks of animal diseases.

A large number of research proposals were developed by ILRI in partnership with institutions in the UK and USA, including gastrointestinal parasitism, FMD epidemiology and dynamics, anti-tick vaccines, livestock/disease information platforms for East Africa and African swine fever, among many others. This later led to the Livestock for Life Programme, launched in December 2005.

In January 2007, the Wellcome Trust held a meeting to give scientists funded under earlier grant programmes the opportunity to present research findings, and to consider future needs in the field (the meeting was entitled 'Animal Health Research: Recent Developments and Future Directions'). To coincide with the meeting, a policy review paper was commissioned (Perry and Sones, 2007a), and ILRI presented an invited talk on the challenges of research outputs influencing policy (Perry and Hooton, 2007).

In summary, the epidemiology group at ILRI undoubtedly had a substantial impact on the shaping and development of the Wellcome Trust's programmes of funding for livestock disease control in the developing world, and the impacts were spread to many different research institutions and countries.

The Broader Economic Impact Contributions

Economic impact assessments gained increasing momentum as ILRI's mandate broadened. In a paper prepared as an invited plenary presentation to the 17th International Conference of the

World Association for the Advancement of Veterinary Parasitology, Perry and Randolph (1999) wrote: 'The traditional veterinarian views disease as evil, and often embarks on a career with a "Superman" like determination to destroy it, regardless of how important it is. To the classical healer, economic considerations are secondary. The economist on the other hand sees animal disease as just one, and often an insignificant one, of a great spectrum of constraints to human and societal wellbeing that needs to be put in context.' They concluded that no longer should studies of the economics of diseases of production animals be limited to animal scientists seeking the collaboration of agricultural economists to affix prices to estimated productivity losses. Rather, a new discipline of animal health economics emerged in which the quality of economic evaluations depended on integrating the products of good epidemiological studies into economic frameworks.

In addition, during 1998, the ILRI Epidemiology and Disease Control group leader was approached by the director general of the OIE to coordinate the design, compilation and editing of a special edition of the *OIE Scientific and Technical Review on Animal Health Economics*. This peer-reviewed edition comprised nine chapters on different demands for economic impact knowledge, and seven case study chapters addressing specific diseases and different circumstances affecting the validity of economics studies. This book, in combination with the study by Perry and Randolph (1999) mentioned above, served as important milestones for the integrated science of epidemiology and economics. Rushton (2009) described as it as 'the first book to bring together a number of important themes in animal health economics: farm-level economic assessments; trade implications of sanitary requirements; and veterinary service delivery'.

ILRI later did an economic analysis of the potential costs, benefits and competitiveness of trade in meat from Ethiopia to the Middle East (Rich *et al.*, 2008). This report was further developed for a peer-reviewed publication, presented by Karl Rich at the International Food and Agribusiness Management Association (IAMA) in June 2009 (Rich and Perry, 2009), where it won the Best Paper Award. At the time, it was widely believed that poor countries with abundant livestock were well placed to develop exports to high-value livestock product markets in Europe and elsewhere. The studies in Ethiopia showed that investments in the quarantine and testing required to ensure that beef feedlots were free of FMD were not the limiting factors affecting the economic viability of beef exports to Middle East markets; rather, it was the high cost of feeding animals to ensure that the product arriving in the market was competitive with others coming from Australia, Brazil and other sources.

ILRI later studied the potential role of commodity-based trade on international market access by developing countries (Rich and Perry, 2009, 2011). This work concluded that, on a geographical basis, the benefits of commodity-based trade are much more likely to be felt in countries like Argentina, Brazil and India than in African countries. Opportunities exist for southern Africa but are predicated largely on continued preferential access that may or may not be sustainable in the long term. While there are numerous opportunities for some African countries in niche markets, it is also important to balance this potential with the sound exploitation of livestock resources and a pragmatic understanding of the challenges in marketing and competitiveness. The constraints that complicate market access for Africa are much more those related to infrastructure, productivity and efficiency throughout the livestock supply chain, and it is in these areas that policy attention is urgently required.

The Responses to Highly Pathogenic Avian Influenza

The emergence of HPAI, initially in East and South-east Asia with subsequent spread to Africa, caused disquiet in all animal health research communities and institutions, and ILRI, in collaboration with the International Food Policy Research Institute (IFPRI), initiated a wide-ranging consultation to discuss where research could contribute (ILRI/IFPRI, 2006). It was not a straightforward process, providing the challenge of developing a framework and methods for designing appropriate control strategy interventions, and generating evidence of the potential trade-offs with poverty reduction objectives.

ILRI was active in providing several background guidance and methodological frameworks for the global response to HPAI. In 2009, ILRI was a partner in the production of a manual entitled *Introduction to Participatory Epidemiology and its Application to Highly Pathogenic Avian Influenza Participatory Disease Surveillance. A Manual for Participatory Disease Surveillance Practitioners* (Ameri *et al.*, 2009). ILRI also developed a user guide for initial bird flu risk maps as a contribution to improving the surveillance for bird flu (Stevens *et al.*, 2009). These have recently been built on and updated in a new risk mapping report (Gilbert *et al.*, 2014).

A Nigerian Avian Influenza Control and Human Pandemic Preparedness and Response Project (NAICP) began in July 2006 and invited ILRI to do an independent impact assessment of the project. The evaluation developed ten 'outcome pillars' to depict the benchmark 'gold standard' of best practices against which to evaluate NAICP (as discussed in Perry *et al.*, 2010). The evaluation report was presented to the Government of Nigeria (Perry *et al.*, 2011) and there were also two independent peer-reviewed publications (Henning *et al.*, 2013; Bett *et al.*, 2014).

The ISVEE Experience

The International Symposium on Veterinary Epidemiology and Economics, known commonly by its acronym ISVEE, has been held every 3 years since the inaugural meeting in Reading, UK, in 1976. It brings together directors of veterinary services, disease control planners, quantitative epidemiologists, agricultural economists, modellers and statisticians to present and discuss on a wide range of diseases and issues. Kenya was proposed by ILRAD's epidemiology group and later confirmed as the venue for 1994 at the 6th ISVEE in Ottawa in 1991, with Brian Perry as secretary of the organization (ISVEE, 1991). This provided the first opportunity to bring ISVEE to Africa, and to engage national and regional programmes in presenting their work and participating in the meeting. Through the hard work and commitment of John Rowlands, a statistician at ILCA, the full proceedings were handed to participants as they registered, a first for ISVEE, in a special edition of the *Kenya Veterinarian*. The full meeting proceedings are now also available online (ISVEE, 1994).

The next ISVEE was held in Paris in 1998 with a strong representation from ILRI and its partners. But from here the level of participation grew substantially, and the 9th and 10th ISVEEs (in Colorado and Viña del Mar, Chile, respectively) brought the research of ILRI's epidemiology group to new levels of recognition; in the Chile meeting of 2003, the group had 29 papers and posters accepted. At this meeting, under joint sponsorship with the International Association of Agricultural Economists, Tom Randolph organized a mini-symposium on Animal Health Economics, which comprised plenary papers, independent papers and a discussion forum. In this, he concluded that animal health economics has established a solid, although remarkably narrow, foundation in the literature, but that it had not exploited its potential (Randolph *et al.*, 2003). While ILRI continues to be represented at subsequent meetings, the commitment to and impact of ILRI seen during the period 1994–2006 has waned.

The Role of Epidemiology in ILRAD and ILRI

Veterinary epidemiology and socio-economic impact research has gone through both administrative and locality changes during its existence over the last 27 years. It was a unified entity for 15 years, but in 2002, when the new ILRI strategy was developed, epidemiology and impact assessment became both fragmented and diminished in human resource capacity.

From 1987 to 1994 under ILRAD, it was the Epidemiology and Socioeconomics Programme, also varyingly referred to as the Epidemiology and Socioeconomics Unit and Socioeconomics Programme in emerging documentation. In the early days of ILRI from 1995 to 1997, epidemiology was accommodated under the newly created Systems Analysis and Impact Assessment Group, placing it under the Production Systems Programme, but this did not last for long, and from 1997 to 2002 it became the Epidemiology and Disease Control group under the Animal Health Programme.

The Impacts of ILRAD and ILRI's Epidemiology

Capacity development in veterinary epidemiology and impact assessment

During the 15-year period from 1987 to 2002, a substantial number of MSc and PhD students were trained through incorporation into research activities; these were predominantly from African countries. In addition, as mentioned in the section on ISVEE, the group and its associated students presented at many international meetings and in most cases published their research findings in peer-reviewed journals.

Impacts on national animal health departments and services

The epidemiology group provided a role model of investigative problem solving, which was picked up, copied and adopted by other institutions. However, this mostly occurred where there was a specific donor-funded project to support the establishment of an epidemiology group and was more common in academic than in public service bodies such as veterinary departments. Many newly trained graduates return to their institutions with a sound training but do not have the opportunity to build on that, often because of institutional weaknesses, with inadequate financial resources for research and for staff development. Veterinary epidemiologists rely on collaboration with colleagues at the bench, in the field and in the planning arena, and particularly with agricultural economists and other social scientists, so may find substantial difficulty functioning in a 'conservative' public sector environment.

Impacts on animal health constraints in developing countries

ILRI's epidemiology research has made substantial contributions to the understanding and control of ECF and trypanosomiasis in Africa, to the preparedness and responses to RVF in eastern Africa, to a greater understanding of the economic impact of rinderpest in Africa and of FMD in Africa, Asia and Latin America, and to regional understanding of the drivers of rabies control. More recently, epidemiology research at ILRI has contributed substantially to our understanding of food safety risks in formal and informal markets, and to the dynamics and risks of zoonotic diseases. The research has also contributed to the global understanding of the importance of these and other diseases to African livestock systems, and to the particular animal health constraints facing the poorer sectors of Africa's livestock-engaged communities.

Impacts on ILRI's research and strategy

During the days of ILRAD, the epidemiology and socio-economics programme had little or no impact on ILRAD's research and strategy; rather, it was seen as providing evidence justifying the existence of the laboratory-based vaccine research for the two target haemoparasitic diseases. Nevertheless, after ILRI's birth in 1995, the group did play an important role in providing impact assessment services, which progressively enhanced the engagement of the institution with different national, regional and donor clients. This situation changed dramatically in 2002 following the publication of the DFID-commissioned study on animal research priorities for poverty reduction (Perry *et al.*, 2002b). The matrix of three 'pathways out of poverty' (see Perry *et al.*, 2002b, Table ES1: securing assets, reducing constraints to intensification and improving market opportunities) and three research and development opportunities (transferring knowledge and available tools; improved tools, better strategies better delivered; and new tools and approaches) provided the framework of the new institutional thematic structure, not just for animal health research but also for ILRI's entire programme. Ironically, while a key product of the epidemiology and disease control group provided the framework for ILRI's new strategy, by the same token it also triggered the decline of epidemiology as an institutional entity in ILRI.

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Notes

[1] It had been conceived at the University of Florida by former ILRAD tick ecologist Andy Norval. On the tragic death of Norval in April 1994, ILRI assumed project leadership.

[2] Currently, the OIE Sub-Regional Representation for South-East Asia (SRR-SEA) is engaged in FMD control in the region. The SRR-SEA evolved from the South-east Asia Foot and Mouth Disease Regional Coordination Unit (SEAFMD RCU), which was created in 1997 for the control of FMD in South-east Asia, coordinating various prevention and control initiatives in countries of the region, in particular Cambodia, Lao People's Democratic Republic, Malaysia, Myanmar, the Philippines, Thailand and Vietnam. In 2010, the OIE and Association of Southeast Asian Nations (ASEAN) supported the membership of the remaining ASEAN countries (Brunei Darussalam and Singapore) and China, which has resulted in a vastly expanded programme, now renamed the South-East Asia and China Foot and Mouth Disease campaign (SEACFMD).

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