Towards a healthier planet

Veterinary epidemiology research at the International Laboratory for Research on Animal Diseases (ILRAD) and the International Livestock Research Institute (ILRI), 1987–2014

ILRI RESEARCH REPORT

38

Towards a healthier planet

Veterinary epidemiology research at the International Laboratory for Research on Animal Diseases (ILRAD) and the International Livestock Research Institute (ILRI), 1987–2014

Brian D Perry

Visiting Professor, Nuffield School of Medicine, University of Oxford;
Honorary Professor, College of Medicine and Veterinary Medicine, University of Edinburgh

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ILRI is a member of the CGIAR Consortium

Box 30709, Nairobi 00100, Kenya
Phone: + 254 20 422 3000
Fax: +254 20 422 3001
Email: ILRI-Kenya@cgiar.org

Box 5689, Addis Ababa, Ethiopia
Phone: +251 11 617 2000
Fax: +251 11 617 2001
Email: ILRI-Ethiopia@cgiar.org

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Foreword

The good health of livestock, and of the humans who tend them, market them, consume their products and benefit from the resources they offer to populations across the world, has been central to our international development agenda for the past decade. It emerges with even stronger emphasis in the sustainable Development Goals (SDGs).

Understanding health constraints to development, and how these can be reduced or mitigated, demands structured and well-coordinated research that can inform policy and evidence-based practices for disease control and prevention. This is the fundamental principle of epidemiology, whether applied to human or animal diseases.

For almost thirty years, the International Laboratory for Research on Animal Diseases (ILRAD) then ILRI benefited from a strong research program in the epidemiological sciences. Over time, it progressively broadened its coverage in disease, disciplinary and geographic terms. The results of this work have now been assembled in this impact narrative, which carefully documents the wide range of issues addressed by the teams of researchers, and presents them in an illustrated and highly readable format.

This publication is authored by Brian Perry. He was recruited to lead the Epidemiology and Socio-economics Program when it was founded in 1987; he continues to play an active role in international development on the global stage.

I have known Brian for many years, going back to my early days at the International Livestock Centre for Africa (ILCA) before it merged with ILRAD, and during my tenure at the World Bank, when I enthusiastically supported his efforts to raise the capacity of developing countries to tackle livestock and human health constraints.

Brian is one of ILRI's most distinguished alumni. In 2004 he received the CGIAR International Outstanding Scientist award, the only time this was given to a livestock scientist. In his acceptance speech he said 'in a system whose strength in numbers is in crops, it is refreshing to see livestock being recognised, given the important role they play in poverty reduction. And on the disciplinary side, in a system dominated by economists, it is also refreshing to see that quantitative epidemiology is critical to getting the numbers right.'

I am truly grateful to Brian for taking the time to properly document the numbers behind the diseases that decimate millions of livestock. I trust this work also serves to inform and guide ILRI's future work in this area.

Jimmy Smith
Director general
ILRI
July 2015

Acknowledgements

I wish to thank ILRI and in particular John McIntyre for inviting me to prepare this review and impact narrative on the veterinary epidemiology contributions of ILRAD and ILRI over the last 27 years, as part of ILRI's marking 40 years international livestock research.

I thank several ILRI scientists for providing comments and contributions to this narrative, in particular Bernard Bett, Eric Fevre, Delia Grace and Tom Randolph, and former ILRI scientist Bill Thorpe for his insightful comments on an earlier draft.

Beyond ILRI, I would also like to thank Carolyn Benigno, Martyn Jeggo and Roger Morris for providing independent impact statements on the contributions of ILRI's products in the fields of epidemiology and economics, which are included in the text.

Executive summary

Veterinary epidemiology was introduced into ILRAD in 1987 to provide more substantive justification for the investments being made into fundamental research on vaccine development for the two African vector-borne diseases—theileriosis (East Coast fever, ECF) and trypanosomiasis—on which ILRAD focused. Under the Epidemiology and Socio-economics Program a small multidisciplinary team set up a series of institutional collaborations to undertake impact assessments of these two diseases in different regions of Africa. The term epidemiology was not completely new to ILRAD, but it had been used in the context of parasite strain variations, not in the context of understanding disease dynamics in different livestock production systems, and the impacts on people who derived their livelihoods from them.

For the next seven years, until the merger of ILRAD and the International Livestock Centre for Africa (ILCA) in 1995 and the establishment of ILRI, the program focused almost exclusively on the dynamics and impacts of tick and tsetse-borne pathogens of livestock in Africa. In the new institutional environment following the merger, the geographic focus, disease focus, disciplinary makeup and range of tools used by the group 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 based at what became known as the 'Epicentre', serving a range of institutional and externally commissioned needs; it became increasingly recognized internationally for its focus on animal health issues affecting economic development and poverty reduction. Through a major study of animal health research priorities commissioned by the UK's Department for International Development (DFID), the team made a substantial contribution to the design of ILRI's new strategy which emerged in 2002. But ironically the new institutional structure which emerged to serve the new strategy did not include an epidemiology and disease control program, and epidemiological capacity at ILRI over the last decade has become scattered throughout the institute and regions, the emphasis on quantitative epidemiology has decreased, and the focus has moved to new areas such as food safety, zoonoses and emerging diseases. Food safety and zoonoses is now the only one of ILRI's 10 programs that has epidemiology focus and leadership.

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 which have been applied in virtually all corners of the world. The products of these sciences have also contributed to disease control policies and strategies in different ways, and a vast cadre of epidemiologists trained at ILRAD and ILRI is now serving different institutional needs in Africa, Asia, Australia, Europe and Latin America.

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 which 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 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. But 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 partnership and support at international, regional, national and local levels, and in extensive building capacity in epidemiological tools, techniques and approaches.

The arrival of the 'soft science' group at ILRAD

Somewhat surprisingly in today's context, the fundamental and widespread belief at ILRAD in the early 1970s when the institute was born (barely 10 years after Kenya's independence) was that the two priority diseases in Africa were East Coast fever (ECF) and trypanosomiasis. While they undoubtedly continue to feature in any livestock disease ranking in Africa, today's context would likely ask the question 'priorities to whom?... and on what evidence?' The evidence that was 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 largely servicing livestock production enterprises of the colonial powers in most African countries. But despite that, there was little if any economic data to quantify the impacts these diseases had even in these commercial systems and the potential returns to the use of any vaccines, should one emerge from the research laboratories.

ILRAD alone among the 13 international agricultural research centres of CGIAR had a mandate to carry out uniquely basic research (Lewin 1982)[1] and as such undertook very little of the technology transfer functions so central to the more applied research of its sister centres at the time (including ILCA, with which ILRAD was to merge in 1994). Pressure progressively increased from donors and other quarters to quantify the impacts these two diseases were having on African agriculture and livelihoods, and the differences that any vaccines emerging from the research would make, in order to better justify the substantial investment in laboratory-based science for vaccine development for just two diseases. In 1986, the year before the arrival of the Epidemiology and Socio-economics team, ILRAD's staff included 49 senior scientific and administrative staff, 24 specialized technicians, 48 technical support staff and 285 general support staff (ILRAD 1986).[2]

So it was some 15 years after the establishment of ILRAD that veterinary epidemiology was first introduced into the institute. The Rockefeller Foundation (RF), central to the establishment of ILRAD itself in 1973, provided complementary investment, initially for a period of three years (and subsequently extended for a further two years), to support what was termed the Epidemiology and Socio-economics Unit (which became the Epidemiology and Socio-economics Program). At the time ILRAD received so-called 'core unrestricted funding' through CGIAR for its laboratory research, and the introduction of funds for this unit was under a separate envelope, an early taster of the 'soft' funding that was to progressively overwhelm CGIAR institutions. The support covered the costs of a multidisciplinary team of three professional staff, with the initial mandate to determine the impact of the two diseases, which had provided the focus for the laboratory work at the time, namely ECF or theileriosis and trypanosomiasis. The team initially comprised a social anthropologist (Barbara Grandin), an agricultural economist (Adrian Mukhebi), a PhD student in epidemiology (Pierre Lessard) and a veterinary epidemiologist (Brian Perry) who headed the unit.

The group was joined by an ecologist (Robin Reid) as a RF postdoctoral fellow in 1992, to explore the environmental impacts of trypanosomiasis control.[3] Barbara Grandin left in 1989, and was replaced by John Curry in 1990; he left in 1993 during a financial crisis at ILRAD, during which 10 positions were closed, including that of the social anthropologist.

1. Lewin, R. 1982. Nairobi laboratory fights more than disease. *Science* 216(4545): 500–504. http://www.sciencemag.org/content/216/4545/500.extract

2. https://cgspace.cgiar.org/handle/10568/49951e

3. Reid, R.S. and Ellis, J.E. 1995. *The environmental implications of controlling tsetse-transmitted trypanosomiasis*. Final Report to the Rockefeller Foundation, ILRI, Nairobi, Kenya. 49 pp.

After a decade with the group, Adrian Mukhebi left in 1998 to join the private sector, setting up the Kenya Commodity Exchange, and was replaced by Tom Randolph. The team progressively expanded in the late 1990s, to include John McDermott (epidemiologist), Paul Coleman and Bruno Minjauw (postdoctoral fellow livestock economist).

While seen to be an important and long overdue investment by CGIAR donors and governors, the arrival of the new small team was viewed internally as rather inconsequential. It was labelled the 'soft science' group, the mandate and context of which was seen by many ILRAD bench scientists as irrelevant to the 'real' science being undertaken in the laboratories.

The group rapidly laid out a plan for its work, which hinged upon establishing databases on the rapidly evolving livestock production systems in Africa at risk to the two diseases, and on methodologies for determining the impacts they were having. The donors were seeking numbers and monetary values, which needed data on where the diseases were, how much of them there was, and what effects they had on livestock and people.

The inaugural ILRAD Epidemiology and Socio-economics team, 1987

This challenge rapidly opened up the realization that disease incidence and prevalence data in Africa were extremely scarce, and what little was available was often unreliable, let alone data on the denominators, such as the size, structure, composition and ownership of the populations at risk. And so the need for structured quantitative epidemiology capacity emerged, which led to a sustained program of data assembly, digital data documentation and assembly, the development of modelling techniques, and of course the gathering of field data.

The term epidemiology was not completely new to ILRAD, but it had been used in the context of parasite strain variations, not in the context of understanding disease dynamics in different livestock production systems, and the impacts on people who derived their livelihoods from them.

The opening of Lab 8 in 1989 by ILRAD director general Ross Gray (left)

Initial focus on an East Coast fever vaccine

Field studies in Kenya

The group realized that it needed to access real data in the field on ECF, and clearly the closest location was Kenya, but also one with diverse ecosystems and disease impacts, and with national research partners already in the field. Through the good offices of Sam Chema, the then director of the livestock research program at the Kenya Agricultural Research Institute (KARI), new collaborative agreements were established to build on existing research programs underway in Kenya. The first of these to take off was in Kilifi District at the Kenya coast, at sites in which KARI was starting to work with sister CGIAR centre ILCA. A collaborative program between ILCA and KARI was established in 1988 at KARI's Mtwapa Regional Research Centre, near Mombasa, and was led by Bill Thorpe. This program was the start of the wider, ILRI–KARI–Kenya Ministry of Livestock Development Smallholder Dairy Project, which went on to undertake a range of different research activities in support of dairy enterprises, and which won an outstanding communications award from CGIAR.[4]

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 made more effective. Specifically, the study estimated the demand for milk and dairy products, identified technical and policy constraints to 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 at the time by antibodies to *Theileria parva* in the indirect fluorescent antibody test (IFAT), 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 [1975][5] study in Kenya, in Figure 1, next page, reported by Kariuki [1988]).[6]

4. http://www.cgiar.org/web-archives/www-cgiar-org-enews-december2004-story_10-html/

5. FAO (Food and Agriculture Organization of the United Nations). 1975. *Research on Tick-Borne Cattle Diseases and Tick Control, Kenya Epizootiological survey on tick-borne cattle diseases.* Technical Report AG: DP/KEN/70/522 No. 1. Rome: FAO.

6. http://www.fao.org/wairdocs/ilri/x5549e/x5549e04.htm

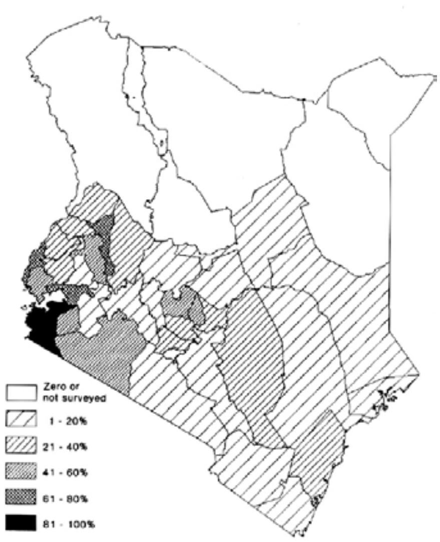


Figure 1. Kariuki 1988.

In 1983, the Farm Management Handbook of Kenya was published (Jaetzold and Schmidt 1983),[7] which provided a unique landscape synthesis of Kenya's agricultural environment, aggregating a variety of variables into a kaleidoscope of systems representing suitability for different crops and agricultural enterprises (see Figure 2, below). 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.

A series of studies was set up in coastal Kenya to determine the prevalence and incidence of ECF and the other tick-borne infections of anaplasmosis and babesiosis, and to evaluate the role of immunization against ECF using the infection-and-treatment (ITM) method. 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 and in improved dairy cattle in three different agro-ecological zones (AEZ). This work was reported in a series of publications (Deem et al. 1993;[8] Maloo et al. 2001a, 2001b, 2001c),[9] with the associated PhD students or postdoctoral scientists as the first author.

Figure 2. Kenya's agricultural environment.

The coast work provided an opportunity to engage at the front line with national partners, and 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, Kenya where larger scale dairy and beef production was being rapidly replaced by small-scale commercial dairy enterprises (Mukhebi et al. 1992).[10] This work coincided with the introduction of human nutrition into the impact equation, and the engagement of Rebecca Huss-Ashmore as a visiting scientist from the University of Pennsylvania, considering the nutritional benefits of livestock keeping and production (Curry et al. 1996).[11] Ironically, while the relationship between livestock, animal source foods and human nutrition is now receiving substantial attention in CGIAR, the visiting external program and management review of ILRAD in 1992 (which included Carlos Seré in the team) recommended that this work be stopped, as it diluted efforts to gather economic impact data!

In 1992, the focus of the ECF epidemiology studies moved to the central highlands of Kenya, first to Kiambu District, where Chris O'Callaghan, a Canadian PhD student at the University of Guelph, started a one-year study of the dynamics of theileriosis (O'Callaghan 1998).[12]

7. Jaetzold , R. and Schmidt, H. 1983. *Farm management handbook of Kenya, Vol II. Natural conditions and farm management information*. Ministry of Agriculture, Kenya in cooperation with the German Agricultural Team (GAT) of the German Agency for Technical Cooperation (GTZ).

8. Deem, S.L., Perry, B.D., Katende, J.M., McDermott, J.J., Mahan, S.M., Maloo, S.H., Morzaria, S.P., Musoke, A.J. and Rowlands, G.J. 1993. Variations in prevalence rates of tick-borne diseases in Zebu cattle by agro-ecological zone: implications for East Coast fever immunisation. *Preventive Veterinary Medicine* 16: 171–187.

9. Maloo, S.H., Thorpe, W., Kioo, G., Ngumi, P., Rowlands, G.J. and Perry, B.D. 2001. Seroprevalences of vector-transmitted infections of smallholder dairy cattle in coastal Kenya. *Preventive Veterinary Medicine* 52:1–16.
Maloo, S.H., Rowlands, G.J., Thorpe, W., Gettinby, G. and Perry, B.D. 2001. A longitudinal study of disease incidence and case fatality risks on smallholder farms in coastal Kenya. *Preventive Veterinary Medicine* 52: 17–29.
Maloo, S.H., Ngumi, P., Mbogo, S., Williamson, S., Thorpe, W, Rowlands, G.J. and Perry, B.D. 2001. Identification of target populations for immunisation against East Coast fever in coastal Kenya. *Preventive Veterinary Medicine* 52:31–41.

10. Mukhebi, A.W., Curry, J.J., Perry, B.D. Mining, S.K., Delehanty, J.M., Huss-Ashmore, R.A. and Kruska, R.L. 1992. *Targeting Smallholder Livestock against East Coast fever in Uasin Gishu District, Kenya*. Poster presented to the International Seminar on Livestock Services for Smallholders, Yogyakarta, Indonesia, 15-20 November 1992.

11. Curry, J.J., Huss-Ashmore, R.A., Perry, B.D. and Mukhebi, A.W. 1996. A framework for the analysis of gender, intra-household dynamics and livestock disease control, with examples from Uasin Gishu District, Kenya. *Journal of Human Ecology* 24:161–189.

12. O'Callaghan, C.J. 1998. *A study of the epidemiology of theileriosis on smallholder dairy farms in Kiambu District, Kenya*. http://www.collectionscanada.gc.ca/obj/s4/f2/dsk2/ftp03/NQ35807.pdf

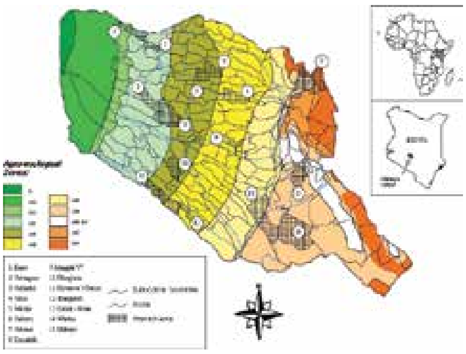


Figure 3. Agro-ecological zones in Murang'a District, Kenya, from Gitau et al. 1997.

This was followed, in 1994, by a series of studies in the neighbouring Murang'a District of Kenya, which hosted a range of livestock production systems in diverse AEZs. The work was led by George Gitau, as part of his PhD research at the University of Nairobi, supervised by Brian Perry and Alan Young at ILRAD. There were five distinct AEZs within Murang'a District (see Figure 3), giving the opportunity to investigate the influence of a range of climate, livestock breed, and farming practice variables on ECF dynamics. The work started with a cross-sectional serological study on 750 smallholder dairy farms in Murang'a District, selected in a stratified random sample (Gitau et al. 1997),[13] which showed the markedly different prevalences of *Theileria parva* infection across AEZs. The area was typical of the highland areas of eastern Africa in which the process of smallholder dairy intensification was booming. The investigation continued with a study which related prevalence with incidence, case morbidity and case mortality (Gitau et al. 1999),[14] and with a study of how these infections affected weight gains in calves (Gitau et al. 2001),[15] and concluded with a synthesis of the implication of the research on disease rick and the potential role of vaccination against ECF (Gitau et al. 2000).[16]

The synthesis concluded that in predominately zero-grazing areas, ECF risk is low. Thus, tick control or future vaccination programs will likely only be used by very risk-averse farmers who wish to protect their cows from the low risk of ECF mortality. In contrast, for open grazing systems, particularly in the lower-elevation UM4 zone, the risk of ECF is much greater and probably more variable. In this system, there will be much more substantial direct impact of ECF control programs. 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 for sufficient challenge, offers the best prospect to establish endemic stability. It was quite clear from these studies that attention needs to be paid to variation in ECF risk, both spatially (since ECF risk changes over relatively short geographic 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 various other parts of Kenya, following the successful submission of a research proposal to the International Fund for Agricultural Development (IFAD), which was funded from early 1998.[17] The proposal was designed to be an ex post assessment of the new p67 ECF vaccine then under development at ILRI, but substantial delays occurred in the laboratory research on vaccine development; as a result, IFAD accepted a revised design which strengthened the epidemiology and impact assessment components, and placed them in an *ex ante* context.

The vaccine efficacy trials were limited to two sites in Kenya, while the impact assessment broadened into new areas. These included evaluation of mechanisms for optimal delivery, adoption and impact of the p67 vaccine, 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, such as the work by PhD student Horace Ochanda (Ochanda et al. 1998).[18] The project finished in December 2001 and the final report was submitted in December 2003.

13. Gitau, G.K., Perry, B.D., Katende, J.M., McDermott, J.J., Morzaria, S.P. and Young, A.S. 1997. The prevalence of tick-borne infections in smallholder dairy farms in Murang'a District, Kenya: a cross-sectional study. *Preventive Veterinary Medicine* 30:95–107

14. Gitau, G.K., Perry, B.D. and McDermott, J.J. 1999. The incidence, calf mortality and calf morbidity due to *Theileria parva* infections in smallholder dairy farms in Murang'a District, Kenya. *Preventive Veterinary Medicine* 39:65–79

15. Gitau, G.K., McDermott, J.J., McDermott, B. and Perry, B.D. 2001. The impact of *Theileria parva* infection and other factors on calf mean daily weight gains in smallholder dairy farms in Murang'a District, Kenya. *Preventive Veterinary Medicine* 51:149–160

16. Gitau, G.K., McDermott, J.J., Katende, J.M., Brown, R.N. and Perry, B.D. 2000. Differences in the epidemiology of theileriosis on smallholder dairy farms in contrasting agro-ecological and grazing strata of highland Kenya. *Epidemiology and Infection* 124: 325–335

17. http://www.ifad.org/lrkm/tags/376.htm

18. Ochanda, H., Young, A.S., Medley, G.F. and Perry, B.D. 1998. Vector competence of seven rhipicephalid tick stocks in transmitting two *Theileria parva* parasite stocks from Kenya and Zimbabwe. *Parasitology* 116:539–545.

Below is a synthesis of the various studies undertaken in Kenya, illustrating the differences in impacts by region, agro-ecological zone and grazing management (Table 1).

Table 1. Comparison of the emerging epidemiological characterization of ECF risk in different regions of Kenya by epidemiology graduate students

Study	O'Callaghan (1998)		Gitau (1998)		Maloo (1993)	
Age category[1]	Calves		Calves		Calves	
Incidence rate type[2]	(≤1 year of age) Incidence density		(≤6 months of age) Cumulative incidence		(≤1 year of age) Incidence density	
Grazing management[3]	Zero-grazing	Pasture	Zero-grazing		Pasture	Zero-grazing
Number of animals	93	108	134	91	38	50
ECF morbidity rate	5.5	10.9	11.8	49.0	36.4	68.8
ECF mortality rate	0	2.2	1.7	20.6	20.8	49.7
Case-fatality proportion	0	25.0	28.6	38.1	57.1	72.2
Sero-conversion rate	41.4	56.5	58.4	74.0	–	–
Sero-conversion morbidity proportion	13.3	7.7	12.2	36.1	–	–

1 Calves corresponds to animals aged less than one year (O'Callaghan and Maloo) or less than six months (Gitau).

2 Incidence density rates are expressed per 100 animal years at risk, cumulative incidence as annual risk-rate [= 1-(1-biannual risk-rate)2].

3 Pasture grazing denotes farms where dairy cattle had unrestricted access to pasture while zero-grazing refers to the practice of severely or completely restricting grazing, i.e. where forage is cut and carried to livestock housed in a zero-grazing unit.

There was 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',[19] to international presentations[20, 21, 22, 23, 24, 25, 26, 27, 28, 29] and peer-reviewed papers in scientific journals.

19. http://www.ifad.org/lrkm/tans/2.htm

20. Leneman, J.M., McDermott, J.J., Okuthe, O.S. and Randolph, T.F. 2000. *Farmers' perceptions of East Coast fever risk and adoption of control strategies in Kenya*. In: Salman, M.D., Morley, P.S. and Ruch-Gallie, R. (eds). Proceedings of the 9th Symposium of the International Society for Veterinary Epidemiology and Economics, August 6–11, 2000, Breckinridge, Colorado. Compact disk.

21. Wanyangu, S.W., Kiara, H., Randolph, T.F., Leneman, J.M., Okuthe, O.S., Emongor, R. and Ndenga, E.A. 2000. *The Infection and Treatment Method for East Coast fever immunization: Assessing its impact in Kenya*. In: Salman, M.D., Morley, P.S. and Ruch-Gallie R. (eds). Proceedings of the 9th Symposium of the International Society for Veterinary Epidemiology and Economics, August 6–11, 2000, Breckinridge, Colorado. Compact disk.

22. Kiara, H., O'Callaghan, C.J., Randolph, T.F., McDermott, J.J. and Perry, B.D. 2000. *Targeting East Coast fever control strategies based on the assessment of biological risk*. In: Salman, M.D., Morley, P.S., Ruch-Gallie, R. eds. Proceedings of the 9th Symposium of the International Society for Veterinary Epidemiology and Economics, August 6–11, 2000, Breckinridge, Colorado. Compact disk.

23. Ndung'u, L.W., Randolph, T.F., Coetzee, G., Krecek, R.C. and Perry, B.D. 2000. *An economic assessment of current delivery pathways for the control of tick-borne diseases in Kenya*. In: Salman, M.D., Morley, P.S., Ruch-Gallie, R. eds. Proceedings of the 9th Symposium of the International Society for Veterinary Epidemiology and Economics, August 6–11, 2000, Breckinridge, Colorado. Compact disk.

24. Ndung'u, L.W., Randolph, T.F., McDermott, J.J., Kiara, H.K. and Perry, B.D. 2003. *Best bet pathways for the delivery of East Coast fever vaccines to smallholder dairy systems in Kenya*. Proceedings of the 10th International Symposium for Veterinary Epidemiology and Economics (ISVEE), Vina del Mar, Chile, 17–21 November 2003, Compact disk.# 432.

25. Di Giulio, G., Lynen, G., Medley, G.F., O'Callaghan, C.J., Kiara, H.K. and McDermott, J.J. 2003. *Characterization of Theileriosis in pastoral production systems in Northern Tanzania*. Proceedings of the 10th International Symposium for Veterinary Epidemiology and Economics (ISVEE), Vina del Mar, Chile, 17–21 November 2003, Compact disk. #482

26. Karimi, S.K., McDermott, J.J., McDermott, B.M., Gitau, G.K., Gathuma J.M. and Kinuthia RN. 2003. *Risk factors for sero-prevalence of tick-borne diseases of calves in Maasai pastoral herds in Majiado District, Kenya*. Proceedings of the 10th International Symposium for Veterinary Epidemiology and Economics (ISVEE), Vina del Mar, Chile, 17–21 November 2003, Compact disk.# 507

27. Kiara, H.K., McDermott, J.J., O'Callaghan, C.J., Randolph, T.F. and Perry, B.D. 2003. Estimating biological parameters for modelling the transmission dynamics of *Theileria parva* infection. Proceedings of the 10th International Symposium for Veterinary Epidemiology and Economics (ISVEE), Vina del Mar, Chile, 17–21 November 2003, Compact disk

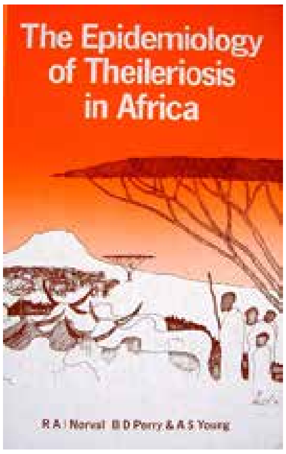
28. O'Callaghan, C.J., Medley, G.F., Kiara, H.K., McDermott, J.J., Musoke, A.J., Morzaria, S.P. and Perry, B.D. 2003. *Quantitative analysis of dose-response effects in the transmission dynamics of Theileria parva and the impact of sporozoite-neutralising vaccines*. Proceedings of the 10th International Symposium for Veterinary Epidemiology and Economics (ISVEE), Vina del Mar, Chile, 17–21 November 2003, Compact disk

29. Diaz, C.M., Massawe, S.C., Clemence, A., Gitau, G.K., Kiara, H.K., Muraguri, G.R., O'Callaghan, C.J. and Perry, B.D. 2003. *Risk Mapping of East Coast fever in coastal and highland regions of Kenya based on predicted mortality and morbidity incidences*. Proceedings of the 10th International Symposium for Veterinary Epidemiology and Economics (ISVEE), Vina del Mar, Chile, 17–21 November 2003, Compact disk

In a review article of the ECF work[30] 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. These are:

- 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 pure-bred taurine cattle bred under tick-free conditions are highly susceptible to disease, 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



Authors of (l to r: Brian Perry, Alan Young, Andy Norval)
The Epidemiology of Theileriosis in Africa

At the beginning of these intense epidemiological investigations in Kenya a regional meeting on tick-borne diseases was held in Lilongwe, Malawi in 1988 (Dolan 1989),[31] organized by ILRAD, FAO and the AU/IBAR (then known as the Organization for African Unity; OAU).

It provided an opportunity for a sharing of information and understanding on theileriosis throughout the eastern and southern African region, and it became apparent that there were significant differences in the disease epidemiology between the eastern and southern regions. Whether this was real, or due to the diversity of studies that had been undertaken, or to interpretations thereof was not entirely clear. Whatever the source, it stimulated a discussion, and the Lilongwe meeting was where a book on theileriosis was conceived. In the preface to *The Epidemiology of Theileriosis in Africa* (Norval, Perry and Young 1992),[32] it states 'during discussions after the day's session, Alan Young suggested that the three of us (Andy Norval, Brian Perry and Alan Young) attempt to prepare a review article on the epidemiology

30. Perry, B.D. and Young, A.S. 1995. The past and future roles of epidemiology and economics in the control of tick-borne diseases of livestock in Africa: The case of theileriosis. *Preventive Veterinary Medicine* 25:107–120.

31. Dolan, T. (ed). 1989. *Theileriosis in Eastern, Central and Southern Africa:* Proceedings of a Workshop on East Coast Fever Immunization, Held in Lilongwe, Malawi, 20–22 September 1988. The International Laboratory for Research on Animal Diseases https://cgspace.cgiar.org/handle/10568/49784

32. Norval, R.A.I., Perry, B.D. and Young, A.S. 1992. *The epidemiology of theileriosis in Africa*. Academic Press, London, 481.

of theileriosis throughout its distribution in Africa, with the objective of rationalising the differences in patterns of the disease, particularly those between eastern and southern Africa. During early gestation, it became clear that a review article would not accommodate this objective, and the project quickly grew into a book'. The book was published by Academic Press with ILRAD supporting the time contributions of the three authors and the preparation of camera-ready copy, it has become the reference point for all working on the dynamics and control of the disease. This book is the only textbook on theileriosis, and remains 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 program, with the last case occurring in Swaziland in 1960. Nevertheless, *T. parva* infections persisted, but with the official eradication declared, the names of theileriosis and Corridor disease were used to describe outbreaks. This curious confrontation of science and officialdom relating to disease and parasite nomenclature was reviewed in an article entitled 'The naming game: the changing fortunes of East Coast fever and *T. parva* (Perry and Young 1993).[33] It is encouraging to see how strong a groundwork these studies laid to current understanding of theileriosis epidemiology, illustrated by the recent review by Gachohi et al. (2012).[34]

Heartwater studies in Zimbabwe

Through funding from the United States Agency for International Development (USAID), a five-year project on the epidemiology and impact of another important tick-borne disease of livestock in Africa, heartwater (*Ehrlichia ruminantium* infection), was initiated in 1994. It had been conceived by former ILRAD tick ecologist Andy Norval, in collaboration with ILRI scientist Brian Perry, and on the tragic death of Andy in a car crash in Florida in April 1994,[35] the leadership of the project was transferred to ILRI. This work subsequently received ILRI'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 and Warwick and ILRI determined and quantified the infection dynamics of heartwater in the major production systems and agro-ecological zones 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. Specific project outputs were:

- Distributions of tick vectors in Zimbabwe were defined and documented. A national survey of 3000 collections determined that *A. hebraeum* is the dominant tick in the south and that it had spread into central and eastern areas of the highveld. The survey also found that *A. variegatum* is present mainly in the northwest but that it is also found in central and eastern parts of the highveld, with some overlap of the two species (Norval et al. 1994;[36] Peter et al. 1998;[37] Peter et al. 1999).[38]
- Spread of heartwater was documented and quantified and factors affecting the spread determined. *A. hebraeum* had spread far north due largely to movement of cattle (and some wildlife) to the highveld. A gradual reduction in acaricide use, particularly in the communal lands, contributed to the expanding distribution of this tick (Norval et al. 1992).[39]
- 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 reduction in acaracide use with a transition to endemic stability and subsequent natural infection boosting the vaccinal immunity.

33. Perry, B.D. and Young, A.S. (1993). The naming game: the changing fortunes of East Coast fever and *Theileria parva*. *The Veterinary Record* 133:613–616.

34. Gachohi, J., Skilton, R., Hansen, F., Ngumi, P. and Kitala, P. 2012. Epidemiology of East Coast fever (Theileria parva infection) in Kenya: past, present and the future. *Parasites and Vectors* 5:194. https://cgspace.cgiar.org/handle/10568/21766

35. Perry, B.D. 1994. *Experimental and Applied Acarology* 18:381–382

36. Norval, R.A.I., Perry, B.D., Meltzer, M.I., Kruska, R.L. and Booth, T.H. 1994. Factors affecting the distributions of the ticks *Amblyomma hebraeum* and *A. variegatum* in Zimbabwe: implications of reduced acaricide use. *Experimental and Applied Acarology* 18:383–407.

37. Peter, T.F., Perry, B.D., O'Callaghan, C.J., Medley, G.F., Shumba, W., Madzima, W., Burridge, M.J. and Mahan, S.M. 1998. Distribution of the vectors of heartwater, *Amblyomma hebraeum* and *Amblyomma variegatum* (Acari; Ixodidae) in Zimbabwe. *Experimental and Applied Acarology* 22:1–16.

38. Peter, T.F., Perry, B.D., O'Callaghan, C.J., Medley, G.F., Mlambo, G., Barbet, A.F. and Mahan, S.M. 1999. Prevalence of *Cowdria ruminantium* infection *in Amblyomma hebraeum* ticks from heartwater endemic areas of Zimbabwe. *Epidemiology and Infection* 123:309–316.

39. Norval, R.A.I., Perry, B.D. and Hargreaves, S.K. 1992. Tick-borne disease control in Zimbabwe: What might the future hold? *Zimbabwe Veterinary Journal* 23:1–15.

- 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;[40] Martinez et al. 1999b).[41]
- Infection dynamics models were developed using data generated by the research. A mathematical model of the infection dynamics of the heartwater pathogen, *C. 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).[42]
- 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;[43] Chamboko et al. 1999).[44]
- Economic impact of heartwater, and of future vaccine use, was determined. The annual total direct losses in Zimbabwe (acaracide costs, milk losses, treatment costs) from heartwater were estimated to be USD 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).[45]
- Efficacy of future vaccine use was evaluated in epidemiological models. The timing of vaccination, and frequency of revaccination, were shown to have greater effect 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).[46]
- Economic impact of the disease, and of its control through vaccines, was evaluated and quantified in the countries of the Southern African Development Community (SADC) region. Thirty-one (31) million cattle and 28 million small ruminants were found to be at risk to 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 USD 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-oriented systems of the region (Minjauw et al. 1998;[47] Minjauw et al. 2000).[48]

The successes of this collaborative project were considerable, with all objectives met and all findings published within a period of five years. Results of the project gave scientists a sound understanding of factors influencing the distribution of tick vectors, the infection dynamics and impacts of the disease in different agro-ecological zones 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 had 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. Members of the five-year project produced 23 papers in peer-reviewed scientific journals, 15 of which were authored by VRL scientists. Project staff produced another 36 publications, including

40. Martinez, T.A., Meltzer, M.I., Perry, B.D., Burridge, M.J. and Mahan, S.M. 1999. The effect of subclinical *Cowdria ruminantium* infection on the health and productivity and breeding ewes. *Preventive Veterinary Medicine* 41:89–103.

41. Martinez, T.A., Meltzer, M.I., Perry, B.D., Burridge, M.J. and Mahan, S.M. 1999. The effect of subclinical *Cowdria ruminantium* infection in ewes on the growth and milk consumption of pre-weaning lambs. *Preventive Veterinary Medicine* 41:105–118.

42. O'Callaghan, C.J., Medley, G.F., Peter, T.F. and Perry, B.D. 1998. Analysis of the epidemiology of heartwater (*Cowdria ruminantium* infection) in a transmission dynamics model. *Parasitology* 117:49–61.

43. Perry, B.D., Chamboko, T., Mahan, S.M., Medley, G.F., Minjauw, B., O'Callaghan, C.J. and Peter, T.F. 1998. The economics of integrated tick and tick-borne disease control on commercial farms in Zimbabwe. *Zimbabwe Veterinary Journal* 29:21–29.

44. Chamboko, T., Mukhebi, A.W., O'Callaghan, C.J., Peter, T.F., Kruska, R.L., Medley, G.F., Mahan, S.M. and Perry, B.D. 1999. The control of heartwater on large scale commercial and smallholder farms in Zimbabwe. *Preventive Veterinary Medicine* 39:191–210.

45. Mukhebi, A.W., Chamboko, T., O'Callaghan, C.J., Peter, T.F., Kruska, R.L., Medley, G.F., Mahan, S.M. and Perry, B.D. 1999. An assessment of the economic impact of Heartwater (*Cowdria ruminantium* infection) and its control in Zimbabwe. *Preventive Veterinary Medicine* 39:173–189.

46. O'Callaghan, C.J., Medley, G.F., Peter, T.F., Mahan, S.M. and Perry, B.D. 1999. The effect of vaccination on the transmission dynamics of heartwater *(Cowdria ruminantium* infection). *Preventive Veterinary Medicine* 42:17–38.

47. Minjauw, B., Perry, B.D., Kruska, R.L., Peter, T.F., Mahan, S.M., Medley, G.F. and O'Callaghan, C.J. 1998. *Economic impact assessment of heartwater in Southern Africa*. Ninth International Conference of Association of Institutions of Tropical Veterinary Medicine (AITVM), Harare, Zimbabwe, 14–18th September 1998.

48. Minjauw, B., Kruska, R., Odero, A., Randolph, T.F., McDermott, J.J., Mahan, S.M. and Perry, B.D. 2000. *Economic impact assessment of Cowdria ruminantium infection and its control in southern Africa*. In: Salman, M.D., Morley, P.S. and Ruch-Gallie, R. (eds), Proceedings of the 9th Symposium of the International Society for Veterinary Epidemiology and Economics, August 6–11, 2000, Breckinridge, Colorado. Compact disk.

22 presentations at scientific meetings and 10 articles in the project newsletter, *The Tick-ler*, which had a wide distribution in the region and targeted farmers and farmer organizations as well as other end users of the research.

There was a substantial down side to the impacts of these studies. Despite having developed an integrated epidemiology and economics modelling system, in which the effects of vaccine use under different systems and ecological zones were calculated, the implementation of emerging recommendations was overtaken by the collapse of Zimbabwe's economy, which consigned many of the details of future control to the archive of studies that do not withstand the test of time.

Economic impact assessments

The first opportunity to undertake an economic impact assessment came in the late 1980s with the KARI partnership at the Kenya coast, where an immunization trial was being carried out using the method ITM to control ECF. Economist Adrian Mukhebi and colleagues showed greater profitability in immunized cattle compared to un-immunized, through lower mortality and higher weight gains in a partial budgetary analysis (Mukhebi et al. 1989).[49] A solid first piece of perhaps predictable evidence, but gathered under rather unrealistic and unrepresentative circumstances, undertaken on a state-run Agricultural Development Corporation beef ranch. The authors comment '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)[50] then dissected the complicated vaccine preparation process and calculated the costs of establishing a vaccine production facility (at a hypothetical site in Kenya, but a generic methodology. These initial forays into the economics of ECF and its control led into an Africa-wide definitive assessment, presenting the estimated total costs of ECF in affected countries in 1989 as USD 168 million, a figure which is still cited in research proposals 22 years later (Mukhebi et al. 1992).[51] In this paper, and almost as a postscript, and drawing heavily on what Mukhebi described as 'a complicated series of assumptions', the authors draw on the above studies and calculate 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. Again the authors issue a strong health warning, saying '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 payoffs to the use of ITM vaccination, drawing on data collected from Uasin Gishu (Nyangito et al. 1994;[52] Nyangito et al. 1995;[53] Nyangito et al. 1996).[54] Hezron went on to be appointed permanent secretary in the Ministry of Health Services of the Kenya government in 2008.

A series of economic impact assessments were carried out on the heartwater project in Zimbabwe, and these are reported above in the section on heartwater. The paper of Mukhebi et al. (1999)[55] provided one of the first attempts to truly integrate the epidemiology and economics models to predict future economic impacts of different control scenarios under a set of epidemiological scenarios.

49. Mukhebi, A.W., Wathanga, J., Perry, B.D., Irvin, A.D. and Morzaria, S.P. 1989. Financial analysis of East Coast fever control strategies on beef production under farm conditions. *Veterinary Record* 125:456–459.

50. Mukhebi, A.W., Morzaria, S.P., Perry, B.D., Dolan, T.T. and Norval, R.A.I. 1990. Immunization against East Coast fever: Production and delivery costs of the infection and treatment method. *Preventive Veterinary Medicine* 9:207–219.

51. Mukhebi, A.W., Perry, B.D. and Kruska, R.L. (1992). Estimated economics of theileriosis control in Africa. *Preventive Veterinary Medicine* 12:73–85.

52. Nyangito, H.O., Richardson, J.W., Mukhebi, A.W., Mundy, D.S., Zimmel, P., Namken, J. and Perry, B.D. 1994. Whole farm economic analysis of East Coast fever immunisation strategies in Kilifi District, Kenya. *Preventive Veterinary Medicine* 21:215–235.

53. Nyangito, H.O., Richardson, J.W., Mukhebi, A.W., Mundy, D.S., Zimmel, P. and Namken, J. 1995. Whole farm economic evaluation of East Coast fever immunization strategies on farms in Uasin Gishu District of Kenya. *Computers and Electronics in Agriculture* 15:19–33.

54. Nyangito, H.O., Richardson, J.W., Mukhebi, A.W., Zimmel. P., Namken, J. and Perry, B.D. 1996. Whole farm simulation analysis of East Coast fever immunisation strategies on mixed crop–livestock farms in Kenya. *Agricultural Systems* 51:1–27.

55. Mukhebi, A.W., Chamboko, T., O'Callaghan, C.J., Peter, T.F., Kruska, R.L., Medley, G.F., Mahan, S.M. and Perry, B.D. 1999. An assessment of the economic impact of heartwater (*Cowdria ruminantium* infection) and its control in Zimbabwe. *Preventive Veterinary Medicine* 39:173–189.

Tick and 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 contact was made with the 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 continent-wide assessments, running the software ARC/INFO from Environmental Systems Research Institute (ESRI). A memorandum of understanding was drawn 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. This was in the person of Russ Kruska, who was instrumental in setting up and running the GIS facility at ILRAD and ILRI for a period of almost 20 years. Research in the late 1980s and early 1990s centred on vector-borne disease distribution and impact studies, but the group also contributed to the establishment, in 1992, of the UNEP/CGIAR partnership on the development and dissemination of digital datasets for research on a wide range of topics including natural resources, ecology, environment and socio-economic factors.[56] Brian Perry and Russ Kruska attended the GRID-Arendal I and the GRID-Arendal II workshops in 1992 and 1995,[57] supported by ILRAD's director of research Jack Doyle.

Efforts to model the potential distribution of *R. appendiculatus* were assisted by two key inputs. The first was a substantial database on tick field samplings assembled by Jane Walker,[58] started when she was a scientist at the East African Veterinary Research Organization, Muguga, Kenya, and continued through her long career as a tick ecologist, latterly at the Onderstepoort Veterinary Institute (OVI) in Pretoria, South Africa. The second was a climate matching model 'Climex' developed by Australian scientist Robert Sutherst, with parameters established 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 Africa-wide distribution of *R. appendiculatus*,[59, 60, 61] but when compared with the database of Jane Walker and others of where the tick had been recorded, the predicted distribution exceeded the historical records, suggesting that Climex did not tell the whole story. This stimulated exploration of other predictive modelling approaches to estimate tick distribution (Randolph 1993),[62] in which much closer attention was placed to the climatic requirements of all three instars of the tick, eventually leading to a more biologically sound and plausible spatial prediction platform (Randolph and Rogers 1997).[63]

In a follow up case study of predicting outbreaks of theileriosis in Zimbabwe using multiple climatic variables (Duchateau et al. 1997),[64] the methodology for assessing distribution drivers using climate databases was addressed. The database was considered to suffer from co-linearity, 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, which more efficiently describe the important features of the database.

56. http://www.grida.no/prog/global/cgiar/arendal2/ilripap.htm

57. http://www.grida.no/prog/global/cgiar/arendal2/arendal2.htm#ap1

58. http://en.wikipedia.org/wiki/Jane_Brotherton_Walker

59. Lessard, P., L'Eplattenier, R., Norval, R.A.I., Kundert, K., Dolan, T.T., Croze, H., Walker, J.B., Irvin, A.D. and Perry, B.D. 1990. Geographical information systems for studying the epidemiology of cattle diseases caused by *Theileria parva*. *Veterinary Record* 126:255–262.

60. Perry, B.D., Lessard, P., Norval, R.A.I., Kundert, K. and Kruska, R. 1990. Climate, vegetation and the distribution of *Rhipicephalus appendiculatus* in Africa. *Parasitology Today* 6:100–104.

61. Perry, B.D., Kruska, R., Lessard, P., Norval, R.A.I. and Kundert, K. 1991. Estimating the distribution and abundance of *Rhipicephalus appendiculatus* in Africa. *Preventive Veterinary Medicine* 11:261–268.

62. Randolph, S.E. 1993. Climate, satellite imagery and the seasonal abundance of the tick *Rhipicephalus appendiculatus* in southern Africa: a new perspective. *Medical and Veterinary Entomology* 7(3):243–58. http://dx.doi.org/10.1111/j.1365-2915.1993.tb00684.x

63. http://ora.ox.ac.uk/objects/uuid:06c3adf2-76cb-47b6-9d81-8c3470d2e63e/datastreams/ATTACHMENT01

64. Duchateau, L., Kruska, R.L. and Perry, B.D. 1997. Reducing a spatial database to its effective dimensionality for logistic regression analysis of livestock disease distribution data. *Preventive Veterinary Medicine* 32:207–218.

An important early stage in the impact assessment process had been to determine more accurately the distribution of diseases and their vectors. This was at the time a new initiative, and it had four major impacts.

1. To enhance the understanding of disease vector distributions, and factors affecting these, such as climate and vegetation.

2. To enhance the understanding of the role of geographical information systems in predicting disease and vector distributions, and the need for appropriate high resolution geo-referenced databases, including the use of satellite derived imagery

3. To explore new methods for improving the predictive capacity of distribution models (illustrated in the paper of Duchateau et al. 1997).

4. The alerting of Ethiopia, where *R. appendiculatus* had never been recorded, to the climatic suitability for its survival in certain parts of the country (Norval et al. 1991).[65] This stimulated the Ethiopian government to revise its policy on importation of live cattle from Kenya. Interestingly, over 20 years later, a new study confirming the susceptibility of Ethiopia to ECF introduction has been published (Leta et al. 2013),[66] repeating the warnings made by ILRAD in 1991.

Modelling the dynamics of vector-borne diseases

Soon after the observational studies at the Kenya coast had started, it was felt that there was a need to develop a mathematical model of *T. parva* infection dynamics which could contribute to the understanding of disease impacts, and offer a framework to test the effect of interventions, such as vaccination. Aware of the work at the time being undertaken on modelling of infectious diseases (Anderson and May 1991),[67] Brian Perry visited Roy Anderson at Imperial College in London to seek modelling expertise in developing a model of ECF, and was directed to his then postdoc Graham Medley.

This started a 15-year collaboration on infection dynamics of tick-borne infections, which eventually moved from theileriosis to *Cowdria ruminantium* infection (the disease heartwater; the organism is now called *Ehrlichia ruminantium*). This sowed the seed to a wider exploration of the role 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),[68] at which Graham Medley and Roy Anderson presented the opening plenary paper.

The collaboration with Imperial College, 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).[69] 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 the field studies in different regions, the model was updated and reported by O'Callaghan et al. (2000).[70] This report was accepted at the 10th Symposium on Veterinary Epidemiology and Economics in Chile, but unfortunately as a poster rather than an oral presentation, the authors' aspiration; however, that did not prevent Chris O'Callaghan squeezing everything he had lined up for the paper (see below, probably unreadable in this format)!

65. Norval, R.A.I., Perry, B.D., Gebreab, F. and Lessard, P. 1991. East Coast fever: A problem of the future for the Horn of Africa? *Preventive Veterinary Medicine* 10:163–172.

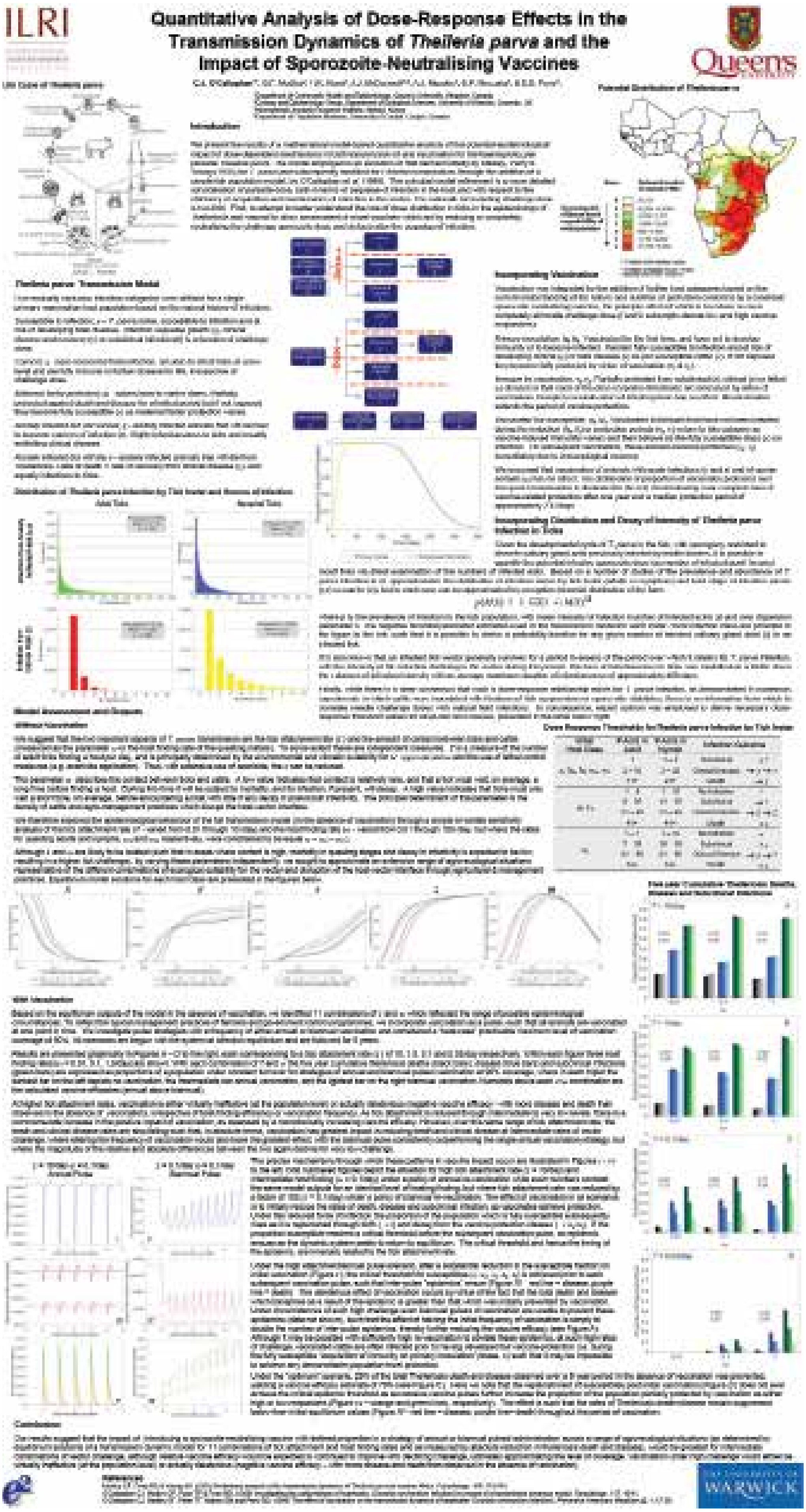
66. Leta, S., de Clercq, E. and Madder, M. 2013. High-resolution predictive mapping for *Rhipicephalus appendiculatus* (Acari: Ixodidae) in the Horn of Africa. *Experimental and Applied Acarology* 60:531–542.

67. Anderson, R. M. and May, R. M. 1991. *Infectious diseases of humans: dynamics and control.* Oxford and New York: Oxford University Press

68. Perry, B.D. and Hansen, J.W. (eds). 1994. *Modelling of Vector-borne and other Parasitic Diseases*. International Laboratory for Research on Animal Diseases, Nairobi, pp 369..

69. Medley, G.F., Perry, B.D. and Young, A.S. 1993. Preliminary analysis of the transmission dynamics of *Theileria parva* in eastern Africa. *Parasitology* 106:251–264 https://cgspace.cgiar.org/handle/10568/29401

70. O'Callaghan, C.J., Medley, G.F., Kiara, H.K., McDermott, J.J., Musoke, A.J., Morzaria, S.P. and Perry, B.D. 2003. *Quantitative analysis of dose-response effects in the transmission dynamics of Theileria parva and the impact of sporozoite-neutralising vaccines*. Proceedings of the 10th International Symposium for Veterinary Epidemiology and Economics (ISVEE), Vina del Mar, Chile, 17–21 November 2003, Compact disk https://cgspace.cgiar.org/handle/10568/1071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Quantitative Analysis of Dose-Response Effects in the Transmission Dynamics of Theileria parva and the Impact of Sporozoite-Neutralising Vaccines
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The principles behind this first model were then applied to heartwater, and a quantitative framework was produced which demonstrated, for the first time, the concept of endemic stability (O'Callaghan et al. 1998).[71] The approach went on to explore the effects of vaccination against heartwater (O'Callaghan et al. 1999).[72]

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 erhlichiosis, and the implication of different interventions, particularly tick control, of the 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, Perry and Woolhouse 2001).[73] This *Lancet* publication won ILRI's award (and a nomination for CGIAR Chairman's Award) for the outstanding scientific article of 2002.

71. O'Callaghan, C.J., Medley, G.F., Peter, T.F. and Perry, B.D. 1998. Analysis of the epidemiology of heartwater (*Cowdria ruminantium* infection) in a transmission dynamics model. *Parasitology* 117:49–61.

72. O'Callaghan, C.J., Medley, G.F., Peter, T.F., Mahan, S.M. and Perry, B.D. 1999. The effect of vaccination on the transmission dynamics of heartwater *(Cowdria ruminantium)* infection. *Preventive Veterinary Medicine* 42:17–38.

73. Coleman, P. G., Perry, B.D. and Woolhouse, M.E.G. 2001. Endemic stability: a veterinary idea applied to human public health. *The Lancet* 357:1284–1286.

The impacts of trypanosomiasis and its control

Economic impact of trypanosomiasis

The weight of focus in impact assessment of the group remained almost exclusively on tick-borne pathogens of livestock for almost 10 years until the recruitment of John McDermott in 1997, and subsequently Tom Randolph in 1998, however, with two exceptions. In the early 1990s, the epidemiology group partnered with AP Consultants, in the person of agricultural economic Alexandra Shaw, to adapt the spreadsheet model, which had been used in the theileriosis impact assessment to quantify the impacts of trypanosomiasis and its control in different countries. The countries selected were Cameroon, Gambia, Côte d'Ivoire and Zimbabwe. The model estimated the proportion of the national herd at risk to the disease, the annual economic cost of the disease and the breakdown of the costs into production losses or input costs. The study was reported in a consultancy report to ILRAD from AP Consultants (Shaw 1992),[74] and in the ILRAD Annual Scientific Report of 1993 (Mukhebi et al. 1993).[75] Alex Shaw has subsequently drawn on this and other studies to expand on our understanding of the economic impacts of this disease (see for example Shaw 2009).[76]

Then in the mid-1990s economist Patti Kristjanson was taken on by ILRI as a consultant to evaluate the returns to ILRI's research through economic models. The first issue she tackled was the investment in developing a vaccine against trypanosomiasis, using geographic information systems (GIS) to spatially link a biophysical herd simulation model with an economic surplus model. The results (Kristjanson et al. 1999)[77] indicated that the potential benefits of improved trypanosomiasis control, in terms of meat and milk productivity alone, were USD 700 million per year in Africa. The disease was estimated to cost livestock producers and consumers USD 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 USD 288 million, with an internal rate of return of 33% and a benefit–cost ratio of 34:1.

This is a widely cited paper, particularly as it is one of the few peer-reviewed publications which presents estimates of the cost of the disease and of the potential returns to controlling it. It has had substantial impact. However, the linking of the returns to control to a future trypanosomiasis vaccine proved controversial within the epidemiology group, prompting the authors' acknowledgements to state: 'The authors wish to acknowledge the contributions from many ILRI colleagues, collaborators and critics who provided estimates for the analysis, but emphasize that they are not responsible for any of the interpretations made by the authors'.

74. Shaw, A.P.M. 1992. *Development of a methodology for assessing the losses due to trypanosomiasis in Africa*. Consultancy report. A.P. Consultants, Andover, UK. 50 pp.

75. Mukhebi, A.W., Curry, J., Perry, B.D., Reid, R., Ellis, J., Swallow, B. and Rowlands, G.J. 1993. *Comparative case studies of the economic costs of trypanosomiasis*. ILRAD Annual Scientific Report 105–106.

76. Shaw, A. 2009. Assessing the economics of animal trypanosomiasis in Africa–history and current perspectives. *Onderstepoort Journal of Veterinary Research* 76(1):27–32.

77. Kristjanson, P.M., Swallow, B.M., Rowlands, G.J., Kruska, R.L. and de Leeuw, P.N. 1999. Measuring the costs of African animal trypanosomiasis, the potential benefits of control and returns to research. *Agricultural Systems* 59:79–98.

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 are already available. It could also be an evaluation of more effective deployment of tsetse traps, of genetically engineered livestock resistance to the effects of trypanosomiasis, 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 likely benefits from trypanosomiasis control, it was arguably inadequately 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 five years ago. And also notable is ILRI's decision to abandon the trypanosomiasis vaccine work in 2002.

The epidemiology of resistance to trypanocides

In the late 1990s, John McDermott set up a variety of research projects on the epidemiology and impact of trypanosomiasis in different countries with many partners and independent sponsors. This was a period in which central 'unrestricted' funding for research was extremely limited, and so while focusing on one of ILRI's priority vector-borne diseases, the agenda built on key partnerships, taking advantage of and adapting to funding opportunities as they came up. The trypanosomiasis work was subsequently described by colleague Tom Randolph as being 'largely opportunistic'.

Field work was undertaken in Uganda (in collaboration with CRU-Uganda and the Free University of Berlin), Kenya, Tanzania and Zambia (in collaboration with National Agricultural Research System (NARS) and the University of Glasgow) and Burkina Faso (in collaboration with Centre International de Recherche-Développment sur l'Elevage en zone Subhumide (CIRDES) and the Free University of Berlin). The various studies are summarised below.

- The German Federal Ministry for Economic Cooperation and Development (BMZ) has supported several phases of an ILRI/CIRDES/FUB project on the epidemiology of trypanocide resistance in West Africa. A fuller account of this is provided in section 4.6 below.
- A collaboration on an European Union (EU)-funded trypanocide resistance project in eastern Africa (Kenya, Tanzania and Zambia).
- A supervision of an analysis of the epidemiology of drug resistance in Mukono County, Uganda, project.
- Some supervisory support for drug resistance studies undertaken by the Kenya Trypanosomiasis Research Institute (KETRI), Kenya, in collaboration with Glasgow University.

These studies resulted in a series of multi-author and multi-institutional publications (see for example Knoppe et al. 2006;[78] Gall et al. 2004).[79]

Development of a modelling technique to evaluate control options

An area of emphasis was the development and modification of models as tools to better understand factors influencing transmission dynamics of trypanosomiasis and assessing and predicting the impact of different control strategies. The principal objective of this research was to determine if transition models, as proposed by Diggle et al. (1994),[80] could be adopted for this purpose. This modelling approach offered two major advantages over standard methods. The first was that risk factor associations can be assessed simultaneously for both new (incident) infections and recurrent infections after chemotherapy.

78. Knoppe, T., Bauer, B., McDermott, J.J., Peregrine, A.S., Mehlitz, D. and Clausen, P.H. 2006 Isometamidium sensitivity of *Trypanosoma congolense* stocks from cattle in West Africa tested in mice and the drug incubation infectivity test. *Acta Tropica* 97:108–116.

79. Gall, Y., Woitag, T., Bauer, B., Sidibé, I., McDermott, J., Mehlitz, D. and Clausen P.H. 2004. Trypanocidal failure suggested by PCR results in cattle field samples. *Acta Tropica* 92:7–16.

80. Diggle, P.J., Liang, K.-Y. and Zeger, S.L. 1994. *Analysis of longitudinal data*. Oxford: Oxford Science.

The second was that such statistical methods can allow for monthly, rather than weekly or fortnightly, sampling intervals in the field. This latter feature is crucial logistically and allows for the analysis of data from a much wider variety of sampling sites, since monthly sampling is commonly employed. The use of transition models allowed distinguishing 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).[81] 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).[82]

The real benefit of using a transition model to investigate infection dynamics of trypanosomes in cattle is its ability to assess both 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 and raised interesting hypotheses for further investigation (e.g. potential of selection of trypanotolerance in local Ethiopian breeds). Transition models, thus, appear to offer solid promise as a tool in better understanding infection dynamics of parasite infections in natural settings.

Sustainable trypanosomiasis control in Uganda

The ILRI epidemiology group, predominantly through John McDermott, Tom Randolph and postdoc Paul Coleman, collaborated on a series of projects in Uganda. These were funded by the Systemwide Programme on Collective Action and Property Rights CAPRI (Enhancing the role of community actions in disease control and natural resource management; the control of human and animal trypanosomiasis); DFID (Decision support for sleeping sickness control in southeastern Uganda); and the International Development Research Centre—IDRC (Links between sleeping sickness and natural resource endowments and use: What can communities do?). This collaboration built on earlier work exploring the historical resurgence of sleeping sickness in Uganda (Welburn et al. 2001;[83] Fevre et al. 2001),[84] and went on to explore different potential control options using modelling techniques (McDermott and Coleman 2001).[85]

Sleeping sickness remains an important disease in Uganda and cattle is 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. rhodesiense* or sleeping sickness. Activities included: development of tests to differentiate human infective and non-infective *T. brucei* spp.; studies into cattle movement in new outbreaks of sleeping sickness; and studies to evaluate factors that influence sleeping sickness risk, burden and under-reporting.

Sustainable trypanosomiasis control in Ghibe, Ethiopia

The initial modelling work described above using long-term data from ILCA's extended research in the Ghibe Valley of Ethiopia evolved 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 (SIT) 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 Program Against African Trypanosomiasis (PAAT). John McDermott had earlier consulted to IAEA in 1998 on the sensitivity and specificity of eradication confirmation on Unguja island, Zanzibar, and was invited to submit a proposal on broader impacts in the southern Rift Valley of Ethiopia. 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).[86]

81. Schukken, Y.H., Van Schaik, .G, McDermott, J.J., Rowlands, G.J., Nagda, S.M., Mulatu, W. and d'Ieteren, G.D.M. 2004. Transition models to assess risk factors for new and persistent trypanosome infections in cattle – analysis of longitudinal data from the Ghibe Valley, Ethiopia. *Journal of Parasitology* 90(6):1279–1287.

82. Snow, W.F. and Rawlings, P. 1999. Methods for the rapid appraisal of African animal trypanosomiasis in the Gambia. *Preventive Veterinary Medicine* 42(2):67–86.

83. Welburn, S.C., Fèvre, E.M., Coleman, P.G., Odiit, M. and Maudlin, I. 2001. Sleeping sickness: A tale of two diseases. *Trends in Parasitology* 17:19–24.

84. Fèvre, E.M., Coleman, P.G., Odiit, M., Magona, J.W., Welburn, S.C. and Woolhouse, M.E. 2001. The origins of a new *Trypanosoma brucei rhodesiense* sleeping sickness outbreak in eastern Uganda. *The Lancet* 358(9282):625–628.

85. McDermott, J.J. and Coleman, P.G. 2001. Comparing apples and oranges–model-based assessment of different tsetse-transmitted trypanosomiasis control strategies. *International Journal for Parasitology* 31:603–609.

86. Wilson, C.J., Reid, R.S., Stanton, N.L. and Perry, B.D. 1997. Effects of land use and tsetse fly control on bird species richness in southwestern Ethiopia. *Conservation Biology* 11(2):435–447.

This set the stage for ILRI's role in developing a framework for monitoring the environmental and social impacts of the African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC), although ILRI stayed on the sidelines of the initiative itself, given widespread reservations about the challenges and potential controversies it faced.

Spatial modelling of tsetse distributions

Underlying several of the studies on trypanosomiasis impact were studies on predicting the distribution of different tsetse fly 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. 1993),[87] and exploited by Robin Reid when she joined the epidemiology group as a postdoc under a Rockefeller Fellowship. Robin went on to explore various aspects of the environmental impacts of tsetse control in Africa (see for example Reid et al. 2000)[88] 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 (see for example Rogers et al. 1996[89] and Wint and Rogers 2000).[90] 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).[91]

ILRI later outsourced some of the spatial analysis for trypanosomiasis (and indeed for tick-borne diseases) to consultants such as Avia-GIS.[92] More recently veteran GIS specialist Tim Robinson has returned to ILRI from FAO, and has picked up the mantle of spatial analysis, including a renewed partnership with Alex Shaw of AP Consultants on the economic impact of trypanosomiasis (Robinson et al. 2014).[93]

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

In April 2012, the final report on 'Preventing and containing trypanocide resistance in the cotton zone of West Africa' was presented to BMZ. It represented the fourth in a series of BMZ-funded research projects exploring the problem of drug resistance in trypanosomiasis control and closed a cycle of problem identification to formulation of solutions. The goal of the project was to protect and improve the sustainable livelihoods of resource-poor livestock keepers in agropastoral production systems in sub-humid West Africa by ensuring the continued effectiveness of trypanocides to control trypanosomiasis. A previous project focused its efforts on adapting and validating methods and evaluating the extent of resistance to trypanocides in northeast Guinea, south Mali (Affognon et al. 2009;[94] Talaki et al. 2009)[95] and southwest Burkina Faso (Der et al. 2011),[96] and testing integrated control strategies to reduce the risk of new drug resistance emerging. 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 scale up the prevention strategies developed earlier. Appropriate strategies were also being developed for containing—and, if possible, reversing—resistance in the pockets previously characterised, and a specific study was undertaken to assess the impact of the trypanocide resistance research efforts to date.

87. http://www.fao.org/docrep/004/t4885b/T4885B03.htm

88. Reid, R.S., Kruska, R.L., Deichmann, U., Thornton, P.K. and Leak, S.G.A, 2000. Human population growth and the extinction of the tsetse fly. *Agriculture, Ecosystems and Environment* 77:227–236.

89. Rogers, D.J., Hay, S.I. and Packer, M.J. 1996: Predicting the distribution of Tsetse Flies in West Africa using temporal fourier processed meteorological satellite data. *Annals of Tropical Medicine and Parasitology* 90(3):225–241.

90. http://www.fao.org/ag/againfo/programmes/en/paat/documents/maps/pdf/tserep.pdf

91. McDermott, J.J., Kristjanson, P.M., Kruska, R.L., Reid, R.S., Robinson, T.P., Coleman, P.G., Jones, P.G. and Thornton P.K. 2001. *Effects of climate, human population and socio-economic changes on tsetse-transmitted trypanosomiasis to 2050*. In: Seed, R. and Black, S. (eds), *World Class Parasites* – Vol. 1. The African Trypanosomes, Kluwer, Boston, 25–38.

92. http://www.avia-gis.com/sites/default/files/pdf/TrypGIS_ParaTodayPaper.pdf

93. http://news.ilri.org/2014/07/25/new-map-benefits-of-controlling-trypanosomiasis-in-the-horn-of-africa/

94. Affognon, H., Coulibaly, M., Diall, O., Grace, D., Randolph, T. and Waibel, H. 2009. *Etude des politiques relatives aux stratégies de gestion de la chimiorésistance dans le cadre de la lutte contre la trypanosomose en Afrique de l'Ouest: Cas du Mali*. ILRI Research Report No. 17. ILRI, Nairobi, Kenya. pp 69..

95. Talaki, E., Sidibé, I., Diall, O., Affognon, H., Grace, D., Djiteye, A., Bocoum, Z., Diarra. B., Belem, A.M.G. and Pangui, L.J. 2009. Variations saisonnières et facteurs de risques des trypanosomoses animales dans un contexte de chimiorésistance dans la zone de Sikasso au Mali. *Bulletin of Animal Health and Production in Africa* 57(2).

96. Der, D., Affognon, H. and Sidibe, I. 2011. Réseaux sociaux et échange d'informations vétérinaires: cas de la trypanosomose animale chez les éleveurs de Solenzo dans la province des Banwa, Burkina Faso. *Sciences et Médecines d'Afrique/Sciences and Medicines in Africa* 3(1):402–411.

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;[97] Clausen et al. 2010).[98] 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 with 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);[99] 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;[100] 2009).[101] There is a better understanding of how farmers access information about animal health care and 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 likely 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 adequate returns will be achieved to justify the investment (Affognon et al. 2010).[102]

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), the FAO program against Africa Trypanosomiasis (PAAT),[103] and a five-year, US$ 3.1 million project involving the principal German partners and CIRDES to extend the project approach and findings to new countries (Togo, Ethiopia, Mozambique).

97. McDermott, J., Woitag, T., Sidibé, I., Bauer, B., Diarra, B., Ouédraogo, D., Kamuanga, M., Peregrine, A., Eisler, M., Zessin, K-H., Mehlitz, D. and Clausen P.-H. 2003. Field studies of drug-resistant cattle trypanosomes in Kénédougou Province, Burkina Faso. *Acta Tropica* 86:93–103.

98. Clausen, P.H., Bauer, B., Zessin, K.H., Diall, O., Bocoum, Z., Sidibe, I., Affognon, H., Waibel, H., Grace, D. and Randolph, T. 2010. Preventing and containing trypanocide resistance in the cotton zone of West Africa. *Transboundary and Emerging Diseases* 57:28–32.

99. Delespaux, V., Vitouley, H.S., Marcotty, T., Speybroeck, N., Berkvens, D., Roy, K., Geerts, S. and Van den Bossche, P. 2010. Chemosensitization of *Trypanosoma congolense* strains resistant to isometamidium chloride by tetracyclines and enrofloxacin. *PLOS Neglected Tropical Diseases* 4(9):e828.

100. Grace, D., Randolph, T., Diall, O. and Clausen, P-H. 2008. Training farmers in rational drug-use improves their management of cattle trypanosomiasis: A cluster-randomised trial in South Mali. *Preventive Veterinary Medicine* 83(1):83–97.

101. Grace, D., Randolph, T., Affognon, H., Dramane, D., Diall, O. and Clausen, P-H. 2009. Characterisation and validation of farmers' knowledge and practice of cattle trypanosomiasis management in the cotton zone of West Africa. *Acta Tropica* 111(2):137–143.

102. Affognon, H.D., Randolph, T.F. and Waibel, H. 2010. *Economic analysis of animal disease control inputs at farm level: the case of trypanocide use in villages under risk of drug resistance in West Africa Livestock Research for Rural Development* 22: Article #224. Retrieved from http://www.lrrd.org/lrrd22/12/affo22224.htm

103. http://www.fao.org/ag/againfo/programmes/en/paat/home.html

Rabies research; a networking role in Africa

ILRAD had no mandate in rabies research, but when he joined ILRAD in 1987, Brian Perry had a track record in rabies research on disease epidemiology and the development of oral vaccines and their delivery to wildlife and domestic dog populations, and had been the external examiner of PhD candidate Chris Foggin in Zimbabwe. In his letter of appointment, Perry was allocated up to three weeks per year to work on the disease. Soon after arriving at ILRAD, he was invited, in 1988, to chair the first World Health Organization (WHO) consultation on oral rabies immunization of dogs in Geneva, and subsequently participated in the WHO consultation on the requirements and criteria for field trials on oral rabies vaccination of dogs and wild carnivores in 1989.[104]

In the early 1990s, a group called the 'Southern and Eastern Rabies Group (SEARG)' was born, under the leadership of the late George Bishop, chief veterinary researcher at the Allerton Laboratory in Pietermaritzburg, South Africa, and the late Arthur King, rabies scientist at the Central Veterinary Laboratory, UK. SEARG had its first meeting at the Ridgeway Hotel in Lusaka, Zambia, and ILRI presented an overview paper on the epidemiology of rabies in Africa (Perry 1992).[105]

As part of the capacity building function of ILRI's epidemiology and socio-economics program, partnership with the rabies control groups in Kenya and neighbouring countries was established and Brian Perry served as chairman of the Kenya Veterinary Association rabies committee from 1989–1993. John McDermott, who was to join ILRI's epidemiology team in 1997, was at that time leading the establishment of a series of veterinary epidemiology courses at the University of Nairobi, under a technical cooperation program with the University of Guelph, supported by the Canadian International Development Agency (CIDA).

Together with Brian Perry, they supervised Philip Kitala in his PhD research on rabies in Machakos District of Kenya, and a series of papers emerged (Kitala et al. 2000;[106] Kitala et al. 2001;[107] Kitala et al. 2002).[108] Philip Kitala is now a professor of public health at the University of Nairobi. Other strategic contributions emerged from ILRAD and ILRI (Bingham et al. 1993;[109] Bingham et al. 1995;[110] Perry 1993;[111] Perry and Wandeler 1993;[112] Perry 1995).[113] In addition, Brian Perry 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 (McDonald et al. 1992).[114]

104. http://www.who.int/rabies/animal/en/whorabres8932.PDF

105. Perry, B.D. 1992. *The epidemiology of dog rabies and its control in eastern and southern Africa.* In: Proceedings of an International Meeting on Rabies in Eastern and Southern Africa, (ed, King, A.) Lusaka, Zambia, Editions Fondation Marcel Merieux, Lyon, France, pp 107–121. http://searg.info/fichiers/articles/1992107121L.PDF

106. Kitala, P.M., McDermott, J.J., Kyule, M.N. and Gathuma, J.M. 2000. Community-based active surveillance for rabies in Machakos District, Kenya. *Preventive Veterinary Medicine* 44:73–85.

107. Kitala, P., McDermott, J.J., Kyule, M., Gathuma, J., Perry, B.D. and Wandeler, A. 2001. Dog ecology and demography information to support the planning of rabies control in Machakos District, Kenya. *Acta Tropica* 78:217–230.

108. Kitala, P., McDermott, J., Coleman, P. and Dye, C. 2002. Comparison of vaccination strategies for the control of dog rabies in Machakos District, Kenya. *Epidemiology and Infection* 129:215–222.

109. Bingham, J., Perry, B.D., King, A.A., Schumacher, C.L., Aubert, A., Kappeler, A., Hill, F.W.G., Aubert, A. and Flamand, A. 1993. Oral vaccination of jackals against rabies: recent progress in Zimbabwe. *Onderstepoort Journal of Veterinary Research* 60:477–478.

110. Bingham, J., Kappeler, A., Hill, F.W.G., King, A.A., Perry, B.D. and Foggin, C.M. 1995. Efficacy of SAD (Berne) rabies vaccine given by the oral route in two species of jackal (*Canis mesomelas* and *Canis adustus*). *Journal of Wildlife Diseases* 31:416–419.

111. Perry, B.D. 1993. Dog ecology in eastern and southern Africa: Implications for rabies control. *Onderstepoort Journal of Veterinary Research* 60:429–436.

112. Perry, B.D. and Wandeler, A.I. 1993. The delivery of oral rabies vaccines to dogs: An African perspective. *Onderstepoort Journal of Veterinary Research* 60:451–457.

113. Perry, B.D. 1995. Rabies control in the developing world: can further research help? *Veterinary Record* 137: 521–522.

114. Macdonald, D., Artois, M., Aubert, M., Bishop, D.H.L., Ginsberg, J.R., King, A., Kock, N. and Perry, B.D. 1992. Cause of wild dog deaths. *Nature* 360:633–634.

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. SEARG has now become an institution with its own website,[115] which includes pdf files of all the papers presented since its inception in 1992. 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),[116] the need for a sound understanding of population (in this case dog) ecology in order to target vaccination initiatives (Perry 1993),[117] and the need to exploit community engagement in rabies vaccination campaigns (Perry et al. 1995),[118] findings which have been built on by others in the subsequent 20 years.

In the light of today's wide range of diseases considered by ILRI and the emphasis placed on One Health, it is interesting to note that these contributions were not always appreciated within ILRI at the time. The following is a quote from a memorandum from the then director general of ILRI to Brian Perry relating to his 1995 annual research report:

> Your list of publications raises a sticky issue for ILRI. Do we utilize ILRI resources for research outside our mandate? If so, how should we do so? Specifically, I refer to the publication on rabies. As an animal health professional, your contributions to this topic are, I am sure, well received. Presumably, however, these papers are written as an 'avocation' rather than as part of your professional contribution from ILRI. Therefore, I suggest that you include these papers on your personal C.V. but do not include them as part of the publications from your ILRI supported research project'. Understandably, there was an epidemiological response, which read: 'We wish that this institute broadens its horizons in the area of animal health. The issues of better delivery of available technologies, in this case vaccines, to animal populations in the developing world is one which is of utmost relevance. Rather than discard these contributions as not relevant to ILRI's mandate, I would argue that they should be included to demonstrate that we are thinking broadly about this issue, and drawing on other examples to help us seek effective solutions for the vaccines of primary interest to us.

Brian Perry went on to chair the sixth WHO consultation on the oral immunization of dogs against rabies in Geneva in 1995, and to present a plenary paper on Rabies in Africa in 1997 at an international meeting on rabies control at the Pasteur Institute in Paris.[119]

115. http://searg.info/doku.php

116. Coleman, P.G. and Dye, C. 1996. Immunization coverage required to prevent outbreaks of dog rabies. *Vaccine* 14: 185–186.

117. Perry, B.D. 1993. Dog ecology in eastern and southern Africa: implications for rabies control. *Onderstepoort Journal of Veterinary Research* 60:429–436.

118. Perry, B.D., Kyendo, T.M., Mbugua, S.W., Price, J.E. and Varma, S. 1995. Increasing rabies vaccination coverage in urban dog populations of high human population density suburbs: a case study in Nairobi, Kenya. *Preventive Veterinary Medicine* 22:137–142.

119. Perry, B.D. 1997. *The epidemiology and control of rabies in Africa*. International Meeting on Rabies, Pasteur Institute, Paris, March 13–14, 1997.

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 latter part of the nineteenth century. In its classical form it was responsible for high levels of mortality. In addition, its mere presence constrained the trading opportunities in livestock and livestock products. On top of this, there have been high control costs. During the 1960s, the first coordinated international control program was put in place, known as Joint Project (JP) 15.

Although largely successful, rinderpest returned in a major epidemic throughout much of the continent after it concluded in the late 1970s. As a result, the Pan-African Rinderpest Control (PARC) program was initiated under the auspices of the Interafrican Bureau for Animal Resources (IBAR) of the Organization of African Unity (OAU), which was funded by the European Union 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 highly pathogenic avian influenza (HPAI) in Indonesia. Just before the merger of ILCA and ILRAD in 1995, the European Union, which at the time was making large investments in rinderpest eradication through IBAR, approached both institutions. The PARC program had been planning for some time to undertake an economic evaluation of the rinderpest control program. 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 haemoparasite diseases, turned down the offer, while ILCA accepted it.

The two institutions were amalgamated, and ILRI was born, and the newly created Systems Analysis and Impact Assessment Group: SA/IA (the successor to the Epidemiology and Socio-economics program) 'inherited' the project. This provided a new opportunity for ILRI to work with the African Union–Interafrican Bureau for Animal Resources (AU–IBAR), and two agricultural economists were recruited (Emmanuel Tambi and Onesmus Maina) together with an administrative support person, all housed in the AU–IBAR premises in Nairobi, but falling under the leadership and supervision of the SA/IA group. The project was given high priority because of the importance of the donor. However, institutionally the project struggled, with inadequate resources, requiring ILRI to support salaries and other functions through its unrestricted core funds. And there were extremely high expectations by the EU and by PARC.

The study indicated that for a sample of 10 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 USD 0.30 to USD 0.66 (Tambi et al. 1999).[120] Benefit–cost analysis revealed that the benefits of the campaign in each of the 10 countries covered the value of the investment. The estimated average return over the 10 countries of USD 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 USD 32 million indicates that the rinderpest campaign has been a wise public investment decision.

120. Tambi, E.N., Maina, O.W., Mukhebi, A.W. and Randolph, T.F. 1999. Economic impact assessment of rinderpest control in Africa. *Revue scientifique et technique* 18(2): 458–477. https://cgspace.cgiar.org/handle/10568/35032

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 USD 64 million in net value of production losses avoided due to rinderpest control in the 10 countries , while consumers derived approximately 20% in net benefits from increased supplies leading to lower prices.

The impact assessment led to the development of stronger institutional links between ILRI and AU–IBAR, as the latter institution embarked on the new Pan African Control of Epizootics (PACE) program to address the effective control of other major diseases constraining livestock productivity, food security and improved human welfare in the continent.

Following the eradication of rinderpest, former ILRI agricultural economist Karl Rich teamed up with former FAO rinderpest control coordinator Peter Roeder to add an economic perspective to the rinderpest eradication story, as part of a set of agricultural success stories assembled by ILRI (Roeder and Rich 2009).[121]

121. Roeder, P. and Rich, K. 2009. *Conquering the Cattle Plague: The global effort to eradicate rinderpest* https://cgspace.cgiar.org/handle/10568/155

Foot-and-mouth disease

First steps out of Africa: The Southeast Asia program

With the formation of ILRI, the new institution embarked on the building of an appropriate research role in what was a new sphere of influence for the institution, 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 World Organisation for Animal Health-OIE (Yoshihiro Ozawa) facilitated a discussion with multiple partners on where ILRI could provide added value to ongoing initiatives.

For ILRI to make an effective and meaningful move into Asia in the area of animal health research, it was considered it should exploit the generic research capacity it had developed in epidemiology and economics, rather than its traditional disease focus of vector-borne haemoparasites of ruminants, as these are 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 program, 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 foot-and-mouth disease (FMD) in the region, and the impact of alternative FMD control strategies, as a case study. 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 new OIE coordinated FMD control and eradication program which had been set up.[122] 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 ILRI was invited to sit. The first meeting was held in Bangkok on 1 March 1998, attended by Brian Perry. This set the scene for the first of the FMD economic impact studies, which focused on Thailand within a Southeast Asia regional context. Thai epidemiologist Wantanee Kalpravidh, (now regional epidemiologist based at the Emergency Centre for Transboundary Animal Diseases Regional Unit for Asia and the Pacific (ECTAD RAP)), was assigned to the study, and economic impact support was initially provided by Suzan Horst of Wageningen University; the World Reference Laboratory for FMD (WRL–FMD) in Pirbright provided the FMD-specific technical support. Later in 1998, when Tom Randolph was recruited to the epidemiology group, he took over the economic impact contributions to the initiative.

122. 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 Southeast Asia Foot-and-mouth Disease Regional Coordination Unit (SEAFMD RCU), which was created in 1997 for the control of FMD in Southeast Asia, coordinating various prevention and control initiatives in countries of the region, in particular Cambodia, Lao PDR, Malaysia, Myanmar, the Philippines, Thailand and Vietnam. In 2010, the OIE and ASEAN supported the membership of the remaining ASEAN countries (Brunei Darussalam and Singapore) and China, which has resulted in a vastly-expanded program, now renamed the South-East Asia and China Foot-and-mouth Disease campaign (SEACFMD).

The epidemiology team in Thailand: Paul Coleman, Brian Perry, Wantanee Kalpravidh, farm manager, Suzan Horst, Laurie Gleeson

The first product of this initiative was presented at the annual meeting of the Southeast Asia Food and Mouth Disease (SEAFMD) group, under the auspices of OIE, in Phnom Penh, Cambodia, in February 1999,[123] and emerged as a peer-reviewed report later the same year (Perry et al. 1999).[124] Very much influenced by Tom Randolph's philosophy that economic impact assessments should be forward looking, it provided a cost–benefit analysis of different FMD control scenarios and different emerging trading opportunities which resulted from greater FMD control. This approach was fully appreciated by the host country, Thailand, but raised the question from others as to whether economic impact assessments should focus on identifying total costs of the disease, figures which could then be used in funding proposals.

During the Phnom Penh meeting in 1999, ILRI was approached by the national coordinator of the FMD control program in the Philippines, Carolyn Benigno (now senior epidemiologist at FAO's regional office for Asia and the Pacific), who requested that a similar study be undertaken there, including capacity building and training in economic impact assessments. An initial visit by ILRI (Brian Perry and Tom Randolph) was made in November 1999, and as the work progressed, Carolyn Benigno and Amy Agbayani travelled to ILRI[125] in Nairobi during the data analysis process. The report (published in Randolph et al. 2002)[126] had also developed a set of scenarios, based on the plans and timetable of the Government of the Philippines, and more optimistic and pessimistic assumptions, each discussed in detail with stakeholders in the country. The study included an analysis of the distribution of the benefits, a component which had a substantial impact. It illustrated that while the FMD control program 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. This was used very effectively by Carolyn Benigno and her colleagues to lobby for private sector investment in the FMD control efforts, and to bring them into the control program leadership and decision-making.

Impact statement: On 31 August 2014, Carolyn Benigno, former director of FMD control, Government of the Philippines, wrote: 'As then Head of the Philippines National FMD Task Force, I thought the Philippines would benefit from an impact assessment. We were at a critical time then when the government was asking us how long would they have to allot a budget for FMD control; is it worth it; and who benefits? The study conducted by the ILRI team led by Brian Perry proved to be a turning point for the Philippines FMD control and eradication program. When the results clearly indicated the benefits of FMD eradication and that the producers stands to benefit from it, I presented this study in as many fora as possible to convince policymakers that the investment was worthwhile and to convey a message to the private producer that they would benefit given an FMD free setting. That turned the tide as producers came together and became active in the consultation process, became vigilant to meat importations as well as vaccines of doubtful quality, which they thought would jeopardize the FMD status of the country. They assisted in funding activities of the Task Force, contributing to public awareness campaigns and paying for the salaries of checkpoint guards assigned to man ports of FMD free areas. Suddenly,

123. Perry, B.D. 1999. *Economic impact of foot-and-mouth disease and its control in Southeast Asia.* Presentation to the 5th meeting of the OIE sub-commission for foot-and-mouth disease in Southeast Asia, with the participation of FAO/IAEA, Phnom Penh, Cambodia, 22–26 February 1999.

124. Perry, B.D., Kalpravidh, W., Coleman, P.G., Horst, H.S., McDermott, J.J., Randolph, T.F. and Gleason, L.J. 1999. *The economic impact of foot-and mouth disease and its control in Southeast Asia: a preliminary assessment with special reference to Thailand*. In: The Economics of Animal Disease Control, (ed B.D. Perry), OIE *Scientific and Technical Revue* 18 (2):478–497.

125. ILRI had started holding Friday morning informal coffee meetings at which visitors were introduced, and asked to say a few words. Aware of the love of singing in the Philippines, Brian and Tom told Carolyn and Amy that they would be expected to sing a song when they were introduced, and this they did, to the delight of the assembled ILRI staff!

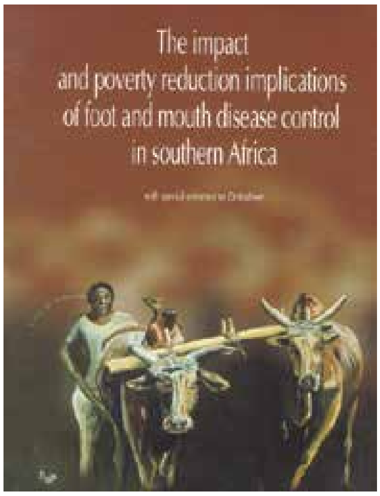
126. Randolph, T.F., Perry, B.D., Benigno, C.C., Santos, I.J., Agbayani, A.L., Coleman, P., Webb, R. and Gleeson, L.J. 2002. The economic impact of foot-and-mouth disease and its control in the Philippines. *OIE Scientific and Technical Revue* 21:645–661.

the Task Force became a force to reckon with. We had tremendous support from the producers and this continued until the last zone was declared free in 2011, leading to the whole Philippines being recognized as FMD free. Today, markets have opened up for the Philippines, such as those in the Middle East and East Asia. Local producers have also upgraded their facilities to get accreditation from the importing countries. Plans are afoot to establish high-grade facilities in provinces (and not just private undertakings) to encourage smallholder farms to have their animals processed at these facilities and have their produce be exported as well'.

Immediately after the following SEAFMD meeting in Hanoi in March 2000, at the invitation of the Government of Laos, ILRI undertook a collaborative study on the impacts of waves of FMD epidemics on smallholder agricultural enterprises in Savannakhet Province of southern Laos (Perry et al. 2002).[127] This illustrated the widespread impacts that 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 caused by FMD to the livelihoods of smallholders globally.

The southern Africa impact study

The Zimbabwe study team in Harare



In March 2001, DFID's Sarah Holden contacted Brian Perry asking if he and ILRI's epidemiology group would be able to undertake an impact assessment of FMD control in southern Africa, with particular reference to Zimbabwe. Considerable development investments by DFID to Zimbabwe were going on at the time, and FMD control had become controversial in the new pro-poor context being followed by DFID. Coincidentally, the UK was experiencing a FMD outbreak which had started in February 2001. The idea for the study was conceived by Sarah Holden and Peter Bazeley of the IDL Group (formerly Livestock in Development), who had originally contacted Perry and Tony Forman, in 1999, to determine their interest and availability to undertake a study on the impact of foot-and-mouth disease control in southern Africa.

The results (Perry et al. 2003)[128] show that FMD control measures are likely to be of considerable benefit to the national economy of Zimbabwe. This was demonstrated in several ways. Firstly, 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 USD 1 that Zimbabwe disinvested in the FMD control program, a further USD 5 was 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 southeastern 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. In addition, the effects of declining FMD control infrastructures on the control of other diseases were not taken into account.

127. Perry, B.D., Gleeson, L.J., Khounsey, S., Bounema, P. and Blacksell, S. 2002. The dynamics and impact of foot-and-mouth disease in smallholder farming systems in Southeast Asia: A case study in the Lao Peoples Democratic Republic. *OIE Scientific and Technical Revue* 21:663–673.

128. Perry, B.D., Randolph, T.F., Ashley, S., Chimedza, R., Forman, T., Morrison, J., Poulton, C., Sibanda, L., Stevens, C., Tebele, N. and Yngstrom, I. 2003. *The impact and poverty reduction implications of foot-and-mouth disease control in southern Africa, with special reference to Zimbabwe.* Nairobi, Kenya: ILRI.. http://hdl.handle.net/10568/896

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 World Organisation for Animal Health (Office International des Epizooties, OIE), there would be returns of approximately USD 1.5 for every USD 1 invested. As in the disinvestment scenario, this did not incorporate benefits to the region as a whole through greater disease security for FMD control, nor did it include the other benefits that would result from an enhanced national veterinary service. This analysis did not consider in depth whether Zimbabwe would be able to maintain the capacity, in terms of quantity and quality of beef, to supply the export market following the dramatic reduction in the commercial cattle breeding herd associated with current land reforms in the country.

Importantly, the distributions of the costs and benefits turned out to be highly skewed. Expenditures from FMD control were borne almost entirely by the public sector, but when losses from trade bans resulting from FMD outbreaks were included, private sector costs were dominant. Most impacts of FMD and the benefits from its control were related to the ability to trade internationally, and so most of the benefits accrue to commercial cattle producers beef processors and related input industries and services. The Social Accounting Matrix/Computable General Equilibrium (SAM/CGE) modelling indicated 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 of FMD on the poor, and of measures established to control it, were very limited. FMD has not been a problem in communal areas where most of the poor live, and its effects on indigenous cattle are considerably less than on commercial herds. Furthermore, despite the fact that about 75% of poor households own or have access to cattle, over 60% of these own less than five animals. Most of these households use cattle for wealth storing and other livelihoods functions such as traction, and only about 2% of households are engaged in regular marketing of cattle. For most of Zimbabwe's poor, livestock sales, particularly of cattle, are opportunistic, aimed at raising needed finance for school, medical, and other expenses. Livelihoods studies were not carried out in the other exporting countries of the region, and variations in the contribution of the smallholder sector to cattle marketing are reported.

This study provided one of the most extensive analyses of FMD impacts, applying new methods such as the SAM/CGE modelling, to a most complex subject. And the interpretations of the different component of the study were not straightforward. Randolph et al. (2005)[129] explored further the highly skewed equity impacts emerging from this study.

Impacts in Peru and Colombia

At the amalgamation of ILRAD and ILCA and the emergence of ILRI in 1995 there had been much discussion on new roles outside Africa, and the Andean region had indeed been discussed.[130] Brian Perry made a visit to Colombia, Bolivia, Brazil, Argentina and Chile in May 1998 to discuss potential collaboration (including with the project in Bolivia mentioned in the footnote), but ILRI struggled to assess its comparative advantage in the region and no new projects emerged.

In April 1999, the FAO/IAEA Joint Division contacted Brian Perry requesting technical support on an economic impact assessment of FMD control and eventual eradication in Peru. IAEA had been investing in diagnostic support technologies for the FMD program, and aware of the work of ILRI's epidemiology and impact assessment groups on FMD in Southeast Asia, wished to build capacity in the Andean region. Perry undertook an initial planning and study design mission in December 1999, working with the director of veterinary services in Lima, and the University of San Carlos, and presented seminars on economic impact assessment of FMD control. A follow up visit was made by Brian Perry and Tom Randolph in December 2000, and a masters student, Beatriz Chirinos from the Universidad de San Carlos was

129. Randolph, T.F., Poulton, C. and Morrison, J.A. 2005. Evaluating equity Impacts of animal disease control: The Case of foot-and-mouth disease in Zimbabwe. *Review of Agricultural Economics* 27:465–472.

130. In 1997 Tony Irvin, then head of Animal Health at ILRI, notified staff that he had been in contact with the DFID-supported animal health project in Bolivia, which had expressed interest in linking with ILRI. In response Brian Perry wrote impertinently: 'Thank you for this communication from "our man" in Bolivia. Your strategy, to first identify where Her Majesty is investing in bilateral aid programs in South America, and then promote some activity in what your colleague terms "a mutually fruitful area for collaboration", is certainly one way for ILRI to respond to CGIAR call to address livestock research issues in South America. But is it what we are supposed to be doing? I am unsure. I would have thought that IICA, BID, PAHO or other such regional bodies would be our first point of contact, rather than the "old boy" DFID network. You suggest that Bolivia might be appropriate as it is "a country east of the Andes (which) could complement our work in Peru etc. on the west". What are the criteria influencing our proposed work in South America? Geographical representation either side of the Andes?'

brought into the study. She undertook a study and training visit to ILRI, together with Colombian collaborator Jaime Romero, to set up the databases required and initiate the analysis. While in the region, Perry and Randolph participated in an impact assessment planning meeting in Bogota, Colombia, organized by Romero, from which an economic impact assessment plan emerged.[131]

Unlike the Southeast 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, awareness raising and methodology development. The impacts for ILRI were an endorsed understanding of the need for strong regional backstopping, and the human, financial and time resources necessary to complete full impact assessment studies.

FMD impacts in India: An extended engagement

Following the Southeast Asia studies, the ILRI epidemiology group was invited, in February 2003, to contribute to a regional training program in the Australian Animal Health Laboratory (AAHL) in Geelong, Australia, on the diagnosis and impact of FMD, organized by the FAO/IAEA Joint Division in Vienna. This started a long-standing contact with Ramamurthy Venkataramanan, who was at that time principal scientist at the Indian Veterinary Research Institute (IVRI) in Bangalore.

He wanted to undertake a similar economic impact study in India, where the momentum for FMD control was gathering. In August 2004, the new deputy director general of the Indian Council for Agricultural Research (ICAR), Vijay Taneja, visited ILRI and requested such a study be undertaken. But things took time. In January 2006, an ICAR/ILRI joint meeting took place in Delhi where the study was agreed in principle, and in November of the same year, a workshop on epidemiology/economics collaboration took place in Delhi, followed in December by a draft work plan from ILRI. In January 2007, Taneja left ICAR, and the change in leadership affected the momentum of the study.

In March 2007, Brian Perry left ILRI. In August 2007, a meeting was held in Delhi to resuscitate the FMD impact assessment plan, and in April 2008, the ICAR/ILRI budget for it was approved. In June 2008 an ILRI agricultural economics training course was run at ICAR by Karl Rich, followed in September 2008 by an 'inaugural workshop' to get the project off the ground. In January 2009, a revised proposal was developed and approved and ICAR funding assigned (in principle). For the first time an Indian scientist, Ganesh Kumar, was identified and assigned to lead the task under the direction of Perry and Rich. But that was not the end of the story. In 2009, Santanu Bandyopadhyay, the animal husbandry commissioner and long-standing supporter of the project, left India to take up a post with FAO in Vietnam, further affecting the momentum and commitment in India.

In August 2009, Karl Rich travelled to India to meet Kumar and resuscitate the initiative. In August 2011, a workshop was held in Delhi, jointly organized by the National Centre for Agricultural Economics and Policy Research (NCAP) and ILRI, to review the outcomes of the pilot project to determine the economic impact of FMD in selected regions of India. Despite the shortcomings of the pilot project, the workshop was deemed a great success. ICAR colleagues were happy to have the first sight of some figures on FMD impact, however imperfect, and an opportunity to comment on the analysis and the process. But it was not until February of 2012 that the final product appeared, presented at a regional meeting organized by FAO[132] on the progressive control of FMD in India (Kumar et al. 2012,[133], [134]); a long and tortuous trail.

Distinct from the engagement with ICAR, in April 2006, Brian Perry approached the Wellcome Trust and the European Union for support for an international workshop on the research needs for better FMD control in endemic settings of many developing 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 in November 2006.[135] The Global Roadmap was subsequently launched in April 2007.[136]

131. Romero, J.R., Villamil, L.C., Perry, B.D., Randolph, T.F., Vera, V.J. and Ramírez, G.C. 2001. Valoración del impacto económico del programa de control y erradicación de la fiebre aftosa en Colombia. *Revista Colombiana de Ciencias Pecuarias*, Suplemento, Vol 14.

132. http://www.fao.org/fileadmin/user_upload/eufmd/docs/India_meeting_feb_2012/Report_Draft_sent.pdf

133. http://www.fao.org/docs/eims/upload/299846/an367e00.pdf

134. http://www.fao.org/fileadmin/user_upload/eufmd/docs/India_meeting_feb_2012/32_Kumar_Socio_economic_impacts.pdf

135. Perry, B.D. and Sones, K.R. (eds). 2007. *Global roadmap for improving the tools to control foot-and-mouth disease in endemic settings*. Report of a workshop held at Agra, India, 29 November –1 December 2006. Nairobi, Kenya, ILRI. https://cgspace.cgiar.org/handle/10568/1691

136. http://www.fao.org/ag/againfo/commissions/docs/Workshop/Launch/Agenda_launch.pdf

Joseph (Jemi) Domenech, chief veterinary officer of FAO (left) and Brian Perry at the launch of the Global Roadmap at FAO, Rome, April 2007

The Global Roadmap workshop participants outside the Taj Mahal, India

The Global Foot-and-Mouth Disease Research Alliance

At a regional training program on the diagnosis and impact of FMD, organized by the FAO/IAEA Joint Division in Vienna and held in the Australian Animal Health Laboratory (AAAL) in Geelong, Australia, an informal discussion was convened by AAHL's then director, Martyn Jeggo, on the need for greater investment in FMD research and greater coordination between the research institutions undertaking work on diagnostic tools, vaccines and epidemiological tools. Involved in the discussion were representatives of the Institute for Animal Health's laboratory in Pirbright, UK; the US Department of Agriculture's laboratory at Plum Island, New York, USA; the Australian Animal Health laboratory at Geelong, Australia; the National Centre for Foreign Animal Disease laboratory, Winnipeg, Canada; and Perry representing ILRI. The informal discussion progressively became a formal alliance, and after signing a confidentiality agreement, Brian Perry took on the task of writing a research proposal. The research proposal comprised five research pillars.

These were:

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 the latter pillar. The USD 70 million proposal was launched as a Strategic Global Research Partnership for the Control of FMD at the US Department of Agriculture in Washington DC, in April 2004. The proposal was received with enthusiasm on the scientific side, but participants urged for 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, DEFRA in the UK; EU; and CIDA in Canada; and various partners in the US).

Considering the different contexts of FMD control in the developed and developing world, the GFRA revised its approach to adopt two complementary programs. Program 1 was targeted at the FMD vaccine and diagnostic needs of FMD free countries, and their trading opportunities, while Program 2 focused on the needs of endemic settings, principally in developing countries. At this point, Brian Perry assumed the leadership of Program 2, and initiated contact with potential research sponsors and development agencies. Program 1 was assigned to the four participating research laboratories in Australia, Canada, UK and USA, 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 research tools for Program 2 and that this work could occur both inside and outside of the current GFRA partner institutes. It was foreseen that for Program 2 much still needed to be done in the area of epidemiology and impact assessment, and that ILRI would take the lead in this.

However, ILRI management was not at the time supportive of ILRI's engagement with GFRA, in part because it was considered FMD did not rank highly enough in the health constraints facing smallholder producers, and in part because engagement was centred on one scientist. Brian Perry left ILRI in early 2007, and he represented ILRI at a GFRA meeting at Plum Island in early 2008 (see image below), following which ILRI's links with GFRA and with FMD research ceased.

Impact statement. Martyn Jeggo, former director of the Australian Animal Health Laboratory (AAHL) in Geelong, Australia, and coordinator of the GFRA, made the following comment on 31 August 2014. 'In setting up GFRA and placing it on a sound footing both in terms of the developing as well as developed countries, ILRI, and particularly Brian Perry, provided crucial and globally unique insights and information on the epidemiology of FMD, especially from a developing country perspective. Placing FMD control and potential eradication into the economic reality of the poorer nations of the world, was something that Brian and his team were able to do in a way that no-one else at that time understood. They provided GFRA with global leadership at this crucial time of its development'.

The GFRA meeting at Plum Island, USA, May 2008

Rift Valley fever

Impacts of the 2006/2007 outbreak in Kenya

Research into Rift Valley fever (RVF) 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 Northeastern region of Kenya, thought to be the epicentre of the epidemic in Kenya. The outbreak occurred between December 2006 through March 2007 and it 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 synthesised and published (Jost et al. 2010).[137] The key observations made were that there were major weaknesses in preparedness and 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).[138] This demonstrated that the disease induced substantial production losses, employment losses and reduction 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 USD 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 (Group for RVF Decision support 2010).[139] This is considered as a major contribution by ILRI and FAO to RVF contingency planning given that this tool has now been incorporated into the Kenya 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.

137. Jost, C. C., Nzietchueng, S., Kihu, S., Bett, B., Njogu, G., Swai, E.S. and Mariner, J.C. 2010. Epidemiological assessment of the Rift Valley fever outbreak in Kenya and Tanzania in 2006 and 2007. *American Journal of Tropical Medicine and Hygiene* 83: 65–72

138. Rich, K. M. and Wanyoike, F. 2010. An assessment of the regional and national socio-economic impacts of the 2007 Rift Valley fever outbreak in Kenya. *Journal of Tropical Medicine and Hygiene* 83: 52–57

139. Consultative Group for RVF Decision Support. 2010. Decision support tool for the prevention and control of Rift Valley fever epizootics in the Horn of Africa. *American Journal of Tropical Medicine and Hygiene* 83:75–85.

Economic assessment of control options and DALYs calculation

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 Disability Adjusted Life Years (DALYs). Estimates that have been generated suggest that the 2006/2007 outbreak caused a total of 3974 DALYs, or 1.5 DALYs per 1000 people. This work is being undertaken by an ILRI PhD graduate fellow. Provisional results further show that strategies to enhance mass vaccination of cattle and camels over a sustained two-year period would greatly reduce DALYs. It also shows 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.

Risk maps for East 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 that have been done by NASA and other research institutions such as 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 recent 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 (NDVI). Such maps could also be used to enhance the understanding of ecological niches for the virus, particularly if the existing hotspots can be classified based on their abilities to support the 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 or literacy levels.

Current work on land use change and disease dynamics

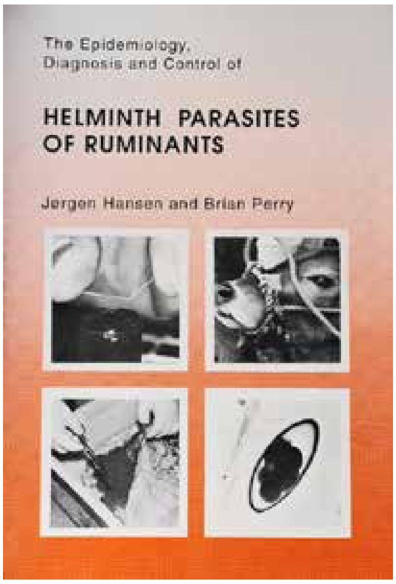
With increasing awareness on the impacts of RVF epidemics, there is a growing interest in determining processes that cause RVF occurrence and transmission, as well as those that promote its persistence during inter-epidemic periods. ILRI is currently leading a project in Kenya that seeks to understand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

Gastro-intestinal parasites

While the genetics program of ILRI had a basic science program on factors affecting the resistance to gastro-intestinal parasite infestations, the epidemiology group was not involved. However, inherited from earlier work undertaken in the USA by Brian Perry and parasitologist Jorgen Hansen, ILRAD agreed to publish a field and laboratory handbook on the subject. The book *The Epidemiology, Diagnosis and Control of Gastro-Intestinal Parasites of Ruminants in Africa* was published by ILRAD in January 1990.

The emergence of the handbook caused considerable disquiet to the institute's management, and a memorandum was sent to James Lenahan, then training officer, and Perry asking why funds were being used to publish a book on a subject that appeared to have no relevance to the vector-borne disease mandate of ILRAD. However, the demand for the book exceed that of any other of ILRAD's publications, and so a second edition was produced, with the title *The Epidemiology, Diagnosis and Control of Helminth Parasites of Ruminants* in 1994, closely followed by a French edition published by FAO. These provided simple cookbook style manuals of techniques which have now be widely distributed to many countries in Africa.



The Inter-Agency Donor Group (IADG) commissioned study on animal health research and poverty reduction

On 22 November, 2000 Brian Perry received the following email:

'DFID is rethinking the way in which we provide support to animal health research. This will involve a reorientation of the research program to focus on diseases that are important to poor people, rather than diseases of production (the two may or may not be the same). To kick-start the process we need to commission a study to identify and prioritise those disease research issues that are likely to be important to poor livestock keepers. Would you be interested/able/willing to do the study for DFID?'

The answer was of course yes, and this initiated a process which brought together scientists and opinion leaders in Africa, Asia, Europe and North America, and which was to deliver one of the highest impact products of ILRI's epidemiology group (Perry et al. 2002).[140] The IADG had just been born, as part of a process to bring greater coordination between its membership in the funding of livestock research.[141] 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.[142] This required first defining poverty and the association with livestock, and then quantifying the association, a process which continues to be refined at ILRI (Robinson et al. 2014).[143]

There were seven major component processes to the study.[144] The first was to describe and quantify the distribution and extent of poverty in Southeast 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 also commissioned by DFID (Thornton et al. 2002),[145] that developed sets of maps and tables to locate and quantify populations of poor livestock keepers and predict how poor livestock-keeping populations are likely to change over the next five decades. The results provided data on the number of poor (people living on less than USD 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 literature review and through stakeholder workshops in West Africa, eastern, central and southern Africa, South Asia and Southeast Asia.

140. Perry, B.D., Randolph, T.F., McDermott, J.J., Sones, K.R. and Thornton, P.K. 2003. *Investing in animal health research to alleviate poverty.* Nairobi, Kenya, ILRI. pp 140 plus CD-ROM https://cgspace.cgiar.org/handle/10568/2308

141. https://www.donorplatform.org/livestock-development/major-events

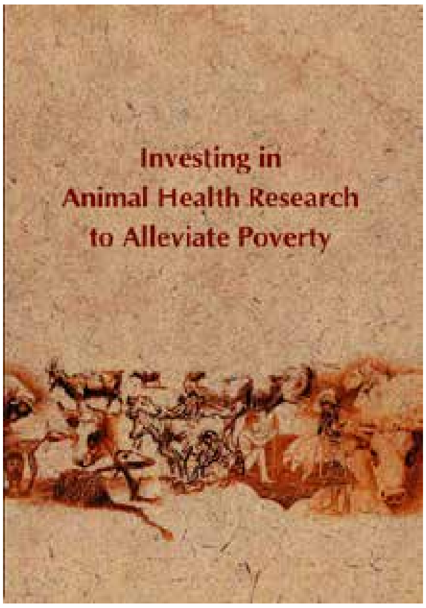
142. http://r4d.dfid.gov.uk/PDF/Outputs/RLAHAnnRep_2001-2002.pdf

143. Robinson, T.P., Wint, G.R.W., Conchedda, G., Van Boeckel, T.P., Ercoli, V., Palamara, E., Cinardi, G., D'Aietti, L., Hay, S.I. and Gilbert, M. 2014. Mapping the global distribution of livestock. *PLoS ONE* 9(5):e96084.

144. https://cgspace.cgiar.org/handle/10568/2308

145. https://cgspace.cgiar.org/handle/10568/915

Third was to identify and quantify the disease constraints to these species and rank them. 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 socio-economic (primarily production losses and control costs incurred by the poor), zoonotic (for those diseases transmissible from animals to man) 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 synthesised by commissioned reviews. Then research opportunities to alleviate these constraints were 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),[146] synthesise the disease impacts on the poor with research needed to reduce them and identify priority research opportunities. A conceptual framework matrix was developed to classify different types of disease-specific research (1: transferring knowledge and available tools; 2: developing improved tools and strategies, better delivered; and 3: 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 of poverty and livestock and for applying greater emphasis to the impacts that research in animal health has on processes of poverty reduction, rather than simply on national agricultural development. The methodology has been further developed (Perry and Grace 2009;[147] Perry et al. 2011).[148]

The three 'pathways out of poverty' also had a substantial impact within ILRI, setting the agenda for ILRI's new research strategy developed on the arrival of Carlos Seré as director general in 2002.

146. Shaw, A.P.M., Randolph, T.F., Heffernan, C.L., Rushton, J. and Perry, B.D. 2003. A framework for prioritizing animal health constraints in developing countries according to their impact on the poor. Proceedings of the 10th International Symposium for Veterinary Epidemiology and Economics (ISVEE), Vina del Mar, Chile, 17–21 November 2003, Compact disk

147. Perry, B.D. and Grace, D. 2009. The impacts of livestock diseases and their control on growth and development processes that are pro-poor. *Philosophical Transactions of the Royal Society B* 364:2643–2655.

148. Perry, B.D., Grace, D. and Sones, K.R. 2011. Current drivers and future directions of global livestock disease dynamics. Proceedings of the National Academy of Science https://cgspace.cgiar.org/handle/10568/3673

Wellcome Trust epidemiology initiatives

The Wellcome Trust has long supported epidemiology research, and in 1997 Brian Perry was approached by Tricia Chisholm of the Trust to develop a short document on what she termed the 'pinch points' constraining the further development and exploitation of epidemiological tools for the health sciences in Africa, as part of a background paper for the governors on future zoonotic disease program sponsorship. Later in the year, the Trust announced an International Partnership Research Awards initiative to provide project grant support for collaborative veterinary epidemiology research in the field of zoonotic disease and food-borne diseases of animal origin. While this was of great interest to ILRI's epidemiology group, and Perry attended a discussion workshop at the Trust to learn more about the awards, ILRI discovered certain institutional challenges of partnership with the Trust. The Trust indicated that they would fund projects in the developing world emerging from this initiative through recognized institutions in Europe/USA/UK, not directly to ILRI. This apparently stemmed from the Trust's experiences of the difficulties associated with infrastructure, or lack of it, in parts of the developing world, and/or the complications of currency transfer etc. As a result, no ILRI projects emerged.

In January 2002, the DFID commissioned study entitled 'Investing in animal health research to alleviate poverty' was published. As described above, this had been commissioned by the Inter-Agency Donor Group (IADG) on pro-poor livestock research and development,[149] of which the Wellcome Trust was a member and had been represented at meetings 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 'Investing in animal health research to alleviate poverty' report, in July 2002, the Trust announced a new funding program entitled 'Animal health in the developing world', under which it set aside GBP 25 million over a period of five years to fund researchers to develop methods of predicting and controlling outbreaks of animal diseases. In its press release announcing the awards, the Trust quoted the coordinator of ILRI's Epidemiology and Disease Control group.[150, 151] Preceding the launch of the initiative in June 2003, the Trust held a workshop in March to discuss the types of research that might merit funding and invited scientists from many corners of the world.

A large number of research proposals were developed by ILRI in partnership with institutions in the UK and the US, including gastro-intestinal parasitism, FMD epidemiology and dynamics, anti-tick vaccines, livestock/disease information platforms for East Africa, African swine fever, among many others.

149. https://www.donorplatform.org/livestock-development/on-common-ground

150. http://www.scidev.net/global/capacity-building/news/boost-for-animal-health-in-poor-nations.html

151. http://www.evaluategroup.com/Universal/View.aspx?type=Story&id=230688&sectionID=&isEPVantage=no

The momentum continued from the Trust, which initiated a workshop and training meeting on capacity building and veterinary research training, held at Hinxton in 2005, to which the epidemiology group was invited to attend and present. This contributed to laying the groundwork for the next Trust funding initiative targeted at the developing world, namely the Livestock for Life program,[152] launched in December 2005.

In January 2007, the Wellcome Trust held a meeting to give scientists funded under earlier grant programs 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 and launched on the morning of the opening ceremony (Perry and Sones 2007),[153] and ILRI presented an invited presentation on the challenges of research outputs influencing policy (Perry and Hooton 2007).[154]

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

152. http://www.evaluategroup.com/Universal/View.aspx?type=Story&id=230688

153. Perry, B.D. and Sones, K. R. 2007. Poverty reduction through animal health. *Science* 315:333–334. https://cgspace.cgiar.org/handle/10568/750

154. Perry, B.D. and Hooton, N. 2007. *Translating research outputs into policy and intervention outcomes: the art of knowing and influencing one's ultimate clients*. Animal Health Research: Recent developments and future directions. Wellcome Trust Scientific Meeting, Hinxton Hall, Cambridge, January 24–26th 2007.

The broader economic impact contributions

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. However, there is evidence that as early as 1992, a member of the ILRAD external program and management review team stated that the epidemiology component of impact assessment was not required; what was needed, he argued, was more in the way of crude economic assessments. The review recommended that the epidemiologist post be cut and replaced by more economists, a recommendation rejected by ILRAD management. In his acceptance speech for CGIAR award of International Outstanding Scientist in October 2004, Brian Perry said:

> 'In a system whose strength in numbers is in crops, it is refreshing to see livestock being recognized, given the important role they play in poverty reduction. And on the disciplinary side, in a system dominated by economists, it is also refreshing to see the recognition that quantitative veterinary epidemiology is considered critical in getting the numbers right'.

Nevertheless, economic impact assessments gained increasing momentum, and the arrival of Tom Randolph to ILRI and the epidemiology team in October 1998 brought a broader view of the role of agricultural economics in the tasks of impact assessment assigned to the group at ILRI. Within a few months, Randolph and Perry were working on a review of how well economic impact assessments of the past had been handled and exploring the opportunities for more effective exploitation and integration of the social science discipline.

In a paper prepared as an invited plenary presentation to the 17th International Conference of the World Association for the Advancement of Veterinary Parasitology, in Copenhagen, Denmark in August 1999, they 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 well-being that needs to be put in context' (Perry and Randolph 1999).[155]

And 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 as simple 'bean counters' to add prices to estimated productivity losses. Rather, a new discipline of animal health economics has emerged in which the quality of economic evaluations will depend on the ability to integrate the products of good epidemiological studies into economic frameworks.

Also during 1998, the ILRI Epidemiology and Disease Control group leader was approached by the director general of 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 *Veterinary Parasitology* paper mentioned above, served as important

155. Perry, B.D. and Randolph, T.F. 1999. Improving the assessment of the economic impact of parasitic diseases in production animals. *Veterinary Parasitology* 84:143–166.

milestones for the integrated science of epidemiology and economics. Jonathan Rushton, who was an invited contributor to the OIE book, co-authoring a chapter on methods of economic impact assessment, described it in his 2009 text book on the economics of animal health and production 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' (Rushton 2009).[156]

Agricultural economist Karl Rich moved from the International Food Policy Research Institute (IFPRI) to ILRI in June 2006, and built up the component of the economic impact of market access for livestock products, in particular international trade. He and Brian Perry were invited by former ILRI director general Hank Fitzhugh to provide an economic analysis of the potential costs, benefits and competitiveness of trade in meat from Ethiopia to the Middle East, as part of a USAID-sponsored study undertaken by Texas A&M University (Rich et al. 2008).[157] This report was further developed for a peer-reviewed publication, presented by Rich at the International Food and Agribusiness Management Association (IAMA) in Budapest in June 2009 (Rich et al. 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 products arriving in the market were competitive with others coming from Australia, Brazil and other sources.

Rich and Perry were then invited to undertake a study for DFID on the potential role of commodity-based trade (CBT) on international market access by developing countries (Rich and Perry 2009),[158] and this was further developed into a peer-reviewed publication (Rich and Perry 2011).[159] The authors concluded that on a geographical basis, the benefits of CBT 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 that 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.

156. Rushton, J. 2009. *The economics of animal health and production*. CABI, UK.

157. Rich, K.M., Perry, B.D., Kaitibie, S., Gobana, M. and Tewolde, N. 2008. *Enabling livestock product exports from Ethiopia: understanding the costs, sustainability and poverty reduction implications of sanitary and phytosanitary compliance*. Final report for the Texas Agricultural Experiment Station, Texas A&M University Sanitary and Phytosanitary Livestock and Meat Marketing Program. http://borlaug.tamu.edu/files/2012/03/Enabling-Livestock-Product-Exports-from-Ethiopia-understanding-the-costs-sustainability-and-poverty-reduction-implications-of-SPS-compliance.pdf

158. Rich, K. and Perry, B.D. 2009. *The impact of changing global animal health trading standards on market access for livestock products by developing countries; assessment of commodity based trade*. Commissioned report to the Department for International Development (DFID) of the Government of the United Kingdom, pp 72..

159. Rich, K.M. and Perry, B.D. 2011. Whither commodity-based trade? *Development Policy Review* 29:331–357.

The food safety and zoonotic disease focus

In 2003, under the restructuring resulting from the ILRI strategy revision, a new research program emerged (Livestock Keeping and Human Health Impacts) devoted to enhancing the human health and nutritional benefits of livestock keeping by low-income households, and mitigating the health risks to the poor associated with livestock and their products. This brought a new set of epidemiology contributions, not under a specific epidemiology group, but rather under a multidisciplinary thematic research program. These included a wide range of topics undertaken in partnership with other world leaders in the different fields. The thrusts of the project were food safety, zoonotic diseases and the nutritional impact of animal source food.

Understanding the links between livestock keeping and nutritional status

This research thrust addressed this gap in knowledge by developing a conceptual framework of the pathways by which livestock keeping affects nutritional status and summarizing the available evidence regarding the links along these pathways, their mechanisms, and their relative importance. Collaborators in the Cornell International Nutrition and Agricultural Economics Departments produced a literature review.

To guide the development of its new research program on human health impacts of livestock keeping, state-of-the-art reviews were conducted on the links between livestock keeping and nutritional well-being among the poor (in collaboration with Cornell University, USA). A major strategic product of this thrust was the invited paper by Tom Randolph and colleagues entitled 'Role of livestock in human nutrition and health for poverty reduction in developing countries' (Randolph et al. 2007),[160] which provided a widely cited baseline for the continuing debate on livestock's role in the world.

To begin teasing out the complex links between livestock keeping and nutritional well-being in low-income households, ILRI initiated a project in Ethiopia with the Swiss Federal Institute of Technology (Zurich) to follow a cohort of 400 weaning-age infants. The study focused on the nutritional impact of animal source foods in the weaning diets and how livestock activities in the household affect consumption patterns. This was somewhat ironic and illustrates the waxing and waning of disciplinary fortunes in CGIAR research. In the early stages of the Epidemiology and Socio-economics program, ILRI brought in a consultant, Rebecca Huss-Ashmore, to undertake a preliminary study of the human health benefits of livestock keeping in Uasin Gishu, Kenya (Curry et al. 1996),[161] but in its wisdom, the external review of ILRAD in 1991 recommended discontinuing her position and recruiting more economists.

There has been increasing interest in the potential role that livestock can play in improving care for people living with HIV/AIDS. Animal source foods offer a particularly dense, micronutrient-rich complement to plant-based foods. Households affected by HIV/AIDS suffer loss of labour and knowledge, reducing productivity in labour-intensive agricultural activities.

160. Randolph, T.F., Schelling, E., Grace, D., Nicholson, C.F., Leroy, J.L., Cole, D.C., Demment, M.W., Omore, A. Zinsstag, J. and Ruel, M. 2007. Role of livestock in human nutrition and health for poverty reduction in developing countries. *Journal of Animal Science* 85:2788–2800. https://cgspace.cgiar.org/handle/10568/664

161. Curry, J.J., Huss-Ashmore, R.A., Perry, B.D. and Mukhebi, A.W. 1996. A framework for the analysis of gender, intra-household dynamics and livestock disease control, with examples from Uasin Gishu District, Kenya. *Journal of Human Ecology* 24:161–189.

Livestock, particularly small stock such as poultry, may offer an alternative food and income-generating activities that can be practiced near the home and with low labour and knowledge inputs, and so could be promoted as a coping strategy. These potential benefits of livestock have been evaluated and an evidence base created (see for example Kang'ethe et al. 2012).[162] Challenges of study design have not yet permitted assessments of the risks to immuno-compromised livestock keepers associated with increased exposure to zoonoses.

Improving food safety systems

Media attention to food safety issues and mounting pressure to comply with food safety standards for international trade are raising awareness and demand for improved food safety in developing countries. Attention currently tends to focus on formal, commercial production and marketing systems, especially those oriented to export trade. Little attention has been given to strategies for improving food safety in local domestic markets, particularly informal markets typically beyond the purview of public regulation and surveillance, and where the majority of the poor sell and buy livestock and their products.

Activities around food safety in informal markets started with collaboration from Cornell University, led by Delia Grace, a jointly-appointed scientist, who had undertaken a PhD in the trypanocide resistance project. This built on research to assess human health risks associated with urban livestock keeping in a series of studies in Nigeria, Uganda and Kenya as well as previous work on milk safety as a barrier to smallholder market access in Kenya, Tanzania and Ghana. A series of bilateral projects were funded including: risk assessment in eight African countries; gender and food safety in Nigeria; assessing milk safety in Kampala, (Uganda), Assam, (India) and Debre Zeit, (Ethiopia); and pork safety in Nagaland, India and Vietnam. These covered more than 30 livestock and fish value chains and confirmed that informal markets are the most important source of meat, milk and eggs for poor people in Africa and Asia and are likely to continue to be so for at least the next decade.

The livestock and fish products assessed often contained hazards. Moreover, research in West Africa and India suggests that as value chains become longer and more complex, transport larger and comprising more diversely-sourced volumes of food, placing larger distances between producers and consumers, so hazards increase (Grace et al. 2011).[163] The work confirmed the literature suggesting that in some contexts high levels of disease in developing countries are associated with food. For example, an assessment in Nigeria found a high risk from beef-borne pathogens and suggested beef-borne disease was costing Nigeria nearly USD 1 billion a year (ILRI 2011).[164]

However, a series of studies in some informal milk (and later meat) markets showed that although hazards are always common in informal markets, risks to human health are not necessarily high. Stochastic models based on data derived from a number of sites in eastern Africa showed that milk had many hazards but less risk, mainly because of the consumer practices of boiling milk (Grace et al. 2008).[165] In Nigeria, however, there was a clear link between consumption of beef and increased illness. Studies in eastern Africa, northeast India and Vietnam came to the surprising conclusion that food sold in formal markets, although commonly perceived to be safer, may have lower compliance with standards than informally marketed food (Fahrion et al. 2013).[166]

Economic studies across seven Asian and African countries showed that a wide range of consumers (48–97%) care about food safety, manifest by purchasing behaviour. For example, consumers (20–40%) switch to alternative meats in the wake of animal disease epidemics. Willingness-to-pay studies indicated that consumers will pay a 5–15% premium for safety-assured products, and demand for food safety increases with economic development, rising income, urbanization, increased media coverage and education level (Jabbar et al. 2010).[167]

162. Kang'ethe, E, McDermott, B., Grace, D., Mbae, C., Mulinge, E., Monda, J., Nyongesa, C., Ambia, J. and Njehu, A. 2012. Prevalence of cryptosporidiosis in dairy cattle, cattle-keeping families, their non-cattle keeping neighbours and HIV-positive individuals in Dagoretti Division, Nairobi, Kenya. *Tropical Animal Health and Production* 44(S1):11–16.

163. Grace, D., Lapar, L. and Deka, R. 2011. *Risk assessment of dairy supply chain in Assam, India*. Seventh Asian Society for Agricultural Economics Conference, Meeting the Challenges Facing Asian Agriculture and Agricultural Economics Toward a Sustainable Future, 13–15 October 2011 Hanoi, Vietnam

164. ILRI (International Livestock Research Institute). 2011. *Assessment of risks to human health associated with meat from different value chains in Nigeria: Using the example of the beef value chain*. Nigeria Integrated Animal and Human Health Management Project Draft Report. Nairobi, Kenya: ILRI.

165. Grace, D., Omore, A., Randolph, T., Kang'ethe, E., Nasinyama, G.W. and Mohammed, T. 2008. Risk assessment for *E. coli* O157:H7 in marketed raw and fermented milk in selected African countries. *Journal of Food Protection* 27(2):257–263

166. Fahrion, A.S., Lapar, M.L., Toan, N.N., Thuy, D.N. and Grace, D. 2013. Food-borne hazards in a transforming pork value chain in Hanoi: Basis for future risk assessments. *Vietnamese Journal of Preventive Medicine* 23(4): 18–25

167. Jabbar, M.A., Baker, D. and Fadiga, M.L. (eds). 2010. Demand for livestock products in developing countries with a focus on quality and safety attributes: Evidence from case studies. *Research Report 24*. Nairobi, Kenya, ILRI.

A study on the linkages between gender, collective action and food safety among retail butchers in Ibadan, Nigeria showed the importance of gender as a food safety determinant. The study found butchers' associations with more women members had better food safety practices, better quality of meat and there was less gastro-intestinal illness associated with their clientele (Grace et al. 2012).[168] A study in West Africa found that Fulani believed that because milk was naturally pure, it could not be a source of disease. They boiled milk they sold to customers but not the milk they drank themselves.

As the research program developed, emphasis shifted to risk management. Studies on milk in Kenya and India, and meat in Nigeria, have shown that simple interventions can lead to substantial improvements in food safety. These interventions involved training, simple technologies (such as the use of wide-necked vessels for milk which are easier to clean), social approval, tests for food safety which can be applied by traders and consumers (e.g. lactometer to check for added water) and certification of trained vendors. The study of butchers in Nigeria found that peer training and branding led to 20% more meat samples meeting standards. The intervention cost USD 9/butcher, but resulted in savings of USD 780/butcher/year from reduced cost of human illness (Grace et al. 2012).[169]

Economic assessment of the Smallholder Dairy Project in Kenya showed that recognizing the informal sector and providing training and certification led to benefits worth USD 28 million per annum, demonstrating the high potential impacts of improving food safety (Kaitibie et al. 2010).[170] This study, and others focusing on the livelihood and gender benefits of smallholder value chains, showed the importance of multisectoral approaches to food safety that consider the incentives for change in a given value chain and the aggregate benefits available to the whole sector by way of rewards being paid for quality and spillovers in terms of improved market function.

The work has resulted in multiple publications; see for example Grace et al. 2012a;[171] 2012b;[172] Kang'ethe et al. 2012.[173] This expanded to risk assessment and management in a range of informal value chains for meat, milk and fish in Africa and Asia (see for example Makita et al. 2012;[174] Oguttu et al. 2013;[175] Toyomaki et al. 2013;[176] Yabouet et al. 2013;[177] Fahrion et al. 2014).[178]

The food safety work placed a strong emphasis on risk analysis, and focused on building capacity in risk assessment and adapting it for developing countries. As a new concept it was able to bring some important ideas ('risk is not the same as hazard') and methods (e.g. quantitative microbial risk assessment; QMRA). The development of these tools was timely in providing better methods for evaluating appropriate control strategies for HPAI.

168. Grace, D., Olowoye, J., Dipeolu, M., Odebode, S. and Randolph, T. F. 2012. The influence of gender and group membership on food safety: The case of meat sellers in Bodija market, Ibadan, Nigeria. *Tropical Animal Health and Production* 44 (Suppl 1):S53–9.

169. Grace, D., Dipeolu, M., Olawoye, J., Ojo, E., Odebode, S., Agbaje, M., Akindana, G. and Randolph, T. 2012. Evaluating a group-based intervention to improve the safety of meat in Bodija Market, Ibadan, Nigeria. *Tropical Animal Health and Production* 44(S1):61–66.

170. Kaitibie, S., Omore, A., Rich, K. and Kristjanson, P. 2010. Kenya dairy policy change: Influence pathways and economic impacts. *World Development* 38(10):1494–1505.

171. Grace, D., Kang'ethe, E. and Waltner-Toews, D. 2012. Participatory and integrative approaches to food safety in developing country cities. *Tropical Animal Health and Production.*

172. Grace, D., Monda, J., Karanja, N., Randolph, T.F. and Kang'ethe, E.K. 2012. Participatory probabilistic assessment of the risk to human health associated with cryptosporidiosis from urban dairying in Dagoretti, Nairobi, Kenya. *Tropical Animal Health and Production*.

173. Kang'ethe, E., Kimani, V., Grace, D., Mitoko, G., McDermott, B., Ambia, J., Nyongesa, C., Mbugua, G., Ogara, W. and Obutu, P. 2012. Development and delivery of evidence-based messages to reduce the risk of zoonoses in Nairobi, Kenya. *Tropical Animal Health and Production* 44(S1): 41–46.

174. Makita, K., Dessisa, F., Teklu, A., Zewde, G. and Grace, D. 2012. Risk assessment of staphylococcal poisoning due to consumption of informally-marketed milk and home-made yoghurt in Debre Zeit, Ethiopia. *International Journal of Food Microbiology* 53(1–2):135–141

175. Oguttu, J.W., Makita, K., Grace, D. and McCrindle, C. 2013. Risk assessment of staphylococcal food poisoning through consumption of ready-to-eat chicken sold in informal markets in Tshwane Metropolitan, South Africa. *Food Control* 45:87–94

176. Toyomaki, H., Mahundi, E., Ishihara, K., Kurwijila, L., Grace, D. and Makita, K. 2013. Quantitative risk assessment of acquiring campylobacteriosis from consumption of ready-to-eat beef in Arusha Municipality, Tanzania. *Journal of Veterinary Epidemiology* 16(1):31–32.

177. Yabouet, B.A., Koume-Sina, M., Dadie, A., Makita, K., Grace, D., Marcellin, K. and Bonfoh, B. 2013. Contamination of raw milk with *Bacillus cereus* from farm to retail in Abidjan, Côte d'Ivoire and possible health implications. *Dairy Science and Technology*.

178. Fahrion, A.S., Jamir, L., Richa, K., Begum, S., Rutsa, V., Ao, S., Padmakumar, V.P., Deka, R.P. and Grace, D. 2014. Food-safety hazards in the pork chain in Nagaland, North East India: Implications for human health. *International Journal of Environmental Research and Public Health* 11(1):403–417

Reducing the risk of zoonotic diseases

This thrust is driven by the understanding that the poor are often exposed to relatively high risk of exposure to zoonoses. Poor households that keep livestock often live in close quarters under poor sanitary conditions with multiple species benefiting from little if any veterinary care, and both they and the poor who do not keep livestock typically consume livestock products that have not been subject to inspection or improved processing and storage. For a number of zoonotic diseases, appropriate control strategies are lacking, often because existing control strategies are not suited or affordable to smallholder production systems, little investment has been made to develop the needed control strategies, or there is a lack of coordination between the relevant veterinary and medical sectors.

As a model for zoonotic diseases, cysticercosis which is caused by a pork tapeworm was selected, and ILRI began playing a key facilitator role to support research efforts in Africa and globally to raise awareness about the growing threat to human health of cysticercosis. A senior researcher in veterinary parasitology (Lee Willingham) was seconded from the Royal Veterinary and Agricultural University in Denmark (now part of the University of Copenhagen) to lead this work at ILRI, and organized a regional initiative in East and Central Africa, as well as an international conference at Bellagio in September 2004 to initiate a global control campaign. Studies of various aspects of the epidemiology of cysticercosis in Kenya and Uganda became a thread of epidemiological research at ILRI for several years, in collaboration with university partners in several European countries, albeit never as a major focus of activity until recently. Largely, these comprised prevalence studies in different communities, but more recent work, led by Eric Fevre, has aimed to understand the ecology of domestic pig/human interactions in the communities, and has undertaken formal CODEX style food chain risk assessments. ILRI has also been leading the development of a pen-side diagnostic assay, an excellent example of the coming together of biotechnology approaches and epidemiology; ILRI co-sponsored a recent meeting on global cysticercosis eradication led by WHO (Maurice 2014).[179]

Expertise was also leveraged through an epidemiologist jointly appointed with the Swiss Tropical Institute (Esther shelling), who was based at ILRI for half her time. She brought to ILRI a particular interest in One Health and the economics of zoonoses (Schelling et al. 2007).[180]

The 'People, Animals and their Zoonoses' project was a Wellcome Trust funded project led by Eric Fevre which investigated the epidemiology of zoonoses amongst livestock and their keepers in western Kenya. Western Kenya was chosen as it houses the highest density of both domestic stock and humans in Kenya (outside urban zones), and is broadly representative of the Lake Victoria ecosystem more widely. A summary of the project was published in the *Veterinary Record* (Doble and Fevre 2010),[181] which focused on seven zoonoses. The study was on livestock and the people who keep them, concurrently, at the household level, but also investigated zoonoses in the food chain at slaughterhouses, including the risks of exposure to slaughterhouse workers themselves. A substantial component of the study was also to place zoonoses in the broader context of human and animal health, looking at wealth, nutrition and non-zoonotic co-infections and their relationship to zoonoses. In terms of infrastructure, the project was based in the 'Busia lab' in western Kenya, which is an epidemiological field work facility run as a collaboration between the Government of Kenya, ILRI and university partners. The Busia facility was first established through the Wellcome Trust-funded IDEAL project.[182]

The Urban Zoonoses project is a highly interdisciplinary research project funded under the 'Environmental and Social Ecology of Human Infectious Diseases' Initiative. The main objective is to link an understanding of animal source food value chains in Nairobi as a case study to routes of potential emergence of new human pathogens of livestock origin. This project is a partnership with several UK partners, ILRI, the University of Nairobi, the Kenya-based African Population and Health Research Centre, Kenya Medical Research Institute (KEMRI) and others. The overall objective is to understand the mechanisms leading to the introduction of pathogens into urban populations through livestock commodity value chains, and their subsequent spread.

179. Maurice, J. 2014. Of pigs and people – WHO prepares to battle cysticercosis. *The Lancet* 384(9943):571–572 http://www.thelancet.com/journals/lancet/article/PIIS0140-6736%2814%2961353-2/abstract

180. Schelling, E., Grace D., Willingham, A.L. and Randolph, T.F. 2007. Which research approaches for pro-poor control of zoonoses? *Food and Nutrition Bulletin* (2 Suppl): S345–56.

181. Doble, L. and Fevre, E.M. 2010. Focusing on neglected zoonoses. *Veterinary Record* 166: 546.

182. http://www.vqe.vet.ed.ac.uk/epigroup/ideal_project.html

The focus is on livestock as sources of these pathogens, because emerging diseases are likely to be zoonotic in origin and livestock pathogens, through the close interactions between livestock, their products and people, are at high of risk crossing the species barrier. The focus in this project is on *Escherichia coli*, as an exemplar of many potential emerging pathogens, which exists in a diversity of hosts, in the environment, on food, in waste etc. The geographical focus is the city of Nairobi, Kenya, and its hinterlands. In the microbiology components, the project takes a landscape genetics approach to understanding *E. coli* distribution and spread, with a view to understanding how this is affected by environmental and socio-economic factors.

An assessment of the relative importance of livestock diseases (including zoonoses) in terms of their impact on the poor in sub-Saharan Africa was undertaken (see for example Grace et al. 2012).[183] In addition, a study was commissioned by DFID to map out the interface between poverty and poor livestock keepers and zoonotic diseases (Grace et al. 2012).[184] This was prepared as a planning tool for DFID's subsequent investment, managed by the UK's Biotechnology and Biological Sciences Research Council (BBSRC), of some GBP 20 million into the Zoonoses and Emerging Livestock Systems (ZELS) program, which was formally launched in November 2014.

183. Grace, D., Gilbert, J., Randolph, T. and Kang'ethe, E. 2012. The multiple burdens of zoonotic disease and an ecohealth approach to their assessment. *Tropical Animal Health and Production* 44(S1): 67–73.

184. Grace, D., Mutua, F., Ochungo, P., Kruska, R., Jones, K., Brierley, L., Lapar, L., Said, M., Herrero, M., Phuc, P.D., Thao, N. B., Akuku, I. and Ogutu, F. 2012. *Mapping of poverty and likely zoonoses hotspots.* Report to the Department for International Development. https://cgspace.cgiar.org/handle/10568/21161

Responses to highly pathogenic avian influenza

The emergence of highly pathogenic avian influenza, initially in East and Southeast Asia with subsequent spread to South Asia and Africa, caused disquiet in all animal health research communities and institutions, and ILRI, in collaboration with IFPRI, initiated a wide-ranging consultation to discuss where research could contribute (IFPRI 2006).[185] 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 investigation and responses to HPAI. In 2009, ILRI, in collaboration with AU-IBAR and Veterinarians without Borders – Belgium (VSF-B), trained veterinarians from the veterinary services of 12 African countries in participatory epidemiology in order to make the existing surveillance systems more flexible for emerging diseases such as HPAI H5N1. Over 150 practitioners were trained as well as 38 trainers of which 12 were French speaking. As part of this project, a manual was produced entitled introduction to participatory epidemiology and its application to highly pathogenic avian influenza participatory disease surveillance; A manual for participatory disease surveillance practitioners by Aluma Araba Ameri, Saskia Hendrickx, Bryony Jones, Jeffrey Mariner, Purvi Mehta and Cyrille Pissang.[186] In addition, ILRI developed a user guide for initial bird flu risk maps as a contribution to improving the surveillance for bird flu (Stevens et al. 2009).[187] These have recently been built on and updated in a review (Mariner et al., 2014)[188] and addressed in a new risk mapping report (Gilbert et al. 2014)[189] in which ILRI's Tim Robinson participated. ILRI supported the implementation and evaluation of participatory disease surveillance for avian influenza in Indonesia and Egypt. In Egypt, training of veterinarians in participatory methods resulted in an increase in the detection rate in the household sector that had been largely ignored in the surveillance system used at the time (Rushton and Rushton, 2009).[190] In addition, a further 108 PE trainees and 24 trainers from 15 high risk governorates for HPAI H5N1 were brought into active service. After the end of the ILRI-implemented activities in 2010, the General Organization Veterinary Services (GOVS) decided to continue funding the active surveillance activities of the trainees.

Following a request for assistance by the Federal Government of Nigeria (FGN), World Bank financing of USD 50 million equivalent was approved in April 2006. The Nigerian Avian Influenza Control and Human Pandemic Preparedness and Response Project (NAICP), which resulted, was formally commenced in July 2006. The project management unit of NAICP invited ILRI to undertake an independent end-of-project impact assessment of the investment; ILRI then invited former ILRI epidemiologist and evaluator Brian Perry to lead the evaluation. The evaluation team developed an evaluation framework comprising a set of 10 outcome pillars on which the project was evaluated. The outcome pillars were developed by the evaluation team to depict the benchmark 'gold standard' of best practices against which to evaluate NAICP. For the

185. *How research can support efforts to control avian flu in developing countries: First steps toward a research action plan* https://cgspace.cgiar.org/handle/10568/1875

186. https://cgspace.cgiar.org/handle/10568/367/\

187. https://cgspace.cgiar.org/handle/10568/904

188. Mariner JC, Jones BA, Hendrickx S, El Masry I, Jobre Y, Jost CC, 2014. Experiences in participatory surveillance and community-based reporting systems for H5N1 highly pathogenic avian influenza: A case study approach. Journal of EcoHealth: March 19 DOI: 10.1007/s10393-014-0916-0

189. Gilbert, M., Golding, N., Zhou, H., William, W.G.R., Robinson, T.P., Tatem, A.J., Lai, S., Zhou, S., Jiang, H., Guo, D., Huang, Z., Messina, J.P., Xiao, X., Linard, C., Van Boeckel, T.P., Martin, V., Bhatt, S., Gething, P.W., Farrar, J.J., Hay, S.I. and Yu, H. 2014. Predicting the risk of avian influenza A H7N9 infection in live-poultry markets across Asia. *Nature Communications* 5:4116. http://www.nature.com/ncomms/2014/140617/ncomms5116/full/ncomms5116.html

190. Rushton J, Rushton R (2009) Evaluation of the process of PE/ introduction and impact of the PDS methodology on the national surveillance system in Egypt, Nairobi: International Livestock Research Institute

animal health elements, the outcome pillars drew on (and further developed) the pillars used during the second real time independent evaluation of FAO's global programs on HPAI, (Perry et al. 2010).[191] The task of the evaluation team was to determine, in as empirical fashion as possible, the degree to which the project outputs contributed to the target outcome pillars. The team evaluated both direct and indirect impacts and intended and unintended impacts. The evaluation report was presented to the Government of Nigeria and duly published on an official website (Perry et al. 2011).[192] In addition, two independent peer-reviewed publications emerged from the evaluation (Henning et al. 2012[193] Bett et al. 2012).[194]

191. Perry, B.D., Camus, E., Ellis, T., Mbugua, H., Moore, R., Kapur, S., Isa, K. and Tarazona, C. 2010. *Second real time global evaluation of FAO's work on highly pathogenic avian influenza*. Office of Evaluation, Food and Agriculture Organization of the United Nations, Rome, http://www.fao.org/fileadmin/user_upload/oed/docs/Avian_Influenza_RTE2_2010_ER.zip

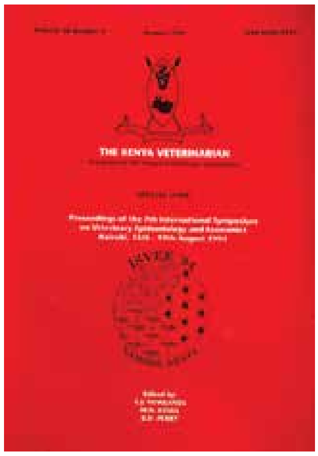
192. Perry, B.D., Randolph, T., Bett, B., Grace, D., Sones, K., Henning, J., Globig, A., Pali, P., Poole, J, Fadiga, M., Hannah, H., Ekanem, E., Abdu, P. and Molokwu, C. 2011. *Independent impact assessment of the world bank-funded Nigeria avian influenza control and human pandemic preparedness and response project (NAICP)*. Government of Nigeria, 258 pp. https://cgspace.cgiar.org/handle/10568/10680

193. Henning, J., Bett, B., Okike, I., Abu, P. and Perry, B.D. 2012. Incidence of highly pathogenic avian influenza H5N1 in Nigeria, 2005–2008, *Transboundary and Emerging Diseases*, https://cgspace.cgiar.org/handle/10568/21083

194. Bett, B., Henning, J., Abdu, P., Okike, I., Poole, J., Young, J., Randolph, T. F. and Perry, B.D. 2012. Transmission rate and reproductive number of the H5N1 highly pathogenic avian influenza virus during the December 2005–July 2008 epidemic in Nigeria. *Transboundary and Emerging Diseases*. 61:60–68 https://cgspace.cgiar.org/handle/10568/24701

The ISVEE experience

The opening ceremony of the ISVEE Nairobi meeting (1994) with the then Kenya Minister of Agriculture Simeon Nyachae (extreme left) being introduced by scientific committee chair Brian Perry (right).



The International Symposium on Veterinary Epidemiology and Economics, known commonly by its acronym ISVEE, has been held every three 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 first proposed by ILRAD's epidemiology group as a future venue for the symposium at the 5th ISVEE meeting in Copenhagen in 1988,[195] and confirmed as the venue for 1994 at the 6th ISVEE in Ottawa in 1991, with Brian Perry as secretary of the organization.[196] This provided the first opportunity to bring ISVEE to Africa and to engage national and regional programs in presenting their work and participating in the meeting. A national steering committee was set up under the chairmanship of the then director of Veterinary Services, Joe Wamukoya, an organising committee under the chairmanship of Sam Chema and a scientific committee chaired by Perry. Through the hard work and commitment of John Rowlands, 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* in order to raise awareness of Kenya's growing national journal (see edition below). The full meeting proceedings are now also available online.[197]

The next ISVEE was held in Paris in 1998 with a strong representation from ILRI and its partners. The level of participation continued to grow substantially and the 9th and 10th ISVEEs (in Colorado, USA and Vina del Mar, Chile, respectively) brought the research of ILRI's epidemiology group to new levels of international 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, though remarkably narrow, foundation in the literature, but that it has

195. http://www.sciquest.org.nz/elibrary/edition/4877
196. http://www.sciquest.org.nz/elibrary/edition/4891
197. http://www.sciquest.org.nz/elibrary/edition/4896

not exploited its potential.[198] He argued that the challenge was to expand the application of economics to animal health issues in more innovative directions and to a broader range of issues, including valuing externalities off-farm associated with livestock health, animal welfare considerations, and the role of animal health in processes of poverty reduction.

While ILRI continues to be represented at subsequent meetings by key ILRI epidemiologists such as Bernard Bett and Delia Grace (in meetings held in Australia 2006, South Africa 2009 and Belgium and the Netherlands in 2012), the commitment to and impact of ILRI seen during the period 1994–2006 has waned.

Impact statement. On 31 August 2014, Roger Morris, inaugural Chairman of ISVEE, wrote:

> 'ILRI and the people associated with it have been very valuable contributors over the last few decades to the development of the International Society For Veterinary Epidemiology and Economics, and especially have ensured that there was strong representation at meetings from a range of African countries and organizations, and that developing country papers received adequate emphasis in the program of the various meetings. Papers to which ILRI staff contributed were prominent at most ISVEE meetings. I was responsible for establishing the International Society in 1979 as the inaugural chairman, and have attended every subsequent meeting, so I am very aware of the range of countries represented and participating presenters. The meeting held in Nairobi in 1994 under the leadership of Brian Perry and other ILRI staff was notable for the strong and diverse African participation, and the overall high standard of the presentations, as well as the excellent atmosphere and organizational arrangements of the meeting. Since then ILRI staff and their collaborators from a range of organizations have continued to make major contributions to the success of ISVEE meetings, and for example at the 2003 meeting in Chile there were over 30 papers from this group, an exceptional achievement. From quite early in the history of the International Society, Brian Perry in particular has provided an outstanding contribution to the development of the field of veterinary epidemiology and economics, and to the growth of the International Society, to the benefit both of ILRI and the successful application of epidemiology and economics in Africa and the rest of the developing world. ILRI can therefore be proud of the leadership it has provided in applying epidemiology and economics to the animal health problems of the developing world'.

198. Randolph, T.F., Saatkamp, H.W. and Perry, B.D. 2003. *A short history of animal health economics*. ISVEE 10: Proceedings of the 10th Symposium of the International Society for Veterinary Epidemiology and Economics, Vina del Mar, Chile: 827 https://cgspace.cgiar.org/handle/10568/1438

The administrative positioning of epidemiology in ILRAD and ILRI

Epidemiology has gone through both administrative and locality changes during its existence in ILRAD and ILRI 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 1987–1994, under ILRAD, it was the Epidemiology and Socio-economics program, also varyingly referred to as Epidemiology and Socio-economics Unit and Socio-economics Program in emerging documentation. During the ILRAD era it was one of four research programs, which comprised Theileriosis, led by Ivan Morrison and later Tom Dolan; Trypanosomiasis, led by Alan Teale; Epidemiology and Socio-economics, led by Brian Perry; and Cooperative Programs, Training and Information, led by Mode Toure. The epidemiology group was initially located in the finance office of the administration wing for a few months, then moved to the new Training Block as the first occupants. It then moved to Lab 8 when that building was completed in 1991, and finally moved to the Epicentre, the converted laboratory animal unit, in 1998. The Epicentre has since been demolished to make way for Mara House.

In the early days of ILRI, from 1995–1997, epidemiology was accommodated under the newly created Systems Analysis and Impact Assessment Group, placing it under the Production Systems Program, but this did not last for long, and from 1997–2002, it became the Epidemiology and Disease Control Group under the Animal Health Program.

Following the arrival of Carlos Seré in 2002, the epidemiology group ceased to exist as such and the scientists involved spread to different institution themes. From 2003–2004, Brian Perry led the Livestock Resources Group, from 2003–2008, Tom Randolph and Delia Grace were accommodated under the People, Livestock and Environment Program and from 2004–2007 Brian Perry and Amos Omore contributed to the Markets Theme.

The impacts of ILRAD and ILRI's epidemiology

Impacts on human resource capacity 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 their incorporation into various research activities; these scientists were predominantly from African countries and a listing is provided in Annex 2. In addition, as mentioned above under 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 some institutions. However, this mostly occurred where there was a specific donor-funded project to support the establishment of an epidemiology group and more common in academic institutions rather than public service bodies such as veterinary departments. Many newly-trained graduates returned to their institutions with a sound training, but did 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, 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

As far as specific diseases are concerned, 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 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 understandings of food safety risks in formal and informal markets, and to the dynamics and risks of zoonotic diseases and other emerging 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 program 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. 2002). The matrix of three 'pathways out of poverty' (see Table 2: 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 ILRI's entire program. 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 demise of epidemiology as an institutional entity in ILRI. Some epidemiology research continued under the Markets Theme (led by Brian Perry), some under the People, Livestock and Environment theme (led by Tom Randolph and Delia Grace); and in 2003 epidemiologist John McDermott became deputy director general, removing him from active research (but placing an epidemiologist in institutional leadership).

Table 2. Animal research priorities for poverty reduction matrix

Research and development categories	Contributions to poverty alleviation		
	Securing assets	Reducing constraints to intensification	Improving market opportunities
Transferring knowledge and available tools			
Improved tools, better strategies better delivered			
New tools and approaches			

Epidemiology survived, and perhaps even flourished, with new programs emerging in Asia (Jeff Gilbert and Fred Unger), the responses of Jeff Mariner and Christine Jost to the avian flu epidemic in Indonesia and the new focuses on food security, risk assessment and zoonotic diseases. Nevertheless, ILRI lost epidemiology and impact assessment as an institutional program. Another irony perhaps in that the global prominence of ILRI's epidemiology during those 15 years was largely a result of the opportunistic approach taken by them during the period in which core funding progressively declined, and the institutional strategy became less clear, demonstrating the demand for structured quantitative epidemiology to support intervention programs.

The Epicentre, as it was known, was at the core of ILRI's research program, and supported work in several other areas. Since 2014, the epidemiology research is now undertaken much more through collaboration. This is illustrated by the position of epidemiologist Eric Fevre, who has a professorial appointment at University of Liverpool but is based at ILRI in Kenya. Many of his team are linked to University of Edinburgh, the Royal Veterinary College and other institutions, but are at ILRI as visiting scientists on joint appointments. These arrangements are driven by external funds, with largely external or semi-external expertise. This has other implications, with the need to work hard at internal ILRI collaborations, as scientists in other program areas see this modality as 'another project', rather than something that underlies the fundamental core research of ILRI.

Annex 1. Scientists in epidemiology and impact assessment at ILRAD and ILRI

Silvia Alonso, epidemiologist

Derek Baker, economist

Bernard Bett, epidemiologist

Paul Coleman, postdoc, epidemiologist

John Curry, social anthropologist

James Delehanty, social anthropologist

Luc Duchateau, statistician

Eric Fevre, epidemiologist

Jeff Gilbert, epidemiologist

Delia Grace, epidemiologist

Barbara Grandin, social anthropologist

Nina Hahn, visiting scientist

Heather Hannah, epidemiologist

Frank Hensen, mathematical modeller

Rebecca Huss-Ashmore, nutritionist

Mohamed Jabbar, economist (animal health and food safety)

Christine Jost, epidemiologist

Simeon Kaitibie, agricultural economist

Henry Kiara, epidemiologist

Theo Knight-Jones, epidemiologist

Russ Kruska, GIS analyst

Lucy Lapar, economist (animal health and food safety)

Pierre Lessard, PhD student

Johanna Lindahl, epidemiologist

Kohei Makita, epidemiologist

Stella Massawe, GIS analyst

John McDermott, epidemiologist

Onesmus Maina, agricultural economist

Jeff Mariner, epidemiologist

Bruno Minjauw, postdoc livestock economist

Saskia Hendrickx, epidemiologist

Adrian Mukhebi, agricultural economist

Florence Mutua, epidemiologist

Alejandro Nin Pratt, agricultural economist

Hung Nguyen, epidemiologist

Chris O'Callaghan, postdoc, epidemiologist

Horace Ochanda, PhD student

Amos Omore, epidemiologist

Brian Perry, epidemiologist

Tom Randolph, agricultural economist

Robin Reid, ecologist

Karl Rich, agricultural economist

Esther Schelling, epidemiologist

Mwansa Songe, epidemiologist

Nadhem Mtimet, economist (food safety)

Barbara Szonyi, epidemiologist

Emmanuel Tambi, agricultural economist

Fred Unger, epidemiologist

Cris Verdugo, epidemiologist

Tennyson Williams, PhD student

Lee Willingham, epidemiologist

Annex 2. Some graduate students in veterinary epidemiology at ILRAD and ILRI

- Pierre Lessard, PhD, Geographic informations systems for the study of theileriosis in Africa.
- Paul Coleman, PhD, Dynamics of rabies in Africa.
- Bernard Bett, PhD, Evaluating the impact of a tsetse-repellent technology on the incidence of trypanosomiasis in cattle managed under pastoral production systems in selected sites in Kajiado and Narok districts, 2002–2008.
- Delia Grace, PhD, Epidemiology and control of cattle trypanosomiasis in villages under risk of trypanocide resistance in West Africa, 2002–2006.
- Stephen Karimi, PhD, Calf health and production in the southern rangelands of Kenya, 2002–2007.
- Lea Berrang, PhD, Spatial and temporal factors associated with the occurrence of rhodesiense sleeping sickness in Uganda, 2002–2006.
- Francis McOdimba, PhD, Genotypic and phenotypic characterization of field isolates of *Trypanosoma brucei* isolated from a longitudinal study, 2001–2006.
- Jeff Mariner, PhD, Disease dynamics and control of rinderpest and CBPP in pastoral areas in the Horn of Africa, 2002–2006.
- Katherine Downie, PhD, Investigating risk factors and prevalence for neurocysticercosis: A case study of Busia District, Kenya, 2009.
- Christine Thuranira, PhD, Socio-economic factors influencing productivity and the uptake of veterinary services in mixed crop–livestock systems in tsetse-infested areas of Kenya, 2001–2004.
- Martin Oditt, PhD, Sleeping sickness in Uganda: spatial and temporal risk factors and efficacy and impact of potential treatment and control options, 2000–2003.
- Noreen Machila, PhD, Tools to improve targeting of drug treatment for African bovine trypanosomiasis, 1999–2004.
- Thomas Gitau, PhD, An integrated assessment of agroecosystem health in smallholder dairy farming in Kiambu District, Kenya, (part-time 1994–1997) 1997–2004.
- Boucader Diarra, PhD, Caractérisation de la sensibilité aux médicaments des trypanosomes isolés sur le terrain dans la province du Kénédougou, Burkina Faso, 1998–2001.
- Gitonga Muraguri, PhD, Epidemiological and financial impact of integrated control of tick-borne diseases and trypanosomiasis in the coastal lowlands of Kenya, 1997–2000.
- Deo Olila, PhD, Pharmacological and epidemiological studies on the drug sensitivity of trypanosomes isolated from a peri-urban dairy production system in Uganda, 1995–2000.
- Julius Kilungo, PhD, Economics of smallholder dairy production in Kiambu District, Kenya, 1992–1999.

- Philip Kitala, PhD, Studies in the epidemiology and control of rabies in Machakos District, Kenya, 1991–1999.
- George Gitau, PhD, A study of factors influencing endemic stability and instability to theileriosis and babesiosis on dairy production in Murang'a District, Kenya, 1993–1998.
- Chris O'Callaghan, PhD, A study of the epidemiology of theileriosis on smallholder dairy farms in Kiambu District, Kenya, 1992–1998.
- Virginia Kimani, PhD, Pesticide residues and their health effects associated with the use and handling of pesticides in a mixed-farming irrigation scheme in Central Kenya, 1992–1997.
- Amos Omore, PhD, Epidemiology and economics of mastitis in the smallholder dairy sector of Kiambu District, Kenya, 1991–1997.
- Mutsuyo Kadohira, PhD, Assessing tropical infections at multiple levels of aggregations, 1990–1994.
- Samuel K. Mugasi, PhD, Enhancing the role of community actions in disease control and natural resource management: The control of human and animal trypanosomiasis, 2011.
- Hamady Djouara, PhD, Etude des circuits d'approvisionnement en trypanocides et facteurs institutionnels de la lutte contre la trypanosomose animale dans les foyers à forte chimiorésistance.
- Patrick Irungu, PhD, An economic analysis of potential adoption of a new tsetse repellent among pastoral communities in Kenya.
- Hippolyte Affognon, PhD, (*magna cum laude*), Economic analysis of trypanocide use in villages under risk of drug resistance in West Africa.
- Tabitha Kimani, MSc, Economic analysis of current tsetse and trypanosomiasis control practices and *ex-ante* assessment of potential demand of a new tsetse repellent.
- Leah Ndung'u, PhD, Assessing animal health delivery for tick and tick-borne disease control in smallholder dairy systems of Kenya: An application of new institutional economics.
- Isaac Ngugi, MSc, Potential demand estimation of East Coast fever vaccines in Makuyu Division, Kenya: An application of contingent valuation and conjoint analysis.
- Dénis Ouédraogo, Doctorat Unique, Analyse socio-économique des pratiques de gestion de la trypanosomose animale et les facteurs associés au développement de la chimiorésistance dans la Province du Kénédougou (Burkina Faso).
- Jospeh Kungu, PhD, Makerere University, Uganda.
- Kristina Roesel, PhD, Free University Berlin.
- Natalie Carter, PhD, University of Guelph.
- Anima Sirma, PhD, University of Nairobi.
- Daniel Senerwa, PhD, University of Nairobi.

Safe Food, Fair Food student theses

Alexander Heeb	Participatory risk assessment on game products marketed through formal and informal chains: Hazard identification and risk assessment.	MSc thesis. Stuttgart, Germany: University of Hohenheim
Flavien Ndongo	Choice of breeds and husbandry practices influencing the safety of milk and milk products from smallholder dairy cattle farms around Nairobi, focusing on brucellosis.	MSc thesis. Stuttgart, Germany: University of Hohenheim
Fanta Dessisa	A risk assessment of *Staphylococcus aureus* poisoning through consumption of raw milk in Debre Zeit, Ethiopia.	MSc thesis. Addis Ababa, Ethiopia: Addis Ababa University
Kaiza Kilango	Food safety in milk markets of smallholder farmers in Tanzania: A case study of Temeke Municipality.	MSc thesis. Morogoro, Tanzania: Sokoine University of Agriculture
Valentin Kone	Représentation sociale de la qualité des aliments au Sahel: Perception et motivation des acteurs dans la sécurité sanitaire des denrées d'origine animale à Cinzana au Mali.	MSc thesis. Abidjan, Côte d'Ivoire : Université de Cocody
Edgar Mahundi	Food safety risk analysis and marketing access of beef in Arusha Municipality, Tanzania.	MSc thesis. Morogoro, Tanzania: Sokoine University of Agriculture.
Ibrahim Sow	Evaluation du risque de brucellose lié à la consummation du lait frais dans la commune rurale de Cinzana, Mali.	MSc thesis. Université de Bamako, Mali
Marisa Spengler	Assessment of water and milk quality in rural mixed crop–livestock farming systems: a case study of Lume and Siraro districts, Ethiopia.	BSc thesis. Stuttgart, Germany: University of Hohenheim
Joy Appiah	Assessment of the risk of consuming milk/ milk products contaminated with Listeria monocytogenes from the informal markets.	M.Phil Food Science, University of Ghana, Legon
Kennedy Bomfeh	Risk assessment for *Listeria monocytogenes* in traditionally processed fish from informal markets in Accra and Tema.	M.Phil Food Science, University of Ghana, Legon
Kevin Kabui	A study of milk quality control by quality based payment system in smallholder farms in Limuru and Eldoret, Kenya.	MVEE thesis, University of Nairobi
Anabela dos Muchangos	Pre-requisites for hazard analysis critical control Points in small-scale poultry production and processing in Maputo, Mozambique.	MSc thesis, University of Pretoria
Cameline Mwai	Risk of contamination of beef carcases with *Escherichia coli* O157:H7 from slaughterhouses in Nairobi, Kenya.	MSc Veterinary Epidemiology, University of Nairobi
Shashi Ramrajh	Risk assessment of game meat and formal/ informal value chain crossover in South Africa.	MMedVet thesis, University of Pretoria.
Haruya Toyomaki	Most probable number of *Thermophilic Campylobacter* in raw and roasted beef in Arusha, Tanzania.	BVSc thesis, Rakuno Gakuen University
Kebede Amenu	Assessment of water sources and quality for livestock and farmers in the Rift Valley area of Ethiopia: Implications for health and food safety.	PhD thesis, University of Stuttgart-Hohenheim

Sylvie Kouamé-Sina	Contribution to risk management for microbial contamination and genotypic diversity of Bifidobacterium species isolated from local milk production chain in Abidjan.	PhD thesis, Université Nangui-Abrogoua
Daniel Qekwana	Occupational health and food safety risks associated with traditional slaughter practices of goats in Gauteng, South Africa.	MMedVet dissertation, University of Pretoria
Sylvain Traoré	Risques de contraction des affections à *Vibrio* spp. et à *Paragonimus* spp. liés à la consommation des crabes et des crevettes vendus sur les marches d'Abidjan et de Dabou.	PhD thesis, Université Nangui-Abrogoua

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