ZELS

Zoonoses &
Emerging Livestock Systems

One Health Research In Action

ZELS programme impact report

UK Research and Innovation

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from the British people

Foreword: A message from Professor the Lord Trees

It has been my great pleasure to lead the Advisory Group for the Zoonoses and Emerging Livestock Systems (ZELS) programme. It has brought together researchers, PhD scholars and others from a range of disciplines and across the world in support of research to improve the livelihoods of some of the poorest and most vulnerable people on Earth, by improving the health of the animals on which they depend and by reducing the transmission of zoonotic pathogens from their animals to themselves.

As scientists, it is easy to get so involved in our own area of expertise that we forget the benefits of other perspectives and, importantly, the application of our science in the real world. ZELS has had real-world impact as its goal from the start. It is gratifying to see evidence from ZELS guiding policymakers in Africa and Asia and feeding into new interventions too. The creation of the ZELS programme was prescient and pre-Covid, but it has helped establish knowledge, expertise and research capability which is absolutely relevant to the prevention of zoonotic pandemics.

Many ZELS researchers found themselves diverted during the pandemic to assist the global response to COVID-19. If we needed any warning of the effect of zoonosis, Covid has surely delivered that, and the ZELS programme has created a substantial foundation for our future preparedness.

Lord Trees
Chair, ZELS Independent Panel Advisory Group

Above *Lord Trees*

Executive summary

In 2011 UK Research and Innovation (UKRI), the UK Government's Foreign, Commonwealth and Development Office (FCDO) and the Defence Science Technology Laboratory (Dstl) joined forces to tackle diseases that could pass from animals to humans. Offering over £22M of funding to support research and training, their aim was to reduce the impact of zoonoses on poor people in developing countries and their livestock, while also forging mutually beneficial partnerships between researchers in the UK and the Global South. This report highlights some of the most significant outcomes and impacts of the Zoonoses and Emerging Livestock Systems (ZELS) programme.

Since the programme's launch, 11 multinational interdisciplinary teams have investigated a range of zoonotic infections, including avian influenza, bovine tuberculosis, brucellosis, campylobacter, human African trypanosomiasis, Rift Valley fever, salmonella and schistosomiasis. ZELS researchers have also trained a cohort of 16 directly funded doctoral students.

ZELS has contributed to new high-tech science facilities and supported the creation of in-country cadres of zoonoses technicians, researchers and surveillance experts.

Our research has been at the forefront of providing up to date information on the spread and causes of disease, and in suggesting control strategies, including locally developed vaccines and diagnostics.

Community initiatives led by ZELS have strengthened ground-level One Health knowledge, skills and understanding.

In line with the programme's aims, ZELS has helped to forge partnerships between researchers in the UK and those from more than 30 overseas institutes and organisations. Between them, these partnerships have generated scientific evidence to inform the selection of risk-based and cost-effective prevention and control options which may contribute to decreasing the likelihood of occurrence, prevent the transmission, and reduce the impact of major zoonotic diseases.

UK research teams not only provided expertise and advanced laboratory technology, but, through their international collaborative links, they also benefited from gaining new knowledge related to changing and emerging zoonotic risks that could potentially threaten the UK. In addition, through international partnerships, UK researchers are able to collaborate with the best scientists overseas, work across nations to tackle global challenges and ensure that there is impact from our bioscience research, skills and innovation for public good.

As at the end of 2021, ZELS researchers had published over 200 papers, 97% of which are in Open Access journals. The papers have been cited 4,463 times by other researchers, that is 84% more often than the expected world average for work published in the same field and year. Our projects also employed creative dissemination methods to ensure their findings reached as wide an audience as possible.

A research programme is not without risk, and we identify the most significant risks and challenges faced by ZELS.

This report concludes with a summary of each project, highlighting some of the impact of our research.

The constant threat of new and emerging zoonotic diseases appearing in the human population was brought dramatically to prominence by the COVID-19 pandemic. Evidence suggests the rate of appearance of zoonoses is increasing and it should be expected that new and unexpected diseases will continue to appear in the future. Looking ahead, there is an urgent need for a more integrated and systematic global coordination of research and innovation to prevent, prepare for, respond to, and recover from future zoonotic disease outbreaks using a One Health approach.

Further information about the ZELS programme can be found on UKRI's website: *https://www.ukri.org/our-work/browse-our-areas-of-investment-and-support/zoonoses-and-emerging-livestock-systems*

Contents

Introduction

Zoonoses and emerging livestock systems (ZELS): a programme for the changing world

The ZELS vision is to make a step change in the research evidence available to inform decision makers on how to minimise the health risks associated with the rapidly changing nature of livestock systems in developing countries, focusing on those risks which impact on the livelihoods and health of poor people.

This programme forms the basis of a strategic partnership between the UK Government's Foreign, Commonwealth and Development Office (FCDO)*, UK Research and Innovation (BBSRC, MRC, ESRC and NERC) and the Defence Science and Technology Laboratory (Dstl).

Background

In 2011, the FCDO commissioned a series of reports on aspects of zoonoses. These reports provided the information from which the design of a research programme could be developed.

There followed an open call by the co-funders for research proposals. A thorough appraisal process led to the selection of 11 projects, worth £18.5M of funding, investigating emerging and endemic zoonotic diseases in developing countries. Projects started to get underway in 2014, with a duration of up to five years.

Common Indicators

£22.6m investment from funding partners

11 projects

64 institutions worldwide

In the same year, grantholders were invited to apply for funding through an Associated Studentship scheme, worth £1.5M. Grantholders were encouraged to apply as a consortium. Fifteen studentships were available, with all students to start at the same time. One award was made, and the student cohort commenced in October 2015.

Key aims of the programme:

To reduce the impact of zoonoses on poor people and their livestock.
The initiative recognises that priorities for endemic, new and/or (re)-emerging zoonotic diseases may vary from region to region. It will address the problem of zoonoses by generating high quality research in technical and policy areas

To forge mutually beneficial inter- and multi-disciplinary partnerships between researchers in the UK and developing countries
that create trans-national added value through meaningful intellectual collaboration and enhance the scientific capabilities of southern partners for the longer term.

* FCDO was formed following the merger of DFID with FCO in September 2020

In 2019, a further tranche of £2.6M funding was made available to allow six projects to take earlier or ongoing ZELS research to the stage of practical application to deliver benefit and impact in developing countries

In this short report, we highlight some of the impact made by the programme to date. It is recognised, however, that the full impact will not be apparent until after the programme's end in 2022.

Each project, with Principal Investigators in UK universities and research institutes, has worked in partnership with research organisations, government departments and others in low- and middle-income countries. The countries involved in the programme are Ethiopia, Kenya, Tanzania, Senegal, Cameroon, Niger, Pakistan, Bangladesh, Myanmar and Vietnam. Additional ZELS research in the form of surveys and trials has taken place in other African countries.

The projects are investigating a range of zoonotic infections that include endemic diseases, such as brucellosis, food-borne zoonoses and bovine tuberculosis, and epidemic diseases such as Rift Valley fever. Also included are zoonotic infections that have previously attracted little attention but have the potential to be of major importance. Examples include zoonotic schistosomiasis and Q fever in Africa.

Right (from top) *TB skin testing (Credit Stefan Berg); Goat check-up (Credit Eric Fèvre); Poultry farm (Credit Guillaume Fournié); Adult schistosomes in mesenteries (Credit Joanne Webster)*

Projects and Principal Investigators

An integrated approach for surveillance and control of zoonoses in emerging livestock systems (Myanmar Pig Project).
Professor Alexander (Dan) Tucker, *University of Cambridge.*

Behavioural adaptations in live poultry trading and farming systems and zoonoses control in Bangladesh (BALZAC).
Professor Dirk Pfeiffer, *Royal Veterinary College.*

Combating bird flu by developing new diagnostic tools and vaccines.
Professor Munir Iqbal, *The Pirbright Institute.*

Epidemiology and evolution of zoonotic schistosomiasis in a changing world.
Professor Joanne Webster, *Royal Veterinary College London.*

Establishment of a multi-sectoral strategy for the control of brucellosis in the main peri-urban dairy production zones of West and Central Africa.
Professor Javier Guitian, *Royal Veterinary College.*

Ethiopia Control of Bovine Tuberculosis Strategies (ETHICOBOTS).
Professor James Wood, *University of Cambridge.*

Hazards Associated with Zoonotic enteric pathogens in Emerging Livestock meat pathways (HAZEL).
Professor Ruth Zadoks, *University of Glasgow.*

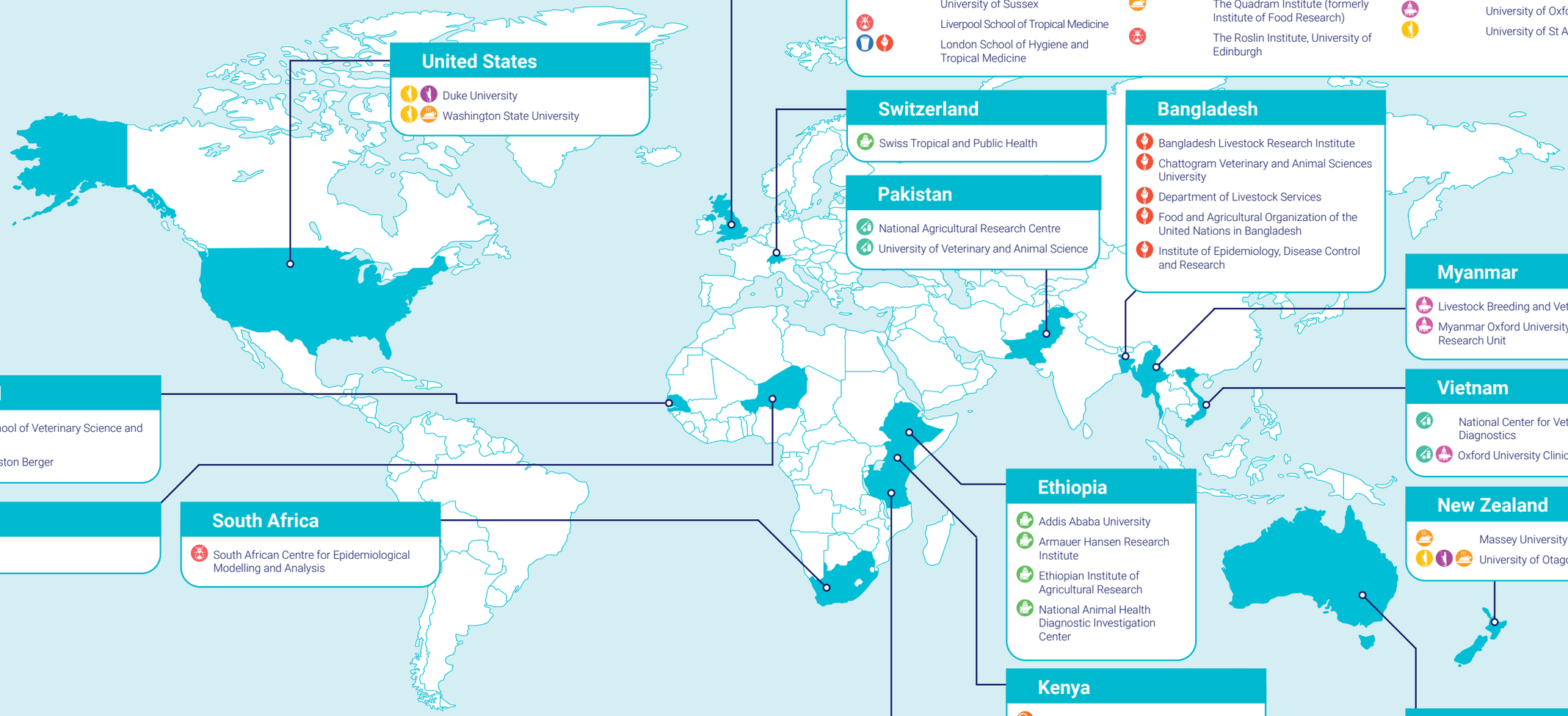
Molecular epidemiology of brucellosis in northern Tanzania.
Professor Daniel Haydon, *University of Glasgow.*

Social, Economic and Environmental Drivers of Zoonoses in Tanzania (SEEDZ).
Professor Sarah Cleaveland, *University of Glasgow*

Tackling Human African Trypanosomiasis on the edge of wilderness areas.
Professor Stephen Torr, *Liverpool School of Tropical Medicine*

Zoonoses in Livestock in Kenya (ZooLinK).
Professor Eric Fèvre, *Institute of Infection and Global Health, University of Liverpool.*

ZELS research around the world



United Kingdom

- Aberystwyth University
- Animal and Plant Health Agency
- Chatham House
- GALVmed
- Imperial College, London
- Institute of Development Studies, University of Sussex
- Liverpool School of Tropical Medicine
- London School of Hygiene and Tropical Medicine
- National Institute for Medical Research
- Royal Veterinary College
- Scotland's Rural College
- The Natural History Museum
- The Pirbright Institute
- The Quadram Institute (formerly Institute of Food Research)
- The Roslin Institute, University of Edinburgh
- University College London
- University of Cambridge
- University of Edinburgh
- University of Glasgow
- University of Liverpool
- University of Nottingham
- University of Oxford
- University of St Andrews

United States

- Duke University
- Washington State University

Switzerland

- Swiss Tropical and Public Health

Pakistan

- National Agricultural Research Centre
- University of Veterinary and Animal Science

Bangladesh

- Bangladesh Livestock Research Institute
- Chattogram Veterinary and Animal Sciences University
- Department of Livestock Services
- Food and Agricultural Organization of the United Nations in Bangladesh
- Institute of Epidemiology, Disease Control and Research

Myanmar

- Livestock Breeding and Veterinary Dept.
- Myanmar Oxford University Clinical Research Unit

Vietnam

- National Center for Veterinary Diagnostics
- Oxford University Clinical Research Unit

Senegal

- Interstate School of Veterinary Science and Medicine
- University Gaston Berger

Niger

- RISEAL

South Africa

- South African Centre for Epidemiological Modelling and Analysis

Ethiopia

- Addis Ababa University
- Armauer Hansen Research Institute
- Ethiopian Institute of Agricultural Research
- National Animal Health Diagnostic Investigation Center

New Zealand

- Massey University
- University of Otago

Kenya

- International Livestock Research Institute
- Kenya Medical Research Institute
- University of Nairobi

Australia

- University of Queensland

Tanzania

- Clinical Research Institute
- Food and Agricultural Organization of the United Nations in Tanzania
- Kilimanjaro Christian Medical College
- Kilimanjaro Clinical Research Institute
- Ministry of Agriculture, Livestock and Fisheries
- National Institute for Medical Research
- Nelson Mandela African Institution of Science and Technology
- Sokoine University of Agriculture
- Tanzania Veterinary Laboratory Agency
- Tanzania Wildlife Research Institute
- Vector and Vector-Borne Diseases Research Institute

Key to project

- Behavioural adaptations in live poultry trading and farming systems and zoonoses control in Bangladesh (BALZAC)
- Molecular epidemiology of brucellosis in northern Tanzania
- Establishment of a multi-sectoral strategy for the control of brucellosis in the main peri-urban dairy production zones of West and Central Africa
- Combating bird flu by developing new diagnostic tools and vaccines
- Ethiopia control of bovine tuberculosis strategies (ETHICOBOTS)
- Hazards associated with zoonotic enteric pathogens in emerging livestock meat pathways (HAZEL)
- Life on the edge: tackling human African trypanosomiasis on the edge of wilderness areas
- An integrated approach for surveillance and control of zoonoses in emerging livestock systems (Myanmar Pig Partnership)
- Epidemiology and evolution of zoonotic schistosomiasis in a changing world
- Social, economic and environmental drivers of zoonoses in Tanzania (SEEDZ)
- Zoonoses in Livestock in Kenya (ZooLinK)

Building capacity

The ambitions of ZELS went beyond impact from research findings. Ensuring that partner countries were left better placed for future zoonoses research and practice – and so a virtuous circle of impact secured – was also a top priority.

There are significant challenges to achieving such long-term benefits in poorer parts of the world, so to maximise the potential for sustainable impact all 11 projects included capacity building in their plans. The result: ZELS has contributed to new high-tech science facilities in Asia and Africa and supported the creation of in-country cadres of specialist zoonoses technicians, researchers and surveillance experts.

Facilities and Infrastructure

In most of our partners countries, the barriers to lab work were great. For example, microbiological supplies were often not available locally, and shipment of supplies was expensive, lengthy and administratively challenging. Equipment was often old, unsuitable or non-existent, and service engineers hard to access. Sometimes a reliable power supply could not be guaranteed.

Laboratories were established or upgraded in Ethiopia, Kenya, Myanmar, Pakistan, Senegal and Tanzania. In Tanzania, a dedicated Zoonoses Lab, at the Kilimanjaro Clinical Research Institute, was inaugurated for the three projects operating in the north of the country.

Above *Field lab, Busia (Credit Laura Falzon); In the lab (Credit Munir Iqbal)*

For the ZooLinK project in Kenya, the team equipped a field diagnostic laboratory in Busia so it could assess the prevalence of the diseases under study.

In Myanmar, a major laboratory refurbishment saw Yangon's Veterinary Diagnostic Laboratory enabled to carry out microbiological tests and services for the Myanmar Pig Partnership project as well as support long-term regional diagnostic capacity for disease and AMR surveillance. It more than doubled its processing capacity.

In Pakistan, a new state-of-the-art avian influenza laboratory at the University of Veterinary and Animal Sciences in Lahore increased Pakistan's capacity to identify the avian influenza virus strains causing local outbreaks as well as to develop and analyse the efficacy of vaccines against them.

The project in Ethiopia has successfully established a bovine TB laboratory at the National Animal Health and Diagnostic Investigation Center (NAHDIC, the Government body responsible for animal health diagnostics). This is a key development that has significantly improved the national diagnostic capability for bovine TB in Ethiopia.

The schistosomiasis project set up and equipped field diagnostic laboratories in both study sites (Richard Toll and Barkedji) in Senegal.

People

However, infrastructure initiatives are of limited long-term value without skilled people, so, infrastructure strengthening went side by side with extensive One Health training and development. For example, in Kenya, 24 trainees from the country's Animal Health and Industry Training Institute gained vital skills in One Health and disease surveillance through three-month internships with the ZooLinK project. In Pakistan, the new lab was used, and will continue to be used, to train postgraduates and other students as well as poultry industry stakeholders.

Among other ZELS contributions to global zoonoses research capacity building, the brucellosis project in West and Central Africa saw 19 students from eight African countries undertake postgraduate research as part of its fieldwork, and it organised more than a dozen training initiatives, ranging from a workshop for lab technicians to training for government veterinary services.

In Bangladesh, the BALZAC team has led the design of the curriculum of the new Field Epidemiology Training Programme for Veterinarians, and is now coordinating its implementation.

Right (from top) *Distribution of gum boots to slaughterhouse workers (Credit Christian Onyando Odinga); Traditional poultry transport (Credit Guillaume Fournié)*

Studentships

The ZELS Associated Studentship (ZELS-AS) programme saw 16 students, including seven from low- and middle-income countries (LMICs) and three social scientists, undertake PhDs as an integral part of a ZELS project.

A key feature of the ZELS-AS, managed by the University of Glasgow, was cohort-based training and networking to complement the students' research training. The students met up on several occasions mixing intensive training modules with the opportunity for them to meet and build relationships with each other. Nearly all our ZELS-AS students have now graduated and are working as One Health practitioners or academics, including one as an Assistant Professor at the University of Veterinary and Animal Sciences in Pakistan and another joining EcoHealth Alliance as a field scientist on a Crimean-Congo Hemorrhagic fever project.

The studies of another 30 PhD students from the UK and beyond, including 13 from LMICs, also benefited from involvement in ZELS projects.

In many ZELS partner countries, community initiatives also strengthened ground-level zoonoses knowledge and understanding, and hence local capacity to prevent disease outbreaks and act quickly when they occur. For example, in Myanmar, Farm Management Workshops and Veterinary Advisory Visits, two innovative discovery-based adult education initiatives, were piloted to support pig farmer learning and build grassroots skills. Initial feedback indicated positive behaviour change from them.

Above from left *Focus group with ZELS-AS student, Bhagya Chengat (right) (No credit); Farm management workshop, Myanmar (Credit Myo Min)*

Influencing policy

ZELS research has been at the forefront of providing up to date information on the spread and causes of disease, and in suggesting control strategies, including locally developed vaccines and diagnostics.

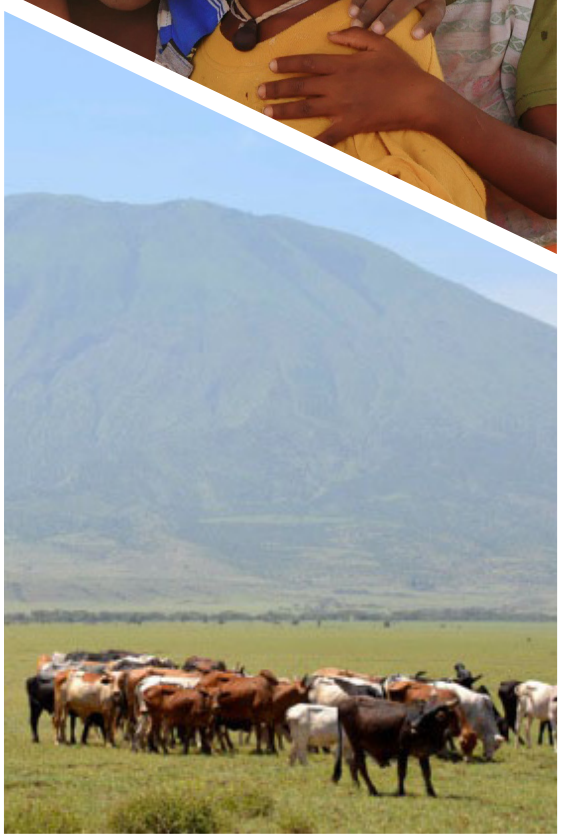
In West and Central Africa, ZELS activities have had a rapid impact on efforts to control bovine brucellosis in the region. Project outputs have shaped brucellosis surveillance and control, with insights into knowledge, attitudes and practices of livestock keepers in peri-urban dairy production areas of 13 countries.

A vaccination trial in Burundi, Cameroon and Togo showed that vaccination of young animals is a cost-effective strategy for controlling bovine brucellosis in low-income endemic settings where elimination by test and slaughter may not be realistic in the short term. The trial also proved that farmers accept the vaccine.

In Togo and Rwanda, evidence from the ZELS project led to the prioritisation of brucellosis for surveillance and control and the introduction of a new surveillance approach. The Togolese government declared brucellosis in cattle, sheep and goats as a notifiable disease, and the government's veterinary services initiated passive and active surveillance activities and public education campaigns. In Rwanda, the strengthening of diagnostic capacity for brucellosis led to the piloting of a new strategy for nationwide surveillance based on regular testing for the presence of antibodies across milk collection centres with promising results.

In Tanzania, a healthcare utilization survey provided fundamental estimates of illness burdens and identified critical points for the improved delivery of healthcare interventions, targeting the largely pastoral population of the Ngorongoro Conservation Area. Incidence estimates of brucellosis at the community level provided robust evidence of disease impact at the population level, while also offering crucial benchmarks to inform policy development and evaluation. In generating and sharing these metrics with stakeholders and decision makers this project can help to address and overcome the shortcomings of current healthcare provision for this and similar pastoral populations, ultimately reducing the burden of brucellosis and multiple other illnesses.

In Myanmar, pilot research findings showed increasing antimicrobial resistance (AMR) in pig meat production in the country's Yangon region. The



Right (from top) *Senegalese boys (Credit Joanne Webster); Mount Longido, Tanzania (Credit Sarah Cleaveland)*

findings have been used to support the strategic objectives in the Myanmar National Action Plan for the Containment of AMR. The evidence can also be used to assist awareness building for producers and consumers, specifically on the potential for reduced effectiveness of antibiotics on farms and the spread of AMR to people and animals via livestock, drainage run-off and meat. Project AMR data underpinned new legislation controlling antibiotics in pig feeds in 2020, and offers insights to support policy reviews on regulations around antibiotics and their use on farms, taking in import, manufacture, labelling, distribution, retail, administration and recording controls. The project also highlighted challenges relating to AMR awareness, antibiotic use and disease prevention for farmers, slaughterhouse workers, veterinarians and others in the pig meat supply chain.

Bangladesh's first National Avian and Pandemic Influenza Preparedness and Response Plan (NAPIP) which defines a five-year roadmap setting priorities and directions for the design and implementation of interventions to reduce pandemic risk, was implemented over a decade ago. Throughout its duration, the BALZAC project worked closely with national policymakers in human and animal health to define BALZAC research activities and interpret their outcomes. This led to the project team being invited to support the revision of the 3rd NAPIP for 2022-2026. They were tasked with re-structuring the NAPIP, reviewing new research evidence and organising participatory and cross-sectoral workshops to co-produce policy recommendations and update the NAPIP. Country-specific and interdisciplinary evidence generated through BALZAC strengthened the feasibility and relevance of policies, creating conditions for effective reduction of Avian Influenza burden and pandemic risk. Long-term cross-sectoral engagement of BALZAC researchers – with environmental, public and animal health sectors, multilateral organisations, NGOs and civil society – was key. It created trust and understanding with and between stakeholders, and facilitated coproduction of policies.

The Government of Tanzania initiated a farmer-led intervention, promoting use of pyrethroids through a subsidy, to control tick and tsetse-borne diseases. The ZELS project completed studies in three districts of Tanzania and found that such use of pyrethroids is widespread and the practice was controlling tsetse populations and hence reducing the prevalence of animal and human trypanosomiasis. This farmer-led approach offers a model of sustainable tsetse control for other countries affected by human and animal trypanosomiasis.

Right (from top) *Field work (Credit Javier Guitian); Woman and child (Credit Joanne Webster)*

Working with communities

Community initiatives strengthened ground-level One Health knowledge, skills and understanding in the countries where our ZELS teams worked. Such local-level capacity building can be critical to prevent disease transmission, to spot disease outbreaks early and to ensure quick and appropriate action when disease outbreaks do occur.

Engaging with the communities among which the research teams worked was also a courtesy and a necessity. Without their support and cooperation, the research often would not have been possible.

Community Engagement

All the projects involved fieldwork working with the communities for mutual benefit.

In Kenya, ZooLinK researchers spotted a community engagement opportunity during the research process when they saw the ragged state of the protective clothing worn by slaughterhouse workers on the site where they were sampling. It led the team to develop a series of training sessions on hygiene, public health and antimicrobial resistance (AMR) for the workers. They combined these sessions, which included training about animal welfare too, with the distribution of protective equipment, enabling them to reach many hundreds of workers.

The ZooLinK project also produced educational videos, including one on AMR which uses engaging storytelling to explain how some harmful bacteria no longer respond to the antibiotic drugs that previously killed them, leaving people without effective medicines. The video goes on to offer clear and simple information on the steps people can take to reduce the development and spread of resistant bacteria, such as good handwashing and vaccination. Taken up by the Government of Kenya, the video is now shown at all Government AMR events and screened in hospital waiting rooms.

Workshops

In Myanmar, innovative participatory adult learning sessions called Farm Management Workshops were piloted. Designed to support learning among pig farmers in the villages where the Myanmar Pig Partnership project

Right (from top) *Community engagement (Credit Alicia Davis); Myanmar focus group (Credit Naomi Marks); Community engagement (Credit Alicia Davis)*

worked, these saw pig farmers meeting fortnightly with a facilitator to explore topics related to pig nutrition, disease and profitability, using observation, experimentation and sharing of experiences by participants.

Initial feedback indicated that the workshops led to positive behaviour change, particularly related to biosecurity, which is essential to protect animal and human health and stop the spread of disease. For example, many of the participating farmers now change their footwear before entering pig pens, and shower and wash their hands more frequently. Groups and whole villages are also now insisting that traders leave their trucks outside their village rather than bring them on to farms and increase the risk of disease spread. A Facebook strategy is further extending the learning from these workshops.

Our ZELS project teams have used other innovative means to report back their findings. In Tanzania, the SEEDZ project re-visited all study communities, providing feedback on the study and information on zoonoses and livestock disease prevention using locally designed, illustrated advice sheets and openly-accessible video material.

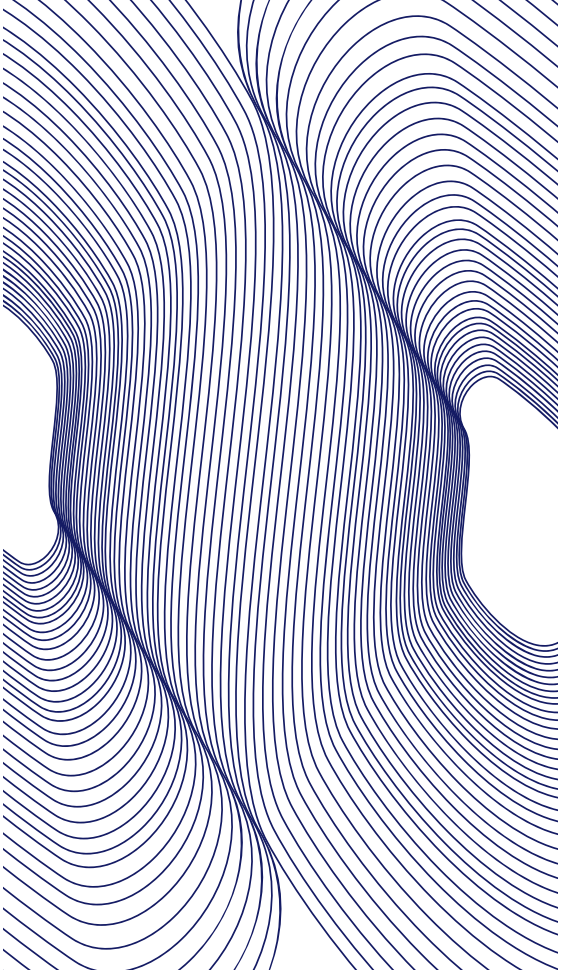
Above *Taking forward Myanmar's AMR National Action Plan (Credit Aung Zaw Moe)*

Partnerships for the future

A main aim of the ZELS programme was to forge strong partnerships between UK and developing country researchers. At the start of the programme in 2015, the 11 projects had established partnership links with 30 research institutes and Government departments in the 9 main countries in which research was to be undertaken (Ethiopia, Kenya, Tanzania, Senegal, Niger, Pakistan, Bangladesh, Vietnam, and Myanmar). As the research developed, partnership links were made with researchers in additional countries which included Cameroon, Togo, and Rwanda, among others.

Each project was led by a Principal Investigator from a UK University or Research Institute, but the research teams also included named Co-investigators both from the UK and elsewhere. Co-investigators assist the Principal Investigator in the management and leadership of the research project as well as frequently undertaking research activities themselves. In the original 11 projects, 99 Co-investigators were listed of which 45 were from the UK, 31 from developing countries and the remainder from universities and research institutes elsewhere in the world.

Above *Partnerships for the future (Credit Mary Ryan)*



As the ZELS projects became established and the research programmes developed, further collaborative links were made with other researchers and projects that has allowed an expansion of the research as well as forming strong working partnerships which can be expected to continue after the ZELS programme is completed. For example, the West and Central Africa brucellosis project (see map on the following page).

Another example of ZELS research leading to an increase in research partnerships is the project in Bangladesh (BALZAC). Outputs from the ZELS project had a significant influence on the vision and research agenda of a large multi-country and interdisciplinary project (the UKRI GCRF One Health Poultry Hub). This project is considering determinants of behaviours of farmers and traders in the design of food safety and pandemic threat prevention programmes aimed at a much needed transformation of the poultry industry in Asia. The Hub is working in Bangladesh, India, Sri Lanka and Vietnam. All the co-investigators and the principal investigator of the ZELS Bangladesh study are involved in this project.

From the outset, the ZELS programme was intended to be run as more than just a collection of 11 separate projects. Co-operation and communication between the projects were encouraged. Annual workshops were organised (in the UK, Tanzania, and Vietnam) to bring the teams together to present and discuss their research and progress. This contributed to the development of research links between the ZELS researchers.

An example of cross-project collaboration is the formation of the ZELS Social Science Group that brings together social scientists from different ZELS projects every few months to discuss possible joint publications and research findings. The group has proved particularly helpful for those social scientists who are early in their careers, some of whom are working in trans-disciplinary projects with natural scientists, veterinarians, and medics for the first time.

The ongoing COVID-19 pandemic has demonstrated the enormous global costs incurred by infectious disease outbreaks, measured in human health and economic terms. Looking ahead, there is an urgent need for a more integrated and systematic global coordination of research and innovation to prevent, prepare for, respond to, and recover from future zoonotic disease outbreaks using a One Health approach.

ZELS research partners in West and Central Africa

An example of partnerships forged by just one project.

Main Partner: Ecole Inter Etats des Sciences et Médecine Vétérinaires de Dakar (EISMV), Senegal

Mali

Laboratoire Central Veterinariare (LCV), Bamako.

Senegal

Laboratoire National d'élevage et recherche vétérinaire (LNERV).

Unité de Recherche sur les Maladies Infectieuses et Tropicales Emergentes (URMITE).

Hôpital Principal de Dakar, Senegal.

FAO's Centre d'Urgence pour les Maladies Animales Transfrontières - Sénégal (ECTAD).

Institut de recherche pour le développement (IRD).

Côte d'Ivoire

Laboratorie National d'Appui au Développement Agricole (LANADA).

Laboratorie Central Vétérinaire de Bingerville (LCVB).

Burkina Faso

Laboratoire National Elevage.

Togo

Institut National d'Hygiène.

Ministry of Agriculture, Livestock and Fisheries.

Laboratoire Vétérinaire de Lomé.

Bénin

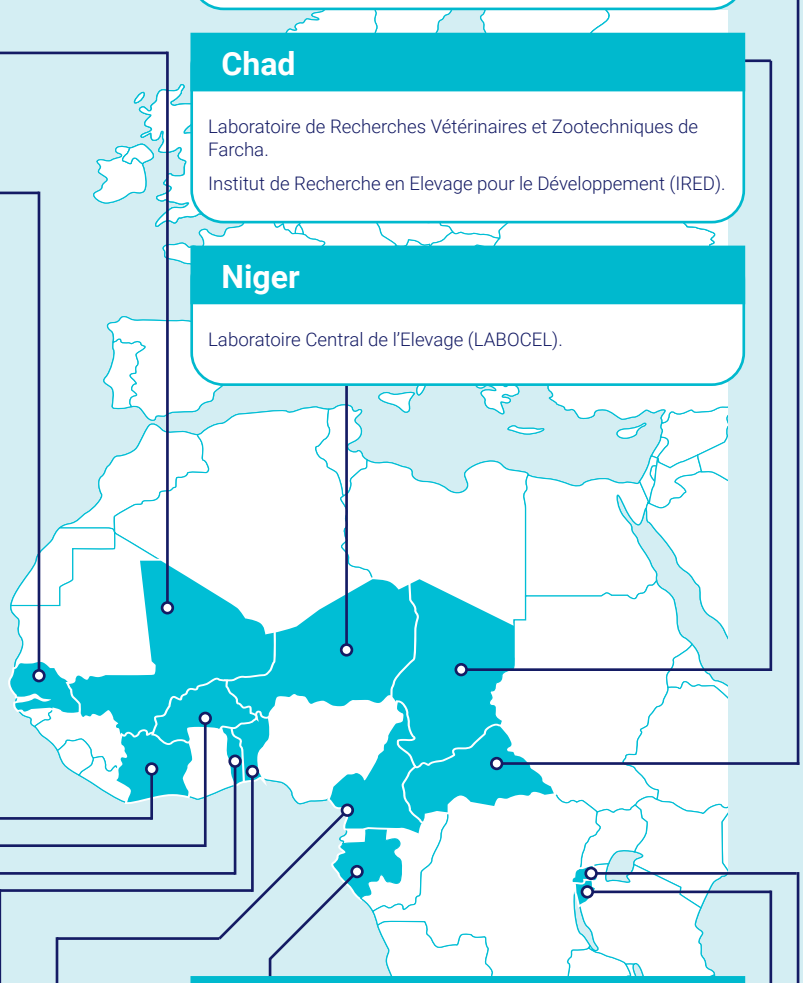
Université d'Abomey Calavi.

Cameroon

Centre de Recherche sur les Filarioses et autres Maladies Tropicales (CRFilMT).

Ecole des Sciences et Médecine Vétérinaire, Université de Ngaoundéré.

Ministry of livestock, fisheries and animal industries, Cameroon.



Central African Republic

Ministère de l'Elevage et de la Santé Animale.

Laboratoire Central Vétérinaire de l'Agence Nationale de Développement de l'Elevage (LANDE).

Chad

Laboratoire de Recherches Vétérinaires et Zootechniques de Farcha.

Institut de Recherche en Elevage pour le Développement (IRED).

Niger

Laboratoire Central de l'Elevage (LABOCEL).

Gabon

Le Centre International de Recherches Médicales de Franceville (CIRMF).

Burundi

Laboratoire National Vétérinaire.

Ministry of the Environment, Agriculture, and Livestock, Burundi.

Rwanda

Rwanda Agricultural Board.

University of Rwanda, College of Agriculture, Animal Sciences and Veterinary Medicine

Benefits of UK-international collaboration

In the area of human and animal zoonotic diseases, the UK has a long history of working with partners from many countries in the world. In the ZELS programme it was the intention to build on these working partnerships as well as developing new collaborative links.

It is important that information on the global prevalence of zoonotic diseases and the emergence of new zoonotic threats is shared widely at an international level. The ZELS programme has contributed to our understanding of such threats through extensive field studies in several countries. UK research teams not only provided expertise and advanced laboratory technology, but they also benefited from gaining new knowledge related to changing and emerging zoonotic risks that could potentially threaten the UK. For example, the Brucellosis and Bovine Tuberculosis research teams at the Animal and Plant Health Agency (APHA) in the UK supported their African partners by providing diagnostic tests, pathogen typing and culturing facilities, as well as training opportunities to scientists and technicians. The benefits of international collaboration went both ways,

Above *UK and international researchers workshop ideas (Credit Naomi Marks)*

with the APHA disease experts maintaining and extending their working links with colleagues outside the UK. Material from the ZELS projects has supported the laboratory work at APHA. For example, through the projects, APHA received serum and pathogen samples from outside the UK that have proved valuable in the development of improved diagnostic tests.

The Avian Influenza research group at the Pirbright Institute in UK has supported the ZELS research in Pakistan, Vietnam, and Bangladesh. Links with researchers in these countries have enabled the Pirbright group to gain up-to-date information on the prevalence and changing patterns of Avian Influenza types. Samples from the ZELS teams are being used in laboratory studies at Pirbright aimed at developing improved diagnostic tests and vaccines.

In addition to UK government-funded organisations, there is considerable One Health and zoonoses research expertise in several universities and other research institutions. The ZELS programme has helped maintain and expand this expertise and knowledge. Strong research teams at the Universities of Cambridge, Glasgow, Liverpool, the Royal Veterinary College, the London School of Hygiene and Tropical Medicine and the Institute of Development Studies (IDS) have led the ZELS studies. These expert groups maintain and grow their expertise and capabilities by working closely with partners in other countries through joint field and laboratory studies.

The programme also provided opportunities for the next generation of British scientists to acquire skills and expertise related to research on zoonotic diseases. As an example, the ZELS programme supported 8 British PhD students through the ZELS Associated Studentship scheme and a further 10 British PhD students, whose stipends were funded through other sources, were linked to ZELS projects and the programmes of research outside the UK.

Right (from top) *Tsetse survey in Tanzania (Credit Steve Torr); Sample collection training (Credit Aung Zaw Moe)*

Publications

The ZELS consortium has produced 226 peer-reviewed published papers during the period 2014 to late 2021 with over 97% of these being in Open Access journals. These are papers where ZELS is acknowledged as a source of funding of the research and/or support for authors of the publication. Papers emanating from the ZELS research programme continue to be published.

Figure 1 gives the number of publications each year. A total of 839 unique authors have contributed to the work from institutions across 63 countries.

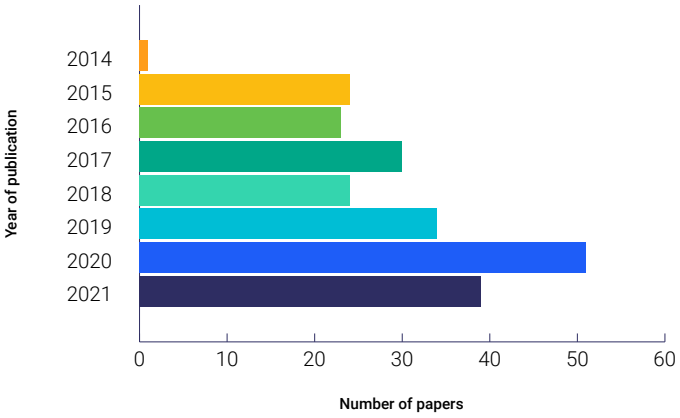


Figure 1: Publications per Year (figure for 2021 represents publications up to Autumn 2021).

By February 2022, the ZELS publications had been cited 4,463 times (mean per paper 21, range 0:739), by 3,578 unique research articles produced by 164 countries, with citation numbers increasing year on year.

On average, ZELS publications have been cited 84% more often than the expected world average for work published in the same field and year. 22% of the publications have been cited more than double and 10% more than three times the world average. 2% of ZELS associated publications made it into the top 1% of cited publications for their field.

Evidence indicates the ZELS projects have provided a strong platform for the development of scientists from Low and Middle Income Countries (LMICs) and early career researchers. 21% of first authors of the papers were scientists from LMICs. Over 7% of the publications had PhD graduates from the ZELS Associated Studentships scheme as first author.

The ZELS programme aimed to support interdisciplinary, collaborative work with researchers from UK, LMICs and elsewhere working together. The data shows that research linked to ZELS is highly collaborative, with over 99% of papers having more than 2 authors (mean 9, range 1:64) and 95% involving multiple institutions (mean 6, range 1:48). The ZELS network provides a strong platform to use as a springboard for future research, information sharing and knowledge transfer.

As the ZELS programme had multi-disciplinarity at its heart, the papers cover a wide range of subjects. Figure 2 divides the papers into categories to give an indication of the number of papers that were judged to address each category, primarily or substantially. Some papers were identified as addressing more than one category.

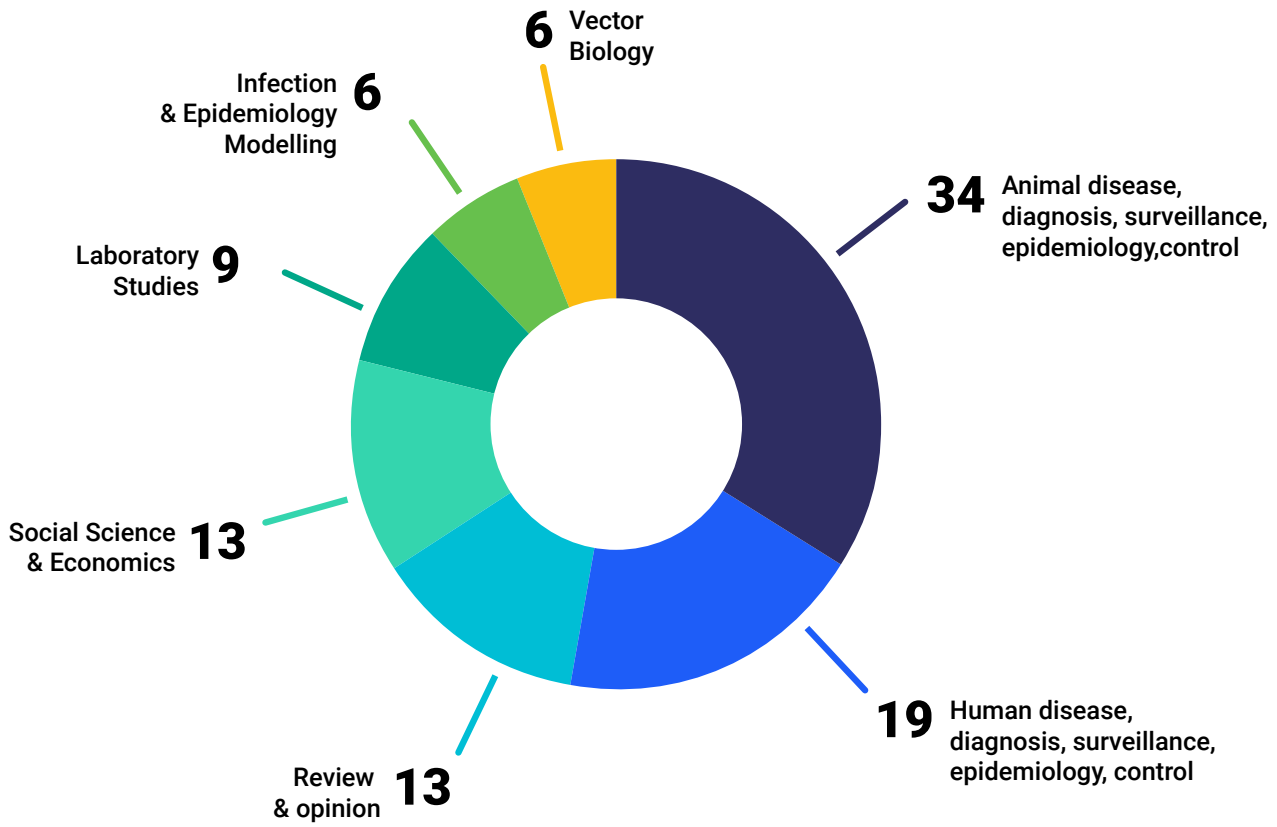


Figure 2: Papers according to subject category (percentages)

Reaching a wider audience

Our researchers understand that making human and animal health-related advances is only one side of the story. Just as important is effective dissemination and communication, especially when it comes to giving people on the ground, such as farmers and village leaders, the confidence to take up the product of the research, thereby reducing the gap between research and practice.

This often involves liaising with key figures of communities to raise awareness. Then, when one community is on board, it is more likely to spread the word.

For instance, our schistosomiasis project in Senegal included one-to-one meetings with village leaders and teachers, significantly increasing community compliance for treatment within certain schools previously refusing treatment.

Such work, through revealing the interdependence between people, animals, parasites and their environment, has helped incorporate a One Health approach into the currently revised WHO guidelines for schistosomiasis elimination in sub-Saharan Africa, as well as facilitating appropriate awareness and treatment practices within disease-endemic regions. The results will also enhance understanding of a wide spectrum of multi-host parasitic diseases of people and animals across our rapidly changing world.

The project produced educational colouring books and made them available for free online in English and French. It also adapted cutting edge peer-reviewed science research papers for students in a Science Journal for Kids article published online in English and French.

In Ethiopia, field work using photovoice was conducted successfully. This participatory approach involved supplying farmers with cameras to record the biosecurity measures they implement. As well as capturing scientific and local knowledge employed by farmers to prevent TB transmission in their cattle, this approach ensures farmers' agency and sees them as creators and consumers of knowledge, not just research subjects.

Right (from top) *Colouring Book English Version (Credit Royal Veterinary College); Educational leaflets (Credit Alicia Davis)*

In Tanzania, a series of television interviews is underway, addressing key issues relating to rabies, brucellosis, anthrax, Rift Valley fever and other emerging diseases. In addition, stakeholders have informed the content of educational leaflets, posters and song lyrics conveying information on multiple zoonotic pathogens. Targeting farmers, these materials aim to make scientific information accessible to a lay audience and non-literate populations.

Above *Farm Management Workshop Myanmar (Credit Myo Min)*

Risks and challenges

All research programmes are subject to risk, from whether enough high-quality proposals meeting the programme goals are received to the call, to project delays due to staffing issues, technical failure, and similar. The risk is heightened when we ask projects to operate across disciplines, organisations and borders for the benefit of international development. Issues such as variations in currency exchange rates, cultural resistance to research uptake, and unanticipated pest/disease outbreaks or weather patterns form barriers to achieving the desired outcomes.

Hence why robust risk management was integrated into ZELS from the outset, at programme and project level. In the research proposals, the projects identified risks that could detrimentally affect research progress and addressed how these risks could be mitigated.

During the programme, significant and unavoidable challenges were encountered forcing projects to change plans and schedules to keep the research going. For example, in Ethiopia and Cameroon serious security issues in certain areas forced the projects to end aspects of field research and move the field studies to other locations.

In Myanmar, the military coup in early 2021 led to the cessation of UK-supported research in the country. Regrettably, not all ZELS project objectives could be achieved as a result.

Delays to research were experienced for various reasons. In Kenya, field research was postponed because an outbreak of Foot and Mouth Disease in livestock, and the ensuing control measures, prevented the research team from working in the area. Unexpectedly protracted administrative procedures delayed the start of research in some countries. Several projects endured a lengthy process to obtain the required approvals for field and laboratory work, as well as ethics sign-off for research studies.

The appearance of COVID-19 presented a significant challenge for all projects. Restrictions brought in to control the pandemic caused delays and, in some cases, cancellation of planned work.

The disease outbreak affected the research in several ways. Movement restrictions prevented field and laboratory research from taking place. Transport and shipping of samples for testing and analysis in other laboratories were not possible. International travel restrictions prevented UK team members from visiting the project sites during much of 2020 and 2021. Planned research and training involving UK researchers and partner country scientists had to be postponed or cancelled. Even when restrictions were eased, the timing was inopportune for certain seasonally dependent field studies. Project extensions and the researchers' willingness to adapt and change research plans has meant that many of the objectives could still be achieved.

Above (from left) *Sensitization on animal welfare during slaughter by one of our field team members (Credit Laura Falzon); Poultry in cage (Credit Erling Hoeg)*

Projects and their research impact

In the following pages, we highlight examples of the impact of each of the ZELS projects.

Tackling disease risk in animals and people

Promoting safer livestock production

Reducing the burden of zoonoses in developing countries

Bringing together scientists from around the world

Training next-generation One Health researchers

Tuberculosis in cattle in Ethiopia

Ethiopia has around 60 million cattle, the largest national cattle herd in Africa. These are mostly of the local zebu breeds which are low milk-yield producers and managed by smallholders.

Above (from top) *Consultation at Koka farm Ethiopia (Credit Stefan Berg); Farmer in cattle shed (Credit Stefan Berg)*

However, Ethiopia's rapidly growing urban populations demand large volumes of milk and milk products. To support this, the Ethiopian Government is encouraging expansion of its dairy sector through investment in high milk-yielding exotic or cross-bred cattle, mostly reared intensively. However, such systems are associated with an increased risk for transmission of infectious diseases, including bovine tuberculosis (bTB).

High bTB prevalence can impact negatively on animal health and dairy productivity, and lead to import restrictions from other countries for dairy and meat products. It is a real threat to further expansion of the dairy sector. In addition to the economic impact from bTB, there is a significant potential human health impact as the disease can transmit from cattle to people.

Extensive field research by the ZELS team has made it possible to estimate transmission rates in Ethiopian dairy herds across the country for the first time and this is helping build scenarios for disease control in different milk production systems. Cattle on 480 farms in Hawassa, Gondar and Mekele regions and areas surrounding Addis Ababa were tested for bTB. The study showed a relatively low average prevalence in the emerging dairy regions as compared to the high prevalence observed in the established dairy belt in the central parts of Ethiopia, especially in and around Addis Ababa City. Implementation of control programmes at this stage could be effective in reducing or possibly stopping further bTB transmission between cattle in the developing dairy regions.

Ethiopia's Ministry of Agriculture showed growing interest in the ZELS project over the project's five-year term, with increased engagement in stakeholder meetings and workshops on animal health and disease control. The project has helped build strong capacity in the field of bTB in the Ministry and the National Animal Health Diagnostic Investigation Center (NAHDIC), as well as at three other Ethiopian research institutes. At NAHDIC, there is now an established research team skilled in diagnostic testing, disease transmission modelling, mycobacterial culturing, and molecular identification of the bTB disease agent, *Mycobacterium bovis* – all critical for the sustainability of future bTB work in Ethiopia. A national bTB steering committee has been set up and a pathway to bTB control is now being drafted, with components aimed at strengthening infrastructure and further capacity building. Plans are underway to support control methods on government and other well-managed farms so these can become demonstration herds showing the way forward for effective bTB control.

Food-borne zoonoses and meat safety in Tanzania

Salmonella is a major cause of disease and death in Tanzania and other countries in sub-Saharan Africa. Typhoid, which is caused by Salmonella, is only transmitted between people, whereas non-typhoidal Salmonella (NTS) types may come from people, animals, or their products. The ZELS project sought to determine the contributions made by red meat to the risk of salmonellosis in humans so that improved control measures in the meat supply chain could be identified and implemented where needed.

The project used methods from both the social sciences and biological sciences and worked together with policy makers and people working in the meat supply chain. Hundreds of samples were collected from livestock, their meat, and the processing environment. The project's laboratory team found NTS in almost every sample type, albeit in low numbers. The bacteria were more common in environmental samples, for example those from butchers' blocks and knives, than in samples from animal hides or meat. DNA sequence data showed that several Salmonella types found in the cattle and goat meat pathway were also found in people in the region, but this didn't include the major disease-causing types in humans. Detection of antimicrobial resistance genes in animal Salmonella was rare compared to human Salmonella. Social science research among butcheries and eateries in northern Tanzania revealed that operators of eateries see their role in meat-handling practices as critically important to maintain meat safety, much more than butchers selling raw meat. The latter place considerable trust in meat inspectors, who inspect and stamp every butchered animal prior to sale to consumers.

Above *Food cooking at an urban eatery (Credit Gerard Prinsen)*

The project recommended that local authorities enforcing policies in a resource-poor context could explore the potential for more efficient or even solicited inspections, building on the finding that meat inspections add commercial value particularly regarding meat sold in butcheries. However, in relation to this, local authorities and researchers need to investigate further the finding that inspections seem to decrease the sense of agency and possibly responsibility regarding meat safety. Unless inspections clearly contribute to better food handling practices, public health benefits are likely to remain elusive or even deteriorate. This is particularly relevant as there is awareness of diseases that may be transmitted by meat or organs with visible abnormalities, but very little knowledge of the presence of disease-causing bacteria such as Salmonella in healthy-looking animals, organs, and meat.

To help prioritise investment in interventions or further research, results from the social and biological science research were integrated in a mathematical model to describe the meat supply chain and investigate the major contributors to the presence of NTS on meat. It showed that control of Salmonella in the ruminant population would have relatively limited impact compared to better environmental hygiene at slaughter and in butchers' shops. The project did not see an increased risk in the more modern, intensive arm of the meat supply chain (slaughterhouse) compared to the traditional arm (slaughter slab), so the emergence of new livestock processing systems gave no reason for food safety concern.

Brucellosis in Northern Tanzania

The research conducted by the *Brucella* project in Northern Tanzania aimed to identify the pathogen and the animal source of human brucellosis, a disease that has significant negative impacts on the livelihoods of people around the world. In Tanzania, uncertainty over the causative *Brucella* species and the livestock source (cattle, sheep and/or goats) of human brucellosis has constrained the design and implementation of effectively targeted control programmes. By working with a community hospital in an area with high suspected prevalence of brucellosis, this project has identified both *Brucella abortus* and *Brucella melitensis* in acutely ill hospital patients and demonstrated that brucellosis is the most common culture-confirmed bloodstream infection in this population. Modelling analyses have identified goats and sheep as the most likely source of human exposure and thus an important target for livestock disease control strategies.

The ZELS *Brucella* project worked with local hospital staff at Endulen hospital to apply diagnostic processes that are not routinely available for study participants and inform treatment decision-making for patients with suspected brucellosis. A bacterial culture and sample transport pipeline to the Zoonoses Laboratory in the Kilimanjaro Clinical Research Institute was established and new diagnostic tools that can be applied for animal and human populations were set up. Continuing medical education sessions and results feedback sessions were also held to guide clinical decision making for brucellosis case detection and management by clinicians beyond the study period. Through these activities, the project has provided training opportunities for nurses, doctors, lab technicians, and PhD students.

At the end of the field work, a series of workshops were held to share project findings with community members and representatives. Key messages communicated about study findings were that *B. melitensis*, most often transmitted to humans from sheep and goats, was the dominant species responsible for cases at Endulen hospital and that cases were most likely in younger individuals who herded cattle, sheep, or goats. Discussions about risk mitigation options focused on the range of existing control strategies which could be most relevant and effective in the study area and how best to try to implement them. Options discussed included reductions in raw milk consumption and improved hand hygiene behaviours particularly around high-risk events such as livestock abortion or parturition.

The project data identifying the pathogens responsible for human illness and the most likely animal source are feeding into Tanzanian policy and control programme development, informing development of policies that can ultimately improve the lives of febrile patients and livestock keepers. Members of the ZELS *Brucella* project team contributed to drafting the National Strategy for Prevention and Control of Brucellosis in Humans and Animals for Tanzania, which includes guidance on brucellosis diagnosis and management in clinical settings.

Above (from left) *Woman with Kid (Credit Felix Lankester); Team walking to patient house (Credit Becca Bodenham)*

Pig production and zoonotic diseases in Myanmar

In Myanmar in recent years there has been a marked increase in meat consumption and this has resulted in a rapid increase in pig production. This has led to profound shifts in the way that meat animals are produced, processed and marketed. At farm level, this is evident in the proliferation of large production units and increased use of purchased inputs e.g. antimicrobials and purchased feeds. The ZELS project, working with Myanmar's Livestock Breeding and Veterinary Department (LBVD), set out to better understand the intensification of pig meat production and supply chains in Myanmar, and how related factors, including challenging socioeconomic conditions for farmers and people's understandings and practices, may affect health risks for people and animals.

A focus of the ZELS project was on how these changes affect the prevalence and likelihood of zoonotic transfer between livestock and people of endemic (*Salmonella enterica*) and emerging (*Streptococcus suis*) bacterial pathogens. There are also concerns about how these changes affect the dynamics of antimicrobial resistance (AMR). South East Asian countries, including Myanmar, are at particular risk from the emergence of AMR because of suboptimal public health and food safety systems. Socio-economic development, consequent rapid expansion and intensification of food production systems, sub-standard livestock health management and a lack of expert advice are all drivers of reliance on antimicrobials and their suboptimal use.

The project has enabled LBVD's Yangon Veterinary Diagnostic Laboratory to implement the first pilot national surveillance of AMR in a livestock species in Myanmar. With the help of the Oxford University Clinical Research Unit in Ho Chi Minh City, the Laboratory was refurbished and equipped, and staff were trained to allow antimicrobial sensitivity testing of Salmonella and other pig-associated bacteria according to internationally recognised standards. Data arising from the project has now provided core information in the Myanmar National Action Plan for containment of antimicrobial resistance.

The project also worked directly with Myanmar pig farmers to promote good pig-keeping practices related to disease prevention. As a result of innovative workshops in which farmers learnt from their farming neighbours, vets and researchers, farmers are now developing new practices whilst taking account of the economic challenges that they face, resulting in improvements in biosecurity at both individual and collective levels – and benefits to both their health and livelihoods.

Above (from left) *Meat at market (Credit Dan Tucker); Myanmar farmer (Credit Naomi Marks)*

Surveillance and zoonoses in Kenya

Western Kenya, which supports one of the highest human and livestock population densities in rural areas of East Africa, has also been identified as a potential hotspot for emerging zoonotic diseases. Animal husbandry practices in this region are changing as production moves from largely subsistence small-holdings to increasing intensification and market orientation. Zoonotic disease risks are changing along with these societal changes. The ZELS ZooLinK project aimed to develop and assess an integrated and cost-effective surveillance and reporting system for 15 zoonotic diseases piloted in the counties of Bungoma, Busia, and Kakamega in western Kenya.

Above (from top) *Distribution of gum boots to slaughterhouse workers (Credit Christian Onyando Odinga); Providing feedback at sentinel livestock market (Credit Eric Fèvre)*

Integrated surveillance systems require political goodwill and commitment, together with adequate funding. In Kenya, the Zoonotic Disease Unit, a government One Health coordinating unit at the national level, creates such a conducive political environment and the project worked in partnership with this unit and with devolved government authorities throughout the course of the studies.

The project established routine sampling and syndromic surveillance activities in hospitals, livestock markets and abattoirs, and obtained accurate, up to date information on the occurrence, prevalence and geographical spread of a range of zoonotic infections. One example of this is a study, that was demand driven by the medical community, to investigate the diagnosis of brucellosis in patients in hospitals. An out-dated and inaccurate test was being widely used and it was shown that a more accurate, cost-effective, and point-of-care test (the Rose Bengal Test) using a high-quality antigen from a trusted source worked well. It was recommended that this should be considered as the nationally approved diagnostic method for brucellosis as it is simple to run and relatively inexpensive. The medical authorities in the study region used these results to lobby nationally resulting in changes in diagnostic approaches that have been integrated into a new national strategy for brucellosis control.

Another study has documented the emergence of cystic echinococcosis, caused by the tapeworm *Echinococcus granulosus*, in western Kenya, an area previously considered free of this disease. Increasing livestock movements to supply the growing demand for meat from disease endemic areas, such as Turkana and West Pokot, into western Kenya have increased the risk of disease importation, and work in abattoirs revealed the high frequency of *Echinococcus* cysts in livestock. The adult tapeworms are found in dogs, and in a survey in the area one dog was found with evidence of a heavy infection. This indicates that the parasitic life cycle between intermediate (ruminant) and definitive (dog) hosts is becoming established, posing a risk for humans who can serve as aberrant hosts. An ultrasound screening programme, also sponsored and managed by ZooLinK, identified cystic lesions in seven human patients in western Kenya, though such infections are yet to be confirmed through pathology investigations. Taken together it appears that a focus of an old disease is becoming established, and that future work should aim at continued surveillance of the disease, more widespread human surveys, and local establishment of diagnostic assays for screening dogs.

Schistosomiasis in Senegal and Niger

Schistosomiasis is a waterborne tropical disease caused by parasitic blood flukes of the *Schistosoma* genus. Animals and humans become infected via freshwater snails that act as intermediate hosts for the parasite. Schistosomiasis has the second highest socioeconomic impact of any parasitic disease (after malaria), and more than 220 million people are currently estimated to be infected, predominantly in low-income and middle-income countries. The infection can be treated with the drug praziquantel but despite many years of mass administration of the drug to school-aged children, the burden of schistosomiasis remains extremely high in many regions across sub-Saharan Africa.

Above (from top) *Livestock and people in river at Thiago (Credit Elsa Leger); Goats in urban area (Credit David Rollinson)*

Through the first ever systematic and extensive sampling of humans and animals for schistosome infection, the ZELS project, working in Senegal and Niger, has revealed the hitherto unrecognised importance of livestock and wildlife in maintaining schistosomiasis transmission within West Africa. This elucidation of the role of zoonotic schistosomiasis in maintaining transmission in Africa has been fed directly back into international and national policy, including WHO guidelines and national control programme implementation.

The ZELS work in Niger and Senegal has improved the capability of human and veterinary health professionals to diagnose human and livestock schistosomiasis. For example, ultrasonography is the diagnostic tool of choice for detecting pathologic conditions associated with human schistosomiasis, both in hospital and field-based settings. It is non-invasive and well accepted by communities, but there was originally no expertise nor facilities available within Senegal. The provision of equipment and training has enabled clinicians in Senegal to become fully proficient in schistosomiasis-related ultrasonography to assess early and late-stage morbidity profiles, as well as identifying, for the first time, a unique morbidity profile associated with hybrid infection.

Working with farmers, it became clear that there was an unmet demand for veterinary-formula praziquantel, which had led to inappropriate use of human drug in livestock. Subsequently, the project began working with international pharma and local suppliers to develop, and maximise access to, a praziquantel formula suitable for livestock. As a result of this, a new formula has been made available in West Africa that field veterinarians in the areas covered by the project are using routinely to treat schistosomiasis in livestock.

Combating avian influenza in Pakistan and Vietnam

Avian influenza viruses (AIVs) are endemic in poultry in many lower- and middle-income countries. The impact of AIV-related poultry mortality and morbidity leads to financial instability of stakeholders involved in all aspects of the poultry value chain, including farmers, traders, and retailers. Outbreaks of disease and detection of highly pathogenic avian influenza (HPAI) have triggered highly disruptive response efforts, including widespread culling, market closures, and erection of trade barriers.

In Pakistan, the ZELS project focused on the H9N2 avian influenza virus that has been endemic in the country since 1998, inflicting direct annual losses of more than US$50m and indirect losses of more than US$80m to the country's poultry sector as well as presenting a risk of zoonotic infection. The ZELS project, through the provision of equipment, reagents, and training, facilitated the opening of a new, high-tech laboratory at University of Veterinary and Animal Sciences (UVAS) in Lahore, enabling important research work in improving AIV disease control systems in Pakistan. The laboratory has increased Pakistan's capacity to identify virus strains, to analyse the potency and efficacy of vaccines against locally prevalent viruses, and to increase awareness about the availability of new disease control tools, including the novel vaccines and diagnostics developed at The Pirbright Institute. An important function of the UVAS AIV laboratory is to serve as a reference centre for the detection of AIV strains. The laboratory helped generate key evidence regarding the impact of AIV mutations on the efficacy of poultry vaccines currently in use in Pakistan.

Above *A farm worker ready to fill feed in the feeding trays with layer birds in cages (Credit Hassaan Bin Aslam)*

Thousands of samples from farmed poultry have now been collected and analysed. The data shows that multiple variants of H9N2 viruses are causing disease outbreaks and new vaccines should target these strains to provide effective protection. The strain selection and vaccine efficacy data from the project was shared with local poultry vaccine producers. As well as the immediate and direct impact on the disease through vaccine and diagnostic development, the research laboratory will continue to facilitate the training of postgraduates, as well as disseminating good biosecurity practices to students and poultry industry stakeholders. Importantly, the project led to a private-public partnership between UVAS and the Pakistan Poultry Association, to promote sustainable and resilient chicken production and continued field-based research on poultry vaccination and diagnostics.

In Vietnam, the ZELS project investigated the transmission of avian influenza viruses and how it is influenced by the structure of live poultry trading networks. Pirbright researchers worked with partners at the National Centre for Veterinary Diagnostics and the Oxford University Clinical Research Unit in Vietnam. Their work has identified the groups that are most likely to employ trade practices that increase the risk of infection in chickens. For example, chickens that retailers bought from middlemen suppliers, who travel between live bird markets and mix poultry stocks, had an increased chance of being infected compared to those that were bought directly from large farms. This better understanding of the dynamics and practices of live bird markets in Vietnam could aid vaccination strategies during outbreaks.

Changes in livestock systems and zoonotic disease risk in Tanzania

In Tanzania, urbanisation is increasing demand for milk and meat products and linking pastoral communities more closely with urban centres. Meanwhile, land-use pressures have resulted in the encroachment of pastoral livestock into wildlife areas. Climate change is also affecting livestock production systems. The ZELS project (SEEDZ) explored the consequence of these changes on livestock-keeping practices and zoonotic disease risk, with a focus on three important zoonoses, brucellosis, Q fever and Rift Valley fever. Field studies were carried out in Arusha and Manyara Regions, northern Tanzania where it was possible to make comparisons between smallholder settings close to urban centre, such as Arusha, agro-pastoral communities and pastoral communities, including those bordering wildlife protected areas. This was a multi-disciplinary project with the research team drawing on social, cultural, political, economic, environmental and epidemiological investigations and analyses.

Qualitative data from social science studies has led to a better understanding of some of the consequences of environmental change and how this affects livelihoods and disease risk. Pastoralists tell of the need to walk their animals further and further in search of adequate water and grazing. Erratic rainfall patterns, combined with human and livestock population growth, and increasingly restricted access to traditional grazing lands, mean that livestock-based livelihoods in the marginal areas of northern Tanzania are becoming ever more precarious. Future climate projections for East Africa suggest that this pattern is set to continue. Rainfall patterns will become more and more variable, with periods of unusually severe drought followed by periods of very heavy rainfall likely to become the norm.

The ZELS research is revealing a range of potential impacts such changes are likely to have on the livelihoods of livestock keepers in northern Tanzania. One area of concern relates to the risk of outbreaks of Rift Valley fever (RVF) that not only has serious health implications in humans, but also important economic consequences as a cause of livestock productivity losses and closure of abattoirs and markets. The disease is of major international concern because of the potential for transboundary spread.

Large outbreaks of RVF are known to be precipitated by unusually heavy rainfall. Although these have historically been rare in Tanzania, the ZELS research shows that the virus is circulating continuously at low levels in livestock-keeping communities of northern Tanzanian during the inter-epidemic periods. These transmission events may represent small-scale RVF outbreaks that are occurring below the surveillance detection threshold but are likely to be causing economic and public health impacts. The project found that human RVF exposure risk is highly clustered within particular communities and that the consumption of raw milk is a significant predictor of human infection. This raises concerns not only for pastoral and agropastoral communities that are highly dependent on milk for food security and nutritional health, but also for urban populations that are served by an expanding peri-urban dairy sector. As a result of ZELS, further funding was leveraged that showed that RVF outbreaks are indeed occurring within the peri-urban dairy sector. These are important and novel findings, and the project is now working closely with the Ministry of Health and the One Health Coordination Desk to develop guidelines for raising awareness about the risks of raw milk consumption during RVF risk periods.

The poultry industry and avian influenza in Bangladesh

Tackling avian influenza is a priority in Bangladesh, where poultry production is the main livestock sector and expected to triple by 2050. The disease is responsible for major poultry production losses and sporadically affects people, sometimes fatally. What's more, the virus which causes the disease has the potential to mutate into new, pandemic human influenza strains.

Until recently, efforts to curb avian influenza focused almost exclusively on the virus itself. However, the ZELS project in Bangladesh explored the behaviour of the people producing and trading poultry. It showed how important people's behaviour is in driving the disease and how the social, economic and cultural contexts in which people in the poultry industry live and work are key in determining the success or failure of disease control and prevention efforts. In particular, the research has revealed how avian influenza viruses are transmitted and amplified along poultry trading networks, leading to their dangerous ubiquity in the live bird markets through which almost all poultry are marketed in Bangladesh.

The project concluded that while technical interventions are important for effective avian influenza control, it is also essential to address factors influencing people's behaviours in the poultry production and trade. These include, for example, the systems for farmers accessing financial capital and credit. The current systems often lead them to make decisions based on short-term rather than long-term goals, making them more likely to engage in risky behaviours.

The end result of this research exploring the daily reality of poultry farmers and its implications for disease spread is a new, more effective One Health approach to controlling avian influenza in Bangladesh. Links with key policy figures were established early on and an inter-ministerial One Health Secretariat, as advocated by the project, had been approved by the time findings were available. Project research evidence, alongside other evidence, has been presented at roundtable meetings attended by key actors from across government, industry and stakeholder organisations. This evidence is now directly contributing to the development of Bangladesh's new National Avian and Pandemic Influenza Preparedness and Response Plan.

Above (from top) *Poultry farm (Credit Guillaume Fournié); Poultry at the market (Credit Ahsanul Hoque)*

Brucellosis in dairy cattle in West and Central Africa

With rapidly growing urban populations in many countries in Africa there has been a marked increase in the demand for dairy products. Peri-urban dairy farms are an expanding livestock system supplying milk but there is the risk that they also pose a threat as a source of *Brucella* infection in humans via contaminated milk. The ZELS project looked at how it may be possible to achieve a sustainable reduction of the prevalence of brucellosis in peri-urban dairy farming systems in West and Central Africa.

Above (from top) *Fieldwork (Credit Javier Guitian); Farmer with cattle herd (Credit Javier Guitian)*

An improved assay was introduced for the detection of *Brucella* antibodies in milk and has now been successfully used in cross-sectional surveys of peri-urban dairy herds in 14 countries in West and Central Africa. The results have shown that brucellosis is endemic in most peri-urban dairy areas in the region and control programmes are absent.

Data on livestock keepers' knowledge, attitudes and practices in several West and Central African countries have been gathered and analysed. The results of the analysis show that a relatively high prevalence of brucellosis often coexists with a low level of awareness among livestock keepers of its potential transmissibility to humans. This component of the project has generated new knowledge of direct applicability as part of public education and awareness campaigns tacking brucellosis. For example, in Senegal it was found that raw milk consumption is deeply ingrained in the local culture. Local people believe that raw milk is healthier and boiling milk will lead to mastitis in cows. This is a key finding as boiling is often recommended as an intervention to ensure microbial safety of milk and milk products. Evidently, this cannot easily be advocated in some communities, as it does not conform to local beliefs. Hence, it was recommended that the focus, in this instance, should be on maintaining good animal health and welfare and better milk hygiene practices.

An objective of the project was to demonstrate the feasibility and practicality of delivering and administering *Brucella abortus* S19 live attenuated vaccine as an approach for control. Vaccine pilot studies were conducted in 5 peri-urban zones of three countries, Burundi, Cameroon, and Togo. During these studies it was possible to vaccinate in a relatively short period, with limited resources and almost no incidents, close to 1500 animals in 176 herds. The pilot trials have provided the veterinary services of these countries with an opportunity to assess the feasibility of a larger intervention, including identifying barriers that may compromise large scale vaccine programmes. The ZELS project has influenced policy and, for example, the Veterinary Services of Togo now includes brucellosis among the zoonotic diseases to be prioritised for surveillance and control and a new surveillance approach has been introduced.

Human and animal trypanosomiasis in Tanzania

Trypanosomes transmitted by tsetse flies cause human African trypanosomiasis (HAT) commonly called sleeping sickness. The infection is fatal unless treated and there is no vaccine or drug to offer protection against the disease. Tsetse also transmit trypanosomes which cause disease in livestock estimated to kill >1 million cattle/year. In East and Southern Africa, HAT is a zoonosis with wild animals (warthog, buffalo) and sometimes livestock (cattle) acting as reservoir hosts. Consequently, wilderness areas where tsetse and wild reservoir hosts are abundant act as foci for HAT and pose a risk to people and livestock living in neighbouring areas.

The ZELS project investigated the transmission dynamics of trypanosomiasis at the interface of wilderness and farming areas with the ultimate purpose of identifying strategies to protect people and livestock living close to wilderness areas. Studies were carried out in the Serengeti District of Tanzania which borders the Serengeti National Park (SNP). Surprisingly, the project did not find any tsetse, a vector which can travel up to 1 km/day, more than 5 km from wilderness areas. A geostatistical model was developed which could identify areas outside the Park where it was predicted tsetse would be abundant but the ZELS team did not catch any flies there either. Cattle across Serengeti District were sampled and none were found to be infected with the trypanosome species causing sleeping sickness. At the edge of the wilderness areas, it was expected that cattle would be the predominant host for tsetse but it was found that only 1% of tsetse had fed on cattle. Against expectation, there was no evidence that HAT was spreading out of the wilderness area.

Investigation by the ZELS team provided an explanation for this unexpected finding. There was evidence that livestock-keepers were independently implementing and sustaining a program of control of tsetse that was interrupting transmission at the interface of settled and wilderness areas. Surveys revealed that 95% of livestock-keepers reported treating their cattle regularly with pyrethroids to control tsetse and ticks. More than half of livestock keepers also treated their animals with trypanocides. Models of HAT predict that these levels of treatment will interrupt transmission of the infection. Studies at the interface of Tarangire National Park, another focus of sleeping sickness, and Simanjiro district showed similar trends. The Government of Tanzania has actively promoted, with a financial subsidy, use of pyrethroids on cattle for tick and tsetse control. It appears that this national policy has created an enabling environment which allows livestock-keepers themselves to control HAT at the interface of wilderness and farming areas.

The findings are an example of a successful One Health intervention against sleeping sickness. This example of livestock keepers protecting themselves and their communities offers two important lessons for other countries and communities at risk across East and Southern Africa. Firstly, the findings show that treating cattle with pyrethroids can contain the risk of HAT. Secondly, the project has provided preliminary but strong indications of how national governments might establish enabling environments that will deliver a One Health solution to the problem of sleeping sickness.

Assessment

Assessment process

The application and assessment process for the ZELS scheme was two-stage. Outline proposals were sought in the first instance, from which selected applicants were invited to submit full proposals.

The assessment process for outline proposals involved separate, parallel sub-panels which met concurrently to consider (primarily) Science Quality (SQ) and Development Relevance (DR) respectively.

Following the separate meetings of the two sub-panels, their chairs met with an overall chair as a Moderating Panel to reconcile the individual panels' outputs, comparing their priority-ordered lists of outline proposals as a basis for deciding which applicants to invite to submit full applications (i.e. only those rated highly by both panels).

Outline stage

Moderating Panel

Professor Richard Bennett *University of Reading, Science Quality (SQ) sub-panel*
Professor Peter Fryer *University of Birmingham – Moderating Chair*
Professor Brian Perry *University of Edinburgh, Chair Development Relevance (DR) sub-panel*
Professor Eleanor Riley *London School of Hygiene and Tropical Medicine - Chair SQ sub-panel*
Professor Peter Roeder *Taurus Animal Health – DR sub-panel*

Science Quality (SQ) sub-panel

Professor Richard Bennett *University of Reading*
Professor Mike Boots *University of Exeter*
Professor Neil Ferguson *Imperial College London*
Professor Jonathan Heeney *University of Cambridge*
Professor Julian Ketley *University of Leicester*
Dr Maggie Mort *University of Lancaster*
Professor Jeremy Mottram *University of Glasgow*
Professor Hilary Ranson *Liverpool School of Tropical Medicine*
Professor Eleanor Riley *London School of Hygiene and Tropical Medicine - Chair*
Professor Judith Smith *University of Salford*
Professor Mark Woolhouse *University of Edinburgh*

Development Revelance (DR) sub-panel

Dr William Amanfu *FAO, Ghana*
Dr Katinka de Balogh *FAO, Italy*
Dr Veronique Chevalier *CIRAD*
Professor Stefan Elbe *University of Sussex*
Dr Lami Lombin *former executive director of the National Veterinary Research Institute Nigeria*
Dr Clare Narrod *University of Maryland*
Dr Miles Nunn *Centre for Ecology & Hydrology*
Professor Brian Perry *University of Edinburgh - Chair*
Professor Peter Roeder *Taurus Animal Health*
Dr Beth Scott *DFID*
Dr Laura Shackelton *Bill & Melinda Gates Foundation*

Final Stage

Dr William Amanfu *FAO, Ghana*
Dr Katinka de Balogh FAO, Italy
Professor Richard Bennett (Deputy Chair) *University of Reading*
Professor Mike Boots *University of Exeter*
Stefan Elbe (Deputy Chair) *University of Sussex*
Professor Neil Ferguson *Imperial College*
Peter Fryer (Chair) *University of Birmingham*
Professor Paul Gibbs *University of Florida*
Dr Peter Jeffries *GALVmed*
Professor Julian Ketley *University of Leicester*
Mrs Lami Lombin *University of Jos, Nigeria*
Dr Anni McLeod *Independent Consultant*
Dr Maggie Mort *University of Lancaster*
Professor Jeremy Mottram *University of Glasgow*
Dr Clare Narrod *University of Maryland*
Dr Miles Nunn *Centre for Ecology and Hydrology*
Professor Brian Perry (Deputy Chair) *University of Edinburgh*
Professor Eleanor Riley (Deputy Chair) *London School of Hygiene & Tropical Medicine*
Professor Mark Stevens *Roslin Institute*

ZELS-Supplementary Research Panel

Dr William Amanfu *FAO, Ghana*
Professor Richard Bennett *University of Reading*
Professor Mike Boots *University of California, Berkeley*
Professor Paul Gibbs *University of Florida*
Dr Anni McLeod *Independent Consultant*
Dr Christie Peacock *Sidai Africa Ltd*
Dr Andrew Simpson *Public Health England Rare & Imported Pathogens Laboratory (RIPL)*
Dr Sanipa Suradhat *Chulalongkorn University, Bangkok*
Emeritus Professor the Lord Sandy Trees *University of Liverpool*
Dr Elma Tchilian *The Pirbright Institute*
Professor Linda Scobie *Glasgow Caledonian University*

Governance and management

Funders Committee (ZELS-FC)

- The ZELS-FC included a representative from each funding partner. It was the programme's executive decision-making authority, with responsibility for setting and driving the commissioning of research, managing the programme, and for the development of an annual reporting structure.
- It agreed and approved the peer review process and the composition of the Assessment Panel.

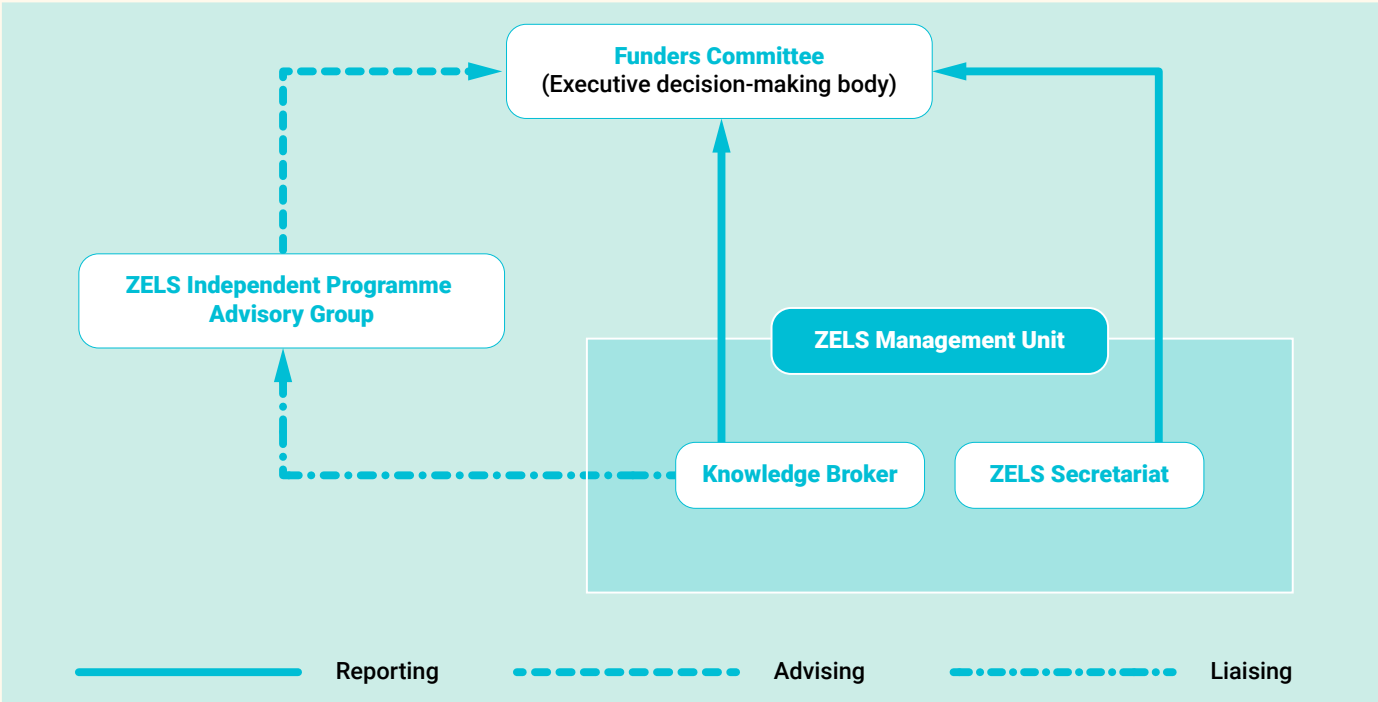
ZELS Independent Programme Advisory Group (ZIPAG)

- Comprised members from key stakeholders nominated by the ZELS-FC, mainly drawn from the Assessment Panel following completion of the assessment process.
- Reported to the ZELS-FC and provided independent advice to the ZELS programme on strategic and technical aspects of the programme.
- Provided quality assurance of the ZELS programme annual review and monitored progress of funded projects.
- Facilitated contact with other initiatives and processes where appropriate via the Knowledge Broker.
- Members of ZELS-FC attended ZIPAG in an observer capacity.

ZELS Management Unit

ZELS was implemented and coordinated by the Management Unit, with two main functions:

- Knowledge Broker: facilitated effective liaison between key stakeholders and researchers.
- Secretariat: decision-making authority on operational and non-strategic matters and provided all administrative and financial management functions related to calls and grants. Managed the commissioning process and provided main point of contact with the individual projects.
- The two functions collaborated to ensure synchronised reporting to the ZELS-FC and ZIPAG in respect of overall operational management and implementation, and knowledge, evidence and communication emerging from the ZELS programme. They provided strategic input to the ZELS-FC regarding programme implementation.



Above *ZELS management structure*

ZELS Independent Programme Advisory Group (ZIPAG) Membership

Dr William Amanfu *FAO, Ghana*
Professor Richard Bennett *University of Reading*
Professor Mike Boots *University of California, Berkeley (Member: 2015–2019)*
Dr Mike Francis *BioVacc Consulting Ltd*
Professor Paul Gibbs *University of Florida*
Dr Anni McLeod *independent consultant*
Professor Dilys Morgan MBE (from 2019) *Public Health England*
Dr Christie Peacock OBE *Sidai Africa Ltd*
Dr Andrew Simpson *Public Health England (member: 2017–2019)*
Emeritus Professor the Lord Sandy Trees *University of Liverpool - Chair*

Project Partners

EUROPE

UK

Aberystwyth University (ETHICOBOTS)
Animal & Plant Health Agency (Brucellosis, Brucella, ETHICOBOTS)
Chatham House (BALZAC)
GALVmed (Brucellosis)
Imperial College, London (Combating bird flu)
Institute of Development Studies, University of Sussex (SEEDZ, HAZEL, Myanmar Pig Partnership)
Liverpool School of Tropical Medicine (Life on the edge)
London School of Hygiene & Tropical Medicine (Brucellosis, BALZAC)
National Institute for Medical Research (Combating bird flu)
Royal Veterinary College (Brucellosis, BALZAC, Schistosomiasis, Combating bird flu)
Scotland's Rural College (Life on the edge)
The Natural History Museum (Schistosomiasis)
The Pirbright Institute (Combating bird flu)
The Quadram Institute (formerly Institute of Food Research) (HAZEL)
The Roslin Institute, University of Edinburgh (Life on the edge)
University College London (ETHICOBOTS)
University of Edinburgh (ZooLinK)
University of Cambridge (Myanmar Pig Partnership, ETHICOBOTS)
University of Glasgow (SEEDZ, HAZEL, Brucella, Life on the edge)
University of Liverpool (ZooLinK)
University of Nottingham (ZooLinK)
University of Oxford (Myanmar Pig Partnership)
University of St Andrews (SEEDZ)

Switzerland

Swiss Tropical and Public Health (ETHICOBOTS)

AFRICA

Ethiopia

Addis Ababa University (ETHICOBOTS)
Armauer Hansen Research Institute (ETHICOBOTS)
Ethiopian Institute of Agricultural Research (ETHICOBOTS)
National Animal Health Diagnostic Investigation Center (ETHICOBOTS)

Kenya

International Livestock Research Institute (ZooLinK)
Kenya Medical Research Institute (ZooLinK)
University of Nairobi (ZooLinK)

Tanzania

Food and Agricultural Organization of the United Nations in Tanzania (HAZEL)
Kilimanjaro Christian Medical College (SEEDZ, Brucella, HAZEL
Kilimanjaro Clinical Research Institute (SEEDZ, Brucella, HAZEL)
Ministry of Health, Community Development, Gender, Elderly and Children, Tanzania (SEEDZ, Brucella)
Ministry of Agriculture, Livestock and Fisheries (SEEDZ, Brucella, HAZEL)
National Institute for Medical Research (SEEDZ)
Nelson Mandela African Institution of Science and Technology (SEEDZ, Brucella, HAZEL)
Sokoine University of Agriculture (SEEDZ, Brucella, HAZEL)
Tanzania Wildlife Research Institute (SEEDZ)
Tanzania Veterinary Laboratory Agency (Life on the edge)
Vector and Vector-Borne Diseases Research Institute (Life on the edge)

Niger

RISEAL (Schistosomiasis)

Senegal

Interstate School of Veterinary Science and Medicine (Brucellosis)
University Gaston Berger (Schistosomiasis)

South Africa

South African Centre for Epidemiological Modelling and Analysis (Life on the Edge)

ASIA

Pakistan

National Agricultural Research Centre (Combating bird flu
University of Veterinary and Animal Sciences (Combating bird flu)

Bangladesh

Bangladesh Department of Livestock Serices (BALZAC)
Bangladesh Livestock Research Institute (BALZAC)
Chittagong Veterinary and Animal Sciences University (BALZAC)
Department of Livestock Services (BALZAC)
Food and Agricultural Organization of the United Nations in Bangladesh (BALZAC)
Institute of Epidemiology, Disease Control and Research (BALZAC)

Myanmar

Livestock Breeding and Veterinary Department, Ministry of Livestock, Fisheries and Rural Development (Myanmar Pig Partnership)

Myanmar Oxford University Clinical Research Unit (Myanmar Pig Partnership)

Vietnam

National Center for Veterinary Diagnostics (Combating bird flu)

Oxford University Clinical Research Unit (Combating bird flu, Myanmar Pig Partnership)

OTHER

Australia

University of Queensland (BALZAC)

New Zealand

University of Otago (SEEDZ, Brucella, HAZEL)

Massey University (HAZEL)

United States

Duke University (SEEDZ, Brucella)

Washington State University (SEEDZ, HAZEL)

Zoonoses &
Emerging Livestock Systems