

Environmental & Social Ecology of Human Infectious Diseases (ESEI)

Understanding the drivers of emerging infections ...





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INTRODUCTION

Environmental and social drivers can play a critical role in the transmission and spread of many infectious diseases. The rapid rate of globalisation and widespread environmental change is increasing the potential threat to human health from both existing and novel infectious pathogens. Over 60% of infections in humans are caused by pathogens that can be spread from non-human animals to people (zoonotic diseases) and transmission can often be complicated by the involvement of specific vectors such as mosquitos and other biting insects.

The Environmental and Social Ecology of Human Infectious Diseases ESEI was an £11million joint initiative between the Medical Research Council (MRC), the Natural Environment Research Council (NERC), the Economic and Social Research Council (ESRC) and the Biotechnology and Biological Sciences Research Council (BBSRC) and the Food Standards Agency (FSA) under the umbrella of the Living With Environmental Change programme.

ESEI was developed to respond proactively to the global problem of potential pandemic, epidemic and emerging infectious diseases by increasing our knowledge of the complex environmental and social interactions involved in the emergence and transmission of pathogens.

KEY OBJECTIVES FOR ESEI

- to establish interdisciplinary teams of researchers, to conduct high quality, innovative integrated research, addressing national/international research priorities and able to inform and impact policy and practice.
- to support research that tackles a complex zoonotic infection, considered a significant threat to public health now or in the future and where an inter-disciplinary approach would provide more comprehensive insight.
- to foster the development of a new paradigm, fostering a 'one health' approach transcending discipline boundaries, and to build capability in this approach to research.
- to encourage the inclusion of policy makers early in the research to increase the likelihood and take up of evidence into practice or policy process.

This groundbreaking scheme adopted a two-phase catalytic approach to consortia building with a series of workshops and investigator meetings to foster relationships across biomedical, social and environmental disciplines as well as nurturing international partnerships.

The three major consortia supported in the final funded phase tackled three very different pathogens on three different continents and involved both diverse scientific expertise as well as close working with leading national and international policy makers. In the five years that these projects have been active they have already demonstrated the power of interdisciplinary approaches and are revealing much needed insights to enable national governments to adopt practice and policy shifts which will improve lives today and in the future.

CONSORTIA PROJECTS

The ESEI projects have taken place in different geographical settings and cultural contexts, but a common thread is rapid and complex change occurring in their individual real-life settings. Each of the projects comprised a diversity of integrated activities and each have contributed to national and international capacity and capability building in their domain. The ESEI consortia have gathered important research outputs and evidence to help inform national and international policy makers in the challenging decisions that need to be taken to mitigate the risks of zoonotic infection.



URBANZOO

Epidemiology, Ecology and Socio-Economics of Disease Emergence in Nairobi

Professor Eric Fevre Institute of Infection and Global Health University of Liverpool & International Livestock Research Institute



Urbanisation and infection

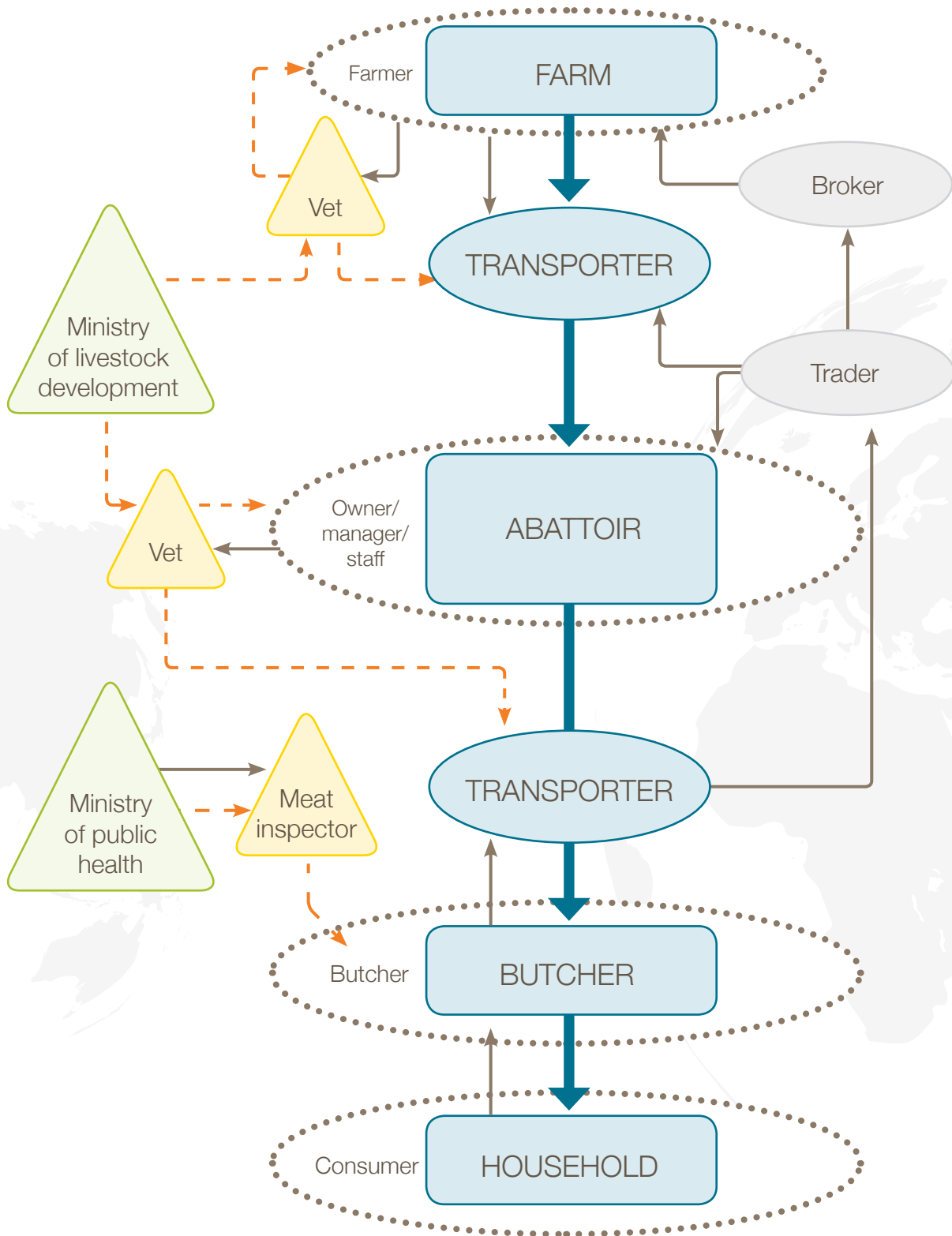
In the developing world, Africa has experienced the highest urban growth during the last two decades at 3.5% per year and this is expected to continue until 2050 (1). Urbanised environments in Africa are frequently melting pots of activity and interactions, with rapid unregulated growth in poorer settlement areas or slums, rubbing shoulders with more affluent areas. Urban livestock keeping is common. In some parts of Kenya's capital Nairobi, 50% of households keep livestock and urban cattle are estimated to produce 40% of the city's milk. This interface between livestock and humans is a potentially important source of pathogen emergence and transmission particularly where livestock live alongside people; human and livestock waste is poorly disposed of near food production areas; formal and informal trading takes place often through complex networks; and the poor live alongside the wealthy.



The URBANZOO study was organised around 12 partner institutions in the UK and Kenya. This interdisciplinary consortia has investigated how the presence of livestock affects the microbial ecology of the city: and how the microbial floras of humans, livestock, other animals (such as rodents and birds) and the wider environment are related.

Using a 'marker' bacteria *Escherichia coli*, the research team collected samples from the broadest range of environments within and around Nairobi in a 'landscape genetics' approach.

At the same time, a series of social and economic studies centred on the concept of the value chain, were undertaken. These examined the drivers of urban livestock keeping, related these to other sources of livestock products, and explored how practices were related to supply and demand. This provided an insight into how the risk of pathogen flow along animal source food systems occurs, and how these risks are likely to change in the future as urban livestock keeping patterns change and the wider issue of urban food security becomes more challenging with increasing rates of urbanization.



The concept of the 'value chain' is used to understand the complexity and contexts of the numerous linkages between urban dweller's consumption of animal products (meat, milk etc) and the source of those products, either from livestock in the city or elsewhere.

URBANZOO outcomes and impact

Emerging cities such as Nairobi often lack a comprehensive policy plan for development. Growth can be driven by short-term economic gain, construction is unregulated and public services such as waste removal and sewage are often not prioritised, especially in low-income settlements (slums). However, these low-income settlements represent 60% of the city's population and supply the workforce for the majority of its industries.

Public policy in all areas of urban planning and health needs to become more integrated, taking a holistic and long-term view to the changing demography of the city. URBANZOO is contributing important inputs for this planning process, and has facilitated intersectoral interaction.



The microbial (bacterial) footprint of Nairobi's urban livestock, wildlife, human population and environment has been mapped from an analysis of the large range of samples collected during the study. Pathogens that are widespread in poverty-stricken neighbourhoods are also present in high-income areas. Wildlife including insects, rodents and wild birds live alongside humans and domestic livestock in Nairobi and this additional interface presents further disease transmission risks, which are complex to manage.

'We're redrawing the map of Nairobi, not based on geography but on the connectedness of animal and human populations, in terms of the bacteria that they share. - Eric Fèvre

<https://www.newscientist.com/article/mg22329842.900-mapping-the-web-of-disease-in-nairobis-invisible-city/#.VRoSNTuUfIF>
NEW SCIENTIST FIELD NOTES
27 August 2014

While not a major focus of the study initially, the work on *E. coli* and the tools used to understand its diversity, has naturally evolved towards work on antimicrobial resistance and members of the team were involved in developing Kenya's National Policy on Antimicrobial Resistance, which launched in May 2017.

Value chains and risk

The value chains that supply animal source food products to a dense urban population are often long and complex. URBANZOO has established that Nairobi's food system is massively diverse, with meat and dairy products produced, sold and consumed across socio-economic boundaries. Some value chains originate and end within the city, where local production feeds local consumption. However, other chains are

Mapping the web of disease in Nairobi's invisible city

By Peter Guest



Bacterial bottlenecks
(Image: Andrew McConnell/Panos Pictures)

THE Dandora landfill site in eastern Nairobi is a monument to the Kenyan capital's runaway growth; a junk monolith built by the city's 3 million citizens.

On its rim is Korogocho, an informal settlement of tens of thousands of people that, like the dozen other such slums in the city, doesn't officially exist. More than 60 per cent of Nairobi's population live in these makeshift suburbs hammered together from scraps of corrugated iron.

They house the hundreds of thousands of people who flock to the city annually, pulled by the promise of work. By 2025, the United Nations predicts that Nairobi will be home to more than 6 million people, the majority of whom will

much longer, extending nationally and internationally. Most chains, no matter what length, exist within a formal rule system but are governed by informal rules. This informality leads to a lack of oversight and give rise to food safety risks, particularly around contaminants and around the consumption of waste food products.

Illness in children and access to animal source food

The URBANZOO case control study focused on the question of the risk factors for diarrhoea in children under five in low income settlements (slums). The team specifically explored the relationship between livestock keeping and diarrhoeal disease in children. Their analysis showed that in such locations, where safe water is provided this can successfully reduce the primary risk of water borne diarrhoeal pathogens. However, the consumption of animal source foods, particularly those sourced from the informal sector trade, is a significant predictor of diarrhoea.

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Mapping for food safety

How and why communities in Nairobi's informal settlements are creating and using maps to ensure their food and the people who sell it are safe

Paolo Cravero

21 December 2015

UrbanFood and agriculture

A red balloon more than a metre in diameter rises above tin roofs in Mathare, one of Nairobi's biggest informal settlements. As the balloon's handler walks through the narrow alleyways, a camera dangling from the balloon snaps a photo every second. This eye in the sky is helping the community identify and deal with threats to their daily food supplies.

Cooking up a storm:

Community-led mapping and advocacy with food vendors in Nairobi's informal settlements

<http://pubs.iied.org/pdfs/10734IIED.pdf>

URBANZOO community surveys and community mapping identified specific risk points in food production trading networks where food safety interventions can take place and these are now being applied.

It is a frequently overlooked point that poor populations with restricted living space and a lack of amenities, do not have facilities for food preparation and often depend on third party foodsellers. Indeed, the informal market for cooked food (essentially a ready-meal) is important for low-income populations, despite the potential food safety risks. Training of vendors and food sellers in better preparation and handling of their foodstuffs is a further area of intervention, which has been well received in the communities.

The URBANZOO results are providing policy support for relevant Kenya ministries around urban livestock keeping, managing food safety risks, and the control of the spread of antimicrobial resistance, where the competing needs of policy need to balance public health risks in largely informal markets, with the need for food and income security.

ENIGMA

Sources, seasonality, transmission and control:
Campylobacter and human behaviour in a changing environment

Professor Sarah O'Brien University of Liverpool

enigma The Study Of *?* Campylobacter

Campylobacter is the most common bacterial cause of human diarrhoeal disease in the developed world, including the UK. These bacteria normally inhabit the intestinal tract of warm-blooded animals such as poultry and cattle, and are frequently detected in foods derived from these animals. In circumstances where food is poorly prepared, this results in foodborne illness (food poisoning) which though commonly mild, can be severe and may cause death. However, Campylobacter can also be found in water and the environment and may result in an alternative 'environmental' transmission route in a significant proportion of cases of human infection. This may explain the interesting seasonal emergence 'spring peak' of cases that has been observed.



The ENIGMA team has focused on understanding the relative roles of foodborne versus the natural environment as a source of human and animal (those animals which are a source of food) exposure to Campylobacter and how human behaviour may affect disease risk attributable to these routes. The interdisciplinary team brought together more than 35 researchers spanning a broad repertoire of expertise including microbiology, bacteriology, epidemiology, genomics, environmental sciences, economics, statistics, bioinformatics, spatial and geographical information, modelling, veterinary and human health and food safety. The study was progressed within five interrelating work packages.

1. Ecological
analysis of patterns
of risk using
historical data



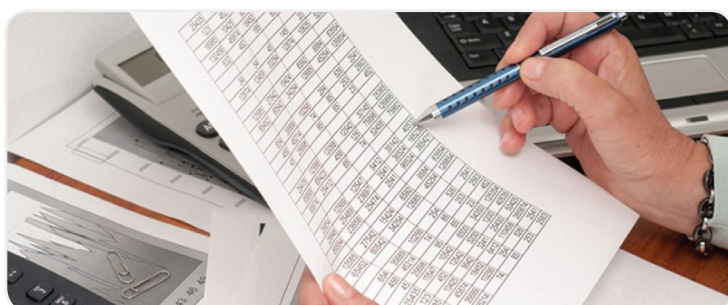
2. The ecology of
Campylobacter infection
on farms: infection of
people through
environment and food

3. Landscape as
a direct source of
human exposure



4. The economic costs
of Campylobacter
and assessment of
interventions to reduce it

5. Alternative
Risk
Futures





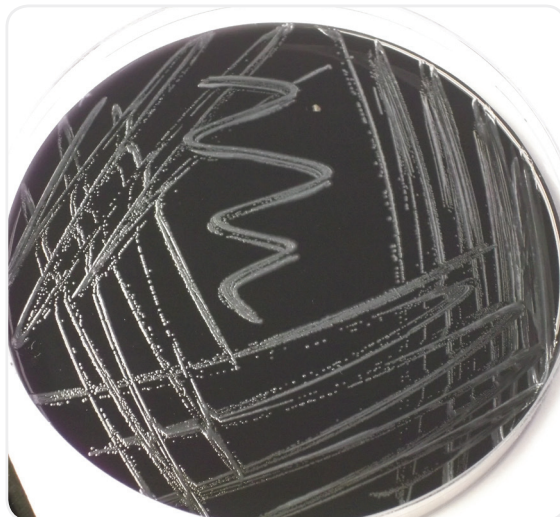
The investigators adopted a genetic profile approach to identify and characterise the populations of campylobacteria in the environment, exploring their persistence, virulence and spatial and temporal variation across contrasting rural environments, to assess seasonal variation in human exposure.

Using a novel 'boot sock' method for sampling pathogens in natural environments, the investigators found that campylobacters are more prevalent on farms and in the natural environment in the winter months than in the summer months and that the bacteria can persist over long periods of time, challenging the notion that the organisms are very fragile in the environment. Moreover, ENIGMA discovered genetic changes in the organism that can help explain how it can survive in a viable state.

In addition to gaining an important understanding of the Campylobacter present in the environment, Enigma explored a range of human behaviours that may also impact on the likelihood of infection from both an environmental exposure route or a foodborne route.

This included studying the risk perceptions of recreational users of the rural environment and urban parks, biosecurity knowledge and behaviours of those involved in poultry farming and production practices and food risk knowledge and behaviours (during preparation, handling, cooking and consumption) of both professional chefs and cooks as well as the general public. Emerging evidence from these studies provide important insights including:-

- Whilst there was a good understanding of the biosecurity threats within the poultry industry, practicalities on the ground meant that good practice was not always followed.
- Amongst members of the public 14% reported not always hand-washing immediately after handling raw meat, poultry or fish, 22% admitted having served meat "on the turn" and 12% admitted serving chicken at a barbeque when they were not totally sure it was fully cooked. Amongst chefs and catering students 32% of had worked within 48 hours of suffering from diarrhoea or vomiting, 33% admitted working in kitchens where meat "on the turn" was served and 16% admitted having served chicken at a barbeque when not totally sure it was fully cooked.
- In the United Kingdom, outbreaks of Campylobacter infection are increasingly attributed to under cooked chicken livers, yet many recipes, including those of top chefs, advocate short cooking times and serving livers pink. During 2015, the team studied preferences of chefs and the public in the United Kingdom. Most chefs correctly identified safely cooked livers but overestimated the public's preference for rareness and thus preferred to serve them rarer. They estimated that 19%-52% of livers served commercially in the United Kingdom fail to reach 70°C and that predicted Campylobacter survival rates are 48%-98%.



The ENIGMA team estimated that during the course of their study there were approximately 280,000 cases of *Campylobacter* spp. per year, resulting in around 3,500 hospital admissions, 26,000 involving long-term effects and 30 deaths. A substantial burden of long term illness was the result of those patients (7.6%) who went on to suffer irritable bowel syndrome. The study team have undertaken a case control study to build a better and more detailed of infection amongst children, the results of this work is still pending.

With new methods for analysing complex datasets from natural, biological, clinical and social sciences, the team have investigated the relative importance of different transmission pathways (recreation, water, food, etc.) to humans. The ENIGMA team have created sophisticated predictive models integrating inputs from the work packages to investigate the seasonality observed, which have been validated against the observed incidence of disease. The model suggests that *Campylobacter* seasonality

reflects interactions between environment, food contamination and patterns of risk behaviours, mediated by human immune status. ENIGMA have concluded that seasonality in numbers of human cases of *Campylobacter* arise from indirect effects of weather that encourage adoption of risk behaviours that result in exposure to the pathogen in rural environments and changes in dietary habits.



ENIGMA informing strategy and policy at the UK Food Standards Agency

The outcomes of the ENIGMA project have already improved policy understanding of *Campylobacter*, and specifically how it relates to the wider environment outside of poultry contamination.

Project evidence is significantly contributing to the development of the new Food Standards Agency - Foodborne disease strategy 2017-2022.

Outputs are also feeding into a key update on *Campylobacter* currently being prepared by the Advisory Committee on the Microbiological Safety of Food, which is an Advisory Non-Departmental Public Body providing risk assessment advice to UK Government on microbiological food safety (mainly Defra, the Food Standards Agency and the Department of Health).

MONKEYBAR

Defining the biomedical, environmental and social risk factors for human infection with *Plasmodium knowlesi*; opportunities for prevention and control of an emerging zoonotic infection

Professor Chris Drakeley, London School of Hygiene and Tropical Medicine



A newly recognised malaria infection in man

Until very recently there were only four recognised species of malaria parasite that were believed to cause human infection. The parasite *Plasmodium knowlesi* was a malaria species thought only to infect certain species of monkeys (long-tailed and pig-tailed macaques). However, there have been increasing reports of human infection and death with this organism, in countries in south east Asia.

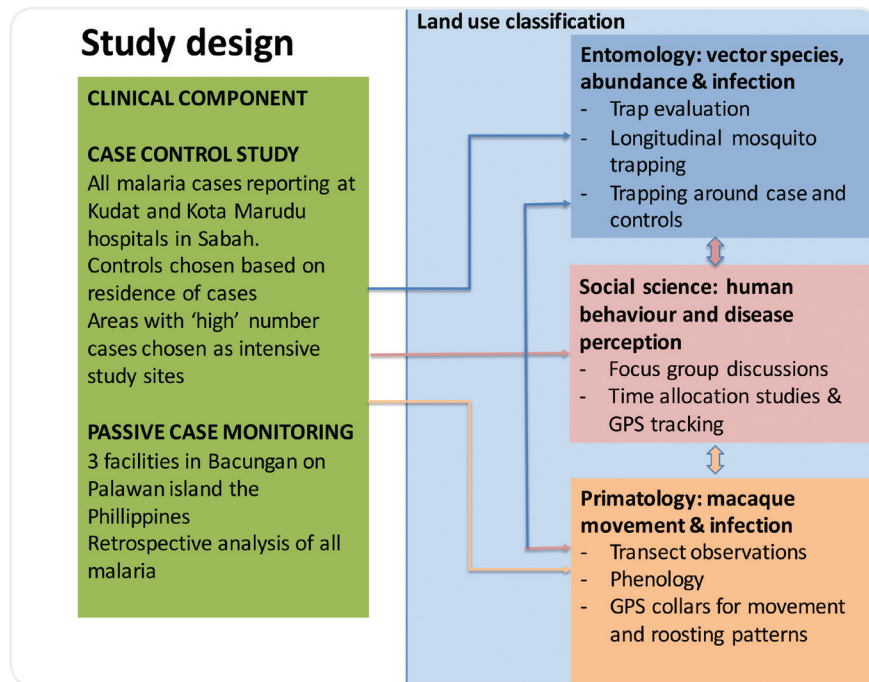
The MONKEYBAR project, an interdisciplinary collaboration of researchers from the UK, Australia, the Philippines and Malaysia was designed to investigate *P.knowlesi* within monkeys, mosquito vectors and man, in two sites where human cases had previously been reported: Sabah in Malaysian Borneo and Palawan Island in the Philippines.

Holistically exploring the changing ecologies of both the natural environment with deforestation and altered land use, together with primate, human and mosquito behaviours, was hoped to reveal how this disease is evolving from a forest-located entity, to one that is found at the forest fringe and is moving into peri-urban areas. Insight into key interactions or risk factors that may be driving transmission of infection is crucial to identify both those populations most at risk and to implement appropriate prevention strategies.

The MONKEYBAR interdisciplinary team brought together a range of expertise including:-

- entomology for the identification and ecology of the mosquito vectors
- parasitology for differential identification of the malaria species present
- clinical expertise to understand the nature of human infection
- primatology for monkey behaviour and infection status
- social sciences for behaviours and perceptions of disease risks
- environmental and geo spatial expertise

A large body of information has been collated and is undergoing analysis with a few key illustrative highlights captured here.



Changing the landscape ...

Characterising and describing land use in the two study areas, underpinned all activities in the project. In addition to historical records and satellite imagery, the MONKEYBAR consortia pioneered the use of drones to provide more detailed images of the landscape.



Land clearing is pictured in Ranau, Sabah, Malaysia. Deforestation has caused macaques to relocate and move closer to humans. Photo credit: Joshua Paul for LSHTM, 2017

In Sabah the team found that there had been substantial land use change, most frequently reflected in natural forest loss and replacement with plantation or farming, with many villages losing a significant proportion of their surrounding forest cover.

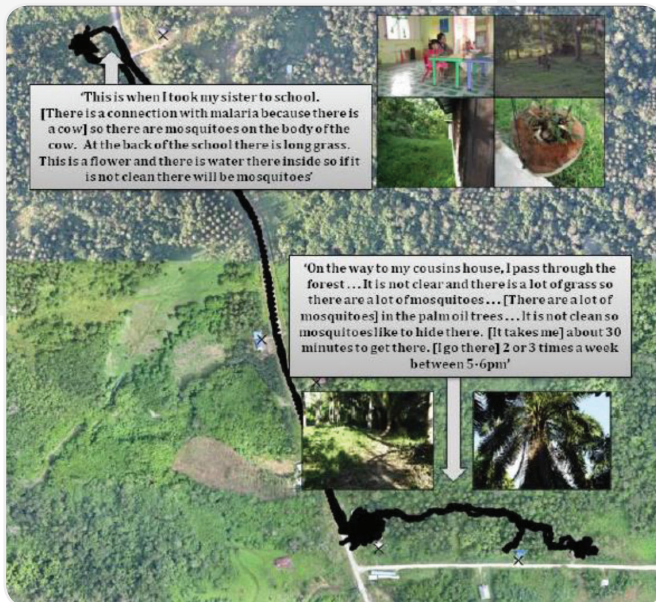
The proportion of forest surrounding a village was found to be associated with the numbers of new of *P. knowlesi* infections detected. The investigators were able to map the houses where cases of human *P. knowlesi* infection were found and identify the types of land cover (forest, plantation, farm, garden etc.) around them to look for associations with risk. The data are complex. For example, the team have determined that the risk of getting *P. knowlesi* depends not just on how much forest is lost but the extent to which it is fragmented (meaning that there are lots of forest edges for macaques to live in). In addition, risk is higher closer to recently cleared forest but also within 1-2km of where new forest growing.

Monkeys on the move...

The MONKEYBAR team found that in Sabah nearly all macaques were infected with malaria parasites, often multiple species and 1/3rd were infected with *P. knowlesi*. Using collars on macaques infected with *P. knowlesi*, the team observed that, not surprisingly, when nearby forest was cut down macaques moved to find shelter in a less disturbed area, often bringing them into contact with humans or the mosquitoes that may feed on both monkey and man.

The team have overlaid the land-use maps and images, with tracking data from collared macaques; and from movement and travel information from volunteers with GPS trackers to see where they might interact.

As part of a social science risk perception component, the local community was asked to carry GPS trackers and cameras to photograph what they considered the 'malaria risks' to be.



This study revealed that most people moved around locally with only a few making long distance or overnight trips.

People did however move through forest and along the forest edge, going to and from work or school at dawn and dusk when the vector mosquitoes bite.

Most people understood the association of water and risk for mosquitoes. However, there was little association of malaria risk with monkeys.

A further key component of the consortia's work was to understand which mosquitos were transmitting *P. knowlesi* malaria, where and when. This is no easy task as there are several possible vectors, whose habits could be changing as the local ecology was changing. The team undertook longitudinal entomological surveys, collecting potential vector mosquito species, and data on their abundance and seasonal dynamics, biting preferences and habitats. The research team has confirmed the species *Anopheles balabacensis* is the primary vector in Sabah and that in villages it is found in greater numbers around houses (rather than inside) and is most likely to bite around dawn/dusk. This has enabled the team to provide important recommendations related to household vector control approaches as bednets in this situation are unlikely to be optimal prevention tools.

Human infection



A nurse checks on a Palawan local at the Rural Health Unit (RHU) in Rizal, Palawan, Philippines
Photo credit: Joshua Paul for LSHTM, 2017

The research team conducted the first case control study for risk of *P. knowlesi* by comparing cases of confirmed *P. knowlesi* infection with both uninfected and those with more classically transmitted human malarias. With data on more than 200 cases of *P. knowlesi* malaria and looking at a large number of possible factors, it was found that adult men who had work associated with plantations or farming, were most at risk. However, there was also a small but significant number of cases in women and young children suggesting some transmission happens near to home (peri-domestic). The use of mosquito control measures such as insecticide residual spraying (IRS) of homes was also found to be associated with decreased risk of *P. knowlesi* infection.

By integrating and synthesising these complex datasets the MONKEYBAR team are providing important evidence that deforestation and associated environmental changes are key drivers in *P. knowlesi* transmission in these areas. They are developing increasingly powerful computational models to generate maps that can better predict risk of infection and, more importantly, highlight opportunities for prevention and control.

MONKEYBAR informing policy and practice

The accumulating research evidence has -

Stimulated the implementation of two primary public health measures

- Awareness campaigns about the risk of P.knowlesi infection. Using the MONKEYBAR study evidence the Sabah malaria control programme has already made significant steps to incorporate key messages re knowlesi infection / prevention on billboards and pamphlets distributed amongst the community. This is important as often malaria control programmes are focused on maternal and child health, but in SE Asia malaria control and elimination programmes will also need to target adult men to be successful.
- Continued use of insecticide residual spraying (IRS) and other household level vector control to prevent transmission and disease

Shaped national treatment guidelines

- The case control component of MONKEYBAR also provided the critical underpinning epidemiological evidence for a closely related clinical trial undertaken by the Sabah Ministry of Health and the Clinical Research Centre, Queen Elizabeth Hospital. The trial has shaped national referral and treatment guidelines. Importantly it has been recognised that P. knowlesi infections can be treated similarly to all malarias, harmonising first-line treatment in the country.

This evidence, in turn has contributed to the latest WHO malaria treatment guidelines and it is likely that these recommendations will be adopted in other knowlesi endemic countries.

Informed a WHO Expert Review Group

- In 2017 consortia members were key contributors to the WHO Expert Review Group (ERG) on P. knowlesi held in Kota Kinabalu. The ERG was convened to identify the most pressing concerns for disease control and to collate the latest important evidence for the Malaria Policy Advisory Committee. A report from this ERG will be available globally and of course be particularly relevant to countries where P. knowlesi is endemic.

<http://www.who.int/malaria/mpac/mar2017/en/>

CAREER DEVELOPMENT IN A CONSORTIA SETTING

The interdisciplinary consortia have provided a broad platform for early career investigators development and progression. Whilst some individuals have followed a more traditional academic pathway, the consortia have also facilitated the development of individuals who have benefitted from the diversity of opportunities arising. A few examples include

James Miser Akoko

- James joined the URBANZOO team as a field technician employed by the International Livestock Research Institute. Early on he expressed an interest in project management, and undertook a diploma at his own cost and in his own time. This enabled his registration for an MSc in International Animal Health, by distance learning at the University of Edinburgh, a course he completed in 3 years, again working on his studies after working hours. This MSc does not require a degree as a pre-requisite for registration, making it ideal for enthusiastic candidates who progress through a less formal route. James successfully applied and was appointed as URBANZOO field co-ordinator, managing the multitude of activities undertaken by the field teams, executing this role brilliantly, becoming a most essential member of the team and indeed 'acted up' as URBANZOO country project manager providing maternity leave cover. On completion of the MSc, James has successfully secured a PhD scholarship on brucellosis epidemiology funded by the Wellcome Trust DELTAs Afrique One ASPIRE and is registered at Maseno University in Kenya. Within URBANZOO James was able to develop his research skills and foster his interests progressing his scientific career through a less formal route. The consortia provided him opportunities to present at national and international conferences, and James is already a co-author on several published and in preparation peer reviewed papers.

Amaziasizamoria Jumail

- AJ started at the Danau Girang Field Centre as a primatology research assistant in the Banggi study site of MONKEYBAR in April 2014. DGFC is a collaborative research and training centre for tropical biodiversity. She quickly progressed to field leader and six months later she was promoted to field team leader for both study sites. Having shown considerable promise, she was employed by DGFC on a permanent basis and in 2016 enrolled in an MSc at the University Malaysia Sabah. Her project focuses on the use of a thermal camera as a handheld device to conduct primate census. Upon completion of her studies, AJ can return to DGFC where she will be in charge of ongoing and future primatology projects under the guidance of the senior primatologist.

Caroline Millman

- Caroline worked for over 18 years in senior technical roles within the food industry, gaining valuable experience and contacts in retail, consultancy and manufacturing. She subsequently undertook a PhD at the University of Manchester, investigating 'foodborne illness in the domestic setting' and in 2012 she took up a research post as part of the ENIGMA programme, on aspects of landscape, infection exposures and economics. Whilst based in the Environmental & Resource Economics group Manchester, the consortia offered her the opportunity to work with epidemiologists, mixed methods researchers and microbiologists at Liverpool and environmental scientists at the University of East Anglia and at Bangor University broadening her knowledge and skill base. Caroline has now secured a Senior Lectureship in the Food & Nutrition Group at Sheffield Business School (Sheffield Hallam University) and is Course Leader for the Food Technical Degree Apprenticeship.

Elli Wright

- Elli obtained a BSc. in Applied Microbiology and a MSc. Medical Microbiology before completing a PhD in human embryonic stem cell differentiation at the University of Manchester. Following her first post-doctoral position, at the University of Liverpool, and a spell at the University of Siena on a FEMS research fellowship, she joined the ENIGMA programme at the University of Liverpool where she studied the ecology of *Campylobacter* spp. in the poultry farm environment. She became passionate about science communication and public engagement after spending time teaching students, visiting schools to talk about her research, and designing and implementing museum and festival exhibits, most notably the BBSRC-funded exhibit "A Twisted Bug's Life" at the Great British Bioscience Festival. She is now a Public Engagement Manager at the Liverpool School of Tropical Medicine.

CATALYST FOR INTERDISCIPLINARITY

From the conception of ESEI there was recognition that a holistic approach to research would require the establishment of highly interdisciplinary teams of investigators. Expertise from a broad swathe of disciplines including public health, clinical human and veterinary medicine, epidemiology, biology, environmental and geographical sciences, ecology, social science, economics was anticipated. The funders also were also keen to encourage the early involvement of individuals directly involved in formulating local and national policy or regulation such that the projects and the evidence were relevant and had strong likelihood of impact. A science coordinator was appointed for the programme with the aim of providing support to facilitate early knowledge exchange between researchers and users, and to coordinate with other relevant initiatives during the first 4 years.

In its aim to encourage and foster the development of such interdisciplinary teams the ESEI initiative supported a series of workshops and investigator meetings and an initial Catalyst phase of exploratory studies. This phase of the ESEI programme brought together emerging interdisciplinary teams of scientists to begin to explore how both man-made and natural changes to the environment and the way people interact with their environment can influence the dynamic of transmission of zoonotic infections. Twelve catalyst projects were supported for a nine month duration where studies included:-

Vector-borne disease systems: from mapping to understanding

Prof. Peter Atkinson University of Southampton

Determining the risks of mosquito-borne viral zoonoses emerging and spreading from East African forests

Dr Catherine Walton University of Manchester

Rodents and bats as reservoirs of zoonoses: ecological and social determinants of human disease risk in Kenya

Prof. Sarah Cleaveland University of Glasgow

From bats to humans: the social, ecological and biological dynamics of pathogen spillover

Prof. James Wood University of Cambridge

The intensification of livestock production and its impact on zoonotic disease risk

Professor Richard Coker LSHTM

Defining the biomedical, environmental and social risk factors for human infection with *Plasmodium knowlesi*;

Prof. Chris Drakeley LSHTM

Measuring, mapping, monitoring and mitigating drivers of the emergence of zoonotic and food-borne diseases: a case study

Prof. Eric M Fèvre University of Edinburgh

EPISYSTEM: Designing biological, social and economic environments to enhance resistance to zoonotic outbreaks

Dr Adam Kleczkowski University of Sterling

Lay perceptions, prejudice and the natural environment in the spread of animal-human and human-human infections

Prof. Robin Goodwin Brunel University

Environmental Aetiology of Diarrhoeagenic Pathogens in Children in a Developing Country Setting

Dr Andrew Singer NERC Centre for Ecology and Hydrology

Gastrointestinal Pathogens in the Environment. GiP-net

Dr Norval Strachan University of Aberdeen

Why is infection unequal?: An inter-disciplinary approach.

Prof. Mark Viney University of Bristol

The catalyst groups demonstrated an impressive enthusiasm for their respective projects, as well as engagement and interaction between project groups, fostering a nascent community of interdisciplinary minded investigators. Whilst not all catalyst groups secured a full consortia award within the ESEI initiative, several of the catalyst projects have underpinned the development of multinational interdisciplinary teams which are now tackling complex research and capacity building activities related to zoonoses and emerging and re-emerging infections for example the DfID, Research Council and DSTL programme in Zoonoses in Emerging Livestock Systems (ZELS).

ESEI LEARNING AND LEGACY

In the last five years the Ebola, Zika and yellow fever outbreaks as well as the critical challenge presented by antimicrobial resistance, have provided continued impetus for research to understand the drivers of emerging or re-emerging infections.

The ESEI projects reflect a diversity of activities across a range of pathogens in very different global settings. The initiative has prompted new thinking with an integrated rather than reductionist approach to tackling complex research questions. It has played a major role in cementing strong international partnerships working collectively across continents and disciplines.

As one of the first cross council interdisciplinary initiatives, ESEI can offer pertinent insight into how future waves of interdisciplinary research may be fostered.

Each of the consortia has been driven by perceptive leadership with ability to inspire and engage not only close colleagues, but those who do not necessarily share the same disciplinary language, methods or priorities. The willingness to embrace differing disciplines, sectors and approaches with a respect for the value each, is an underpinning theme of ESEI.

The science supported has been of highest quality as reflected in the wealth of publications already in the public domain. A truly interdisciplinary approach however takes time to adapt and integrate ways of working, across multiple partners and to build appropriate governance and new tools to support such endeavour. ESEI was strengthened by the catalyst phase and the series of workshops and investigator events supported during the initiative. Such research requires excellent project management and communication links across various domains of research, capacity strengthening and stakeholders and the resources for this are an integral part of the consortia.

Innovative and creative approaches to capturing information need to be appropriate to the context and setting and most importantly, acceptable to the community within which the research will take place. Engaging the community and acknowledging their views can lead to alternative or improvised research approaches. For example two of the projects used landscape imaging in their research, URBANZOO adopting a more 'low tech' 'red balloon' suspended camera, while the MONKEYBAR team used high-tech drones to capture monkey movement in the landscape.

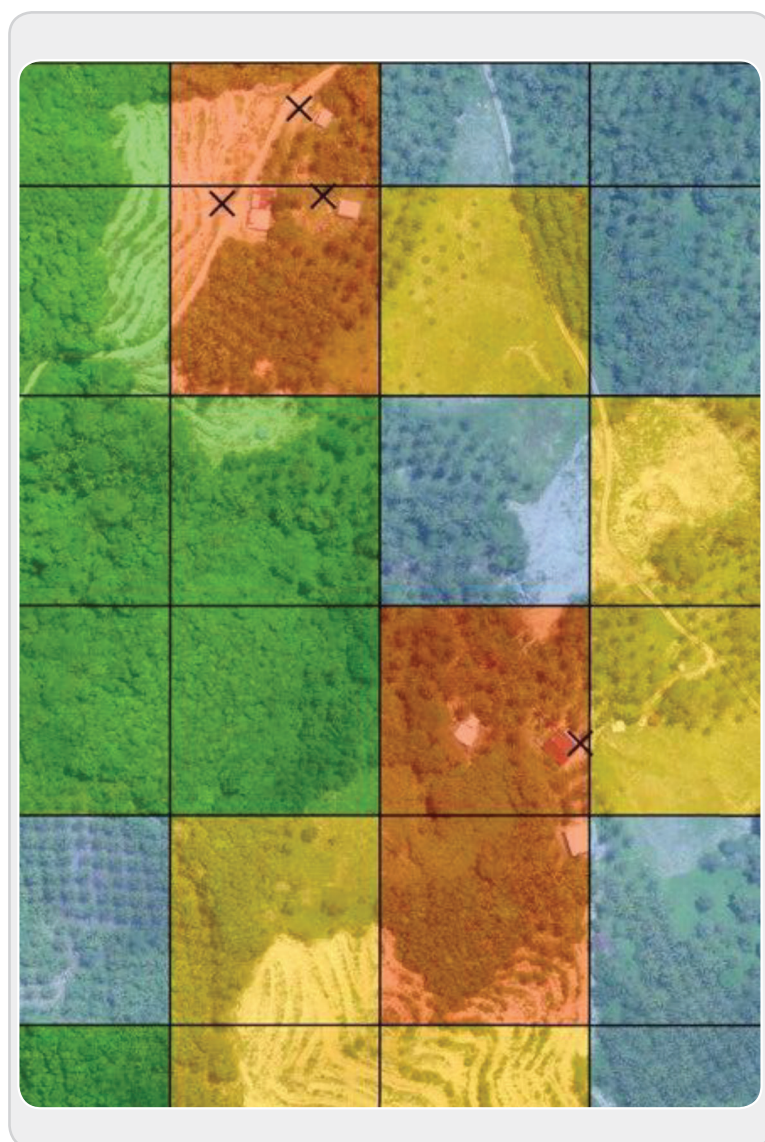


A critical component of interdisciplinary research is the ability to seamlessly integrate large but distinctly differing, quantitative and qualitative (often narrative) information sets. The ESEI projects have developed innovative and creative approaches but this is an area of growing need and where there is opportunity for enhanced methodologies to provide the richest possible evidence and optimal future risk models.

Policy and practice change can happen at multiple levels and in different timescales. Key however, is the identification, early engagement and continual dialogue with appropriate stakeholders to ensure the relevance, uptake and impact of the research evidence that emerges.

Collaboration and cross-disciplinarity are at the heart of the vision for UK Research and Innovation (UKRI). As the Research Councils, Innovate UK and Research England are imminently drawn even closer under this strategic umbrella, we look forward to even greater opportunities for investment in interdisciplinary research.

ESEI projects are developing innovative and creative approaches to integrating and modelling data



Land use stratification and classification can be overlaid with tracking data from monkeys, man and mosquitos

ANNEX – Consortia membership

URBANZOO

Epidemiology, Ecology and Socio-Economics of Disease Emergence in Nairobi

Principal Investigator
Lead Research organisation
Website
Twitter Feed:

Professor Eric Fèvre
University of Liverpool
www.zoonotic-diseases.org
@ZoonoticDisease; #urbanzoo

CONSORTIA MEMBERS Co-investigators

- Professor Julio Davila, University College London (UCL); Urban Planning
- Dr Catherine Kyobutungi, Director, African Population and Health Research Centre (APHRC); Medical epidemiologist
- Professor Erastus Kang'ethe, Professor of Veterinary Public Health, University of Nairobi; Veterinary public health
- Dr Delia Grace, International Livestock Research Institute (ILRI); Informal food systems
- Professor Jonathan Rushton, Chair of Animal Health and Food Systems Economics, University of Liverpool; Animal health economics
- Dr Cecilia Tacoli, Senior Researcher, International Institute for Environment Development (IIED); Informal settlements
- Professor Mark Woolhouse, Chair of Infectious Disease Epidemiology, University of Edinburgh; Epidemiology and genetics
- Dr Timothy Robinson, Food and Agriculture Organization; Spatial analysis
- Professor Samuel Kariuki, Director, Centre for Microbiology Research, Kenya Medical Research Institute (KEMRI); Microbiology

Key collaborators/stakeholders

Stakeholders

- Director of Veterinary Services, Kenya (DVS)
- Director of Medical Services, Kenya (DMS)
- Public Health Department, Nairobi
- City Council Planning department, Nairobi
- Meat inspectorate, Kenya
- Kenya Dairy Board
- Slaughterhouse owners, Nairobi
- Kenya Dairy Traders Association
- Kenya National AMR Stewardship Committee
- Food and Agriculture Organization (FAO), Kenya
- World Health Organization (WHO), Geneva
- OIE, Nairobi
- Kenya Medical Association (KMA)
- Kenya Veterinary Association (KVA)
- County Governments
- Kenya Bureau of Standards
- Kenchic Ltd
- CGIAR
- Zoonotic Disease Unit (ZDU)/ Zoonotic Technical Working Group (ZTWG), Govt of Kenya

Collaborators

- St Louis Zoo, USA
- Animal for Nutrition and Health (A4NH- CGIAR)
- Kenya Field Epidemiology and Training Programme
- Muungano Support Trust, Nairobi
- Zoonotic Disease Unit (Kenya)
- University of Nairobi
- Oxford Human Genetics Unit
- Farmers Choice Ltd
- CGIAR Research Program on Agriculture for Nutrition and Health
- London School of Hygiene and Tropical Medicine
- Leverhulme Centre for Integrated Research on Agriculture and Health
- Kenya Medical Research Institute (KEMRI)
- African Population and Health Research Centre (APHRC)
- USAID Emerging Pandemic Threats 2 Program (EPT-2)
- Animal Health and Industry Training Institute (AHITI), Kenya
- Erasmus University Medical Center (Erasmus MC), Holland
- National Museums of Kenya
- Kenya Wildlife Services
- Biosciences for Eastern and Central Africa (BeCA-ILRI) Hub

MONKEYBAR

Defining the biomedical, environmental and social risk factors for human infection with *Plasmodium knowlesi*; opportunities for prevention and control of an emerging zoonotic infection

Principal Investigator
Lead Research organisation
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@Monkeybar_ESEI

CONSORTIA MEMBERS Co-investigators

- Nick Anstey, Menzies School of Health Research, Senior Principal Research Fellow
- Tock Hing Chua, Universiti Malaysia Sabah, Professor of Pathobiology and Medical Diagnostics
- Judeline Dimalibot, University of the Philippines Los Banos, Assistant Professor in Animal Biology
- Dr. Fe Espino, Research Institute for Tropical Medicine, Head of Department of Parasitology
- Prof. Heather Ferguson, University of Glasgow, Professor of Biodiversity Animal Health and Comparative Medicine
- Steve Torr, Liverpool School of Tropical Medicine / Greenwich University, Professor of Neglected Tropical Diseases
- Indra Vythilingam, University of Malaya, Professor of Parasitology
- Timothy William, Infectious Disease Society Kota Kinabalu Sabah (IDSKKS), President

Key collaborators/stakeholders

Stakeholders

- Asia Pacific Malaria Elimination Network
- Clinicians and community health workers
- Country and regional Malaria Control Programmes
- EcoHealth Alliance
- Environmental and conservation groups
- Institute for Medical Research, Malaysia
- Ministries of Health, the Philippines and Malaysia
- Palawan Sustainable Development Council
- Philippine Council for Health and Research Development
- Sabah State Health Department
- World Health Organization (WPRO/SEARO)

Collaborators

- Cardiff University
- Danau Girang Field Centre / Sabah Wildlife Department
- Durham University
- Eijkman Institute
- Imperial College London
- Royal Veterinary College
- Universiti Malaysia Sabah, School of Social Sciences
- University of Malaysia
- University of Surrey

ENIGMA

Sources, seasonality, transmission and control: Campylobacter and human behaviour in a changing environment

Principal Investigator
Lead Research organisation
Website

Professor Sarah O'Brien
University of Liverpool
www.enigmaproject.org.uk

CONSORTIA MEMBERS Co-investigators

- Malcolm Bennett, University of Nottingham, Professor of Veterinary Pathology
- Rob Christley, University of Liverpool, Reader in Veterinary Epidemiology
- Peter Diggle, Lancaster University, Distinguished University Professor of Statistics
- Kenneth Forbes, University of Aberdeen, Professor of Microbiology
- Rachel Griffith, University of Manchester, Professor of Economics
- Thomas Humphrey, Swansea University, Professor of Bacteriology and Food Safety
- Paul Hunter, University of East Anglia, Professor of Health Protection
- Iain Lake, University of East Anglia, Reader, Environmental Science
- Daniel Rigby, University of Manchester, Professor in Environmental Economics
- Stephen Rushton, Newcastle University, Professor of Biological Modelling
- Norval Strachan, University of Aberdeen, Professor of Physics
- Mike van der Es, University of East Anglia, Project Manager
- Paul Wigley, University of Liverpool, Professor in Foodborne Zoonoses
- Nicola Williams, University of Liverpool, Professor of Bacterial Zoonotic Disease
- Craig Winstanley, University of Liverpool, Professor of Bacteriology)
- Brendan Wren, London School of Hygiene and Tropical Medicine, Professor of Microbial Pathogenesis

Key collaborators/stakeholders

- Centre for Ecology and Hydrology
- Chilled Education
- Food Standards Agency
- Public Health England
- Teachers Food Centre
- UK Poultry Industry
- Ramblers Groups





ESEI Report 2018

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project/urban-zoo-project/](http://www.zoonotic-diseases.org/project/urban-zoo-project/)
ENIGMA - <http://www.enigmaproject.org.uk/>
MONKEYBAR - <https://www.lshtm.ac.uk/monkeybar>