Institution: University of Lincoln		
Unit of Assessment: 14 – Geography and Environmental Studies		
Title of case study: Mapping Malaria Transmission using Hydromorphology to Inform Public Health Strategies in Africa		
Period when the underpinning research was undertaken: 1 Jul 17 – 1 Nov 20		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
THOMAS Christopher J	Global Professor in Water and Planetary Health	1 Oct 19 to date
MACKLIN Mark	Distinguished Professor of River Systems and Global Change	1 Sep16 to date
Period when the claimed impact occurred: 1 Jul 17 – 31 Dec 20		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

The impact of Geography research at the University of Lincoln is on malaria control strategy across sub-Saharan Africa, focusing on Zambia, achieved by linking the physical drivers of transmission (water for breeding by vector mosquitoes) with epidemiology, through new data and process understanding. This research has shown the Zambian Ministry of Health why malaria has not responded to their public health interventions in large areas of the country, leading to new understanding that additional, environmentally tailored, mosquito-control strategies will be required in some areas to achieve their national target for elimination of this disease. The research produced modelling and maps to identify these areas for National and Provincial Medical Services. Capacity for this geographical approach to malaria control, also relevant to other diseases and health risks, has been increased in the region though co-working with partners.

2. Underpinning research (indicative maximum 500 words)

This case study relates to research conducted at Lincoln since July 2017 working with an international, interdisciplinary team of researchers from the UK, Zambia and Canada, and partner organisations (Zambian Ministry of Health [MoH]; Zambezi Water Resources Management Authority [WARMA], University of Barotseland [UBL] and the Zambezi EcoHealth Partnership [ZEP]). The research to which this case study refers is published in Cross *et al* (2020) **[3.1]** and Smith *et al* (2020) **[3.2]**, with an accompanying popular article in Smith and Thomas (2020) **[3.3]**.

Research context

Controlling the mosquitoes that transmit malaria (vectors) is one of the main ways to prevent and reduce the disease. Concerted national malaria control efforts in Zambia (such as bednets and indoor residual spraying of houses with insecticides), have led to a nationwide decline in parasite prevalence among children under 5 from 22% to 9% between 2006 and 2018. However, in some areas, such as Western Province (population 1.1m people) these interventions have not led to reductions and prevalence amongst under-5s in 2019 was 10%, twice as high as 2010 levels. Ecologically, the region is dominated by the Barotse floodplain, comprising a vast network of wetlands flooded seasonally by the Zambezi River and its tributaries: we investigated the relationship between this environment and transmission in order to understand the increase in malaria in the Province.

Malaria vectors are mosquito species of the genus *Anopheles*, with a few considered 'primary vectors' (human specialists, highly efficient vectors of human malaria parasites, main role in transmission) whereas others are 'secondary vectors' (take blood from a range of vertebrates, inefficient vectors, minor role in transmission). This is an important distinction in public health as primary vector species in sub-Saharan Africa tend to bite humans at night and indoors, so are susceptible to bednets and indoor residual spraying of insecticides, whereas secondary vectors predominantly bite humans outdoors during the day and at dusk, and so may evade these interventions. Traditionally, malaria control in sub-Saharan Africa has not been concerned with riverine environments as they rarely provide suitable breeding habitat for primary vectors, which breed in small ephemeral water bodies (e.g. puddles) associated with seasonal rain. Water in riverine habitats tend to be too deep, cold and fast flowing for primary vector species.

UoL research

To address these issues, Lincoln research combined field data collection in Sep-Nov 2017 to Apr-June 2019 in wet and dry seasons (Zambezi bathymetry, mosquito surveys stratified spatially by hydrogeomorphology, remote sensing ground control); time series radar and optical remote sensing of habitats, LISFLOOD modelling of the Zambezi seasonal inundation; large sample, high-throughput genetic sequencing of mosquitoes and climate-transmission modelling. This facilitated detailed comparison of taxon-specific abundance patterns in vectors between ecological zones differentiated by hydrological controls.

We discovered **[3.1]** both an unexpectedly high species diversity of vectors in Western Province and that almost all were secondary vector species, previously thought incapable of maintaining high levels of transmission. We also showed these species were breeding in habitats unsuitable for primary species, being widespread and abundant in floodplains along river margins and associated hydromorphological features. We concluded that these extensive habitats therefore support residual transmission, over much longer seasons, and that in many areas significant levels of transmission is by secondary vectors. This provided an explanation for the continued high prevalence of malaria in the Province and has important consequences for future vector control by the MoH.

It was therefore important to map these hydroclimatic zones across Zambia. To address this problem, we used downscaled daily climate predictions from seven GCMs to run a continental-scale hydrological model for a process-based representation of mosquito breeding habitat availability. A complex pattern of malaria suitability emerges as water is routed through drainage networks and river corridors serve as year-round transmission foci **[3.2, 3.3]**. Using this model, we produced (report to MoH) national maps of malaria transmission by season length and estimates for each province of the areas and populations at risk in these zones, including under projected climate change **[3.2, 3.4]**.

3. References to the research (indicative maximum of six references)

3.1 Cross, D. E., **Thomas, C.J**. (corresponding author), McKeown, N., Siaziyu, V., Healey, A., Willis, T., Singini, D., Liywali, F., Silumesi, A., Sakala, J., Smith, M., **Macklin, M.G**., Hardy, A. J., & Shaw, P. W. (2020). Geographically extensive larval surveys reveal an unexpected scarcity of primary vector mosquitoes in a region of persistent malaria transmission in western Zambia. Parasites & Vectors (accepted 10/12/20), final pre-print version printed online 29/12/20
https://doi.org/10.21203/rs.3.rs-43576/v3

3.2 Smith, M. W., Willis, T., Alfieri, L., James, W. H. M., Trigg, M. A., Yamazaki, D., Hardy, A. J., Bisselink, B., De Roo, A., **Macklin, M.G.**, & **Thomas, C.J.** (2020). Incorporating hydrology into climate suitability models changes projections of malaria transmission in Africa. Nature Communications, 11(1), 4353.
https://doi.org/10.1038/s41467-020-18239-5

3.3 Smith, M., & **Thomas, C. J**. (2020). Malaria: new map shows which areas will be at risk because of global warming. The Conversation. Available at: https://theconversation.com/malaria-new-map-shows-which-areas-will-be-at-risk-because-of-global-warming-144783 [Accessed 30 Oct 2020]

3.4 **Thomas, C.J.** & Smith, M. (2020). This disease kills 400,000 people a year. A new map shows where climate change will make it worse. World Economic Forum. Available at: https://www.weforum.org/agenda/2020/09/malaria-maps-africa-disease-climate-change-global-warming/ [Accessed 30 Oct 2020]. Twitter

4. Details of the impact (indicative maximum 750 words)

The research was designed to achieve impact by co-working with the Zambia Ministry of Health (MoH) and partners throughout. Co-working included: on project aims and study design (workshops in Lusaka and Western Province); planning, adapting and participating in field data collection (MoH officers and UBL BSc Environment and Health students), analysis, interpretation, and preparation of published papers (MoH officers are co-authors, see [3.1]). Throughout the study regular progress meetings were held in Western Province, chaired by the Provincial Medical Office, until Covid19 restricted travel, thereafter via internet. Macklin visited Western Province in May 2019 and Thomas in November 2019.

The primary and most direct impact of this research [3.2] is the increased knowledge within the policy making community that seasonal flooding along major rivers and floodplains extends malaria transmission seasons **[5.1, 5.2]**. More specifically, our research was the first to determine that such flooding extends transmission through secondary vector species; a key aspect that had never previously been considered, leaving a significant gap in malaria prevention strategies.

Other key contributions to strategy making arise from the national/provincial maps of transmission season zones from hydroclimate modelling produced by this research [3.2] which show the areas that need to be considered, and the fine resolution mapping of vector species distribution and abundance in relation to hydrological controls [3.1] is at the operational scale of interventions (village) for use in forward planning **[5.2]**. The MoH report that our research provided:

> *"new information on transmission in large areas of the country that will help us to understand trends in malaria cases and our thinking about future control strategies…..Our goal of malaria elimination remains a top priority for health in Zambia and the results from this research make a significant contribution to this effort"* **[5.1]**

As a result, the MoH are now alert to a fundamental issue in vector control, which they are now able to take steps towards addressing in pursuit of the national malaria elimination goal **[5.1].**

Further impact from this research arises through capacity building for environment and health in Western Province, through field training and use of technology. The collaboration was facilitated by the Zambezi EcoHealth Partnership (ZEP), a partnership led by the MoH, WARMA and the Canadian Coalition for Global Health Research (CCGHR), a knowledge network for global health equity active in 49 countries and involving over 20 Canadian Universities. In this research, a project GIS of source data, field results and analyses generated by UoL research was freely shared to ZEP partners as a 'knowledge platform'. This high quality, high resolution environmental information has formed the basis for new, spatial, approaches to health priorities in the Province other than malaria **[5.1, 5.2, 5.3, 5.4]**. This collaboration has also contributed to successful applications for external funding for PhD training of Zambian physicians and health workers from Western Province in Canada, through the award of QE2 scholarships to the University of Waterloo bringing a range of capacity and capability impacts:

> *"The research you have led … has had a significant impact on the Province's health services approach to the environmental and ecological challenges it faces, particularly*

from malaria. The geographic, technical 'knowledge platform' your research has delivered to ZEP partners has formed the basis for new approaches to other health challenges such as strategies around access to health facilities in flooding landscapes. I am currently working with physicians and researchers from Zambia who are conducting PhD research in my department using this platform to address climate-related challenges to HIV treatment, maternal and child health care and food security. …Your research has therefore contributed impact through an increased capability and capacity of the health system in Western Province to work with technical developments in environmental mapping relevant to public health" **[5.3]**

Our research also included training and experience in fieldwork (GPS, study design, sampling, data recording, field logistics) for local UBL students (104 student-days for 6 students) **[5.4].**

5. Sources to corroborate the impact (indicative maximum of 10 references)

5.1 Letter from Dr Andrew Silumesii, Director of Public Health and Research, for the Permanent Secretary, Ministry of Health, Zambia.

5.2 Letter from Dr Jakob Sakala, Public Health Specialist, Western Province Medical Office, Ministry of Health, Zambia.

5.3 Letter from Professor Craig Janes, Director University of Waterloo School of Public Health Canada and co-Director of the Zambezi EcoHealth Partnership.

5.4 Dr Ndiyoi Mukelabai, Director of Research, University of Barotseland, Zambia and co-Director of the Zambezi EcoHealth Partnership.