

The logo for iDAAlert features the letters 'iDAAlert' in a sans-serif font. The 'i' is white with a blue signal icon above it. 'DA' is white, and 'Alert' is light blue. The background of the top section is a collage: a crowd of people on the left, a flock of birds in flight in the center, and a stylized virus particle on the right.

iDAAlert

Infectious Disease decision-support
tools and Alert systems

Interim synthesis - bi-directionality between social inequalities and infectious disease risk

November 2024



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R=Document, report; **DEM**=Demonstrator, pilot, prototype; **DEC**=website, patent fillings, videos, etc.; **OTHER**=other

PU=Public, **CO**=Confidential, only for members of the consortium (including the Commission Services), **CI**=Classified

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Deliverable Summary

Socioeconomic characteristics and inequality play a significant role in the impact of climate-sensitive infectious diseases (van Daalen, 2024). To date there is insufficient understanding of the extent to which different groups of the population are more or less vulnerable to changes in infectious diseases due to climate change. There are two parts to this intermediate deliverable, which addresses inequality explicitly. The first part empirically explores the relationship between socioeconomic, sociodemographic, and occupational settings, and exposure and vulnerability to infectious diseases. Data sources include European databases such as Eurostat, EU-LFS, and EU-SILC. The second part demonstrates how inequality can be integrated into IDAlert indicators on climate-sensitive infectious diseases. Measures and indicators of inequality include age, gender, income, and employment sector. We present the approach being taken, initial results where available, and plans to progress toward the final deliverable.

Introduction

IDAlert supports policy and decision makers through the development of novel state-of-the-art climate and health indicators which are useful for policy makers and other stakeholders, socially differentiated, and can inform policy development across sectors. The current indicators include dengue, Zika, chikungunya, West Nile fever, malaria and vibriosis. The indicators have been developed for tracking climate change induced hazard, exposure, vulnerability and risks. In the future, further indicators will be developed that track the effectiveness of interventions and can help in the assessment of unintended consequences of climate adaptation and mitigation on health. Incorporating inequality into IDAlert indicators supports governments in their efforts to reduce vulnerability and increase resilience to climate-sensitive infectious diseases.

The modifiers and susceptibility factors of climate risks to health can be investigated by incorporating changing patterns of social inequality. IDAlert research highlights cost-benefits of policy and implementation options and develops tools and checklists for policy makers and users. A social sciences lens is employed in all hotspot studies along with indicator development processes. Our aim is to develop a deep and nuanced understanding of how relevant policies reach and affect different populations, how those populations choose to, or are able to, engage with these policies, and overall outcomes, specifically whether inequalities are reduced or increased. By developing a strong analytical framework, we are able to model, predict, and track both unanticipated and unintended distributional impacts of policies, particularly on less advantaged groups in society. Our explicit focus on populations on the move both ensures that we do not exclude some of the most vulnerable populations, and also brings into focus key issues such as engagement and the role of trust that require particular social science expertise within our team. A novel contribution of IDAlert is the focus on occupational settings: specifically, explicit consideration is taken of how different occupations are differentially affected by climate-sensitive infectious diseases and policies. A macroeconomic assessment reveals and illuminates the economy-wide benefits to society of tackling the emergence and transmission of climate induced infectious diseases at the pan-European level, with sub-national resolution enabling a social and inequality lens.

Though our research covers all occupational groups, specific target groups are likely to directly benefit from our research, including agricultural and construction workers, groups that work outside and/or are relatively more exposed to vectors. These workers have considerable potential to benefit if policy makers action pragmatic cost-effective recommendations linked to IDAlert outputs, that could link to the provision of protective clothing or adjusted working hours.

Part 1. Pan-European analysis of the relationships between socioeconomics and vulnerability to infectious diseases

This first part of the report explores the relationship between socioeconomic, sociodemographic, and occupational settings, and exposure and vulnerability to infectious diseases. We combine data from the EU Statistics on Income and Living Conditions (EU-SILC) and the European Union Labour Force Survey (EU-LFS) and One Health surveillance, and using econometrics, quantify socio-demographic differentials in climate impacts on zoonotic diseases across Europe.

This deliverable starts the process to identify at-risk population groups likely to be most affected by changes in climate-induced infectious diseases. We focus on age, gender, income, income inequality, and employment sectors. An important aspect we address is inequality across occupational settings (for example, those who work outdoors), how occupation affects the probability of being bitten by a mosquito, and the ability of individuals to reduce this vulnerability.

Methods

Changing climatic, ecological, and socioeconomic drivers affect the spread of vector-borne diseases (EUCRA chapters 7 and 14; Palmer et al., 2017; van Daalen et al., 2024). For these diseases, there is evidence, for example, that the changing patterns of human–mosquito interaction, influenced by climate change, can vary substantially across small geographic areas, often linked to complex socioeconomic and sociodemographic conditions (Honório et al., 2009; Unlu et al., 2011; LaDeau et al., 2014; Ali et al., 2017). However, pan-European level evidence is currently not available. To address this gap, for this deliverable we focus on mosquitos, that are a key vector of climate sensitive diseases. We explore the relationship between mosquito bites and income, inequality, poverty, and other parameters such as population density and land cover. Additionally, our novel analysis studies whether the probability of being bitten by mosquitoes is higher in some occupational settings.

Empirical framework

We combine Mosquito Alert Global Minimal Model Estimates with the EU-SILC and EU-LFS at the sub-national level in Europe. Social and ecological dynamics influence number of mosquitoes bites and who is bitten (Palmer et al., 2017), as such it is critical to examine the effects of factors such as occupational settings, income-levels, and prevalence of inequality. We use the temporal and spatial variability in socioeconomic, sociodemographic, and land cover drivers to explore their impact on mosquito bites at sub-national level from January 2021 to April 2023.

Given the overdispersion in the mosquito bites data, we use a negative binomial mixed model. This specification is particularly useful in scenarios where the data are hierarchical or clustered, such as repeated measures within subjects or observations nested within groups. The "mixed" aspect of the allows capturing both the overall trends in the data and the individual differences between clusters. The negative binomial mixed model is more flexible than Poisson distributions in handling overdispersion. The specification includes a dispersion parameter that adjusts for the extra variability in the data. The fixed effects include covariates that influence the count outcomes, while the random effects account for unobserved heterogeneity.

$$y_{it} = \delta Income_{it} + \theta Inequality_{it} + \varphi Occupation_{it} + \pi X_{it} + \alpha_{is} + \gamma_{ts} + \varepsilon_{it}$$

$\delta Income_{it}$ includes either mean income per capita, income quantiles, or the share of low-income households in region i and time period t . $\theta Inequality_{it}$ includes measures of inequality including Gini coefficient, Atkinson Index, and material and social deprivation. Given that workers in the outdoor sectors such as agriculture, construction, forestry, fishing, and mining quarrying are more likely to be exposed to mosquito bites, we include the share of outdoor workers in region. We also include vegetation cover (NDVI), share of dwellings reporting having a garden, and population density.

Data

Key data sources are EU labour force surveys, collected by individual countries, Mosquito Alert, and EU statistics on income and living conditions.

Mosquito Alert Data

Mosquito Alert is a non-profit cooperative citizen science project, coordinated by different public research centres. The goal is to study, monitor, and fight the spread of invasive mosquitoes capable of transmitting global diseases such as dengue, Zika, or West Nile fever. The new version of the app allows users to report mosquitoes of five different species of concern in Europe, the Asian tiger mosquito (*Aedes albopictus*), the yellow fever mosquito (*Aedes aegypti*), the Asian bush mosquito (*Aedes japonicus*), *Aedes koreicus*, and the common house mosquito (*Culex pipiens*).

Surveillance is carried out with the Mosquito Alert app, which allows anyone to notify, by means of a photo, the possible discovery of one of the mosquitoes studied, as well as that of their breeding places in public spaces. Along with the photo the location of the observation and other necessary information to help in the identification of the species are collected. A human team of expert entomologists oversees validating the photos received and notifying the participant of the result. The outputs are publicly available as maps and the probability models developed from the citizen observations. The information obtained through the Mosquito Alert app complements the scientific work in the surveillance of invasive mosquitoes and can be used by public health managers to monitor and control these mosquitoes in neighbourhoods

and cities. While the mosquito bites data is also available at the GADM-4 level, the highest geolocation information provided in the survey datasets is GADM-2, thus we use GADM-2 level data to match the survey data.

Mosquito bite (Figure 1; left-panel) estimates are the probability of at least one such report being sent during the given month provided at the GADM level 4 (Figure 1; right-panel). The log odds of at least one report is modelled as a function of a set of land cover variables, a set of weather variables, sampling effort, and area, with random intercepts at the GADM 1 level. The model controls for sampling effort, 2-meter temperature, relative humidity, windspeed, proportion of the areal unit covered by discontinuous urban fabric, proportion of the areal unit covered by continuous urban fabric, proportion of the areal unit covered by green urban area, proportion of the areal unit covered by forests, shrubs, and/or herbaceous vegetation, proportion of the areal unit covered by agricultural areas, and country-specific reporting behaviour from Spain, Italy, and the Netherlands.

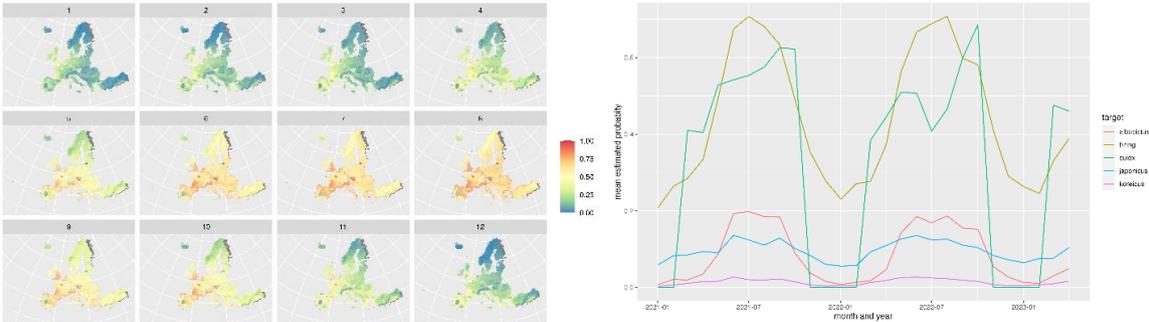


Figure 1: Estimated probabilities of at least one mosquito bite report being sent from each GADM-4 unit by month during 2022 (left-panel); Mean probability estimated for each target by month from 2021 to present assuming uniform sampling effort of 1 (right-panel).

European Union Statistics on Income and Living Conditions for all relevant indicators

The European Union Statistics on Income and Living Conditions (EU-SILC) collects comparable cross-sectional and longitudinal multidimensional microdata on aspects in monetary and non-monetary terms for households and individuals including income (Figure 2; left-panel). Along with income, the survey covers inequality (Figure 2; right-panel), poverty, social exclusion, housing, labour, education, and health in the 27 current Member States of the EU and the four EFTA countries.

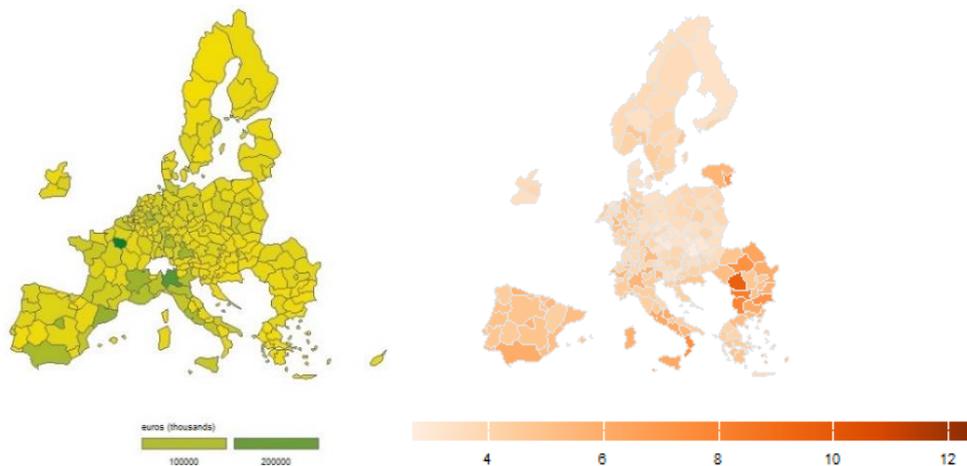


Figure 2: Mean income of households (left-panel) and income quintile share ratio S80/S20 by NUTS-2 region (2021)

European Union Labour Force Survey for all relevant indicators

The European Union Labour Force Survey (EU-LFS) is a rotating random sample survey covering the population in private households in currently 35 European countries (all EU countries, four candidate countries, and three EFTA countries). The sampling units are dwellings, household or individuals depending on the country-specific sampling frames. The main aim of the LFS is to provide comparable information on employed, unemployed and inactive persons of working age (15 years and above) in European countries.

The definitions of employment and unemployment used in the LFS closely follow the International Labour Organisations guidelines. Common classifications used are NACE, ISCO, ISCED, NUTS. Core topics of the LFS are demographic background; labour status; employment characteristics of the main job; hours worked; second job; previous work experience of person not in employment; search for employment; methods used during previous four weeks to find work; main labour status; education and training; situation one year before survey; income; atypical work.

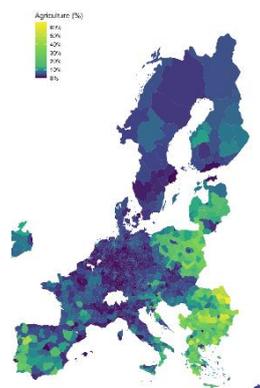


Figure 3: Agriculture share of employment in the EU (2021)

Results

For this intermediate deliverable, we present data only for mosquito bites. Our empirical analysis provides strong evidence that both socioeconomic and demographic drivers affect the probability of an individual being bitten by a mosquito in Europe. The socioeconomic factors of income, inequality, and poverty significantly influence the probability of mosquito bites. We use three different model specifications. Specification 1 in Table 1 is our base specification. Additionally, we have undertaken two additional specifications as robustness tests. In column 2, we replace the share of low-income households in each NUTS-2 region with log of per capita income, and in column 3, we use number of hours worked in the outdoor sectors instead of share of the workforce in the outdoor sectors as our indicator of occupational settings. Our results are consistent across a range of different specifications (Table 1).

	(1)	(2)	(3)
Share of low-income households	0.205*** (0.009)		
Log of income		-0.131** (0.016)	-0.122** (0.010)
Gini coefficient	0.219*** (0.003)	0.224*** (0.001)	0.201*** (0.005)
High-exposure occupation share	0.337*** (0.026)	0.319*** (0.021)	
Log of hours worked outdoors			0.176*** (0.029)
NDVI	0.120 (0.552)	0.155 (0.244)	0.142 (0.307)
Population density	0.205** (0.020)	0.214** (0.019)	0.197** (0.013)

Robust p-values in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 1: Relationship between socioeconomic and demographic drivers on mosquito bites

Our results show that for regions (NUTS-2) with a higher share of households in a country's low-income quantile, the probability of an individual being bitten by a mosquito is also higher. These findings are consistent with evidence that shows that low-income neighbourhoods are more susceptible to mosquito-related issues (Palmer et al., 2017). When we use income per capita as our dependent variable, we find that higher income in a given region is associated with a lower probability of being bitten by a mosquito, indicating that higher overall economic well-being can mitigate the risk of being bitten. Additionally, greater income inequality, measured by Gini coefficient, also is associated with a higher probability of being bitten by a mosquito in a region. This highlights the complex interplay between economic inequalities and public health outcomes related to mosquito-borne diseases.

Outdoor workers tend to be more exposed to environments where mosquitoes are prevalent. We find that a higher share of outdoor workers at the NUTS2 level is associated with a higher likelihood of being bitten by a mosquito. We also show explicitly that the higher number of hours worked outdoors directly increases the probability of mosquito bites.

The characteristics of land cover and population density affect the probability of someone being bitten by a mosquito . Our findings show that higher population density is linked to a higher incidence of mosquito bites, likely due to the greater availability of human hosts in densely populated areas and that greater population density generally increases the human and vector interaction. However, we find no significant effect of vegetation cover on the probability of mosquito bites. A possible explanation could be that the slowly changing aspects of vegetation cover do not influence mosquito bite prevalence.

Part 2. Integrating dimensions of societal inequality into IDAlert indicators

The second part of this deliverable focuses on indicator development and lays out how inequalities can be incorporated. We take an interdisciplinary approach which is essential for effective policy making that reaches and benefits diverse population groups, especially the most vulnerable including lower-income households and populations on the move. To ensure this, first, the proposed indicator development is grounded within epidemiology, public health, and One Health. Second, each indicator is viewed through a socioeconomic lens and disaggregated to identify and track inequalities with respect to exposure and vulnerability. Third, stakeholder involvement has been integrated into the project from its inception.

Methods

To achieve the goal of integrating dimensions of inequality into infectious disease indicators, sub-population groups most at risk from changes in climate-induced infectious diseases are identified. Each indicator considers how societal inequalities in Europe interact with climate-sensitive zoonotic diseases through disaggregation of indicators. Indicators are disaggregated, focusing on age, gender, income, income inequality, and employment sectors

Data

To identify sub-population groups most at risk from changes in climate-induced infectious diseases, we integrate household and labour force surveys, demographic and population data, and One Health surveillance to quantify socio-demographic differentials in climate impacts on zoonotic diseases across Europe.

Indicator	Demo-graphics	Rural-urban	Income	Mobility	Outdoor work	Notes
Hantavirus	x		x			The indicator will incorporate the following dimensions of inequality: population structure, GDP per capita. These dimensions have been chosen based on evidence from the literature.
West Nile Virus		x				Rural populations are generally poorer than urban and have been found to be particularly at risk from WNV.
Dengue, Chikungunya, and Zika						Movement of people from dengue-endemic regions to Europe.
Malaria		x	x		x	Low levels of urbanization, inadequate housing infrastructure, outdoor work, and peri-urban and rural regions with limited access to healthcare services.
Leishmaniasis				x		Vulnerable populations including migrants and refugees, internally displaced, and marginalised populations.
Tick-borne diseases					x	High risk among those engaged in agriculture or residing in peri-urban and rural areas.

Table 2: Summary of indicators and inequality drivers currently being investigated

Results

For West Nile Virus, the relative increase in WNV outbreak risk in 2013-2022 compared to 1951-1960 was 256%, with the highest relative risk increase seen in eastern Europe (516%) and southern Europe (203%). Evidence shows that among three topological categories (urban, intermediate, and rural), the highest risk of an outbreak tends to occur in the rural topological regions, which are associated with lower-than-average incomes.

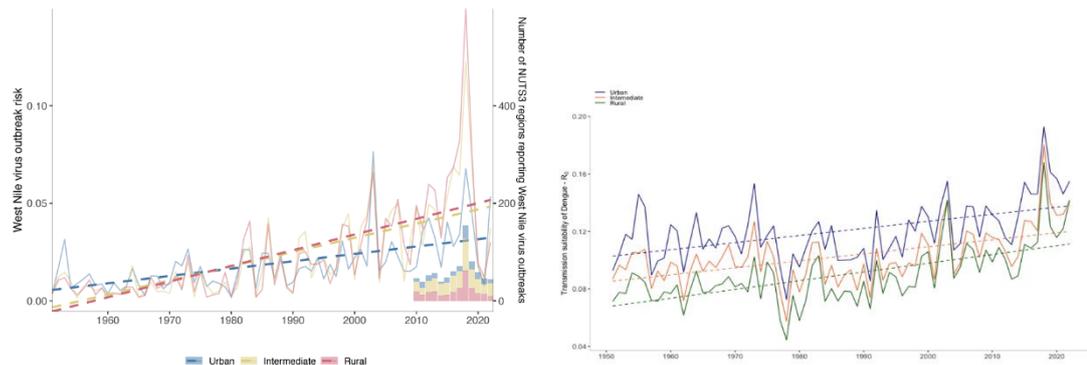


Figure 4: Annual West Nile virus risk trends categorized into three topological regions shown along left vertical axis. The bar plots (right vertical axis) show the corresponding number of NUTS3 reporting the virus outbreaks in each category. Annual change in transmission suitability of dengue in three topological regions (urban, rural, and intermediate) (right-panel).

For Dengue, Chikungunya, and Zika, the transmission suitability R_t was 55.9% higher during 2013-2022 compared to the 1951-1960 baseline with the highest absolute increase in southern Europe (6.9%), followed by eastern Europe (6.7%). Increased human mobility and rising climatic suitability contribute to the surge in arboviral diseases in Europe. The occurrence of these diseases is linked to socioeconomic factors such as the movement of people from dengue-endemic regions to Europe, where conditions are becoming more suitable for transmission.

For non-cholerae *Vibrio*, 21 countries in Europe showed suitable conditions for *Vibrio* in 2022, with an accumulated number of days per country of 2,188, the third highest number in record. Risk factors of *Vibriosis* likely differ among different European regions. Behavioural habits associated with both the use of coastal water for recreational activities and seafood consumption further vary across Europe and may affect population groups with different socioeconomic status, age groups, and other underlying factors such as pre-existing medical conditions. Though most of the infections are self-limiting, inequalities in access to healthcare among marginalised and lower socioeconomic populations may result in a higher infection rate.

For Malaria, the climatic suitability for *P. vivax* transmission has increased by 0.34 months in western Europe and 0.22 months in eastern Europe between 1951-1960 and 2013-2022. The indicator that tracks climatic suitability for malaria transmission will explore inequalities through socioeconomic status and rural/urban topology. These dimensions have been based on evidence that malaria tends to be a disease of rural communities, possibly due to a combination of *Anopheles* mosquitoes preferring rural environments and because of socioeconomic/behavioural differences, for example, rural communities are more likely to live with and closer to livestock, which is often the preferred host for *Anopheles* blood-meals (Hay et al., 2005; Ricci, 2012; Noble and Austin, 2016). Furthermore, rural communities globally often

see higher levels of poverty, compared to their urban counterparts. Higher levels of poverty have been associated with higher levels of malaria transmission, due to poor access to piped water, a decrease in access to healthcare and inadequate living conditions. The data sources come from the United Nations [Human Development Index](#) and Copernicus [CORINE](#) Land Cover Classes.

Climatic suitability for leishmaniasis has increased in Europe in the last two decades (2001-2020), with more noticeable changes in southern and eastern European countries. This indicator will incorporate socio-economic status to explore inequalities. This dimension has been chosen based on the knowledge that leishmaniasis is considered a paediatric disease in areas where poverty is prevalent, particularly in Eastern European countries (Ready, 2010). Climate change can affect food insecurity, particularly populations of low socioeconomic status, and malnutrition is a known risk factor for development of leishmaniasis, particularly in children. In Western European countries, the majority of leishmaniasis cases occur in adults with comorbidities (such as HIV), in those undergoing immunosuppressive therapies, and in immunocompetent people lacking acquired immunity to the parasite (ECDC, 2022). Socially vulnerable populations include migrants and refugees, internally displaced and marginalised populations. Inequalities in access to healthcare, social and economic burdens and stigma associated with leishmaniasis, whilst not as pronounced as in endemic low-income countries, are to be expected in the more marginalised and lower socioeconomic populations of Europe.

Eastern Europe and western Asia exhibited the highest suitability for tick species *Ixodes ricinus* feeding activity, particularly in rural areas and areas with high social deprivation levels. In total, 1455 (96%) of 1,514 NUTS3 regions monitored increased in suitability during 2013-2022 compared to 1951-1960. The suitability for ticks, which transmit diseases like Lyme borreliosis and tick-borne encephalitis, is increasing. The distribution and habitats of *Ixodes ricinus* ticks are associated with the presence of social inequalities regarding the exposure to and prevention of TBDs (Rizzoli et al., 2014). The indicator that tracks tick-borne diseases will incorporate vulnerable occupational groups and recreational groups to explore inequalities. Tick-borne diseases can arise from recreational and occupational exposure to tick habitat, or through unpasteurized food products and animal slaughter in the case of tick-borne encephalitis and Crimean-Congo Haemorrhagic Fever, respectively. Taking into account land suitability, it is possible to stratify results “*weighted by forest*” and “*weighted by agricultural area*”. With this stratification, it will be possible to detect exposure trends in vulnerable populations working in the agricultural sector. The data sources come from: Copernicus [CORINE](#) Land Cover Classes.

Our analysis will underscore how socioeconomic factors including income and education interact with the changing distribution of climate-sensitive infectious diseases to drive changes in inequality in Europe. These socioeconomic factors affect the vulnerability of different populations to these diseases.

Conclusion and next steps

IDAAlert’s work on incorporating societal vulnerabilities and social asymmetries in the indicators of impacts and responses is already revealing important and concerning implications for

inequality. The next phase of this work will not only generate the heterogeneous impacts of climate change on infectious diseases but will allow targeted and tailored decision making.

Using individual-level health registry data (mortality, demographic, social-care, and housing registries), we are undertaking three detailed studies in Sweden, Spain, and Bangladesh, to identify individual level risk which will provide tailored advice and evidence to policymakers and labour groups in distinct locations such as Barcelona and the Girona province in Spain, and Dhaka and Teknaf in Bangladesh. The combined results are used to inform the seasonal early warning indicators and models developed in WP3 and WP4 and the intervention evaluations in WP5.

In collaboration with case studies teams in Spain, Greece, and Bangladesh, we will combine novel surveillance data to investigate the bi-directional relationship between mosquito-borne diseases and inequalities, poverty, and other social factors. A focal area will be inequality across occupational settings with respect to the probability of being bitten by mosquitoes (e.g., those working outside) and ability of individuals to reduce this vulnerability.

References

- Alduchov O, Meteorology REJ of A, 1996 U. Improved Magnus form approximation of saturation vapor pressure. journals.ametsoc.org [Internet].
- Aydin H, Uyanik MH, Karamese M, Sozdutmaz I, Timurkan MO, Gulen A, Ozmen E, Aktas O. Serological investigation of occupational exposure to zoonotic crimean-congo hemorrhagic fever infection. *The Eurasian Journal of Medicine*. 2020;52(2):132.
- Benali A, Nunes JP, Freitas FB, Sousa CA, Novo MT, Lourenço PM, et al. Satellite-derived estimation of environmental suitability for malaria vector development in Portugal. *Remote Sens Environ*. 2014 Apr;145:116–30.
- Camp, J. V., & Nowotny, N. (2020). The knowns and unknowns of West Nile virus in Europe: what did we learn from the 2018 outbreak? *Expert review of anti-infective therapy*, 18(2), 145-154.
- Colón-González, F. J., Sewe, M. O., Tompkins, A. M., Sjödin, H., Casallas, A., Rocklöv, J., ... & Lowe, R. (2021). Projecting the risk of mosquito-borne diseases in a warmer and more populated world: a multi-model, multi-scenario intercomparison modelling study. *The Lancet Planetary Health*, 5(7), e404-e414.
- ECDC. (2022b, June 20). *Surveillance, prevention and control of leishmaniases in the European Union and its neighbouring countries*. European Centre for Disease Prevention and Control.
- Epidemiological Update: West Nile Virus transmission season in Europe, 2018. Retrieved November 16 from <https://www.ecdc.europa.eu/en/news-events/epidemiological-update-west-nile-virus-transmission-season-europe-2018>
- Farooq, Z., Rocklöv, J., Wallin, J., Abiri, N., Sewe, M. O., Sjödin, H., & Semenza, J. C. (2022). Artificial intelligence to predict West Nile virus outbreaks with eco-climatic drivers. *The Lancet Regional Health-Europe*, 17, 100370.
- Fischer, L., Gültekin, N., Kaelin, M. B., Fehr, J., & Schlagenhauf, P. (2020). Rising temperature and its impact on receptivity to malaria transmission in Europe: a systematic review. *Travel medicine and infectious disease*, 36, 101815.
- Grover-Kopec EK, Blumenthal MB, Ceccato P, Dinku T, Omumbo JA, Connor SJ. Web-based climate information resources for malaria control in Africa. *Malar J* [Internet]. 2006 May;5. Available from: <https://pubmed.ncbi.nlm.nih.gov/16689992/>
- Hay SI, Guerra CA, Tatem AJ, Atkinson PM, Snow RW. Urbanization, malaria transmission and disease burden in Africa. *Nature Reviews Microbiology*. 2005 Jan 1;3(1):81-90.
- Johnson, L. R., Ben-Horin, T., Lafferty, K. D., McNally, A., Mordecai, E., Paaijmans, K. P., ... & Ryan, S. J. (2015). Understanding uncertainty in temperature effects on vector-borne disease: a Bayesian approach. *Ecology*, 96(1), 203-213.
- Leggewie, M., Badusche, M., Rudolf, M., Jansen, S., Börstler, J., Krumkamp, R., Huber, K., Krüger, A., Schmidt-Chanasit, J., & Tannich, E. (2016). *Culex pipiens* and *Culex torrentium* populations from Central Europe are susceptible to West Nile virus infection. *One Health*, 2, 88-94.

- Lessler, J., Chaisson, L. H., Kucirka, L. M., Bi, Q., Grantz, K., Salje, H., ... & Rodriguez-Barrquer, I. (2016). Assessing the global threat from Zika virus. *Science*, 353(6300), aaf8160.
- Mordecai, E. A., Caldwell, J. M., Grossman, M. K., Lippi, C. A., Johnson, L. R., Neira, M., ... & Villena, O. (2019). Thermal biology of mosquito-borne disease. *Ecology letters*, 22(10), 1690-1708.
- Muñoz Sabater J. ERA5-Land hourly data from 1950 to 1980. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). 2021.
- Noble MD, Austin KF. Rural disadvantage and malaria in less-developed nations: a cross-national investigation of a neglected disease. *Rural Sociology*. 2016 Mar;81(1):99-134.
- Patz JA, Graczyk TK, Geller N, Vittor AY. Effects of environmental change on emerging parasitic diseases. *Int J Parasitol*. 2000 Nov;30(12–13):1395–405.
- Ready PD.. Leishmaniasis emergence in Europe. *Eurosurveillance*, 2010;15(10):19505. <https://doi.org/10.2807/ese.15.10.19505-en>.
- Ramadona, A. L., Tozan, Y., Lazuardi, L., & Rocklöv, J. (2019). A combination of incidence data and mobility proxies from social media predicts the intra-urban spread of dengue in Yogyakarta, Indonesia. *PLoS neglected tropical diseases*, 13(4), e0007298.
- Reiter, P. (2010). West Nile virus in Europe: understanding the present to gauge the future. *Eurosurveillance*, 15(10), 19508.
- Ricci F. Social implications of malaria and their relationships with poverty. *Mediterranean journal of hematology and infectious diseases*. 2012;4(1).
- Rizzoli A, Silaghi C, Obiegala A, Rudolf I, Hubálek Z, Földvári G, et al. *Ixodes ricinus* and Its Transmitted Pathogens in Urban and Peri-Urban Areas in Europe: New Hazards and Relevance for Public Health. *Front Public Health*.
- Rocklöv, J. et al. Co-producing integrated decision-support tools to build climate resilience to emerging infectious diseases in Europe and beyond. (N.D. - under review).
- Rocklöv, J., & Tozan, Y. (2019). Climate change and the rising infectiousness of dengue. *Emerging Topics in Life Sciences*, 3(2), 133-142.
- Semenza, J. C., Sudre, B., Miniota, J., Rossi, M., Hu, W., Kossowsky, D., ... & Khan, K. (2014). International dispersal of dengue through air travel: importation risk for Europe. *PLoS neglected tropical diseases*, 8(12), e3278.
- Semenza, J. C., Trinanès, J., Lohr, W., Sudre, B., Löfdahl, M., Martínez-Urtaza, J., Nichols, G. L., & Rocklöv, J. (2017). Environmental suitability of *Vibrio* infections in a warming climate: an early warning system. *Environmental health perspectives*, 125(10), 107004.
- van Daalen, K.R., Romanello, M., Rocklöv, J., Semenza, J.C., Tonne, C., Markandya, A., Dasandi, N., Jankin, S., Achebak, H., Ballester, J. and Bechara, H. (2022). The 2022 Europe report of the *Lancet* Countdown on health and climate change: towards a climate resilient future. *The Lancet Public Health*, 7(11), pp.e942-e965.
- Zeller, H. G., & Schuffenecker, I. (2004). West Nile virus: an overview of its spread in Europe and the Mediterranean basin in contrast to its spread in the Americas. *Eur J Clin Microbiol Infect Dis*, 23(3), 147-156.
- Zhao, X., Smith, D. L., & Tatem, A. J. (2016). Exploring the spatiotemporal drivers of malaria elimination in Europe. *Malaria journal*, 15, 1-13.