Biodiversity and pandemics: Interdisciplinary research and action priorities.

A report of the Eklipse Expert Working Group on biodiversity and pandemics

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Eklipse Report - 02/2023

Biodiversity and pandemics: Interdisciplinary research and action priorities.

Full title of the request: "Building on existing relevant work on research agendas and knowledge gap analysis, identifying interdisciplinary research and action priorities, that contribute to a strategic research agenda on biodiversity and pandemics addressing the critical interlinkages between relevant sectors needed to make future actions more effective."

October 2023

A report of the Eklipse Expert Working Group on biodiversity and pandemics

Soushieta Jagadesh[1], Alexandre Caron[2], Claire Lajaunie[3], Hatice Mahur Turan[4], Nils Bunnefeld[5], Andrew Cunningham[6], Miguel Fernandez[7], Alister Scott[8], Norbert Tchouaffe Tchiadje[9], Adam Izdebski [10], Julie Teresa Shapiro[11]

1 ETH Zürich, Switzerland
2 ASTRE, University of Montpellier, CIRAD (French Agricultural Research Centre for International Development), INRAE (National Research Institute for Agriculture, Food and Environment), Montpellier, France; Universidade Eduardo Mondlane, Maputo, Mozambique
3 INSERM, Institut national de la santé et de la recherche médicale (Inserm), Laboratoire Population Environnement Développement (Aix-Marseille Université, IRD), Marseille, France; Strathclyde Centre for Environmental Law & Governance, Strathclyde University, Glasgow, Scotland
4 TUBITAK, The Scientific and Technological Research Council of Turkiye, Turkiye
5 University of Stirling, UK
6 Institute of Zoology, Zoological Society of London, UK
7 German Center for Integrative Biodiversity Research, Germany; Environmental Science and Policy, George Mason University, US
8 University of Northumbria, UK
9 Pan-African Institute for Development, African Academy of Sciences and University of Dschang, University of Ebolowa, Cameroon
10 Max Planck Institute of Geoanthropology, Jena, Germany
11 Ben-Gurion University of the Negev, Israel / Current affiliation: Epidemiology and Surveillance Support Unit, Anses, Lyon, France

All authors have read and agreed to the actual version of the manuscript.

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Landscapes, south of Ambalavao, Madagascar.

Consortium of requesters:
European Commission Directorate General Research and Innovation (EC-DG RTD)
European Commission Directorate General Environment (EC – DG ENV)
European Commission Directorate General Health Emergency preparedness and Response Authority (EC – DG HERA)
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Project HERA (Health Environment Research Agenda for Europe)
Norwegian Veterinary Institute (NVI)
PREZODE (Preventing ZOonotic Disease Emergence)
One Health High-Level Expert Panel (OHHLEP)

Reviewers of the methods protocol:
Paul Martial Tene Tayo - Biotechnology Center of the University of Yaounde 1, Cameroon
Jindani Rahim
Sophie Vanwambeke – Earth & Life Institute, UCLouvain, Belgium
Barbara Kostanjšek – Slovenian Association of Landscape Architects / University of Ljubljana, Slovenia
Shafiq Kakeeto
Sarah Edwards – University College London (UCL), UK

Reviewers of the synthesis report:
Alec Christie – Downing College, Department of Zoology, University of Cambridge, UK
Andy Dobson – Princeton University, USA
Anna Fagre – Colorado State University, USA
Dimosthenis Chochlakis – Laboratory of Clinical Microbiology, School of Medicine, University of Crete, Greece
John Haldon – Princeton University, USA
Julien Capelle – CIRAD (French Agricultural Research Centre for International Development), France
Lee Mordechai – Hebrew University Center for Sustainability, Israel
Merle Eisenberg – Oklahoma State University, USA
Rosa Jolma – Royal Netherlands Institute for Sea Research, Utrecht University, Netherlands
Anonymous reviewer 1 from Nunu
Anonymous reviewer 2
Anonymous reviewer 3
Anonymous reviewer 4

Survey participants:
Claudio Azat, Violet BarasaViolet, Annemarie Bastrup-Birk, Aniruddha Belsare, Nüket Bilgen, Julian Blanc, Pascal Bonnet, Andrew Breed, Patrik Buholzer, Julien Cappelle, Benjamin Capps, Bertrand Chardonnet, Philippe Chardonnet, Dimosthenis Chochlakis, Daniel Cornelis, Michel De Garine-Wlichatitsky, Stephane De la Rocque, Yann Devos, Andy Dobson, Julian Drewe, Raphaël Duboz, Gul Erdem, Anna Fagre, Lyle Fearnley, Eric Fevre, Amanda Fine, Herve Fritz, Francis Gakuya, Patrick Giraudoux, Souana Goumou, Rodolphe Gozlan, Jean-Francois Guegan, Estelle Hamelin, James Hassell, David Hayman, Gilberto Hochman, Markus Hofmeyr, Edward Holmes, Rosa Jolma, Gilles Kleitz, Theo Knight-Jones, Arthur Kocher, Richard Kock, Gulay Korukluoglu, Melissa Leach, Christos Lynteris, Hayley MacGregor, Catherine Machalaba, An Martel, Rebecca Maudling, Fernando Mc Kay, Hugo Mendoza, Anna Meredith, Prisca Mugabe, Musso Munyeme, Hung Nguyen, Roberto Leonan Novaes, Sarah Olson, Antonio Petrini, Silviu Petrovan, Marisa Peyre, Herbert Prins, Delia Randolph, David Redding, Benjamin Roche, Simon Ruegg, Boris Schmid, Danny Sheath, Nigel Sizer, Jules Skotnes-Brown, Marina Sokolova, Prof Dr Simone Sommer, Richard Suu-Ire, Oguz Turkozan, Andres Valenzuela, Neil Vora, Christian Walzer, Linfa Wang, Nick Wilson, James Wood, Rupert Woods, Carlos Zambrana-Torrelio, Jakob Zinsstag, Participant to the survey 84 to 121

Focus Group participants:
Bernadette Abela-Ridder – World Health Organization (WHO)
Assoc. Prof. Nüket Bilgen, DVM, PhD – Ankara University, Faculty of Veterinary Medicine, Department of Genetics, Türkiye
Andy Dobson – Princeton University, USA
Eric Fèvre – ILRI / University of Liverpool, UK
Amanda Fine – Wildlife Research and Training Institute, Kenya
Francis Gakuya – Wildlife Research and Training Institute, Kenya
Richard Kock (retd) – Royal Veterinary College, UK
Christos Lynteris – St Andrews University, Scotland
Rupert Woods – Wildlife Health Australia, WOAH Working Group on Wildlife, Australia

Series editors: Serge Morand, Carla-Leanne Washbourne, Candice Pouget, Karla E. Locher and Marie Vandewalle

Editorial Design: Mira Antonijevic, www.jutro-design.de

EKLIPSE TEAM

Members of Knowledge Coordination Body:	■ Serge Morand - CNRS (French National Centre for Scientific Research) – CIRAD (French Agricultural Research Centre for International Development), France – Faculty of Veterinary Technology, Kasetsart University, Bangkok, Thailand ■ Carla-Leanne Washbourne - University College London, UK
Members of the Methods Expert Group:	■ Alister Scott – University of Northumbria, UK ■ Nils Bunnefeld - University of Stirling, UK
Members of the Eklipse Management Body:	■ Candice Pouget - Helmholtz Centre for Environmental research (UFZ), Germany ■ Karla E. Locher - Helmholtz Centre for Environmental research (UFZ), Germany ■ Marie Vandewalle - Helmholtz Centre for Environmental research (UFZ), Germany

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Glossary

Glossary

TERM	DEFINITION	KEY REFERENCES
Agrobiodiversity	The variety and variability of animals, plants and micro-organisms that are used directly or indirectly for food and agriculture, including crops, livestock, forestry and fisheries. It comprises the diversity of genetic resources (varieties, breeds) and species used for food, fodder, fibre, fuel and pharmaceuticals.	FAO https://www.fao.org/3/y5609e/y5609e01.htm
Agro-ecosystem	A cultivated ecosystem whose ecosystem functions are valued by humans in the form of agricultural goods and services.	Eklipse Expert Working Group
Biodiversity	The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.	UN https://sustainabledevelopment.un.org/index.php?page=view&type=30022&nr=1357&menu=3170
Ecosystem	"Ecosystem" means a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit".	Article 2 of the Convention on Biological Diversity, 2006 https://www.cbd.int/ecosystem
Epidemic	A disease outbreak is the occurrence of cases of disease in excess of what would normally be expected in a defined community, geographical area or season. Epidemics are maintained by infectious agents that spread directly from person to person, from exposure to an animal reservoir or other environmental source, or via an insect or animal vector.	WHO
Epidemiology	The study of the distribution and determinants of health-related states or events (including disease), and the application of this study to the control of diseases and other health problems. Various methods can be used to carry out epidemiological investigations: surveillance and descriptive studies can be used to study distribution; analytical studies can be used to study determinants.	Frérot et al. 2018 https://journals.plos.org/plosone/article/file?type=printable&id=10.1371/journal.pone.0208442
Evidence-based research	The use of prior research in a systematic and transparent way to inform a new study to answer questions that matter in a valid, efficient, and accessible manner.	Robinson et al. 2021 https://linkinghub.elsevier.com/retrieve/pii/S0895435620310957
Evidence-informed policy/ decision making	Evidence-informed decision-making (EIDM) entails identifying, appraising, and mobilizing the best available evidence for safe and effective health policy and programmes.	WHO https://www.who.int/publications/i/item/9789240039872
Interdisciplinary	Integrating information, data, techniques, tools, perspectives, concepts or theories from two or more disciplines or bodies of specialized knowledge.	U.S National Science Foundation https://new.nsf.gov/funding/learn/research-types/learn-about-interdisciplinary-research
Knowledge gap	Unavailability of evidence-based or non- anecdotal knowledge necessary to answer a specific question, leading to the need for further investigation, evidence synthesis, and knowledge exchange.	Collins dictionary
One Health	Is an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals, and the environment. It recognizes the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and interdependent. The approach mobilizes multiple sectors, disciplines and communities at varying levels of society to work together to foster well- being and tackle threats to health and ecosystems, while addressing the collective need for clean water, energy and air, safe and nutritious food, taking action on climate change, and contributing to sustainable development.	OHHLEP (endorsed by WHO/ WOAH/FAO/U NEP) https://journals.plos.org/plospathogens/article?id=10.1371/journal.ppat.1010537 This definition includes the five key underlying principles.

TERM	DEFINITION	KEY REFERENCES
Outbreak	An sudden and apparent change in levels of disease or symptoms in a defined population within a definied geographic area and defined time period.	O'Neil & Naumova,2007 https://link.springer.com/article/10.1057/palgrave.jphp.3200140
Pandemic	The rapid spread of an infectious disease across multiple continents; an epidemic occurring worldwide or over a very large area, crossing international boundaries and usually affecting a large number of individuals.	WHO https://www.who.int/europe/emergencies/situations/covid-19
Preparedness	The knowledge and capacity developed by governments, response and recovery organizations, communities and individuals to effectively anticipate, respond to and recover from the impacts of likely, imminent or current disasters.	UNDRR https://www.undrr.org/terminology/preparedness
Risk	Risk is the probability of an outcome having a negative effect on people, systems or assets. Risk is typically depicted as being a function of the combined effects of hazards, the assets or people exposed to hazard and the vulnerability of those exposed elements.	United Nations for Disaster Risk Reduction https://www.undrr.org/building-risk-knowledge/understanding-risk
Scoping review	A structured, step-wise methodology, preferably following an a priori protocol to collate and describe existing research evidence (traditional academic and grey literature) in a broad topic area, following a systematic map methodology but with components of the process simplified or omitted to produce information in a short period of time.	Eklipse https://eklipse.eu/wp-content/uploads/website_db/Methods/Method15_Scoping_review.pdf
Spillover	The transmission of a pathogen from a host species to a new species.	Shapiro et al. 2021 https://www.mdpi.com/1999-4915/13/7/1356#B124-viruses-13-01356
Theory of change	A theory of change is a method that explains how a given intervention, or set of interventions, is expected to lead to specific development change, drawing on a causal analysis based on available evidence.	UN https://unsdg.un.org/sites/default/files/UNDG-UN-DAF-Companion-Pieces-7-Theory-of-Change.pdf
Transdisciplinary	Integrating knowledge across academic disciplines and with non-academic stakeholders to address societal challenges.	Klein, 2008 https://www.sciencedirect.com/science/article/abs/pii/S0749379708004200?casa_token=9RFXQKEMaRIAAAAA:v42lIm3sdzK5OYMWL2uQtEU0bRJ3Ud_4EUyoqe1t9Pt8leUVgQGKgUQH4vhTNg4TV8tmVBFlIO8
Triangulation	Triangulation is the use of multiple theories, data sources, methods or investigators within the study of a single phenomenon.	UNESCO https://unesdoc.unesco.org/ark:/48223/pf0000381664.locale=en
Zoonotic spillover	The transmission of a pathogen from a vertebrate animal to a human being.	WHO https://www.who.int/publications/m/item/prevention-of-zoonotic-spillover
Zoonosis	A disease or infection that is naturally transmissible from vertebrate animals to humans.	WHO https://www.who.int/news-room/fact-sheets/detail/zoonoses

Abbreviations

Abbreviations

CAP	Common Agricultural Policy
CBD	Convention on Biological Diversity
EC	European Commission
EC - DG AGRI	European Commission's Directorate-General for Agriculture and Rural Development
EC – DG ENV	European Commission's Directorate-General for Environment
EC – DG HERA	European Commission's Directorate-General for Health Emergency preparedness and Response Authority
EC- DG RTD	European Commission's Directorate-General for Research and Innovation
CGIAR	Consultative Group on International Agricultural Research
EWG	Eklipse Expert Working Group
FAO	Food and Agriculture Organization of the United Nations
MEG	Eklipse Method Expert Group
NVI	Norwegian Veterinary Institute
OHHLEP	One Health High Level Expert Panel
PREZODE	Preventing ZOonotic Disease Emergence
Project HERA	Health Environment Research Agenda for Europe
UNEP	United Nations Environment Programme.
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNDRR	United Nations office for Disaster Risk Reduction
W/D/H interface	Wildlife / Domestic animal / Human interface
WHO	World Health Organization
WOAH	World Organisation for Animal Health

Executive Summary

1. Executive Summary

This report outlines recommendations for science policy regarding biodiversity and pandemics that need to be implemented in order to develop broader transformative policies for human, animal, and ecosystem health. In particular, we focus on policies to support and promote research needed to better prevent and manage spillover events in which pathogens originating in wildlife cause disease outbreaks or even pandemics in humans or large-scale disease events in domesticated animals (panzootics).

The report was prepared by an Eklipse Expert Working Group (EWG) active from 2022-2023. The EWG consisted of scientists with relevant expertise in the natural, biomedical, and social sciences. The group undertook a scoping review of scientific literature and collected input from a large body of external experts through an online survey and focus group discussions. Using these results, the EWG formulated recommendations for shaping a strategic research agenda on biodiversity and pandemics. These recommendations address the critical interlinkages between relevant sectors and stakeholders via targeted transdisciplinary research to make future actions more effective. Crucially, in the following recommendations **we call for moving beyond incremental changes to science policy and bringing about transformative change to how research is carried out,** organised, and financed. Only in this way will science itself deliver the knowledge and insights needed to develop policies that will help transform human animal and ecosystem health, avoiding the accumulation of problems generated by the still widespread business as usual approach to both research and broader policy-making. Our ability to deliver this transformative change is essential to confront other global crises, including the climate and biodiversity crises, that are currently threatening our societies.

Recommendations

1. Promote the development of a science of the **wildlife/ domestic animal/human interface**.
2. Promote interdisciplinarity that **integrates the social sciences and humanities** into the science of the interface.
3. Promote transdisciplinarity **that involves local communities and civil society** in the science of the interface.
4. **Formulate problem-led** funding calls beyond the current standard 3-5 year project cycle.

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Desert warthog and a young calf in the Garissa region of Kenya, 2003

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Group of women workers in Sierra Leone.

Recommendation 1:
Promote the development of a science of the wildlife/domestic animal/human interface.

Spillovers – events in which pathogens "jump" from wild to domestic animals and / or to humans – can occur in areas (natural or modified) where humans and their d animals comes into contact with wildlife. This may happen in many different kinds of habitats or ecosystems, ranging from high biodiversity hotspots that contain a high host and pathogen diversity to urban contexts where a reduced number of wild hosts (e.g., certain common rodent or bird species) may host pathogens with pandemic potential. Wherever they occur, these spillovers are triggered by contact at a wildlife/domestic animal/human (W/D/H) interface. Because of the diversity, complexity, and dynamics of these interfaces, they have not been extensively studied, and most often through a relatively limited, disciplinary lens. We need to overcome these shortcomings by developing an integrated science of the wild-domestic-human interface that will have the power to better understand the mechanisms of pathogen spillover and inform policies to better manage future pandemic threats.

Recommendation 2:
Promote interdisciplinarity that integrates the social sciences and humanities into the science of the interface.

Wildlife / domestic animal / human interfaces are both natural and social phenomena created primarily through the expansion of human activities (including the creation of human infrastructures and introduction of domestic animals) in natural habitats where biodiversity persists. Consequently, understanding spillover dynamics at these interfaces requires not only the natural and biomedical sciences but true collaboration and integration with the social sciences and humanities to address how historical, cultural, and economic forces have shaped the current interfaces and predict how they are likely to change in the future. The full range of academic disciplines that work on understanding and predicting human perceptions, behaviour, beliefs, and values provide critical information for understanding human use and practices at W/D/H interfaces. This requires the contribution of diverse disciplines, such as anthropology, history, archaeology, sociology, political science and economics. The representatives of these disciplines need to be given equal voice in the integrated science of the interface alongside the natural sciences such as ecology or epidemiology.

Recommendation 3:
Promote transdisciplinarity that involves local communities and civil society in the science of the interface.

W/D/H interfaces are the result of both global and local drivers making each interface highly local and specific. Each interface comes into existence and operates within a particular area and cultural context. The local communities that experience and manage such interfaces on a daily basis (sometimes for generations) have accumulated detailed knowledge of how they function and the challenges they pose. The new science of the W/D/H interface must build on and incorporate this local knowledge, with the collaboration of local communities and civil society.

In this respect, the social sciences and humanities, such as anthropology, sociology, history, and political science, have an essential role to play. The science of the interface must produce knowledge through transdisciplinary processes and promote policies for human and domestic animal health as well as the conservation of wildlife with the participation of the local communities and civil society from the beginning to the end. This transdisciplinary process will ensure not only the production of more diverse forms of knowledge but also that any research and interventions (e.g. surveillance or control) that are more likely to be accepted and implemented locally. Close engagement with the local partners is the best guarantee of success for any future evidence-based policies.

Recommendation 4:
Formulate problem-led funding calls beyond the current standard 3-5 year project cycle.

The science of the interface should be driven by inter- and transdisciplinary practice-led problems and not by academic questions of general interest. While interface science projects require excellence in the humanities, social and natural sciences, they should be oriented toward solving real-world questions and providing evidence as well as concrete ideas for health and wildlife policies. Further, to study the diversity, complexity, and dynamics of W/D/H interfaces across space and time, long-term study sites are needed and require consistent resources to operate and capture long-term trends.

Developing the integrated science of the interface will therefore not happen overnight. It requires innovative approaches to sustained funding and constant evaluation and extension of the results and insights achieved so far. Consequently, the new science of the interface cannot be subject to the usual science funding cycle in which projects last 3-5 years. The funding should be more predictable and aimed at preserving the social learning accumulated in earlier project phases.

Introduction

2. Introduction

2.1 Background

Biodiversity, the variety of life on Earth, plays a crucial role in delivering essential ecosystem services and regulating ecological functions (Sandifer et al., 2015). These services and functions are pivotal in supporting human societies and food systems (IPBES, 2019). However, human activities such as land-use change – largely for agricultural production, urban development and resource exploitation – are causing a rapid loss of biodiversity and bringing humans and domestic animals into closer contact with wildlife, likely increasing the risk of pandemics (IPBES, 2020). A study by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) found that "zoonotic diseases - diseases that are transmitted from animals to humans - represent a growing threat to global health security and are responsible for a significant proportion of emerging infectious diseases in humans" (IPBES, 2020). The COVID-19 pandemic, caused by the SARS-CoV-2 virus, has reignited the conversation regarding links between biodiversity loss and infectious diseases (Morand and Lajaunie, 2021). Several studies have shown that the destruction of natural habitats and the loss of biodiversity can lead to the emergence and spread of zoonotic diseases (Keesing et al., 2010; Gibb et al., 2020; Johnson et al., 2020).

Further, the COVID-19 crisis has revealed how fragile and vulnerable our societies are to pandemics and how challenging it is to enact informed political and policy responses when faced with such an emergency. As a global community, we were not prepared for a novel zoonotic pandemic despite scientific predictions that this was very likely to occur (Cunningham, 2005; Morand and Lajaunie, 2021) due to the current unprecedented rates of land degradation and conversion, consumption of natural resources, increasing livestock production, and accelerating biodiversity loss.

The pandemic also revealed how vulnerable biodiversity research and management can be in the face of a crisis (Corlett et al., 2020) while highlighting the urgent need for global, standardized, and automated monitoring of species in order to accurately measure changes in biodiversity world-wide (Sugai, 2020).

In addition, the COVID-19 pandemic has revealed a broad range of science-policy challenges and knowledge gaps related to biodiversity and pandemics. Addressing these could reduce the risk of future pandemics while also better preparing us for the next crisis that emerges. Current knowledge gaps range from the role of wildlife trade and consumption in the emergence of zoonotic diseases (Bernstein et al., 2022; Kock and Caceres-Escobar, 2022), to the knock-on effects of climate change, alone or in conjunction with land-use change, on biodiversity (Parmesan et al., 2013; Baisero et al., 2020; Williams et al., 2021) and subsequent disease emergence, and the role of microbial communities in ecosystem functioning and resilience (Delgado Baquerizo et al., 2021). While research has been conducted on each of these topics, there is an urgent need for further investigations to determine their scope, driving mechanisms, and possible interactions, as well as to determine how to manage and mitigate the risk these factors pose.

In terms of biodiversity, a pressing knowledge gap is the impact of climate change on species distribution and adaptation. Research has shown that climate change is driving significant changes in the geographic distribution of many species, which can have cascading effects on ecosystems and human societies (Parmesan et al., 2013). In addition, land-use change and the subsequent habitat loss is likely to interact with climate change and further threaten species (Williams et al., 2021). However, more research

photo © Alexandre Caron

Mwenezi river separating Gonarezhou national park and Sengwe communal land in Zimbabwe, 2011

is needed to understand the mechanisms by which species are responding to changing environmental conditions and how to mitigate the negative impacts of these changes.

Another knowledge gap in biodiversity research is understanding the role of microbial communities in ecosystem functioning and resilience. Microbes play crucial roles in nutrient cycling, soil formation, and ecosystem stability, but we have only just begun to scratch the surface of understanding the diversity and function of these communities (Delgado-Baquerizo et al., 2021). More research is needed to fully understand the role of microbes in ecosystem processes and how to manage microbial communities to promote ecosystem health.

In the context of the possible interactions between biodiversity and pandemics, knowledge gaps include understanding the role of wildlife trade and consumption in the emergence of zoonotic diseases. The COVID-19 pandemic has highlighted the need to address the risks associated with wildlife trade and consumption, but more research is needed to fully understand the scope of the problem and how to mitigate the risks (Bernstein et al., 2022; Kock and Caceres-Escobar, 2022). The growth of commercial wildlife farming is of particular concern in this regard (Morand and Lajaunie, 2021; Green et al., 2023).

In addition to filling knowledge gaps, policy recommendations are important for addressing biodiversity and pandemics by providing concrete suggestions for protecting and conserving ecosystems, as well as preventing the emergence and spread of diseases. Biodiversity loss has been linked to an increased risk of zoonotic disease transmission (Keesing et al., 2010, Gibb et al., 2020), which can lead to pandemics. Therefore, policies that focus on conservation and sustainable use of biodiversity can help to reduce the likelihood of zoonotic disease spillover and transmission. Similarly, strong policies with effective enforcement mechanisms behind them that address the factors that contribute to the emergence and spread of pandemics, such as deforestation, habitat destruction, and the wildlife trade, can help to prevent future pandemics (Dobson et al., 2020, Bernstein et al., 2022). By implementing policies that address these root causes, governments can reduce the risk of future zoonotic disease outbreaks arising from wildlife.

photo © Patrick Assalé on Unsplash

Monitoring of the COVID-19-pandemic.Abidjan, Côte d'Ivoire

2.2 Preparatory work undertaken by Eklipse prior to the Expert Working Group

The request on biodiversity and pandemics aims to enhance our comprehension and utilization of sciences to optimise coordination and coherence across policy sectors, building better resilience and response strategies (proactive and reactive approaches) in the context of the interface between Biodiversity and Pandemics. Eklipse was granted additional funding by the European Commission, under the H2020 Green Deal Call, as part of the EU response to the COVID-19 pandemic in order to answer policy-relevant needs for evidence related to biodiversity and pandemics.

An online cross-sectoral workshop was co-organised in May 2021 by Eklipse and the European Commission - Knowledge Centre for Biodiversity (EC-KCBD) to explore the needs related to Biodiversity and pandemics and to identify highly policy-relevant topics. The workshop brought representatives from a range of European Commission services together with experienced scientists to identify challenges and evidence needs related to the links between biodiversity and human health, including zoonotic and other infectious diseases. During the workshop, seven policy- relevant knowledge needs (hereafter referred to as "Requests") were identified, and the one that was ranked highest was "Developing a strategic research agenda on biodiversity and pandemics, jointly with all relevant agencies and aligned with relevant sectoral policy agendas".

A scoping group composed of members of the Eklipse Knowledge Coordination Body, Methods Expert Group and Eklipse Management Body was created among the Eklipse team. This group proceeded to conduct a literature screening and a Call for Knowledge to gather relevant knowledge and searched for relevant existing or planned initiatives. An online Focus Group was also organised to narrow down the request to be processed by an independent and interdisciplinary Eklipse Expert Working Group (EWG) and to ensure that the selected request would meet all Eklipse criteria to start the answering process. This focus group led to the creation of a cross-sectoral consortium of requesters working with the European Commission's Directorate-General for Research and Innovation (EC-DG RTD), co-developing the knowledge needs and expecting a knowledge synthesis. This consortium will follow up the Eklipse 🔗 process and ensure that the produced evidence will be jointly and timely taken up by policy. A framing exercise led to a provisional formulation of the request: "make sense/some analysis of the existing research agendas/knowledge gap analyses to extract the priorities in the view of interlinkages (between sectors)."

2.3 A Cross-Sectoral Consortium of Requesters

During the focus group mentioned above, one of the key objectives of the scoping phase was achieved through the creation of a cross-sectoral consortium of requesters (see Table 1 below) working with EC-DG RTD to act as key points of contact to further co-develop the knowledge needs and follow the knowledge synthesis process.

Table 1. Consortium of Requesters

REQUESTERS	DESCRIPTION
DG Research and Innovation (EC-DG RTD)	Responsible for EU research agenda.
DG Environment (EC – DG ENV)	Responsible for EU policy on the environment.
DG Health Emergency preparedness and Response Authority (EC – DG HERA)	Responsible for preventing, detecting, and rapidly responding to health emergencies by anticipating threats and potential health crises through intelligence gathering and building the necessary response capacities.
DG Agriculture and Rural Development (EC - DG AGRI)	Responsible for EU policy and research on agriculture and rural development and deals with all aspects of the common agricultural policy (CAP).
Project HERA (Health Environment Research Agenda for Europe)	EU funded project that involves 15 European countries, an international organisation and a European NGO, thus 24 partners in total who are working hard to prepare the Health and Environment Research Agenda 2020-2030. The aim was to set the priorities for an environment, climate and health research agenda in the EU.
Norwegian Veterinary Institute (NVI)	Norwegian national biomedical institute delivers research-based knowledge and contingency support in animal health, fish health, and food safety.
PREZODE (Preventing ZOonotic Disease Emergence)	International initiative with the ambition to understand the risks of the emergence of zoonotic infectious diseases and develop and implement innovative methods to improve prevention, early detection, and resilience to ensure rapid response to the risks of emerging infectious diseases of animal origin.
One Health High-Level Expert Panel (OHHLEP)	An initiative supported by the heads of FAO, WOAH, UNEP and WHO, and the governments of France and Germany, to further enhance the cross-sectoral collaboration, enhance strategic orientations and coordination and provide high political visibility on the subject of One Health

2.4 Final formulation of the request

As a final step, the request was reformulated by the Eklipse scoping group, and the following final reformulation was agreed upon by the consortium of requesters:

> “Building on existing relevant work on research agendas and knowledge gap analysis, identify interdisciplinary research and action priorities that contribute to a strategic research agenda on Biodiversity and Pandemics addressing the critical interlinkages between relevant sectors needed to make future actions more effective.”

It was further agreed that the request process would include:

- Identifying existing research agendas and knowledge gap analysis
- Filtering or analysing research recommendations related to biodiversity and pandemics
- Prioritising the identified research recommendations based on their potential for maximising the impact on policies for relevant sectors.

2.5 The expert working group on biodiversity and pandemics

To answer these primary questions, the Expert Working Group (EWG) on Biodiversity and Pandemics request was established, composed of members from different backgrounds (country distribution and career level) and research expertise (infectious disease, wildlife disease; disease ecology; veterinary virology; biodiversity conservation; one health, global biodiversity change, human ecology and environmental history, spatial modeling of zoonosis, environmental law).

2.6 Objectives of the request

To answer the request following workshops with the requesters, the EWG and the methods expert group agreed on three main objectives:

- to rapidly **review and summarise the current state of evidence and knowledge** as reflected in peer- reviewed articles, reports from organisational websites and grey literature on the topic of Biodiversity and Pandemics via a scoping review.
- **to synthesise knowledge on the ongoing research initiatives, with a focus on funding programmes,** on the relationship between biodiversity and pandemics based on data collected by the Eklipse scoping group and members' knowledge.
- to **validate and extend results collected** in the first objective with **a large number of external experts working on the topic of biodiversity and pandemics and to prioritise research recommendations related to identified knowledge gaps** via an online survey, targeted expert consultation, and a focus group discussion.

photo © Boudewijn Huysmans on Unsplash

Diminution of biodiversity in Nan Province, Thailand.

photo © Annie Spratt on Unsplash

Example of deforestation.

Methodological framework

3 Background and objectives

This section describes the methodology undertaken by the Eklipse Expert Working Group in a two-step approach. In the first step – the methodological framework – we describe the methods in general in relation to the objectives and each other. The second section will describe the methods in more detail. To achieve the objectives formulated section 2.6, the following three approaches were proposed (hereafter referred to as methods; see Figure 1 below for details):

- **Literature-based method: scoping review** to summarise the current state of evidence and outline the key knowledge gaps and address objective 1.
- **Initiative scoping** to identify current research funding programmes and ongoing initiatives relevant to "biodiversity and pandemics" and address objective 2.
- **People-based methods** (**online survey-based expert consultation, optional targeted interviews, and focus groups**) to consolidate and validate results on knowledge gaps obtained from methods 1 & 2 and to prioritise the knowledge gaps and research recommendations identified by the group, thus addressing objective 3.

These methods were conducted in parallel, with a deliberate delayed start of the third method in order to consider the results of the scoping review when formulating the questions in the online questionnaire (first of the two methods used for the objective 3). The use of various approaches and multiple data sources to answer our research question (data triangulation) help provide a more comprehensive answer to the request than a single method.

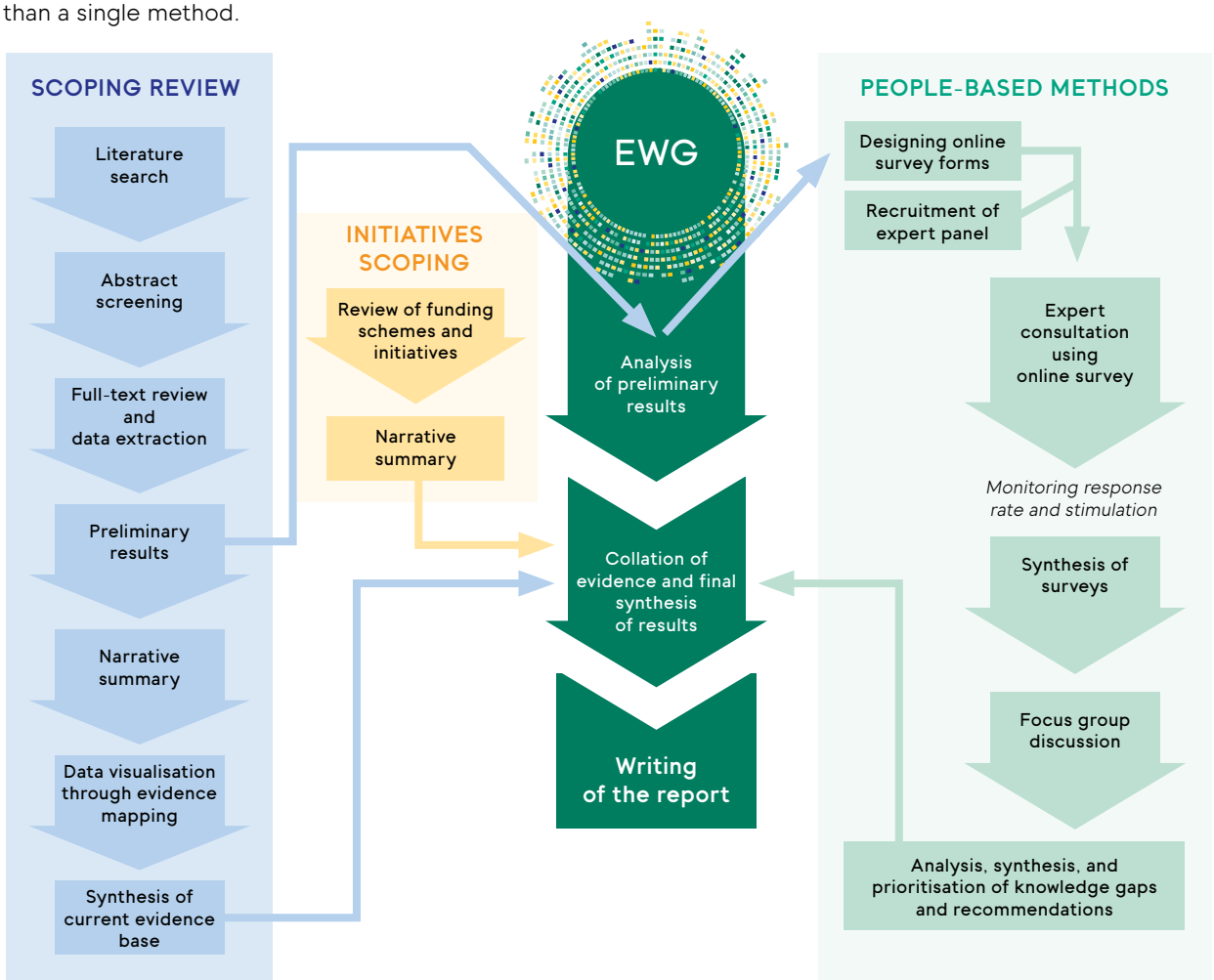


Figure 1. Graphical representation of the methodological framework

3.1 Literature-based method: scoping review

The scoping review aimed to provide an informed overview of the quantity and quality of research evidence on biodiversity and the risk of pandemics. The structured and robust review also provided a summary of what that evidence indicates, exploring positive and negative impacts and helping to formulate recommendations on strengths and gaps.

This method was conducted as follow: The first phase was a structured search of the peer-reviewed articles and reports from organisational websites as well as grey literature to summarise the current state of knowledge and to identify potential contested evidence which might indicate knowledge gaps with the need for further investigation (see the details below). We chose to conduct a broad literature search exploring the impact of biodiversity on disease outbreaks and spillovers and also the effect of such outbreaks on biodiversity.

The second phase consisted of a synthesis of the selected evidence and summarising the existing state of knowledge and gaps in evidence to contribute to the questionnaire and, more crucially, the design and focus of the survey and focus groups for the People-based methods. Finally, we visualised the results of the scoping review using evidence mapping methods to report the knowledge gaps and areas in need of further investigation.

The following methods protocol for the scoping review followed the Reporting Standards for Systematic Evidence Synthesis (ROSES) protocol (Haddaway et al., 2018).

3.1.1 Description of the method

Research question

We defined the key components of the research question based on the PerSPEcTiF framework (Booth et al., 2019) for systematic evidence synthesis (see Table 2 below).

Table 1. Components of the research question based on the PerSPEcTiF framework (Booth et al., 2019)

PERSPECTIVE	SETTING	PHENOMENON OF INTEREST	ENVIRONMENT	TIMING	FINDINGS
International articles and reports relevant to biodiversity and infectious diseases	Global	Impact of biodiversity on disease outbreaks, zoonotic spillovers, cross-species pathogen transmission, and pandemics, and the effect of pandemics on biodiversity.	Terrestrial, freshwater and marine ecosystems	From, and including, 2000	Current state of evidence and knowledge gaps in the area of biodiversity and pandemics

3.1.2 Search strategy

Keyword search and text mining

We conducted text mining using the litsearchr package (Grames et al., 2019) in R version 4.2.1 from abstracts of articles included in the previous literature search conducted by the Eklipse scoping group on the subject 'biodiversity and pandemics' for the development of this request. The use of a quasi-automated method to identify keywords reduced the time to conduct the search and ensured the transparency and reproducibility of the search by using text-mining and keyword co- occurrence networks. We conducted keyword searches across bibliographic databases using the keywords shown in Figure 2 and listed in Table 3 to ensure the completeness of the search. The keywords were defined in an iterative process to reflect the broad scope of this scoping review.

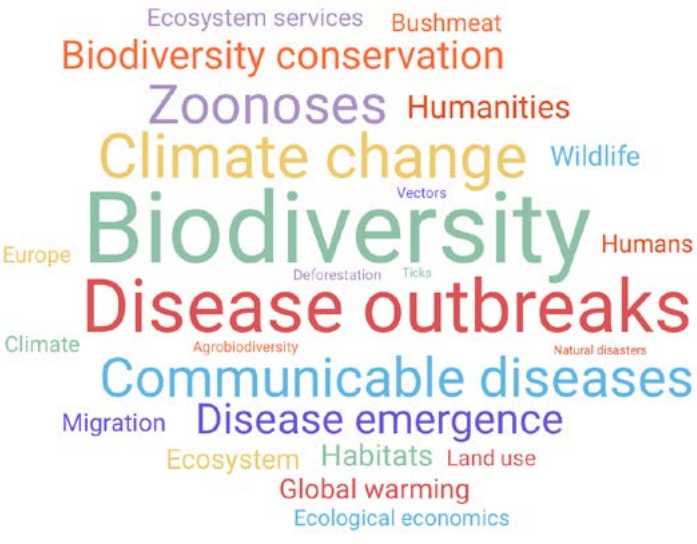


Figure 2. Keywords with more occurrence in the electronic database searches

Table 2. Electronic database searches

TERM	KEYWORDS
Agrobiodiversity	Agricultural biodiversity; Agrobiodiversity Index; food markets, consumption; conservation; seed systems; neglected species; fish richness; soil microbiome
Biodiversity loss	Biodiversity; biodiversity and human health; biodiversity loss; disease ecology; disease reservoirs; ecosystem health; ecosystem service; dilution effect; disease amplification; amplification effect; community structure; Host population threshold; Critical community size
Bushmeat and wild animal trade	Bushmeat preparation; butcher*; bushmeat; bat meat chain, bushmeat handl*; poach*; trophy hunting; wild meat; game meat; illegal animal trade, illegal wildlife trade, wildlife trade, animal traffic, wild animal trade, wild* supply chain; wet market*; fur trade; bushmeat market; traditional medicine; bushmeat consumption; bushmeat vendors; illegal meat; bushmeat bans wildlife farm*; game farm*; ecotourism; wild animal farm*;
Climate change	environment change, climate change; global warming, flood*; climat*, desertification; global temperatures; severe events; rising seas levels
General keywords related to disease and pandemic	Disease; infection*; outbreak*; epidemics; spillover; emerging; infectious disease; zoonotic disease; zoonoses, vector borne diseases; cross species disease; pathogen transmission; human-animal interface; disease spread; disease emergence
General keywords related to policy	Science-policy interface; European research; IPBES; Network of knowledge; conservation policy; sustainability; ecosystem disservices research; ecosystem service research; biodiversity research; social-ecosystem system
Habitat fragmentation	Deforestation; afforestation; forest fragmentation; habitat fragmentation; roads; edge effect; forest edge; suburban edge; logging; logging roads
Land-use modifications	land use change; agricultural land; land conservation; cropland; intensive; agricultural expansion; plantation*; agriculture intensification; industrial agriculture; rapid infrastructure expansion; mining; pasture; concentrated animal feeding operation; livestock; cattle rearing; ranch*; livestock wildlife interface; livestock production; poultry; pig*; pastoralism; animal confinement
Urbanisation	Urban infections; urbanisation; urban pests; urban wildlife; urban vector density; urban reservoirs

Supplementary searches

We conducted supplementary searches by citation chasing to ensure the completeness of the search using citation chaser 🔗 https://estech.shinyapps.io/citationchaser

Bibliographic databases

We searched across the following three electronic databases:
Web of Science 🔗 https://clarivate.com/),
Scopus 🔗 https://www.scopus.com/search/form.uri?display=basic#basic
and **Ebsco** 🔗 https://www.ebsco.com/find-my-organization

Organisational websites

We carried out searches on international and national organisational websites relevant to biodiversity, outbreak preparedness, and OneHealth. The list of websites is inclusive but not restricted to the following:
WOAH 🔗 https://www.woah.org/en/home
WHO 🔗 https://www.who.int
EU Law - Regulations, Directives, and other acts 🔗 https://eur-lex.europa.eu
IUCN 🔗 https://www.iucn.org
FAO 🔗 https://www.fao.org/home/en
Ecohealth Alliance 🔗 https://www.ecohealthalliance.org
UNEP 🔗 https://www.unep.org

(the full list of the websites can be found in the Annex 2)

Grey literature searches

We used reports from international or inter-governmental organisations that address the intersections of pandemics, biodiversity and key issues such as climate change, trade policy and the relationship between nature and human societies. After discussions within the EWG, we specifically opted for reports from the period of 2020-2022 to ensure the information was up to date on a global scale regarding pandemics. For feasibility with the available time and resources, we limited our choice to 20 reports.

At the European level, we included the EU Research Agenda for the Environment, Climate & Health 2021-2030 and the EU Biodiversity Strategy for 2030 as it directly concerns the request "Building on existing relevant work on research agendas and knowledge gap analysis, identifying interdisciplinary research and action priorities, that contribute to a strategic research agenda on biodiversity and pandemics".

Due to time constraints, we excluded reports from non-governmental organisations or those that focused exclusively on the One Health approach, except for the One Health Theory of Change report from the OHHLEP as it aims at strengthening the scientific evidence base, fostering knowledge exchange in assessing the status of biodiversity and its relevance to health; reviewing traditional/indigenous forms of knowledge and inputs of marginalised groups and ensuring inclusive approaches or assessing spillover drivers and identify relevant risk reduction options.

Search language

We included all search languages including those in Table 3 as determined by a preliminary keyword search on Web of Science. The articles in languages that were not within the expertise of the EWG were translated using **DeepL Pro** https://www.deepl.com/translator).

Table 3. Languages included in the bibliographic search based on the preliminary keyword search.

English	French	German	Portuguese	Spanish
Polish	Dutch	Turkish	Arabic	Mandarin

Ensuring the comprehensiveness of the search

- Search not limited to the English language
- More than two bibliography electronic databases searched
- Reports from organisations relevant to but not exclusively on biodiversity, pandemic prevention and One Health/Ecohealth were included in the search.
- Forward citation chasing the selected literature to ensure the comprehensiveness of the search.

Search record database

After the searches were complete, we exported all references into the citation manager Zotero, version 6.0.16. We then used the R package "Revtools" version 0.4.1. for duplicate removal.

3.1.3 Article screening

Screening strategy

We used a single-stage abstract screening strategy due to time constraints involving two members of the EWG: CL and SJ. We used the online software, Rayyan.ai (https://rayyan.ai/) to screen and review the articles obtained from the bibliographic search. To ensure consistency during the screening process, we conducted a pilot test where the two members independently screened a randomly selected set of 20 articles. This test aimed to establish the eligibility (inclusion / exclusion) criteria and evaluate the effectiveness of the screening tool. If the rate of disagreement exceeded 10%, the disagreements were carefully reviewed, and adjustments were made to the eligibility criteria as needed. Once the screening decisions were agreed, the included articles, with their full texts, were assigned to the members of the EWG for data extraction.

Consistency checking

To ensure consistency in the selection of articles, we limited the screening process to two members of the EWG. In cases where the decision of "Maybe" was given to an abstract by one of the reviewers during the screening, the two members simultaneously reviewed the full texts of the articles to reach an agreement on the final decision.

Inclusion criteria

Studies including reviews, descriptive studies, theoretical studies, experimental studies, policy frameworks, and perspectives discussing the following were included for data extraction:

- Impact of biodiversity on disease outbreaks, zoonotic spillovers, and cross-species pathogen transmission.
- Current policy on disease emergence related to biodiversity.
- Impact of pandemics and outbreaks on biodiversity.
- Relationship between agro-biodiversity, soil biodiversity or agricultural biodiversity and disease transmission.
- Effects of wildlife trade and bushmeat exploitation on disease outbreaks and transmission
- Consequences of anthropogenic modifications to the environment on biodiversity and disease.
- Impact of deforestation and climate change on biodiversity and its consequence on human infectious diseases.
- Monitoring and surveillance of pathogen transmission and spillover for pandemic preparedness.

Exclusion criteria

- Books, book chapters.
- Terrestrial and marine studies on diseases specific to non-mammalian taxa which have no transmission potential to humans.
- Plant infectious diseases which have no transmission potential to humans.
- Experimental and in vitro studies which were unrelated to biodiversity (studies related to dilution effect were included).
- Clinical trials.
- Pharmaceutical and therapeutic studies including ethnopharmacological studies.

3.1.4 Data extraction

The data was extracted using a predefined template tool onto the collaborative online platform, Google Sheets. The data extraction tool consisted of a pre-filled metadata section, a data extraction section with dropdown menus for each data point extracted, and an evaluation section for assessing the quality of evidence (see Table 4).

Prior to the data extraction process, one member of the EWG (SJ) presented the data extraction protocol and the usage of the data collection tool to the other members during a weekly meeting. The EWG members conducted a full-text review of the included literature to extract the study attribute data. Each member of the EWG was responsible for reviewing a range of 10 to 30 articles.

Table 4. Data extraction form.

SECTION	ATTRIBUTE	EXPLANATION
Pre-filled metadata	Article source	Web of Science/ Scopus/ Ebsco
	Type of Publication	Review/ Original article/ Comment/ Letter
	Publication details	title, authors, publication year, DOI
	Language of publication	ENG/ CHI/ FRE/ ESP/POR/POL/DUT/ARA
Data extraction	Geographical location	Location or study area of the research
	Scale of the study	Global/ Continental/ Multi-regional/ National/ Regional/ Local
	Theme	Biodiversity/ Wildlife trade/ Climate change/ AMR...
	Ecosystem	Terrestrial/ Freshwater/ Marine
	Pathogen group	Virus/ Bacteria/ Protozoan/ fungal/ Prion/ other/ NA
	Disease by transmission type	Zoonoses/ Vector-borne/ Generalist...
	If recommendations were proposed	Yes/ No/ NA
	Research type	Hypothesis or theoretical/ Experimental/ Field study/ Descriptive...
	Knowledge areas	Model/ Theory/ Framework or protocol/ Lessons learnt...
	Level of biodiversity	Genetic/ Species/ Ecosystem/ NA
	Impact on biodiversity and disease outbreaks	"Extracted word by word from the article"
	Limitations and challenges	"Extracted word by word from the article"
	Knowledge gaps and future research	"Extracted word by word from the article"
	Recommendations and proposed solutions	"Extracted word by word from the article"
Validation	Quality of evidence	High/ Medium/ Low
	Reviewer confidence	High/ Medium/ Low

3.1.5 Data synthesis

We synthesised the extracted data by different themes to derive policy recommendations and to identify knowledge gaps. First, we analysed the term frequency (see keywords for the scoping review in Annex 1), using text mining in R "tm" version 0.7-11. The policy recommendations were then categorised and ranked based on term frequency, and a corresponding recommendation was synthesised from the extracted data. The same process was followed for the knowledge gaps by quantifying the number of articles addressing each specfic topic. This process resulted in a list of policy recommendations and research gaps, which was used for the development of survey questions in the people-based methods.

3.1.6 Data visualisation

We developed an evidence map using EviAtlas 🔗 https://estech.shinyapps.io/eviatlas to detect regions with a local paucity of evidence. We also produced heat maps using the above shiny app, EviAtlas. To visually synthesise the data, we cross-tabulated the policy recommendations and knowledge gaps to illustrate the areas of evidence gap and limited studies.

3.1.7 Approach to organise Knowledge and Data

The list of included and excluded articles was stored in a Google spreadsheet accessible to the members of the EWG, and the focal and contacts points of other Eklipse governance bodies following the review process (Methods Expert Group (MEG), Knowledge Coordination Body (KCB) and Eklipse Management Body (EMB)), along with the tools used through the review process. The data extracted for the purpose of this scoping review was organised by geography and the predominant themes of the literature search in a collaborative spreadsheet. The preliminary results of the scoping review were used in the development of online survey forms in the people - based methods.

3.2 Initiatives–based method: Initiatives scoping

In order to scope funding initiatives relevant to biodiversity and pandemics, we primarily relied on reviewing the database compiled by the Eklipse team prior to the formation of the Expert Working Group together with EWG members' knowledge of funding initiatives. We focused on sources and mechanisms of funding rather than on individual projects. We also searched the internet for other relevant funding sources and programmes through Google using the terms "biodiversity", "pandemics" or "zoonotic disease", and "research funding", as well as the previous keywords with "initiative."

The initiative scoping aimed to provide an overview of the current funding schemes and initiatives relevant to researching and improving our understanding of the relationships between biodiversity and the risk of pandemics.

We summarised the key characteristics of these programmes, focusing on the amount of funding and duration of projects supported by the identified initiatives, as well as the geographic location(s) of both funded research projects and the research teams conducting them. Eligibility in terms of the type of organisation (academic, industry, NGO), discipline, and geographic location of teams were also considered based on publicly available information listed on initiative websites or other documentation.

3.3 People-based methods: online survey and online focus group discussion

While the scoping review could provide information based on published research, we decided to also use people-based methods to capture more recent trends in terms of policy recommendations and knowledge gaps. The research process, from start to published papers takes several years. Thus, people-based methods allowed us to stand closer to the research frontier by engaging with researchers and other experts about their on-going work, drawing on their expertise and experience directly. In addition, the COVID-19 pandemic has undoubtedly increased our knowledge and experience at the biodiversity - pandemic interface. Despite the enormous recent increase in scientific publications, we believed there is probably a great deal more information relating to this that we could capture from experts beyond what is currently available in the published literature.

Specifically, we decided to implement an online survey and a focus group discussion. The online survey provided an opportunity to reach a large number and wide diversity of experts and

professionals across the biodiversity and pandemic nexus while the focus group discussion provided the opportunity to have more in-depth discussion about the outputs of the online survey with a selected number of experts.

3.3.1 Description of the method based on the preliminary results of the scoping review

We linked the scoping review with the people-based methods. To do so, we used preliminary results from the scoping review (based on the first 200 articles reviewed). From these 200 articles, we extracted and synthesised two lists: 12 policy recommendations and 12 gaps in knowledge. Topics for policy recommendations are detailed in Table 5 and topics for research gaps are detailed in Table 6. We built the online survey based on these two lists and we reached out to a wide and diversified group of experts. Based on the outputs of the online survey, an online focus group discussion was implemented, guided by a professional facilitator, to validate, consolidate and prioritise the items on the lists of knowledge gaps and policy recommendations.

Online survey

The online survey was sent to a selected number of participants (n=301). The list was populated, using a structured process, in a few months trying to gather as many experts as possible from different sources. The final list of participants included:

- Relevant experts known by an EWG member (a column captured which EWG member knows this participant personally);
- Relevant experts with no direct connection with an EWG member but well-known through their scientific articles, conference attendance, etc.;
- Authors of relevant articles that were identified through the scoping review.

The selection of participants for the survey covered a wide range of disciplines (e.g., health, environment, social & sustainability sciences, as well as academic, public, private and voluntary sectors), ecosystems and habitats, as well as representing various organisational backgrounds and geographic regions. In the list, contact details (name, email, city & country of residence), professional position and institution were added, along with a column indicating if the participant had relevant experience to be involved in the focus group discussion. EWG members were also allowed to respond to the survey as they were initially selected based on their expertise on the topic.

The target response rate was 30% in order to obtain at least a hundred questionnaires completed out of the 300 participants invited. The survey was open from February, 2nd 2023 until March, 15th 2023 and every two weeks the participants were sent a reminder email to complete the survey. The survey was designed to take 10 to 15 minutes to complete in order to encourage completion by ensuring a small impact on participant activities and to acknowledge the many surveys participants are probably currently exposed to, which may lead to "survey fatigue". Pilot tests on the survey were run by colleagues of EWG members to assess the time needed to complete it.

The EWG submitted their methodology framework to the General University Ethics Panel of the University of Stirling, which was approved on April 6th, 2023 (Application #13714, see Annex 3 and 4). In the application the topic and main objectives of the request were described, as were the proposed methods to be applied: the details of the participant population and the number of participants required (including brief characteristics as well as principal inclusion and exclusion criteria), the method of participant recruitment, and the proposed participant activities, and any incentives that the participants may receive for their participation. The consent and permissions modalities, as well as ethical implications were outlined; details of the data collection methods, data analysis, data storage and types of dissemination were also included in the submission.

The survey was structured as follows (the whole survey can be found in Annex 7A):

- **Introduction.** In this section Eklipse, the request, the objectives of the survey, and how the participants' inputs would be used, were briefly introduced and explained. Each participant had to provide a personal or professional email, their last name and their first name.
- **Section 1. Eklipse privacy policy and GDPR agreement.** Participants were informed of the processing of their personal data under the EU's General Data Protection Regulation (GDPR) and the Eklipse privacy policy (http://eklipse.eu/privacy-policy/).
- **Section 2. List of Policy Recommendations.** A list of 12 items was proposed (see below Table 5). Participants were asked to select the three most important items according to their own opinion, after reading them carefully. In addition, they were requested to add any missing items in an additional space at the bottom of the list. The ordering of the items on the list was random for each participant in order not to influence responses.

Table 5. List of policy recommendations in the online survey

GOVERNANCE	Promote responsible and inclusive governance systems in which policy makers take into account risk uncertainty, mitigation of environmental damage, and are accountable for bottom-up (or societal) requests
COLLABORATION	Foster intersectionality at policy and practitioner levels, interdisciplinarity at practitioner and research levels and transdisciplinarity between all stakeholders including local communities/ general public at risk of pandemics, as promoted by the One Health concept
EDUCATION	Use adult and school education to increase understanding of the One Health (OH) approach and disease prevention in society and to build the future OH workforce
AWARENESS	Build and strengthen awareness in societies and government from local to global about the need for transformative changes to mitigate risks and drivers that contribute to pandemic emergence, biodiversity loss, and the depletion of ecosystem/natural resources
JUSTICE & EQUITY	Ensure that interventions in the context of pandemics and biodiversity account for and improve the situation of disadvantaged and marginalised groups within society, in particular regarding their access to health services and healthy ecosystems
VALUES	Integrate local values and worldviews in the management of health issues, including pandemic prevention, preparedness and response
FOOD SYSTEMS	Radically transform food and livestock production systems, trade, and their governance and policy, especially in their relation to nature and health
CONSERVATION	Decrease the encroachment of human activities into natural habitats and better manage landscape to combine conservation and local development objectives while mitigating the risk of emergence and pandemics
MONITORING	Develop long-term, robust, multi-faceted, open-data monitoring strategies for known and potential pathogens, infectious diseases and their systemic consequences along the anthropogenic gradient from natural to urban habitats, including pathogen genetic/genomic data, to enable prevention and early intervention against infectious disease emergence, including in post-disaster contexts
WILDLIFE	Regulate wildlife use and trade in national and international regulatory frameworks
BUSINESS	Strengthen and regulate links between business, investment and funding related to Pandemics and Biodiversity
RESEARCH	Promote and invest in interdisciplinary research on the links between Biodiversity and Pandemics

› **Section 3 List of Research Knowledge Gaps.** A list of 12 items was proposed (see below Table 6). As was done for Section 2, participants were asked to select the three most important items according to their own opinion after reading them carefully. In addition, they were requested to add any items they felt were missing at the bottom of the list. The ordering of the items on the list was random for each participant in order not to influence responses.

Table 6. List of research knowledge gaps in the online survey

WILDLIFE-KEY SPECIES	Identify key wildlife species and their ecology and roles in infectious diseases emergence.
WILDLIFE-DOMESTIC-HUMAN INTERFACES	Identify drivers of contacts between wildlife, domestic and human animals.
MICROBIAL DIVERSITY	Study microbial diversity, ecology and epidemiology in nature to identify potential future agents at risk of emerging and triggering pandemics, and how this diversity changes in response to environmental change and human activities.
DILUTION	Conduct more research on different contexts to investigate possible biodiversity-modulated mechanisms underlying changes to zoonotic risk from wildlife (e.g. biodiversity loss increasing or decreasing zoonotic risk).
PATHOGENS	Evaluate what characteristics of pathogens from wild animals make them most likely to cross the species barrier and spread in new hosts.
DIAGNOSIS	Develop and invest in rapid and validated diagnostic tools methodologies for emerging infectious diseases in wildlife.
MODELLING	Develop mathematical models regarding the links between Biodiversity and Pandemics including the impacts of environmental changes such as climate change.
WILDLIFE-TRADE	Collect, integrate and make available reliable data on wildlife trade pathways both legal and illegal and their compliance with regulations
URBANISM	Identify and evaluate the risks posed by urban and peri-urban expansion and development in the context of biodiversity interactions and infectious disease emergence.
SOCIAL	Apply social science and humanities-driven methodologies to understand how perceptions, values and behaviours influence human interactions with wildlife and domesticated animals, and how to mitigate the ensuing risks regarding pandemics.
IMPACT	Develop integrated approaches to assess the societal and environmental impact of emerging infectious diseases, including potential prevention, response and recovery plans.
ECONOMICS	Study the return-on-investment for programmes that reduce the environmental changes and the human behaviours and activities that lead to pandemics.

› **Section 4. Additional questions.** Participants were finally asked if they wanted to be acknowledged in the final synthesis report as a participant of the survey or if they wanted to be contacted for the peer-review of the final synthesis report, for an interview, or to attend a workshop or focus group to validate the results.

The outputs of this online survey were two consolidated lists, one each of research knowledge gaps and policy recommendations (later G&Rs). The ranking of G&Rs was synthesised across participants to identify the most commonly prioritised ones. These consolidated lists were used for the focus group discussion.

Focus group discussion

The objectives of the focus group discussion were to further validate, consolidate and prioritise the lists of research knowledge gaps and policy recommendations by key experts. We used the list of online survey participants who agreed to be contacted for a workshop to choose the focus group discussion participants. Among them, we invited specific experts that would create a balanced and diverse group based on their expertise (e.g., epidemiology, ecology, social sciences), geographical location and their survey responses. The objective was to gather between 8 and 12 experts as requested by the methodology and facilitator. The focus group discussion was facilitated online using a facilitation board (Mural) managed by a professional facilitator for the occasion with support from the EWG members for note-taking and organization. 9 experts accepted the invitation and participated in the online focus group.

The focus group discussion was structured in five sessions.

- The first session (40 minutes) consisted of the presentation of the Eklipse request (briefly as all focus group discussion participants had already contributed to the online survey) and the objective of the focus group discussion as referred to above and introductions of participants.
- The second session (40 minutes) focused on the list of Policy recommendations, requesting participants

to comment on the definition of items in the list, possible addition and then commenting on the synthesis of the ordering of the items by the participants.

- The third session (25 minutes) focused on the list of Research gaps, requesting participants to comment on the definition of items in the list and suggest possible additions. We did not comment on the synthesis of the ordering of the items by the participants as each participant could be biased by their own field of research.
- The fourth session (50 minutes) focused on interdisciplinarity. First interdisciplinary priorities were discussed (10 minutes). Then small groups of three to four participants were asked to brainstorm and outline an ideal interdisciplinary project that would gather at least three items on the list of research gaps in order to illustrate how multiple research gaps could be addressed. After 25 minutes of group work, a member of each group presented their outputs, including a project title, objectives, duration, and funding that would be needed.
- Finally, the last session (20 minutes) was devoted to presenting the way forward of the request and thanking participants for their time and dedication to the process.
- The final outputs of the people-based method process are the prioritised lists of research gaps in knowledge and policy recommendations, synthesised and commented on by the EWG.

3.4 Limitations and changes from the original methods protocol

Table 7. Limitations and changes to the original methodology protocol by method

METHODS	STEPS	CHANGES
SCOPING REVIEW	General	Due to time constraints, a full systematic review was not feasible to meet the deadlines proposed.
	Literature search	Although extensive across a broad scope, was non-exhaustive due to language and timeline restrictions.
	Search languages	Addition of Mandarin Chinese
	Article screening	Two instead of three members of the EWG were involved in the screening due to time constraints.
INITIATIVE SCOPING		Results of initiative scoping not integrated into People-Based Methods
		Search only in English language
		Only publicly available information (e.g. websites) used to gather information
		Focus on international funding, limited searches for national and institution-based funding schemes
		Detailed data on eligible expenses not collected
		Heat-maps of initiatives not created
PEOPLE-BASED METHODS	Online Survey	Initially, it was planned to have questionnaire respondents vote for the five most important knowledge gaps and five most important policy recommendations in order to determine the first layer of prioritization. From the scoping review, EWG extracted and synthetised two lists of 12 policy recommendations and 12 gaps in knowledge and agreed that selection of three from each would be more focused and outcome-oriented.
	Targeted Expert Consultation	The survey was only available for a short period of time, limiting the reach to a larger number of responses.
		This tool was considered optional to target individuals who would not have responded to the online survey but were considered important to interview due to their knowledge or position initially. However, the online survey responses were adequate and EWG agreed that the focus group discussion would produce relevant knowledge and recommendations without the need for a targeted expert consultation.
	Focus group discussion	Initially, it was planned to conduct a discussion on knowledge gaps and research recommendations. However, we shifted to a discussion of both policy recommendations and research knowledge gaps based on the results of online survey.
		We had to plan the focus group discussion online to include experts from different geographical regions with different time zones. An in-presence meeting might have been more productive. Due to time constraints, we could only conduct one focus group discussion and this limited the availability of all selected experts at the selected date and hour.

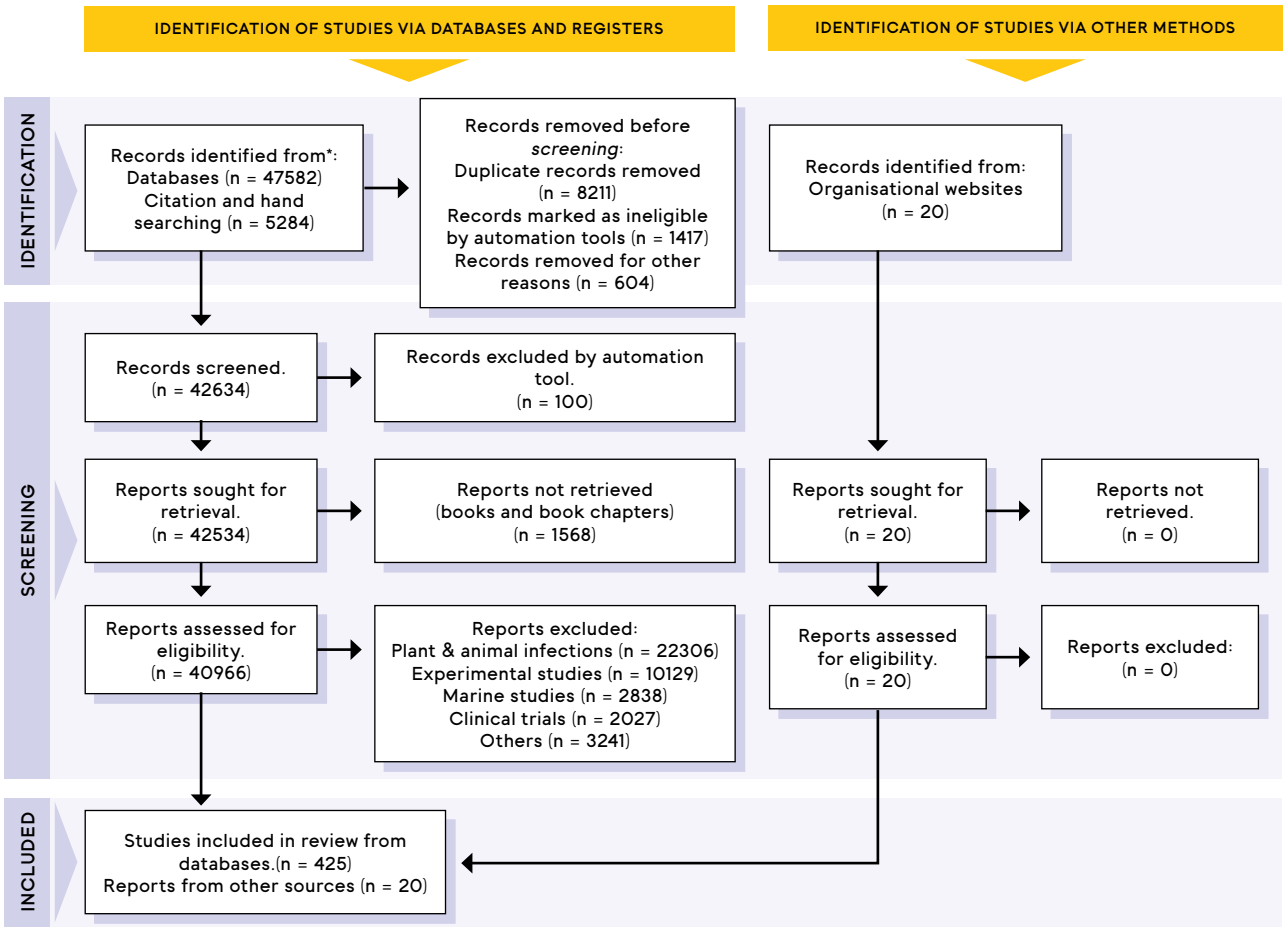
Results

4. Results

4.1 Literature-based method: scoping review

We collected 47582 studies from searching the three databases, Web of Science, Scopus, and Ebsco. An additional 5284 articles were obtained from citation searching and hand searching. A final number of 42634 were included in the screening process following duplicate removal and accessibility errors reported by the citation manager.

Based on the screening steps described in section 3.1.2 and 3.1.3, we included 425 studies and 20 reports from organisational websites for data extraction (list of articles and reports can be found in Annex 8). This is detailed in the PRISMA flowchart (Figure 3).



From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71. For more information, visit: http://www.prisma-statement.org/

Figure 3. Prisma flow chart detailing the records screened and included for data extraction.

To meet the deadlines for the development of the online survey forms, we initially extracted and synthesised data from 200 articles. The selection of articles for the preliminary analysis was based on year of publication with articles published in 2010 or later given priority. We synthesised 12 policy recommendations and 12 research knowledge gaps from the data extracted from the 200 articles for a wide expert consultation (see below in section 3) and then a focus group discussion. The data from the remaining 225 articles were extracted later in parallel with the other methods. Data from all 425 articles was used for the narrative summary and data visualisation of the scoping review.

We observed that the highest number of studies on biodiversity and pandemics, 65 (15.3% of the included studies), was published in the year 2021 (Figure 4). The year of publication was unavailable for 4 articles. Of the 425 included studies, a total of 15 studies were in languages other than English: 10 in French, 3 in Spanish and 2 in Mandarin Chinese.

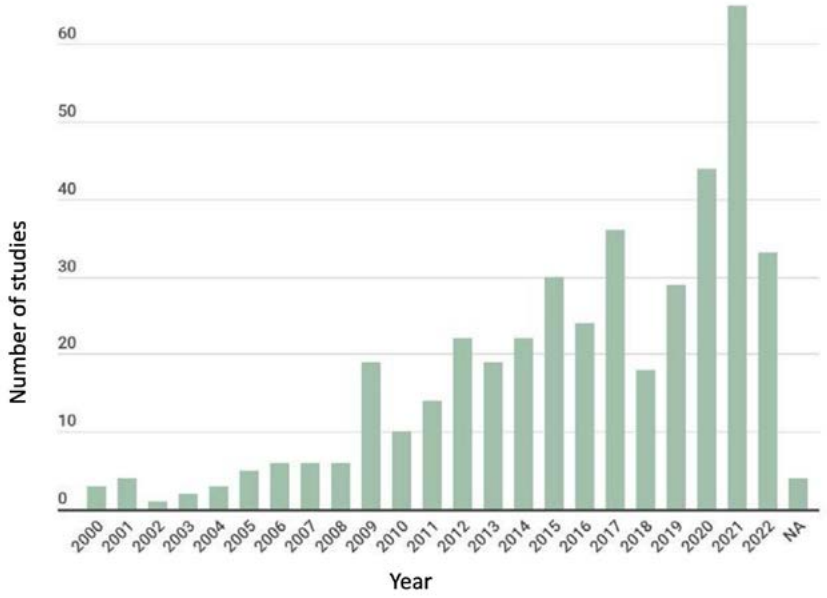


Figure 4. Evidence trends of publication of articles on biodiversity and pandemics.

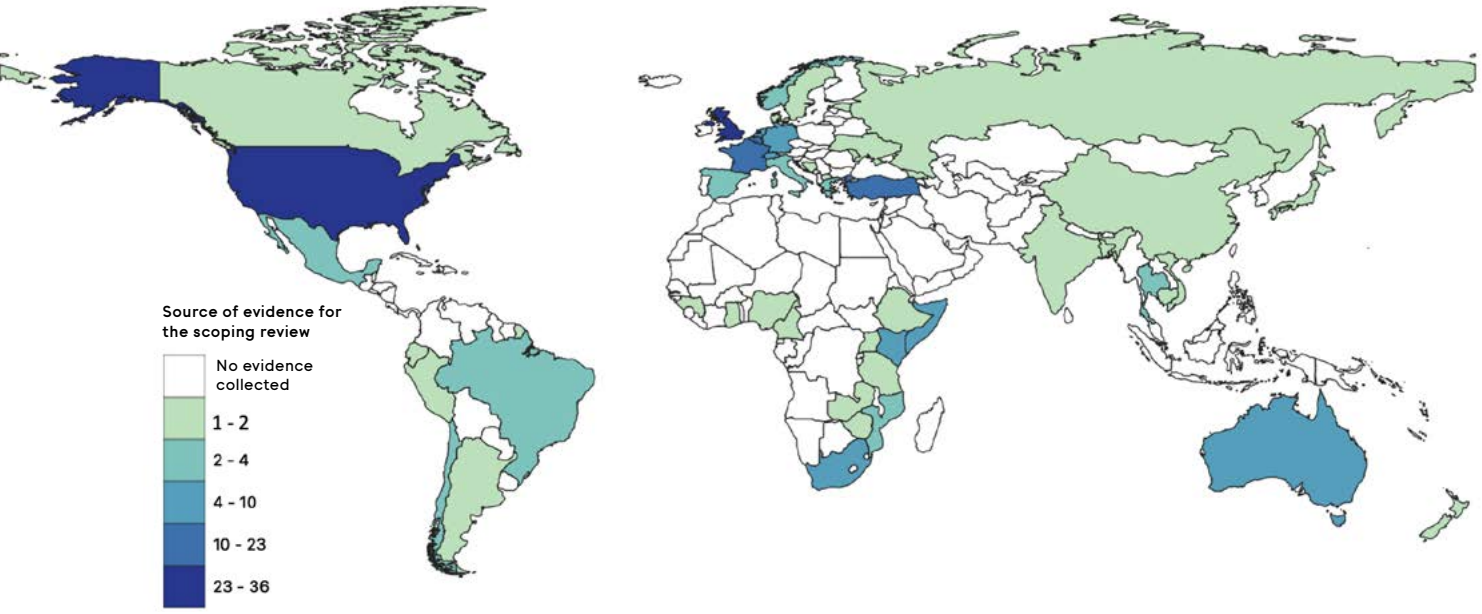


Figure 5. Evidence map illustrating the distribution of study area of the articles on biodiversity and pandemics; the blue dots represent individual studies, and the green circles represent clusters of articles from the same study area.

We chose articles studying biodiversity and pandemics at a local, regional and national scale to illustrate the geographical distribution of evidence. A total of 129 studies were described at a local, regional, and national scale and were plotted (Figure 6). We report that the United States of America had the highest number of articles (n=28, 21.7%) with study areas at a local, regional, and national scale. Although Europe had studies (18/425 included studies) at a continental scale, we observed a lack of evidence at a smaller scale. We observed a large amount of reviews (159/425 studies) and field studies (123/425 studies) among the included articles.

POLICY RECOMMENDATION	FOSTER COLLABRATIVE RESEARCH				STRENGTHEN ONE HEALTH			IMPROVED COMMUNICATION AND AWARENESS ON ONE HEALTH						BETTER SURVEIL-LENCE AND MONITOR-ING			NEED FOR PRIMARY RESEARCH				REDUCTION OF ANTHROPOLOGICAL MODIFICATIONS					WILDLIFE CONSERVA-TION AND POLICY					RESEARCH AND DEVEL-OPMENT			HEALTH SYSTEMS	
	Investing interdisciplinary research	Inclusion of social sciences research	Open source wildlife and wildlife disease data	Promote interdisciplinary and transdisciplinary research	International coalitions	One Health-based governance at all levels	Public-private partnerships	Dialogue between science and policymakers	Education from primary to tertiary levels	Awareness of stakeholder and public	Communication b/w science and stakeholder & public	Enhancement of the health literacy of populations at risk	Integrate diffrent worldviews between humans and nature	Longitudinal monitoring of pathogen at animal/human interface	Effective surveillance for emerging zoonoses	Disease reporting post environmental disasters	Understanding the fundamental ecological processes	Interlinkage b/w health & biodiversity to address env justice	Need to integrate theoretical and empirical approaches.	On introduced/invasive species on host-parasite interactions.	Minimise encroachment of human acitivities into wildlife habitat	Reduce landscape fragmentation	Limiting livestock density and extensive agriculture	Transform food livestock production systems & policy	Immediate action to mitigate climate change	Integration of wildlife in national regulatory framework	Acknowledging the nexus b/w bushmeat, wet markets, & disease	Biosecurity implications of emerging infections from wildlife	Initiatives to eradicate wildlife trade	Health security challenges posed by urban & peri-urban wildlife	Risk assessment at the biodiversity/health nexus	Invest on diagnostics suitable for field use-wildlife species	Genomics and bioinformatics tools targeting key hosts	Strenghten health systems in poor settings	Rapid diagnostic systems in remotes regions to limit outbreak
RESEARCH GAPS																																		
1. Animal health & wildlife management																																		
Disease monitoring systems for mammal populations at risk	X	X	0	X	2	1	2	X	X	X	X	X	1	2	1	X	X	X	X	X	X	X	X	X	0	2	X	2	X	X	2	1	0	X	X
Targeted research on bat reservoirs	2	X	X	1	X	2	X	0	X	X	1	X	X	2	2	X	2	X	X	X	2	2	2	X	1	1	2	3	X	X	2	3	2	X	X
Non-invasive monitoring techniques	0	X	X	X	X	X	X	X	0	X	X	X	X	1	1	X	X	X	X	X	X	X	X	X	X	0	X	2	X	0	2	1	0	X	X
2. Anthrogenic enviromental issues																																		
Effective initiatives to reduce deforestation	2	X	X	X	1	2	X	2	2	1	1	X	2	X	X	X	0	1	X	X	2	2	1	X	1	2	X	X	X	X	X	X	X	X	X
Tackling AMR	2	X	X	X	3	1	1	2	2	1	X	1	X	X	X	X	X	X	X	X	X	X	1	2	X	X	X	X	X	X	X	X	2	2	1
Action against climate change	1	X	X	1	2	X	X	X	X	X	X	X	0	X	X	2	X	X	X	0	0	0	1	1	1	X	X	X	X	X	X	X	X	X	X
3. Biodiversity																																		
Mechanisms of Disease Dilution	1	X	X	1	X	0	X	X	X	X	X	X	X	X	X	X	3	X	3	2	0	0	X	X	X	1	X	1	X	0	X	X	X	X	X
Species-Specific Effects	0	X	X	0	X	0	X	X	X	X	X	X	X	0	X	X	2	X	1	0	X	X	X	X	X	0	X	X	X	0	X	0	X	X	X
Community Dynamics and Disease Reservoirs	2	X	X	1	X	1	X	0	X	X	X	X	X	X	X	X	3	X	3	2	1	1	0	X	X	0	X	1	X	1	X	2	1	X	X
4.Pandemic preparedness																																		
Surveillance and Early Warning Systems	0	X	X	0	3	2	0	X	X	X	X	X	X	2	2	1	X	X	X	X	1	1	X	X	X	0	1	1	X	1	2	1	1	1	0
Rapid intervention strategies	0	X	X	1	0	1	1	1	2	1	X	X	X	X	X	X	X	X	X	X	X	X	X	2	X	0	2	2	X	1	1	X	1	1	1
Pathogen discovery and characterization	2	X	X	2	0	0	X	X	X	X	X	X	X	1	1	0	2	X	X	1	X	X	X	X	X	X	0	0	X	X	1	2	2	X	X
5. Wildlife/bushmeat trade																																		
Trade dynamics and consumer behavior	1	2	X	1	2	X	X	2	X	1	1	2	0	X	X	X	X	X	X	X	2	2	0	0	0	2	2	2	1	X	1	X	X	X	X
Socio-economic dimensions	0	2	X	X	0	0	X	0	X	2	1	X	X	X	X	X	X	X	X	X	1	X	0	0	X	1	2	1	1	0	X	X	X	X	X
Governance and policies	1	1	X	X	2	0	X	2	X	1	1	1	X	X	X	X	X	X	X	X	1	0	1	1	1	2	2	2	1	X	X	X	X	X	X

Figure 6. Narrative summary of the scoping review in a format of a relationship matrix between the policy recommendations and the knowledge gaps. Scoring system: x for knowledge gap/irrelevant association; 0 for 1 - 10% of included articles; 1 for 10 - 30% of included articles; 2 for 30 - 50% of included articles; 3 for > 60% of included articles.

We highlight the areas in need of action with a relationship matrix between the policy recommendations and the knowledge gaps from the included articles of the scoping review. This relationship matrix is intended as a tool for policymakers to help them identify interdisciplinary research and action priorities that should contribute to a strategic research agenda on biodiversity and pandemics. We used the following scoring system in the matrix: 0 if 1-10% of the corresponding articles included in the scoping review addressed the research gap, 1 for 10-30% of the studies, 2 for 30-60% of the studies, and 3 for >60% of the studies. The cells marked "X" in the matrix are research areas that are poorly studied in interaction with mentioned policy recommendations and would require further research prior to translation into appropriate policy recommendations and actions.

Here we highlight pertinent challenges and limitations from the included reports based on the knowledge gaps and policy recommendations. For instance, the EU Biodiversity Strategy for 2030 states that:

"The fight against biodiversity loss must be underpinned by sound science. Research and innovation can develop and test 'green' solutions so that they can be prioritised over 'grey' infrastructure. It can also help authorities to support investments in nature-based solutions and green infrastructure, such as in old-industrialised, low-income or disaster-hit areas."

The Technical Information on Biodiversity and Pandemics (SBSTTA, Note by the Executive Secretary, CBD) highlights the fact that:

"Policies that make the human-environment connection to zoonotic transmission and pandemics clear can increase support for biodiversity conservation, especially for emotive subjects like the commercial trade in wildlife and deforestation. Furthermore, reducing pandemic risks substantially through better management of environmental resources would cost 1-2 orders of magnitude less than estimates of the economic damages caused by global pandemics. Collaboration among conservation biologists and epidemiologists should be strongly encouraged to provide scientific guidance for measures to reduce risk in these cases, such as culling of non-native species that host zoonoses, or launching disease surveillance programmes".
The data extracted from the organisational reports such as the above are detailed in the Annex 8 and could be used by policymakers to prioritise future actions.

4.2 Initiatives-based method: initiatives scoping

4.2.1 Research Funding

Here we highlight several major funding initiatives and programmes relevant to the topic of biodiversity and pandemics. Overall, we find that there are very few research funding programs dedicated specifically and explicitly to Biodiversity and Pandemics, meaning they ask for a direct link to be drawn between biodiversity and pandemics. In addition to funding for research in the academic sense, we also include examples of surveillance networks and funding for implementation projects and highlight agencies that may also be relevant. The funding landscape often changes, with funders sometimes issuing a one-time thematic call related to biodiversity and pandemics, with subsequent calls shifting focus toward other topics. In addition, many funds may relate to biodiversity and pandemics but somewhat indirectly. For example, programs may fund pathogen surveillance in biodiverse regions without explicitly addressing the relationship between biodiversity, pathogen spillover and disease emergence.

We found two primary sources of funding dedicated specifically to the topic of biodiversity and pandemics that use this terminology: The **Horizon Europe** Cluster 6 (Food, Bioeconomy, Natural Resources, Agriculture and Environment) CL6-2023-BIODIV-01-17: "Interlinkages between biodiversity loss and degradation of ecosystems and the emergence of zoonotic diseases". The program was created with extensive input from Eklipse and Prezode. This call follows up on Horizon Europe 2021/2022's topic Cluster 6 CL6-RES-2021-00-00- "What else is out there? Exploring the connection between biodiversity, ecosystems services, pandemics and epidemic risk." That 2021/2022 call funded two projects: BCOMING (4.9€ million over 4 years), coordinated by CIRAD (France) with the aim of investigating how biodiversity conservation can mitigate the risks of emerging infectious disease in Europe and the tropics and BEPREP (5.4€ million over 4.5 years), coordinated by the University of Helsinki, with a focus on if and how nature restoration can prevent disease outbreaks.

The current CL6-2023-BIODIV-01-17: "Interlinkages between biodiversity loss and degradation of ecosystems and the emergence of zoonotic diseases" call, whose deadline was March 2023, is far-reaching with projects required to address the effects of biodiversity loss on disease, particularly emerging zoonoses, mitigation of biodiversity loss to prevent disease, and to use this knowledge to propose practical strategies and monitoring. Up to three projects proposed by international consortiums can be funded, up to 4€ million each, generally lasting 3-4 years. Teams must be interdisciplinary and projects must include social scientists and the humanities. Consortiums should include at least one institution from a Member State and two from Member States or associated countries, other members of consortiums may be based in the EU, Horizon- associated countries, and middle- and lower-income countries. Different types of institutions including academic, civil society or NGO, government, small- and medium-enterprises, and stakeholders or end-users are eligible for the program.

In addition, Horizon Europe Cluster 1 (Health) HORIZON-HLTH-2023-ENVHLTH-02-01: "Planetary health: understanding the links between environmental degradation and health impacts'' welcomed projects related to biodiversity and human health that do not overlap with Cluster 6 (e.g. not related to zoonotic disease emergence) within the scope of Planetary Health. The deadline for applications was April 2023. Teams are directed to include social sciences and humanities in projects. Five projects are expected to be funded up to 5€ million each, generally for 3-4 years. The eligibility criteria are in-line with those of Cluster 6.

The Priority Programme and Equipment for Research (Programmes et Équipements Prioritaires de Recherche; PEPR) funding initiative from the French **PREZODE** initiative broadly focuses on global change, human impact, and emerging zoonotic diseases. PREZODE has a total budget of

30€ over five years. The PEPR call was opened in February 2023. Letters of Intention were required by April 2023 and final project submission will occur in September 2023. Improving knowledge of the relationship between biodiversity loss and pathogen circulation is specifically mentioned as one of six goals within the program's Axis 2, "Strengthening our knowledge on potential reservoir populations and of system-based approaches to understand zoonotic diseases emergence in a changing environment". This initiative funds consortiums led by French research teams with funding of 1-3€ million per project given to French institutions for a duration of 3-5 years.

USAID is a major funder of research projects related to pandemics and zoonotic disease mainly through its **Global Health Security Program**. Large projects have budgets of $100 - 200 million USD for 5 to 10 years duration. These projects are generally led by a US-based university coordinating large consortiums of American and foreign academic institutions, NGOs (principally EcoHealth Alliance), and private companies. Major projects have included PREDICT (2009 – 2020, $200 million USD), coordinated by the University of California - Davis, which focused on identifying viruses in biodiversity hotspots from potential wildlife hosts, DEEP VZN, implemented by Washington State University (5 years, $125 million USD), which targets the discovery and characterization of viruses from selected families with potential for spillover, and STOP Spillover, coordinated by Tufts University ($100 million USD, 5 years), which aims to better understand the dynamics and pathways of pathogen spillover for a selected number of known pathogens with local stakeholder input.

Also based in the US, a less targeted but relevant initiative is the on-going multi-agency **Evolution and Ecology of Infectious Disease** (**EEID**) program coordinated by the **National Science Foundation** (**NSF**). To be eligible, "projects must address the quantitative, mathematical, or computational understanding of pathogen transmission dynamics." The program description does not specifically mention biodiversity (or pandemics) but this could conceivably be an angle for proposed projects if linked to transmission dynamics. Funding is $1.5 - 3 million USD for projects lasting five years. There are several binational agreements with the UK, China, and Israel with additional dedicated funding from the national funding agencies of those countries to support their teams. Projects in, and collaborations with, institutions in low- and middle-income countries are encouraged.

An important point raised in the Focus Discussion Group was the need to directly fund teams in the countries that are most affected by zoonotic diseases and potential pandemics. While partnerships and collaborations are often encouraged by the funding schemes we have identified, this is typically in collaboration with US or EU partners leading the project and these collaborating teams may not always be eligible to receive funding. In this context, one program we wish to highlight is the **NIH International Research in Infectious Diseases program** (https://grants.nih.gov/grants/guide/rfa-files/RFA-AI-23-023.html), which awards funding only to researchers in low-income economies, lower-middle-income economies, and upper-middle-income economies by World Bank Classification. Projects may receive up to $125,000 per year over a maximum of five years (total maximum $575,000). Seven to eight projects may be funded per year.

At a smaller scale, there are many initiatives and centres that have been established at individual universities and institutions. The funding of such initiatives provides a range, from shorter-term projects, often led or implemented by graduate students, with support of several thousand euros to large multidisciplinary projects that may last for several years. Some initiatives may involve large investments. For example, Wageningen University and Research recently launched **ERRAZE@WUR** (Early Recognition and Rapid Action in Zoonotic Emergencies) with 6.5€ millions of funding. Although not exclusive to biodiversity and pandemics, the program has funded projects incorporating biodiversity in disease ecology. University-based funding is generally available only to students, faculty, or other researchers at the specific university or in some cases only to those affiliated to a specific faculty or department.

4.2.2 Open Calls

In addition to these dedicated funds, researchers, particularly academic and/or university-affiliated researchers, may propose projects on the topic of "biodiversity and pandemics" to general funding schemes, such as the EU **European Research Council** funding, organisations such as the Wellcome Trust whose work includes infectious diseases, or national open funding schemes. **National funding schemes** may have restrictions on the location of partners. Some programs, such as the ERC, focus primarily on a single investigator and their laboratory group rather than the consortium of teams" to "rather than a consortium of teams, which may affect the scale of the proposed project. The ERC also has excellence in science as the main assessment criterion, which may limit the policy links and on-the-ground change that ERC projects can achieve. Similarly, early-career researchers may consider postdoctoral fellowships, such as **Marie Skłodowska-Curie Actions** in Europe or equivalent programs in their home and / or host institution countries, which typically include both stipends and some funds for carrying out research.

Table 9 Overview on the Initiatives Scoping

TYPE OF FUNDING	FUNDER	PROGRAM	AMOUNT (MAXIMUM)	DURATION	WEBSITE
Research Funding (on-going)	Horizon Europe	CL6-2023-BIODIV-01-17 (2023)	4€ million each	3-4 years	https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl6-2023-biodiv-01-17
		HORIZON-HLTH-2023-EN-VHLTH-02-01 (2023)	5€ million each	3-4 years	https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/wp-call/2023-2024/wp-4-health_horizon-2023-2024_en.pdf
	Prezode	PEPR (2023)	1-3€ million each	3-5 years	https://anr.fr/fileadmin/aap/2023/France2030-aap-pepr-prezode-2023.pdf
	USAID	Global Health Security Program (ongoing)	$100 -200 million	5-11 years	https://www.usaid.gov/global-health/health-areas/global-health-security
	NSF (USA)	EEID (ongoing)	$1.5 million	5 years	https://new.nsf.gov/funding/opportunities/ecology-evolution-infectious-diseases-eeid
	NIH (USA)	International Research in Infectious Diseases (ongoing)	$575,000	5 years	https://grants.nih.gov/grants/guide/rfa-files/RFA-AI-23-023.html
Thematic calls	Biodiversa	Biodiversity and its influence on animal, human and plant health (2018/2019)	1.5 € million	3 years	https://www.biodiversa.eu/2019/10/07/2018-2019-joint-call/
	VolkswagenStiftung	Global Issues – Preventing Pandemics: the Role of Human-Environmental Interactions (2021/2022)	1.5 € million	4 years	https://www.volkswagenstiftung.de/en/funding/funding-offer/global-issues-preventing-pandemics-role-human-environmental-interactions
	Bill and Melinda Gates Foundation, Chan Zuckerberg Initiative. Chan Zuckerberg Biohub (CZ Biohub)	Global Grand Challenges: Metagenomic Next Generation Sequencing to Detect, Identify, and Characterize Pathogens (2021/2022)	$200,000	2 years	https://gcgh.grandchallenges.org/challenge/metagenomic-next-generation-sequencing-detect-identify-and-characterize-pathogens
	Belmont Forum	Collaborative Research Actions: Climate, Environment, and Health II (2023/2024)	Varies by country	3 years	https://belmontforum.org/cras#open
Networks	US National Institutes of Health	CREID (Centers for Research in Emerging Infectious Diseases)	$150,000 (fellowship)	1 year	https://creid-network.org/
	Ending Pandemics	CORDS (Connecting Organisations for Regional Disease Surveillance)	—	—	https://www.cordsnetwork.org/
	Rockefeller Foundation	Rockefeller Pandemic Prevention Initiative	$150 million total initial investment	—	https://www.rockefellerfoundation.org/initiative/pandemic-prevention-initiative/
	International Atomic Energy Agency	ZODIAC (Zoonotic Disease Integrated Action)		—	https://nucleus.iaea.org/sites/zodiac/SitePages/Home.aspx
Preparedness / Implementation	World Bank	Pandemic Fund	$300 million total initial investment	3 years	https://fiftrustee.worldbank.org/en/about/unit/dfi/fiftrustee/fund-detail/pppr
	International Climate Initiative (IKI), Germany	Nature4Health	50€ million total initial funding		https://nature4health.org/
		Thematic Calls: Pandemic preparedness: natural protective barriers between humans and animals by expanding, linking and improving protected areas	5-30€ million	8 years	https://www.international-climate-initiative.com/en/find-funding/thematic-call/thematic-selection-procedure-2020/
Conservation Initiatives	Critical Ecosystem Partnership		$15,000 (small) $150,000 large		https://www.cepf.net/grants
	Sustainable Wildlife Management Program				https://www.swm-programme.info/

4.2.3 Thematic Calls

One challenge in identifying relevant initiatives is that funders often issue thematic calls that change with each funding cycle. We identified several one-time calls for projects over the past few years that have since closed. Here we show several examples of relevant one-time calls from several organisations and initiatives.

In 2018 - 2019, **Biodiversa** funded a call on the theme of biodiversity and animal, human, and plant health. Although not exclusive, the main theme for Biodiversa funding changes with each call and may include specific ecosystems, such as aquatic habitats. The focus of Biodiversa's 2022-2023 call was on biodiversity monitoring, which could potentially be linked to pandemics or disease emergence. The upcoming call for 2023-2024 will focus on Nature-Based Solutions, followed by Societal Transformation in 2024-2025. Biodiversa funds transdisciplinary teams that include at least three participating countries, with an emphasis on stakeholder engagement, policy relevance, and transnational importance for projects. Participating countries are those who provide funding to the program. There are currently 33 participating countries, primarily in Europe, as well as Brazil, Côte d'Ivoire, South Africa, Taiwan, and Turkey. Funding is generally 1.2- 1.5€ million per project, lasting three years.

In 2021 the Germany-based **Volkswagen Stiftung** program (🔗 https://www.volkswagenstiftung.de/sites/default/files/documents/MB_116d.pdf), issued a call on the theme of "Preventing Pandemics: the Role of Human-Environmental Interactions". Proposals required interdisciplinary teams of 3-5 researchers, including both natural and social scientists. At least one team member was required to be based in Germany and two based in non-European lower- or middle-income countries. Projects could receive up to 1.5 million € for up to four years.

Funding may also address biodiversity in terms of microbial diversity or potential pathogens. In 2021/2022, the **Bill and Melinda Gates Foundation** and **Chan-Zuckerman Initiative** issued a call for its Global Grand Challenge focused on "Metagenomic Next Generation Sequencing to Detect, Identify, and Characterize Pathogens." Funding of $200,000 USD, as well as training and Next Generation Sequencing equipment was offered for projects in low and middle income countries for up to two years focused on pathogen discovery, including within wildlife and domestic animal reservoirs.

Relevant initiatives may also focus on factors that affect biodiversity, such as climate change. For example, the **Belmont Forum** is currently issuing its second call for funding on Climate, Health, and Environment, with an emphasis on priorities for lower and lower-middle income countries. While biodiversity is not directly linked, the role of climate on disease emergence, including zoonoses, is included as a potential topic within the call. The Belmont Forum works in collaboration with a large number of national and international funding agency partners (https://www.belmontforum.org/archives/news/call-announcement-climate-environment- and-health). Eligibility is wide due to the large number of partner agencies, including countries across the income spectrum. Consortiums should include partners from at least three different countries for projects lasting 3-4 years. Funding per project varies, depending on the amount offered by the agency or the eligibility criteria of partner applicants.

4.2.4 Surveillance Networks

There are many initiatives and networks focused on surveillance and preventing pandemics without necessarily explicitly incorporating biodiversity, although the activities may be based in highly biodiverse areas or specific projects may be funded that do address the topic more directly. For example, the **Centers for Research in Emerging Infectious Diseases** (**CREID**), an initiative funded by the US National Institutes of Health (NIH), is a network of laboratories in 28 countries across the world, largely in Africa, the Americas, and Asia. Activities include identifying pathogen hosts, host-pathogen interactions, and diagnostics. Coordination and support are provided for activities such as data management and reagent or diagnostic development. In addition, the program also provides fellowships for early researchers in - low and middle income countries" (LMICs) - or the US for 1-year projects and funding of $150,000.

Connecting Organisations for Regional Disease Surveillance (**CORDS**) is another network connecting six regional networks in Africa, the Middle East, Southeast Asia, and southern Europe (SECID, MECIDS, MBDS, SACIDS, EAIDSNet, APEIR). The goal of CORDS is to catalyse collaboration amongst regional disease surveillance networks across the world in order to improve their capacity to detect and control the spread of epidemics.

The Rockefeller Pandemic Prevention Initiative is a USD $150 million investment working with partners around the world to prevent the spread of infectious diseases through strengthened global pathogen surveillance and response. The Pandemic Prevention Initiative has formed a network of over 40 partner organisations that bridge sectors and geographies to strengthen partnerships and enable an early warning system. Through grants to several network partners, it supports local institutions and health systems, as well as regional and global organisations to elevate national expertise and leadership around the world.

The Zoonotic Disease Integrated Action (ZODIAC) is an initiative led by the International Atomic Energy Agency (IAEA). This initiative aims to create a global network of designated national laboratories monitoring zoonotic disease that will promote collaboration and sharing information to enhance early detection, with an emphasis on South-South cooperation. There are five main pillars of the programme:

- Strengthening member states' detection, diagnostic, and monitoring capabilities through the development of necessary laboratory infrastructure and sampling and analysis protocols using nuclear and related techniques (ELISA, PCR);
- Development of novel technologies for zoonotic disease detection and monitoring and making them available;
- Real-time decision-making support tools for timely interventions through geo-visualization;
- Understanding the impact of zoonotic disease on human health based on medical imaging;
- Providing access to an agency coordinated response for zoonotic diseases.

ZODIAC also provides support for research, training, and capacity-building.

4.2.5 Preparedness and / or Implementation Funding

Apart from funding for strictly research activities, there are a number of initiatives focused on preparedness and capacity-building that are granted to institutions and governments, although they may not necessarily address biodiversity and pandemics explicitly. The **Pandemic Fund** is a long-term financing program for low and middle-income countries established in 2022 and administered by the World Bank to build capacity and implement projects to improve pandemic prevention, preparedness, and response, for example through disease surveillance, laboratory capacity, or strengthening health systems. The first round of funding began with Expressions of Interest in February 2023, with final proposal submission in May 2023. Projects must be proposed by eligible low- and middle-income countries and implemented by at least one of the 13 identified Implementing Entities, which include financial institutions (e.g. African Development Bank, Asian Development Bank) and UN agencies (e.g. FAO, UNICEF). Delivery partners, such as academic institutions, NGOs, private sector, or individuals, may be contracted. No specific funding limits are given for individual projects, but total funding for this round is $300 million. Projects receive funding for up to three years, although they may continue beyond that time frame.

Another major fund focusing on partnerships with governments is **Nature4Health** (nature4health.org), established by the International Climate Initiative (IKI) of the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) with 50€ million initial funding to be disbursed in three phases lasting until 2030; the first phase began in October / November 2022. It is implemented through a consortium of eight partners, which include the IUCN, EcoHealth Alliance, WHO, WOAH/OIE, and several UN agencies. Eligible applicants to the fund are national, sub-national or regional government entities. In each phase, 4-6 country partners may be chosen. The country partners will then work with an Implementing Partner, chosen from the Consortium Partners to analyse local needs for strengthening OneHealth approaches through "One Health fitness" policy assessments. Based on these assessments, partners will then develop and implement OneHealth policies and actions that consider biodiversity and climate change to prevent future pandemics. This may include "capacity building, knowledge management, advocacy and awareness raising programmes and initiatives on the links between biodiversity, climate change and health" as well as strengthening "One Health collaboration and governance structures that facilitate sustained preventative action and policy".

A one-time relevant call for applied project funding was published in 2020 **Germany's International Climate Initiative (IKI)** (🔗 https://www.international-climate-initiative.com/) and included the topic "Pandemic preparedness: natural protective barriers between humans and animals by expanding, linking and improving protected areas" in its "Thematic Call" for funding. Eligible projects were implemented by consortiums of at least two organisations in OECD official development assistance countries, although project partners did not have to be based in these countries. Projects were preferably regional or at least bilateral. Consortiums could include a wide range of organisations including international intergovernmental organisations and institutions, NGO's, research institutions, or commercial enterprises. Projects could receive 5-30€ million and last up to eight years (more recent calls on other topics budget 10-20€ million per project).

4.2.6 Conservation Initiatives

Funds focused on biodiversity and conservation may also fund research and programs relevant to Biodiversity and Pandemics. For example, the **Critical Ecosystem Partnership Fund (CEPF)** is dedicated to providing funding to civil society (non-governmental and academic) to implement projects in identified biodiverse regions that protect important ecosystems, habitats, and species diversity. The small grants program provides up to $15,000 of funding while the large grants are typically $150,000. For example, in the Indo- Burma region, the CEPF designates "Understand[ing] and support[ing] action to address linkages between biodiversity and human health, including the role of biodiversity loss in the emergence of zoonotic diseases" as one of its priorities, along with several actions to combat illegal

wildlife trade and crime under the theme of zoonotic disease mitigation (https://www.cepf.net/our-work/biodiversity-hotspots/indo- burma/priorities).

Another potentially relevant program focused on species conservation is the **Sustainable Wildlife Management Programme** (**SWM**) (https://www.swm-programme.info/). The programme is funded by the European Union with co-funding from the French Facility for Global Environment (FFEM) and the French Development Agency (AFD) and administered by a consortium led by the FAO, in collaboration with CIFOR, CIRAD, and the Wildlife Conservation Society (WCS), which provides funding for wildlife conservation, thus maintaining species diversity through the lens of sustainable use and management. The program focuses on sustainable hunting when ecologically possible, capacity building for management in local and indigenous communities, and reducing demand for wild meat in distant (urban) markets as well as diversifying protein sources through the development of alternative proteins (e.g., chicken / fish value chains). SWM currently operates in 15 countries in Africa, the Pacific, and the Americas. While SWM does not currently work on pandemic prevention or pathogen surveillance, a recent SWM white paper(https://www.fao.org/3/cb1503en/cb1503en.pdf) proposes OneHealth surveillance at sites as a future direction, building on experience of program partners. This may include analyses of human-wildlife-livestock interfaces, sampling, surveillance, and risk assessment. A second phase of SWM is in preparation.

4.2.7 Relevant European Agencies

In addition to the above-listed funding programmes, initiatives, and networks, here we highlight relevant European agencies. While they have not, to our knowledge, issued specific calls related to biodiversity and pandemics, their programmes and mandates are broadly relevant to the topic. They may also contribute to designing EU Research Funding calls, for example through the Horizon Europe programme.

The **European Centre for Disease Prevention and Control**, established in 2005, is an EU agency aimed at strengthening Europe's defences against infectious diseases, including zoonotic diseases. Its mission is to identify, assess and communicate current and emerging threats to human health posed by infectious diseases. The ECDC conducts surveillance on diseases, including emerging or re-emerging pathogens and evaluates prevention and control programs. It assists Member States with outbreak preparedness and response by identifying and sharing best practices, increasing understanding of risk and vulnerability, fostering partnerships, assessing and strengthening laboratory capacity, and supporting the development and use of early warning platforms. The ECDC coordinates several networks, including the Emerging Viral Disease Expert Laboratory Network, the European Emerging and Vector-Borne Disease Network, and the European Influenza Surveillance Network. The agency also identifies needs for research and pilot projects related to health and disease and may issue calls for grant proposals and provide support for EU projects, such as the HERA incubator and EU4Health. Although the ECDC does not directly address biodiversity, it has increasingly promoted OneHealth approaches to health through workshops, reports, and expert consultations.

ECDC frequently collaborates with the **European Food Safety Authority** (**EFSA**), particularly with regards to food-borne zoonotic pathogens, such as Salmonella, Campylobacter, and E. coli. Food-borne illness is primarily transmitted through food with more limited human-to-human transmission and thus is less likely to cause a pandemic. While EFSA does not collect field data, it does provide environmental safety advice, risk assessments, and perform reviews of available data. Although it is not directly connected to pandemics or disease risk, biodiversity protection is a goal in EFSA's environmental risk assessments for EU agro-ecosystems.

The **European Environmental Agency** (**EEA**) is another relevant agency. Its purpose is to support policy development, analyse environmental data and trends, and provide and maintain reporting infrastructure for data. One of its main areas of work is environmental health, with a focus on the health impacts for people of pollution, chemicals, and climate change. The EEA also analyses pressures on biodiversity and biodiversity loss in Europe.
EU executive agencies, which are in charge of managing programmes or projects from EU directorate generals, may also be relevant. **The European Health and Digital Executive Agency** (**HaDEA**) manages funding calls related to health. Although it is not currently funding programs or projects directly related to pandemics and biodiversity, this executive agency could be highly relevant. Current funding calls that HaDEA is involved with are within the Horizon Europe and Digital Europe programs. Other programs (without current funding calls) managed by HaDEA include EU4Health, the Single Market Program: Food, and Connecting Europe Facility.

Finally, in addition to the **European Commission Directorate-General for Research and Innovation** (**EC-DG RTD**), one of the requestors of this report, the **Directorate-General for International Partnerships** (**EC-DG INTPA**) could also play an important role in supporting and promoting the European Union's agenda regarding biodiversity and pandemics. EC-DG INTPA's mission is to advance the EU's goals in sustainable development, poverty eradication, promotion of peace, and protecting human rights through foreign relations, international

cooperation, especially via the management and disbursement of Official Development Assistance, as well as grants, loans, and equity from public and private entities. Currently, the Directorate is involved in efforts focused on both biodiversity conservation (e.g., Global Biodiversity Framework, EU Forest Partnerships, NaturAfrica, Kiwa Initiative in the Pacific region, etc.) and health (e.g. EU Global Health Strategy, COVAX Facility, Team Europe Initiatives, etc.) but has yet to connect these two sectors. Biodiversity and health could also be integrated or considered within the projects for climate change adaptation and resilience under the EC-DG INTPA's umbrella.

4.2.8 Limitations

This list, which is non-exhaustive and non-systematic, should be treated only as a set of examples rather than a definitive or authoritative list. We note the bias towards programs based or organised in the European Union or the United States, although most include much wider eligibility and encourage or require collaborations with a wider range of countries. This may be partially due to the funding sources members of the EWG were familiar with. Further, we searched for funding only in the English language, used only publicly available information (e.g. websites), and focused on international funding with limited searches for national and institution-based funding schemes.

4.3 People-based methods: Online survey and online focus group discussion

4.3.1 Online survey

The survey was structured into two components: the first with policy recommendations and the second with research knowledge gaps. We received 121 responses, a response rate slightly above 40%, exceeding our target of 30%

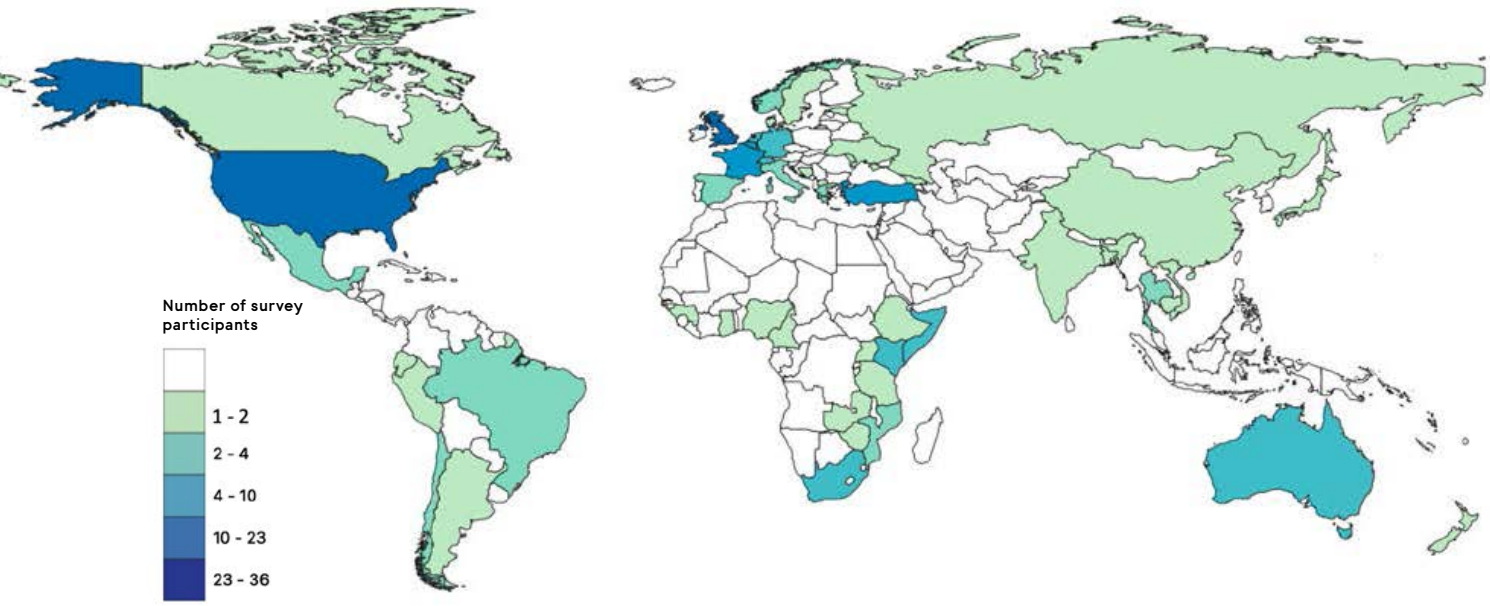


Figure 7. Geographical distribution of survey participants.

Results

Section 2: Ranking of the 12 Policy Recommendations

Overall, the survey responses showed no item dominating policy recommendations but rather indicated support across most items, with 8/12 receiving at least 25% participant responses, with the least cited (**Business**) being the only item selected less than 5%. The two most cited items were **Conservation** (38%) and **Monitoring** (33,9%). Responses for Section 2 (policy recommendations) of the survey provided the results presented in Figure 8 below.

This lack of clear differences in priority between the selected items indicates the need for major changes across domains to address issues related to the Biodiversity/Pandemic linkage. In addition, given that most of the items refer to broad domains (e.g., Conservation , Food System, Governance, Justice & Equity), the policy changes would need to be implemented in a systemic and cross-sectoral way.

Results from the survey
— Policy Recommendations —

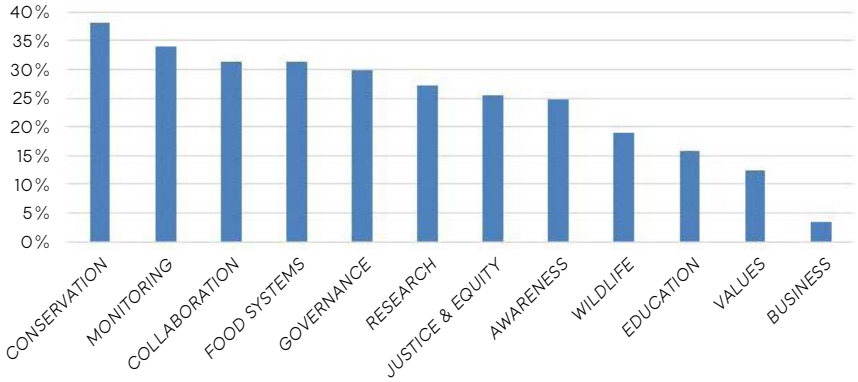


***Figure 8**. Results from the survey - the percentage of times each policy recommendation (see Table 5) was chosen as being one of the top three relevant recommendations for policy. Participants were allowed to select up to three items from the list or add one of their own.*

Conservation refers to the impact of human activities on wildlife and natural habitats, such as human encroachment on remaining biodiversity habitat across the world, that lead to biodiversity loss. Encroachment, for example, is known to increase wildlife/domestic animal/human interfaces which promote the spillover and emergence of infectious diseases, some of which have pandemic potential. This item is therefore about one of the main drivers of pandemic-risk creation at the biodiversity/societies interface that also links to the on-going biodiversity crisis.

Monitoring refers to standardised monitoring over time of the ecological, social and epidemiological indicators at wildlife/domestic animal/human interfaces and along transition zones in order to better know and understand the processes that link biodiversity and pandemics. It therefore showcases the major gaps in knowledge that we still have at the biodiversity/societies interface and the need for long-term monitoring to better understand the dynamics of these interfaces.

The main driver of biodiversity loss and interface creation across the world is land-use change for agriculture. A large part of this agriculture is intensive and aims at feeding humans directly, as well as domestic animals that will feed humans. The need to transform **Food Systems** globally was the third most cited item and relates to the environment and biodiversity crises. Here participants indicated that this item is deeply linked to the risk of pandemics and that it constitutes a root cause of the pandemic risks associated with biodiversity.

The need for more **Collaboration** and **Governance** was also highlighted. Current trends in interdisciplinary approaches such as One Health and other types of integrated approaches to health point to this ambition and its relevance to addressing the complex and wicked problems that lie at the Biodiversity-Pandemic nexus. This cross-sectoral collaboration needs to enhance the relationship between science and policy (for example as the IPCC and IPBES do) in order for politics to take the relevant and challenging decisions needed to address the root causes of environmental crises that determine the risks of pandemics. These decisions to mitigate the pandemic risks at the human/biodiversity interface should be well-informed and made in a holistic context, especially promoting social Justice & Equity in order to make sure no population or group of humans is left behind and that historical injustices towards poor or indigenous human communities are not maintained or amplified.

Finally, the need for Awareness about the pandemic risk across the different levels of societies, including civil society, the general public and various political spheres (e.g., national, provincial, district) is also critical to make sure political decisions are understood and behaviour changes that protect and conserve biodiversity are promoted.

In addition, participants were asked to add any missing items that they considered to be relevant. These items can be found, as written by the participants, below:

- Ensure proper *screening* of research activities and *control* of laboratories manipulating pathogens
- Consider and shift *values* and *narratives* in policy
- Build stronger legal *frameworks* / International *health regulations*
- *Co-design*
- *Wildlife* supply chains
- *Agriculture systems*
- *Risk-based approach*

Overall, the EWG decided that these items did not bring major additional contributions to the list of items from the preliminary work done by the scoping review. However, to be exhaustive they were

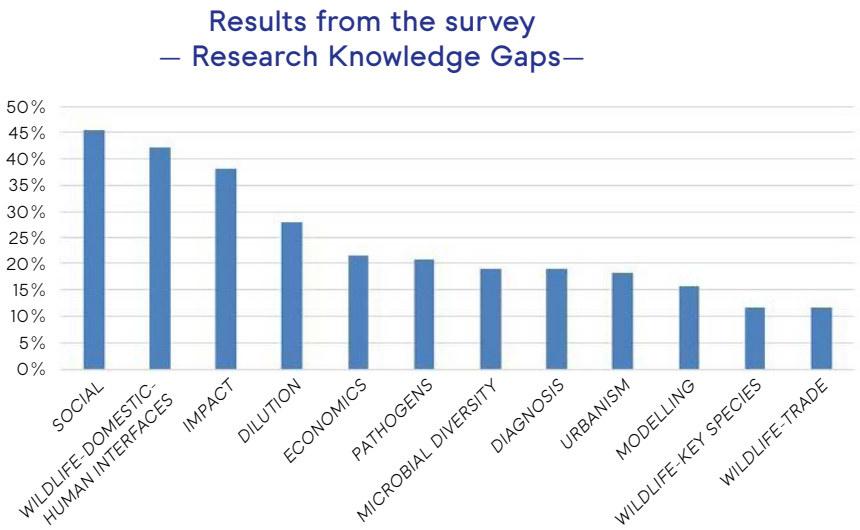


Figure 9. Results from the survey - The percentage of times respondents identified the research knowledge gaps identified (see Table 6) as the most important to be addressed.

displayed as additional comments by participants during the focus group discussion (detailed below).

Results

Ranking of the 12 Research Knowledge Gaps

The result of the selection of the research gap items by the participants revealed significant heterogeneity across the categories with 6 categories selected by more than 20% of respondents (Figure 9). Three items were selected 35 and 45% of times (**Wildlife-Domestic-Human Interfaces; Social; Impact**) of respondents, with the next most selected item being selected less than 30% (**Microbial Diversity**) and another five were close to 20% (**Economics; Pathogen; Dilution; Diagnosis; Urbanism**). **Modelling, Wildlife- Key Species and Wildlife Trade** received less than 20%.

The three most cited items showcase the need to better understand the dynamics of pathogens and risks of emergence at the biodiversity-society interface, especially in ecosystems in which strong wildlife/domestic/human interfaces exist at or inside natural habitats. The need to better understand spillover processes, and the biodiversity - spillover relationship from an ecological perspective (behavioural ecology, community ecology, disease ecology) is met by the need to better understand the interdependent social processes (behaviour, value systems, economics) that create and influence the intensity and frequency of contacts between species at these interfaces. The third most important factor, Impact, highlights the current lack of information and understanding of what are the best ways to manage these interfaces and mitigate the risks of spillover at the biodiversity-society interface. Quantified and qualified assessment of current epidemics and pandemics and the gains made by avoidance of such events through preventive measures are key data to inform policies and trigger the paradigm shifts necessary to adopt relevant policies.

The dominance obtained for the three items (Wildlife-Domestic-Human Interfaces; Social; Impact) may be the result of many of the other items being components of more global and holistic knowledge gaps. For example, **Microbial Diversity** aiming at screening the unknown viral, bacterial and fungal diversity to identify future potential threats is one approach that is used to study the wildlife/domestic/human interface, while Pathogens is identifying the pathogen properties (e.g., receptor) that can make a pathogen more or less susceptible to being a threat for pathogen spillover. The identification of wild maintenance and bridge hosts in pathogen ecology is a fundamental component of disease ecology at the wildlife/domestic/human interfaces. **Dilution**, referring to the dilution effect, is one of the hypotheses currently posited to understand the relationship between biodiversity and pathogen emergence. **Wildlife Trade** is a diverse and global phenomenon at the source of many emergency events, but can still be considered as a sub-component of the wildlife/domestic/human interface. Economics looks at the costs and benefits of interventions used to manage or mitigate disease emergence, and the outcomes of such interventions are an important part of Impact.

Diagnosis and **Modelling** are both essential tools to support research on biodiversity-pandemics. Developing diagnostic techniques adapted to the diversity of potential wildlife hosts (even if one concentrates on the orders more likely to transmit pathogens to domestic animals and humans – e.g., mammals and birds) is an enormous challenge. **Modeling** can help reproduce the complex patterns that unfold at the wildlife/domestic/human interfaces and predict the outcome of interventions or test the long-term evolution of current trends.

Finally, **Urbanism** refers to the most anthropogenic habitats on earth in which a subset of biodiversity has adapted, is currently evolving and hosts a biased subset of pathogen biodiversity. The urban

environment provides specific wildlife/domestic/human interfaces that require the dedicated attention of the scientific community.
In addition, participants were asked to add any missing items that they felt were relevant. These items can be found, as written by the participants, in the list below:

- Ecogenomics: studying the interspecies implications of genomes/genetics/genes
- Environmental and Medical Histories: studying biodiversity loss and occurrence of infectious diseases in history
- Measures of the impact of spillover risks: studying the risks and/or effectiveness of spillover consequent to human activities.
- Drivers of disease emergence: investigating the underlying (or proximal) drivers of disease emergence
- Ecosystem Design: investigate if sustainable design, life friendly ecosystems has an impact
- Impact of wildlife/population dynamics & community structure on pathogens transmission. collating evidence of the impact, and lack of impact, of local, national and international initiatives, policies and measures to conserve biodiversity and or reduce disease emergence.
- Effective mitigation
- Economic cost-benefit analysis
- Preventative measures:
- Implementation & effectiveness of disease surveillance regulations

Overall, the EWG decided that these items did not bring any major addition to the list of items derived from the preliminary work done by the scoping review. However, to be exhaustive they were displayed as additional comments by participants during the focus group discussion (details below).

4.3.2 Focus group discussion

In total 17 experts were invited to participate in a focus group discussion: 13 of them responded positively. Seven experts were able to join for the full session and two joined partially (see the list of participants in Annex 5).
The online focus group discussion was led by professional facilitator Estelle Balian and held on Zoom using Mural to create an environment for the experts to visualize the results of the survey, collaborate on their new ideas and engage in the discussion in an efficient way. A detailed report of the discussion that occurred during the focus group discussion is presented as Annex 6.

Analysis of the focus group discussion is based on different sources:

- Minutes taken during the focus group discussion by a member of the Eklipse Management Body;
- Notes taken by members of the EWG acting as observers and rapporteurs during the FGS;
- Transcription of the audio recording.

Session 1: Introduction

During session 1, The facilitator welcomed the participants and after presenting a few rules of conduct gave the floor to a member of the EWG to summarise the background and objectives of the Eklipse request and of this focus group discussion. After this short introduction, participants and EWG members facilitating the focus group discussion were provided a space on the virtual board followed by a minute or two to introduce themselves. Prior to the discussion, the results of the survey and basic instructions on how to use the online programs and the agenda of the meeting were shared with the experts. Participants were asked if they had any question on the objectives or the process. Clarification of the definition of the request (e.g., what kind of pandemics?) and the outcomes of the process were required by two participants.

Session 2: Policy recommendations

In session 2, the facilitator asked a set of selected questions. During the first session the experts discussed the policy recommendations from the survey. The discussion started with one member of the EWG introducing the topics proposed in the survey and the survey prioritisation results. Then the experts were asked to discuss the proposed policy recommendations, highlighting any surprising results, adjustments needed and important items missing. Next, a discussion followed on the priorities given in the survey, captured by asking the experts what they thought the main criteria were for those priorities. In summary, participants suggested that policy recommendations were too broad as presented and needed to be simplified to provide more concrete policy recommendations for achieving broad aims. It was also noted that separate recommendations and research priorities may be needed for currently circulating versus emerging pathogens or zoonotic diseases. Participants generally agreed that the proposed policy recommendations lacked sufficient integration and reference to social sciences, community involvement, and economic and social drivers. Feedback from policy actors would probably be needed for this section. There was no significant trend observed in the prioritisation of items as differences between scores were low. Generally, as explained for the online survey results, all items in this list were indicated as important with some level of overlap between them.

Session 3: Knowledge gaps and Research Recommendations

The third session's discussion was on knowledge gaps and research recommendations. The discussion proceeded in the same way as the first session, starting with questions from the facilitator. In summary, focus group discussion participants identified a few specific items like: the need for better diagnostics for zoonotic diseases in humans and wildlife; the relevance of the scale of studies within habitat/study site and between them in order to be able to compare them; the need for changing the way social sciences are currently "instrumentalised" in health studies in order to fully incorporate them; the need for more population sciences to understand the impacts of changing demographics on disease for humans and wildlife. An extensive discussion then continued on the relevance of research and its impacts. In terms of relevance, in-depth studies incorporating multi-scale and multi-disciplinary approaches are needed to address the complex systems in which disease and health issues occur. Then, research should be woven into risk-management systems to inform decisions and actions that are relevant for policy makers.

Session 4: Interdisciplinary priorities and possible projects

For the final session, participants were divided into two subgroups of 4-5 participants. The group members were pre-assigned and each group included participants from different disciplines to ensure interdisciplinary discussion. In this session, each group had to design an interdisciplinary research project at the intersection of at least three research gaps. The groups were asked to provide a potential project including a title and a pitch, recommend a time length for the project to achieve its objectives, amount of funding required for such a project, and to give an example of how this could be done (e.g., One Health approach). The objective of this session was to have a more concrete interdisciplinary discussion on priorities and to move from general themes to more concrete research project ideas. During the discussions, the facilitator moved between groups to ensure the instructions were clear and to check how discussions went. Feedback from each group was presented to the entire focus group by one of the experts of each subgroup (see Figure 10 below).

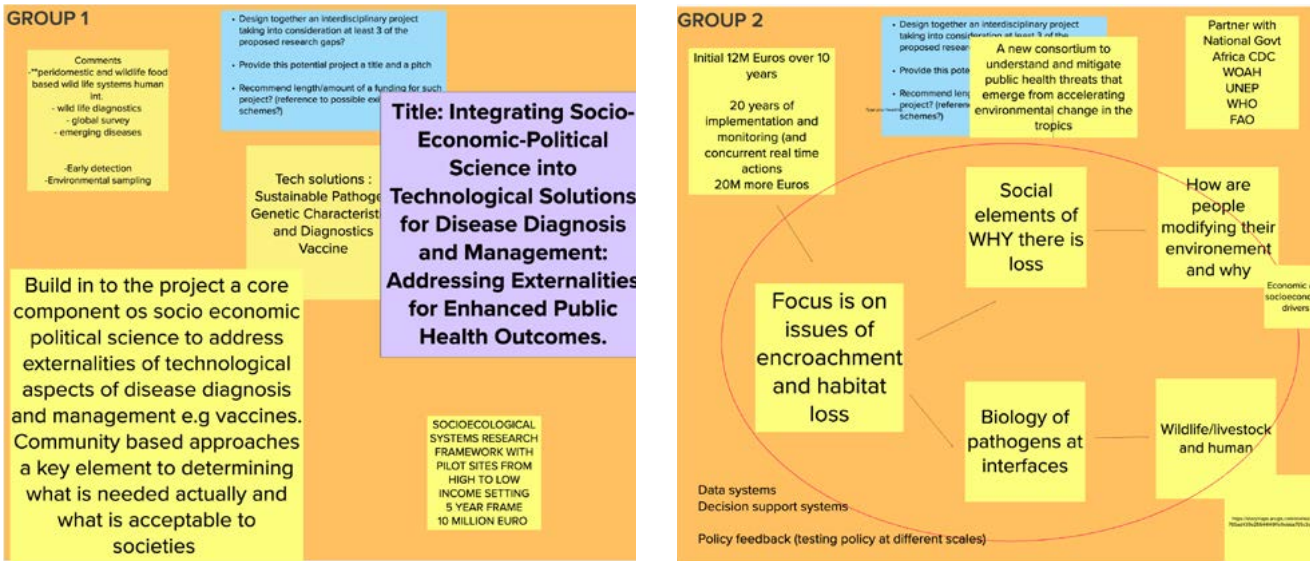


Figure 10. Results of session 4: Interdisciplinary priorities and possible projects developed by each subgroup of the focus group.

Group 1 feedback

Title: Integrating socio-economic-political science into technical solutions for disease diagnosis and management: addressing externalities for enhanced public health outcomes.

This title sets the interdisciplinary frame for the whole thing. We build into the project a core component of socio-economic-political science in relation to externalities. We have the technology development, particularly in relation to the interface, whether it be wildlife, whether it be public health, or zoonosis diagnosis. It's really trying to wrap this thing up so we're beginning to understand pathways and where things come from and go to.

A good example would be vaccines coming out of these management tools in relation to those sorts of pathogens that we see as a potential risk. The issue is that communities are becoming more resistant to things like vaccines because people are not involved a lot in the decision-making process, and the intervention is being imposed upon society in many ways through the political process. The community-based approaches are a key element to determine what is actually needed, and what is acceptable to societies. There's always this danger with medicine which is a bit like developing weapons against microbial nature, and there's an industrial complex that goes with these developments of drugs and vaccines. The socio-ecological systems

research framework is a principle that would be very good, and we need pilot sites, from high to low income settings because they provide very different contexts. A five-year time frame, perhaps with a budget of 10M€. Isn't that modest?

Group 2 feedback

Title: Consortium to understand and mitigate public health threats that emerge from accelerating environmental changes in the tropics

It focuses on public health but is strongly linked to issues related to wildlife, livestock and ecosystem changes. We're looking at an initial period of 10 years potentially, maybe eight, with 12M€ of funding, followed by a 20-year implementation period including monitoring and real-time actions with further funding of potentially 20M€ or more. The focus here responds to the needs on the ground, including addressing the impacts of encroachment and habitat loss. A big element of this is understanding the social elements of why there is loss, how people are modifying their environment and why and what the economic, social and policy drivers are for habitat loss at a national level, but also how communities manage themselves with potentially unwritten policy at another level. Governance will be at all those multiple geographical scales. Secondly, this consortium would have a very specific focus on the biology of the pathogens at these encroached interfaces and a focus on wildlife, livestock and humans and the broader environment in which all of those things sit. We would have to deconstruct those parts of it much more before we would get the funding obviously. This is within a context of very strong Data Systems that support decisions and with real-time policy feedback: tinkering with developing policy interventions at different scales and testing those policy interventions to see what real world impact they have, which is why the timescale is so long, and then altering that policy very proactively to make sure that it's working in the most beneficial way. This speaks to the priorities of national governments which signed up to the priorities of Africa CDC, WHO, WOAH, UNEP and FAO through the OHHLEP mechanism in particular.

Following these two presentations, participants emphasised the need for local scientists to be promoted and supported when they are working on important topics. This is essential to improve countries' abilities to manage the risk of pathogen emergencies in wildlife and transmission at the wildlife/domestic animal/human interface whilst considering the protection of wildlife. This was linked again to the need to build collaborative interdisciplinary environments (including researchers, practitioners and civil society members; local and international scientists) to implement research on the Biodiversity-Pandemics relationship. The comparative advantage of comparing countries in which land conversion has largely happened (e.g., India) and countries in which it is happening (e.g., most African countries) was also noted.

Session 5: Wrap up and next steps

Finally, during the last session, after thanking the participants for their time and involvement, the following comments summarising the discussions were made by two members of the EWG:

- In terms of policy, good governance is a key.
- In terms of knowledge gaps, the participants suggested many approaches and methods such as community-based, risk-based and theory of change.
- For both policy recommendations and research gaps, participants focused on bottom-up approaches and having local communities being more involved to avoid top-down approaches.
- Social sciences were being brought in not just by the social scientists in the group. Recognizing the importance of a better integration of social sciences to address some of the biggest knowledge gaps is necessary because what is happening at the biological level cannot explain everything.
- We also heard the need to have more concrete policy suggestions. Our policy suggestions were very broad, although they did come from our scoping review of the scientific literature.
- There was a little bit of disagreement with the prioritisation of the policies. This comes back to the tension between a trend towards the need for broad transformational transitions at global level versus the need to work more at a local scale
- We noted the tension between the need to use monitoring and predictions in early detections to follow what's happening and to be able to react quickly versus the need to take into consideration overarching recommendations of conservation and food systems transformation in order to make the systems more resilient at their root. These two threads have to work in parallel.
- The project sessions integrated the idea of local chain, local involvement and local context but also brought in a more global vision. Some of these tensions can be resolved partially when putting ideas into practice because it seems one can't do one without the other.

After the participants were offered a moment to reflect back on the focus group discussion during which they thanked the facilitator and the organising team for a short but efficient workshop, then Serge Morand closed the meetings.

Discussion and Recommendations

5. Discussion and Recommendations

The Expert Working Group (EWG), established by Eklipse in June 2022, worked for over a year and undertook a number of different studies aimed at synthesising the current state of knowledge on the relationship between biodiversity and pandemics, identifying the most important research gaps in this field, and forming recommendations for science policy to address them. The group consisted of scientists with relevant expertise in the natural, biomedical and social sciences, and the methods employed included studies of the scientific literature (both peer-reviewed and grey), of the existing funding schemes/initiatives, and a survey and focus group discussion involving external experts. In this way, the EWG was able to fill the gap between the published research - which by its very nature is delayed in terms of reflecting the current research frontier of a given field - and the projects related to biodiversity and pandemics currently being carried out by scientists. The EWG put effort into contacting external experts from a variety of disciplinary and geographic backgrounds, reflecting the vast array of approaches and methodologies used by scientists working in the field of biodiversity and pandemics and achieving the global perspective in its synthesis. Thanks to this combination of methods and our focus on securing a diverse and inclusive set of voices, we consider the results a robust basis for developing science policy recommendations related to biodiversity and pandemics.

Highly biodiverse ecosystems host a large diversity of potential pathogens, mostly unknown, including some that will have pandemic potential. However, the relationship between biodiversity and pandemics is mediated through local epidemiological events (e.g., cross-species transmission) that can then trigger an amplifying transmission process in domestic animals or humans leading to a panzootic or a pandemic. These local events or spillovers happen between individuals and are extremely difficult to predict, with both global and local drivers. The most commonly cited global drivers are globalisation, in particular of food systems, resulting in the associated movement of animal and animal products, the transformation of natural habitats into agricultural land (i.e., land-use change) and human-induced climate change. The most frequently cited local drivers are poverty, poor health services (both for animals and humans) and local practices of managing risks differently than what risk-management requires in a global (i.e., ultra-connected) world. Global drivers strongly influence local drivers. Therefore, the relationship between biodiversity and pandemics has the peculiarity of being an issue of global concern that is defined by small-scale events crafted within local contexts but influenced and impacted by global and local drivers. The relationship between biodiversity and pandemics, once framed as a simple biomedical or ecological problem with straightforward solutions, actually has all the properties of a wicked problem embedded in complexity.

Here we will focus on our recommendations for science policy to address the complexities of the relationship between biodiversity and pandemics. For more specific results of the knowledge gap analysis, readers should refer in particular to the results section for the scoping review. Apart from informing the survey and focus group discussion, the primary stand-alone output of the scoping review is the relationship matrix between the research recommendations and the knowledge gaps (Figure 6). The matrix gives an overview of the current evidence on biodiversity and pandemics: policy-makers can use it for the orientation of their political actions based on the paucity of evidence for some topics. We observed that there was uncertainty in evidence among a few research gaps, in particular mechanisms of dilution effect and species-specific effects. There has not been a clear scientific consensus yet on these topics to lead to policy recommendations. Thus, there is a need for funding for further application-based research on such topics.

Below we discuss our four specific recommendations for addressing biodiversity and pandemics, formulated based on our analyses of the knowledge gaps and our own expertise and experience. Following the request we received from the consortium of requesters, our recommendations concentrate on the policy for science and research. However, their implementation will have consequences reaching far beyond the realm of scientific research. At present, following the failings of the COVID-19 response, it is clear that we need to transition from health and socio-economic policies delivering small-scale incremental change to transformative policies that solve real problems and achieve major progress for humans and wildlife. The type of transformative policies that we mention converge with those needed for other global crises such as the climate and biodiversity crises and call for systemic societal changes in the way we interact with nature, we produce food, we use natural and mineral resources and how we respect and collaborate with each other.

However, to formulate and implement these policies, we need reliable evidence, based in academic as well as non-academic knowledge systems (e.g. indigenous knowledge systems). This evidence and relevant policies are still lacking: implementing the science policy recommendations listed below will be a major step towards developing the transformative health and socio-economic policies the world needs.

Recommendation 1:
Promote the development of a science of the wildlife/domestic animal/human interface.

One of the key challenges in unravelling the relationship between biodiversity and pandemics is understanding spillover events between wild animals - part of biodiversity and the source of most pathogen diversity - and species of interest (i.e., target species in Haydon et al. 2002), often human or domestic animal populations in given ecosystems. These spillover events occur at the so-called wildlife / domestic animal / human (W/D/H) interfaces. The socio-ecology of pathogen transmission at the W/D/H interfaces is therefore an important field of investigation lying at the meeting point between several scientific domains spanning natural and social sciences (de Garine-Wichatitsky et al., 2021). Characterising and understanding such interfaces is a challenge because they are dynamic, constantly evolving and adapting to the changing local contexts impacted by global and local drivers (Caron et al., 2021). There is, therefore, a need for more understanding of W/D/H interfaces in order to be better prepared to prevent spillover events or to detect their first signs. Studying W/D/H interfaces is needed not only in different contexts but also longitudinally over time.

These "interface" studies cannot be pure natural science studies, as many have been up until now because they miss crucial information, such as the social, historical, or economic drivers of behaviour or perceptions, that can only come from the social sciences, leading to biased and incomplete knowledge (see Recommendation 2).

Recommendation 2:
Promote interdisciplinarity that integrates the social sciences and humanities into the science of the interface.

The interdisciplinary science that is needed to understand the interface between man-made/anthropogenic and natural/wild environments must combine on equal terms the social and natural science methods and insights. While the broad knowledge of ecology and other relevant natural science disciplines is crucial, the full breadth of the social sciences - anthropology, sociology, political science, economics, history, and archaeology, psychology, and several participatory sciences are needed to understand the mechanisms of past, present and future disease emergence in the context of colonialism, political ecology, market dynamics, and extractive economies. The need to better understand spillover processes, and the biodiversity-spillover relationship from an ecological perspective (disease ecology, behavioural ecology, community ecology) is met by the need to better understand the interdependent social processes (human behaviour, value systems, economics, etc.) that create and influence the intensity and frequency of contacts between species at these interfaces. The still-dominant science design in which social sciences and humanities are largely relegated to supporting projects grounded in the natural sciences is wrong. Instead, an interdisciplinary model fusing natural and social sciences together is capable of providing actionable knowledge that can help predict, prevent, and manage future spillover events. Without incorporating the social sciences and humanities, we risk repeating the mistakes of the COVID-19 response in which biomedical interventions were often inefficiently or ineffectively implemented due to the disregard for societal and cultural factors, including belief systems. Further, better and more intense inclusion of the social sciences in the field of biodiversity and pandemics is needed in order to successfully involve communities living at the W/D/H interface in research and management (Recommendation 3).

Major topics related to W/D/H interfaces, that require further research:

- How host and non-host populations adapt to changing W/D/H interfaces;
- The consequences that changes at the W/D/H interface have on different pathogen epidemiological dynamics, including the capacity for pathogens to evolve and jump species barriers;
- The risk of spillover at W/D/H interfaces, including the past and present economic, social and cultural drivers of human-animal interactions that increase risk of zoonotic pathogen spillover;
- How to assess the pandemic potential of a given spillover event;
- How to assess processes at multiple spatial scales simultaneously to understand emerging threats and properties when translating from one scale to the other;
- Developing diagnostic tools and integrated data management related to potential pathogens carried by wildlife.

Recommendation 3:
Promote transdisciplinarity that involves local communities and civil society in the science of the interface.

As hotspots of pathogen spillover and disease emergence have been identified in biodiversity rich areas in low- and middle-income countries (Jones et al., 2008), it is essential to involve local human populations (e.g., indigenous people, recently immigrating communities, rural populations) in the design of, implementation and monitoring of research and intervention projects. This is crucial because the complexity of pathogen dynamics at W/D/H interfaces cannot be properly grasped without integrating the social components that influence every single step of transmission dynamics from host ecology (e.g. hunted host) to risk exposure (e.g. hunters) at these interfaces. Moreover, these human populations are not simply passive actors within complex systems that can be studied by external stakeholders; they have developed extensive knowledge of these very systems they co-create on an everyday basis. To formulate truly transformative pandemic-prevention and preparedness policies, the research and policy communities need to understand and consider the broader social context in which these interfaces have been and are created and in which they operate, in order to address not just the results, but the causes of spillovers and resultant health crises. This means engaging with local communities and properly recognizing indigenous knowledge systems that have captured largely untapped knowledge on the relation between biodiversity and health through centuries of living in/with biodiversity.

Implementing this recommendation requires that social scientists specialized in participatory sciences (including futures thinking) have leading positions in project design and implementation. This approach will ensure respect of justice, including procedural justice (e.g., making sure all stakeholders participate in decision making), recognition justice (e.g., encompassing different worldviews of the problem and recognising indigenous knowledge systems) and distribution justice (e.g., making sure the research benefits all) and should prevent replicating injustices when science from wealthy countries is implemented in LMICs to the benefit of those wealthy societies without any concern for local issues.

Recommendation 4:
Formulate problem-led funding calls beyond the current standard 3-5 year project cycle.

At the onset of each project, a systemic framework should be implemented, using theory of change tools, understanding that spillover events occur in complex socio-ecological systems. Beyond the interdisciplinarity required, project design should ensure integration of indigenous knowledge systems in the design, framing, implementation and monitoring of research, ensuring that the research objectives are understood, accepted and shared by all stakeholders.

This recommendation has implications for project design and implementation. Firstly, this means that donors cannot expect a project to be framed in detail before local stakeholders are engaged (i.e., during an inception phase). Secondly, it is essential that external researchers do not neglect local health realities and only target global benefits without taking into account local concerns. Due to their importance at the local level and learnings for disease ecology in general, relationships between biodiversity and neglected endemic diseases should also be the target of such projects, regardless of whether these diseases have pandemic potential.

The multi-stakeholder co-design of projects requires more time and resources than traditionally allocated for research projects; funding should be provided that allows proper and continuous engagement with local stakeholders. Projects with a life-span of 3 or 5 years cannot achieve significant objectives in this domain. Meaningfully addressing the research gaps on the relationship between biodiversity and pandemics will require long-term (e.g. observatory type), well-funded, interdisciplinary and transdisciplinary approaches, possibly implemented in a stepwise manner (e.g., 5 plus 5 years, or 10 plus 10 years). Projects could also build on or strengthen existing initiatives, especially in most highly-impacted and at-risk regions, mainly in the tropics.

photo © Camille on Unsplash

Monkey jumping on a motorcycle with people. Spillovers can occur in natural or modified areas where wildlife comes into contact with humans and/or their domesticated animals.

photo © Alexandre Caron

Wahlberg's epauletted fruit bat (Epomophorus wahlbergi) in a tree at the IYSIS Cattle and Game Ranch near Tshaneni, Eswatini.

Conclusions

6. Conclusion

In this report, we have set out to identify and prioritise research gaps related to biodiversity and pandemics and to tie these to policy recommendations using literature-based methods, initiative scoping, and people-based methods. The relationship between biodiversity and pandemics is complex, encompassing a range of disciplines and local to global spatial scales over long time periods. At the most basic level, pandemics begin with a local spillover event and these are most likely to occur at the interface between wildlife, domestic animal and human (W/D/H), particularly within biodiverse areas, which are generally within low and middle-income countries (LMICs).

Understanding these dynamic interfaces requires inter- and trans-disciplinary research embedded in a systemic framework that gives equal footing to the social sciences and natural sciences and equal emphasis to social and biological drivers of interactions at these interfaces. Further, effective research demands a truly participatory approach, integrating indigenous knowledge and involving local stakeholders in research prioritisation, design, and implementation. Finally, this means reimagining research as a much longer-term endeavour beyond 3 – 4 years projects, with projects continuously building on and strengthening each other.

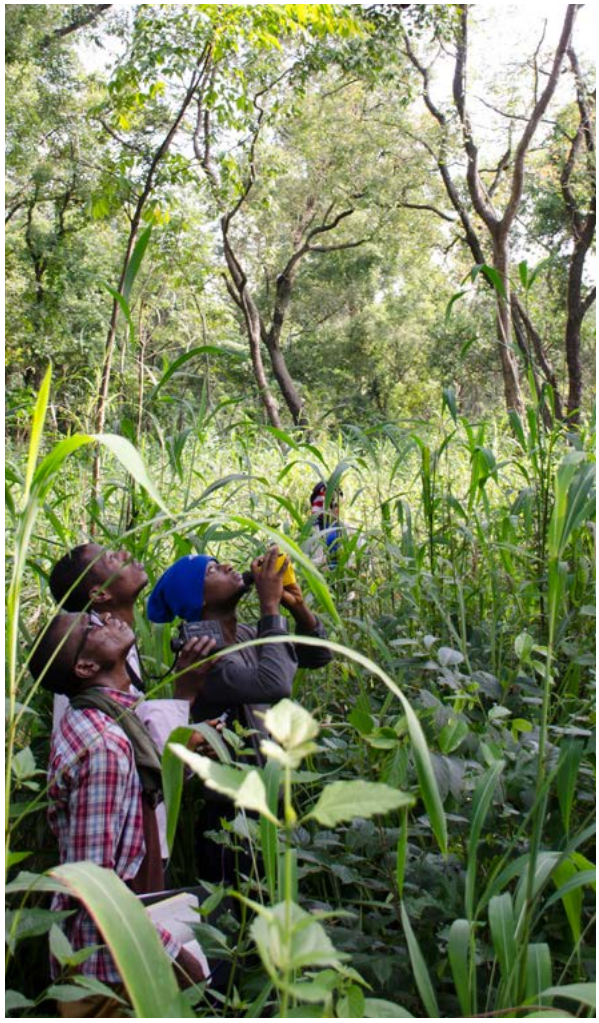


photo © Alexander Shenkin on Unsplash

Field research in Kogyae Strict National Reserve, Adidwan, Ghana.

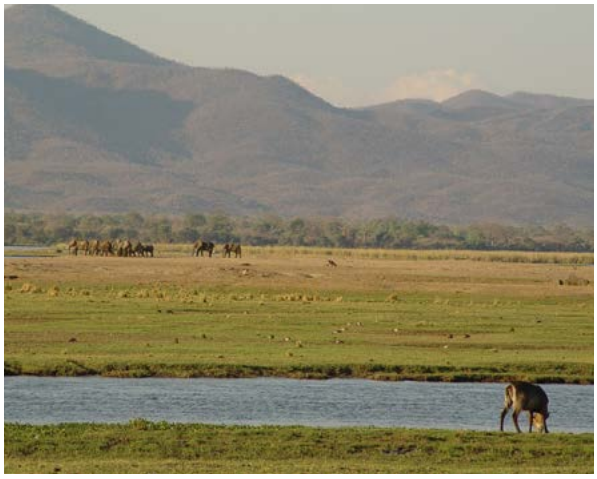


photo © Alexandre Caron

Mana pools national park landscape with a view on the Zambezi River' Zimbabwe.

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Annexes

8. Annexes

Annex 1:
Keywords for scoping review on biodiversity and pandemics

TERM	KEYWORDS
General keywords related to disease and pandemic	Disease; infection*; outbreak*; epidemics; spillover; emerging; infectious disease; zoonotic disease; zoonoses, vector-borne diseases; cross-species disease; pathogen transmission; human-animal interface; disease spread; disease emergence use with "AND"
General keywords related to policy	Science-policy interface; European research; IPBES; Network of knowledge; conservation policy; sustainability; ecosystem disservices research; ecosystem service research; biodiversity research; social-ecosystem system use with "AND"
Biodiversity loss	Biodiversity; biodiversity and human health; biodiversity loss; disease ecology; disease reservoirs; ecosystem health; ecosystem service; dilution effect; disease amplification; amplification effect; community structure; Host population threshold; critical community size
Agro biodiversity	Agricultural biodiversity; agrobiodiversity Index; food market;, consumption; conservation; seed systems; neglected species; fish richness; soil microbiome
Habitat fragmentation	Deforestation; afforestation; forest fragmentation; habitat fragmentation; roads; edge effect; forest edge; suburban edge; logging; logging roads
Bushmeat and wild animal trade	Bushmeat preparation; butcher*; bushmeat; bushmeat handl*; poach*; trophy hunting; wild meat; game meat; illegal animal trade, illegal wildlife trade, wildlife trade, animal traffic, wild animal trade, wild* supply chain; wet market*; fur trade; bushmeat market; traditional medicine; bushmeat consumption; bushmeat vendors; illegal meat; bushmeat bans wildlife farm*; game farm*; ecotourism; wild animal farm*;
Land-use modifications	Land use change; agricultural land; land conservation; cropland; agricultural expansion; plantation*; agriculture intensification; industrial agriculture; rapid infrastructure expansion; mining; pasture; concentrated animal feeding operation; livestock; cattle rearing; ranch*; livestock wildlife interface; livestock production; poultry; pig*; pastoralism; isolation
Climate change	Environment change, climate change; global warming, flood*; climat*, desertification; global temperatures; severe events; rising seas levels

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Annex 2:
Literature review of the reports related to the topic

- ***Title:*** Global guidance framework for the responsible use of the life sciences: mitigating biorisks and governing dual-use research, 186 p.
- ***Year:*** 2022
- ***Organisation:*** WHO
- ***Web Link:*** https://www.who.int/publications/i/item/9789240056107
- ***Knowledge gaps/future research:***

  Intersectoral collaboration: The framework encourages dialogue and cooperation among different stakeholders. Certain stakeholder groups will be better positioned to achieve specific goals. For example, scientists are best positioned to assess the risks and potential benefits of their work; institutions have an essential role in the oversight of biorisk assessment and mitigation; and governments and regulators are critical in reinforcing and requiring biorisk management strategies
- ***Recommendations to decision-makers and proposed solutions***

  As scientific and technological understanding in the life sciences and converging disciplines are advancing, potential safety and security risks have emerged that extend beyond pathogens, life sciences and technologies, and traditional laboratory settings. The rapid pace of advances in the life sciences, the convergence of the life sciences with other scientific disciplines, the diffusion of capacity and knowledge, and the multiplicity of actors and sectors require responsible governance mechanisms and systems that are anticipatory, flexible, responsive and collaborative. As the life sciences evolve and intersect with other scientific fields and technologies, the assessment of risks and benefits is becoming more complex and uncertain. Also, in identifying life sciences research and technologies that could cause harm through accidents, inadvertent or deliberate misuse, we need to think beyond specific pathogens, experiments and biology. Assessment frameworks will need to be adapted to encompass evolving risks and benefits. Clearly, there is a need for a comprehensive and integrated framework approach. Foresight approaches offer tools that can inform assessment methodologies designed to deal with the evolving and dynamic diversification of risks. Overall, these approaches provide guidance at the international level on addressing different risks, outline various tools and mechanisms, and serve different stakeholders. The scale of the need for awareness raising and education should be understood. Globally, there are millions of life scientists, and it is likely that their numbers will increase in the future with the current biotechnology revolution. Only a small percentage of life scientists are aware of, and have the ability to manage, biosafety, biosecurity and dual-use issues. Improving biorisk management will require resources. Collaborative ambition among stakeholders combined with improvements in awareness raising, education, training, professional development and cultural shifts will be critical to help with meeting the challenge. Biorisk management and mitigation activities should be reviewed regularly. Strategies may need to be adapted in light of new developments. Likewise, effectiveness of mitigation strategies should be assessed and processes for accountability ensured.

- ***Title:*** Compendium of WHO and other UN guidance on health and environment, 2022 update.
- ***Year:*** 2022
- ***Organisation:*** WHO
- ***Web Link:*** https://www.who.int/publications/i/item/WHO-HEP-ECH-EHD-22.01
- ***Knowledge gaps/future research:***

  NA
- ***Recommendations to decision-makers and proposed solutions:***

  This compendium provides an overview of guidance by environmental area, and points to more detailed WHO and other UN guidance for the next implementation steps. It serves to outline actions to create healthier environments and to guide and support the user in view of engaging in strategic discussions with other sectors and partners where necessary, to effect these changes. While the main part of each section covers guidance, each section also provides information on assessment of the current situation (local data, exposure modelling, databases) and pollution sources; targets to achieve (guideline values) and selected tools are also provided where relevant. Not all the guidance in this compendium will apply and work equally well in every context. Therefore the local circumstances and priorities should be considered before implementing any interventions, strategies or actions. Local circumstances may include: i) distribution of exposures to the risk factor; ii) effectiveness of source or exposure reduction by the strategy or solution; iii) health impact of the measure; and iv) cost– effectiveness of the measure. Guidance in this compendium can be searched by the following classifiers. • Sector principally involved in planning/implementation:2 health, environment, agriculture, transport, industry, food, water/sanitation, waste, energy, housing, construction, land use planning, education, labour, finance, social welfare and family, sports and leisure, civil defence or multiple sectors. • Level of implementation: national level, community, schools/child-care settings, health care, workplace. The additional classifier "universal health coverage" was attributed to guidance where the health sector directly contributes to achieving universal health coverage (often through prevention efforts by health workers in the community). • Instruments: governance; regulation; taxes and subsidies; infrastructure, technology and built environment; other management and control; assessment and surveillance; information, education and communication; or other action. Although not systematically mentioned throughout each section of this compendium, most areas will require adequate monitoring and evaluation, capacity building and resource mobilization, which will therefore not be repeated in every section. In addition, all policies and plans should consider gender and equity components when being established or implemented. Messages for promoting health in the general population have been developed based on the guidance contained in this compendium and can be used by the audience to more broadly promote health.

- ***Title:*** Nature, biodiversity and health: an overview of interconnections. Copenhagen: WHO Regional Office for Europe; 2021.
- ***Year:*** 2021
- ***Organisation:*** WHO ROE
- ***Web Link:*** https://www.who.int/europe/publications/i/item/9789289055581
- ***Knowledge gaps/future research:***

  Intense global efforts will be needed to prevent future pandemics and slow their spread.

- ***Recommendations to decision-makers and proposed solutions***

  The need to protect nature Nature is a vital support system for human health: it provides energy, food, water and air. Nature contributes to quality of life: it provides inspiration, places to exercise and socialize, and an antidote to the pressures of modern life. Nature protects: it provides dynamic systems that mitigate climate change and defend humans against extreme events. When humans fail to protect nature, however, and fail to recognize the damage already done and still being done to the environment, it also threatens health and well-being. Bold steps are needed to protect the natural environment and thereby to protect human health. Avoidable environmental damage and biodiversity loss threaten the health of people and societies – now and in the future, in the WHO European Region and beyond. Considering the more distant impacts in space and time on biodiversity and health from human actions is essential in terms of the Planetary Health or One Health approaches. One example for such a wider perspective could be the need to consider accountability and global responsibility in relation to current agricultural production standards and trade mechanisms, which may enable low prices through unsustainable production patterns (creating environmental damage as well as social, economic and health implications in the producing countries). The need for action National governments, local decision-makers, businesses and private citizens make choices every day. Most of these choices have direct or indirect impacts on how finite natural resources are used. This report brings together the current state of knowledge on the importance of nature for health, making it available to the many sectors that may benefit from this knowledge and can play an active role in protecting and promoting health while and by preserving nature. Considering dimensions of nature in decision-making in all sectors and at all levels is therefore paramount to protect natural environments as the foundations of human existence – a global challenge that requires multisectoral action and coordinated efforts across sectoral and disciplinary boundaries. Based on this report, the following points emerge as areas for which concerted action across government policies and at different levels of government would be particularly promising and beneficial to support environmentally responsible decision-making. Natural ecosystems and their biodiversity should be protected. Ensuring the functionality of natural ecosystems helps to stabilize and maximize the benefits of the services they provide to societies at the local and international scales. International commitments should be respected and implemented. The Sustainable Development Agenda and existing biodiversity-related multilateral environmental agreements need to be promoted and duly enforced, reflecting the commitments made by national governments. Nature-based approaches should be embedded in policy development. Health in All Policy and Environment in All Policy approaches should be adopted and integrated, and the environment and health incorporated across all departments, sectors and spheres of decision-making as standard. Consideration should be given to how shared outcomes and accountability can be used to ensure meaningful action. Nature-based approaches should be made the norm. Green infrastructure and sustainable agriculture, land use and production schemes with less impact on nature and ecosystems should be incorporated as standard. Horizon-scanning and preparation of long-term strategies (at a minimum 25–50 years) should be undertaken to assess how natural resources can be sustainably managed and preserved in the context of environmental and social change. Action across sectors should be incorporated into the mainstream: One Health, Planetary Health and similar transdisciplinary approaches that balance risks while promoting benefits for both human health and the natural environment should be adopted. Capacity should be built at all levels – international, national and local – to deliver integrated health and environment strategies that protect and preserve natural environments and biodiversity. Local and national action to improve and protect natural settings is required to meet global biodiversity goals, and should be complemented by support for and participation in coordinated global action to meet international biodiversity targets. No-regret solutions and co-benefits should be sought for societal and environmental challenges. These include nature-based solutions, such as protecting and sustainably managing natural ecosystems and restoring modified and transformed ecosystems, addressing societal challenges effectively and adaptively, and simultaneously providing human well-being and biodiversity benefits. Commitment should be made to sustainable financial interventions. Investment in and policy support for environmentally damaging industries, activities and processes should be avoided, and harmful subsidies removed. Instead, the focus should be on investment in sustainable production and consumption mechanisms that protect the environment, and public support should be provided for activities that have positive impacts on nature and health. The consequences of inaction should be acknowledged. The health impacts and opportunities lost from environmental damage and biodiversity loss associated with lack of action should be recognized and debated. Investment should be made in collation of adequate social, health and environmental data to monitor and inform longer-term strategies with sufficient detail to enable short-term, local action. Insights should be shared by evaluating, learning from and sharing good practice on how ecosystems can be sustainably managed and protected, enabling them to generate human health outcomes. Education of people of all ages on the links between nature and health should be supported, and sustainable behaviours that benefit nature and health promoted. Environmental and nutritional labelling should be strengthened to inform consumers about the environmental footprint of various goods and their impacts on biodiversity and health.

- ***Title:*** Biodiversity and the economic response to COVID-19: Ensuring a green and resilient recovery, Policy Brief.
- ***Year:*** 2020
- ***Organisation:*** OECD
- ***Web Link:*** https://www.oecd.org/coronavirus/policy-responses/biodiversity-and-the-economic-response-to-covid-19-ensuring-a-green-and-resilient-recovery-d98b5a09/
- ***Knowledge gaps/future research:***

  The economy and human well-being also depend on biodiversity for food, clean water, flood protection, erosion control, inspiration for innovation and much more. Over half the world's global domestic product is moderately or highly dependent on biodiversity. The ongoing decline of biodiversity therefore poses important risks to society. Investing in biodiversity as part of the COVID-19 policy response can help to minimise these risks, while providing immediate jobsand economic stimulus. While government and business leaders have acknowledged the importance of a "green recovery", the focus has been predominantly on climate change. Yet biodiversity loss and climate change are challenges of a similar magnitude and urgency, and are fundamentally interlinked. They must be addressed together as part of a broader green and inclusive recovery.

- ***Recommendations to decision-makers and proposed solutions:***

  A number of countries have integrated biodiversity measures in their COVID-19 policy response. Examples of biodiversity measures include changes to regulation on wildlife trade to protect human health, and job programmes focussed on ecosystem restoration, sustainable forest management and invasive species control. Despite some good practice examples, many countries have weakened environmental regulations or introduced stimulus measures that threaten to drive further biodiversity loss. Analyses suggest that the volume of potentially harmful spending committed as part of the economic recovery from the COVID-19 crisis outweighs the volume of spending beneficial to biodiversity. Governments can take the following steps to integrate biodiversity considerations into the COVID-19 recovery plans, and drive the transformative changes needed to halt and then reverse biodiversity loss: - Ensure that

COVID-19 economic recovery measures do not compromise biodiversity Maintain and strengthen regulations on land-use, wildlife trade and pollution Attach environmental conditionalityto bailouts to drive sustainability improvements Screen (ex ante) and monitor (ex post) stimulus measures for their biodiversity impactsoScale up investment in biodiversity conservation, sustainable use and restoration Set biodiversity spending targets for COVID-19 stimulus measures and recovery plans Promote jobs in biodiversity conservation, sustainable use and restoration Engage businesses and the finance sector for a biodiversity-positive recovery - Put a price on biodiversity loss Reform subsidies harmful to biodiversity Scale up economic incentives for biodiversity - Foster cross-sectoral and international collaboration Adopt and strengthen the One Health approach Support developing countries to safeguard their biodiversity Develop, adopt and implement an ambitious post-2020 global biodiversity framework.

- ***Title:*** COVID-19, a Warning: Addressing Environmental Threats and the Risk of Future Pandemics in Asia and the Pacific
- ***Year:*** 2022
- ***Organisation:*** UNEP ROAP
- ***Web Link:*** https://www.unep.org/resources/report/covid-19-warning-addressing-environmental-threats-and-risk-future-pandemics-asia
- ***Knowledge gaps/future research:***

The loss of human life and livelihood that has resulted from the ongoing COVID-19 pandemic, as well as the frequency of emerging zoonoses, make it essential to reflect on the factors that contribute to their emergence as well as on feasible mitigation measures. While pre-existing disease, such as Type II diabetes, is an important factor influencing vulnerabilityto andoutcomesofexposuretoCOVID-19(Thakur,RyanandGhebreyesus2021),limitedevidencedoesexistonthesignificance of gender-based anatomical and physiological differences. Results are mixed: higher mortality has been reported for men in Europe, with higher rates reported for women in some parts of the Asia Pacific, namely, India and Viet Nam (Dehingia and Raj 2021). Reflection on factors concerning disease emergence and mitigation measures is especially important in the context of the Asia and Pacific region, which has been identified as home to potential hotspots for emerging zoonotic disease risk, as shown in the heatmap

- ***Recommendations to decision-makers and proposed solutions:***

Defined as diseases transmitted from non-human animals to humans, "zoonoses" are an inadvertent consequence of the domestication, farming, hunting and fishing of animals. Animal and plant domestication enabled large human populations and ongoing close contact between different species of animals and between humans and animals, including peri-domestically. These animals are captured and bred not only for human food but also for the fur and pet trade and for products of claimed medicinal value. The farming of long-domesticated (e.g. cattle, pigs and chickens) and "wild" animals (e.g. palm civets, raccoon dogs, bamboo rats) — for whatever purpose — creates opportunities to bring together species (either in farms or markets). In turn, this creates the potential for viral mixing that could generate novel zoonoses, perhaps even with global pandemic potential. In Asia and the Pacific, demand for meat derived from farmed wildlife species (which possibly generates a higher risk of dangerous zoonoses than from wild-caught species) appears to be mainly driven by culturally shared perceptions of increased status and vitality gained from its consumption rather than by evidence of health benefits. However, in some settings, wild meat is cheaper, more available and more nutritious than farmed meat. Furthermore, for subsistence farmers and others who are very poor, the only possibility to ingest meat may be via animals that are hunted or trapped. Such meat is likely to be extremely valuable to them nutritionally. However, for some, all forms of meat consumption are ethically problematic. If the global consumption of meat (especially non-aquatic) can be substantially reduced but concurrently made more equitable, then substantial benefits will accrue to many humans as well as to the environment. This change in consumption patterns will require courage and leadership—a change likely to be challenged by those who profit from the current situation, including the global meat and livestock industry. Although the health benefits from eating meat and other animal products, such as eggs and dairy, are commonly attributed to increased protein intake, the absorption of micronutrients (especially zinc, iron and vitamin B12) from meat and other animal products may be a more important benefit reason than the ingestion of all essential amino acids. Furthermore, the absorption and tissue availability of iron will be enhanced for millions in the Asia Pacific by the improved treatment and prevention of intestinal parasites such as hookworm. These steps should reduce the need (and demand) for meat as may micronutrient food supplementation especially with zinc, iron and vitamin B12. However, it is likely that consumers who are willing to pay a premium to consume wild animal species have lower levels of parasitic diseases. Better treatment of parasites may reduce the demand for wild meat from populations who hunt such species for food. The farming of wild animal species generates income for farmers and for those involved in the legal and illegal wildlife trade. Alternative livelihoods need to be found for people whose incomes have been reduced by effective pandemic prevention measures. Finally, owing to gender-differentiated roles, women and men participate in different activities in wildlife trade, whether legal or illegal. Understanding these differences in terms of access to and control over resources ought to be considered for effective policy formulation. Finally, zoonoses can also enter human populations via laboratory accidents and errors. However, global warming, deforestation other forms of ecological alteration have also been implicated in the emergence of some zoonoses Irrespective of the true origin of the virus, COVID-19 can be interpreted as a profound warning to civilization—one that is intertwined with other interacting crises, including rising hunger and undernutrition, a record number of displaced persons, climate change, biodiversity loss and widespread pollution. But the crisis caused by the current pandemic could possibly lead to a fundamental awakening to the danger of humanity's recent trajectory, energizing reforms such as improved governance and cooperation, a new economic system, increased gender equality, reduced poverty, reduced corruption—and most important, greater respect for nature.

- ***Title:*** Preventing the Next Pandemic: Zoonotic diseases and how to break the chain of transmission. Nairobi, Kenya
- ***Year:*** 2022
- ***Organisation:*** UNEP, ILRI
- ***Web Link:*** https://www.unep.org/resources/report/preventing-future-zoonotic-disease-outbreaks-protecting-environment-animals-and
- ***Knowledge gaps/future research:*** —
- ***Recommendations to decision-makers and proposed solutions:***

Key messages This evidence-based scientific assessment has identified the following ten key messages for decision-makers: 1. DE-RISKING FOOD SYSTEMS: Many new science- based policy reports continue to focus on the global public health emergency caused by the COVID-19 pandemic, following the fast spread of the infectious SARS-CoV-2 virus of zoonotic origin. We need more evidence-based scientific assessments, such as this one, to examine the environmental and zoonotic context of the current pandemic, as well as the risk of future zoonotic disease outbreaks. 2. URGENCY: Diseases are emerging more frequently from animals. Rapid action is necessary to fill the science gap and fast-track the development of knowledge and tools to help national governments, businesses, the health sector, local communities and other stakeholders—especially those with limited resources—to reduce the risk of future pandemics. 3. REPORT AUDIENCE: To help fill this gap, a scientific assessment was conducted to explore the role of wild and domesticated animals in emerging zoonotic infectious diseases. This rapid assessment is designed for decision-makers in government, business and civil society at all levels and in all regions. 4. SCOPE OF THE PROBLEM: About 60 per cent of human infections are estimated to have an animal origin. Of all new and emerging human infectious diseases, some 75 per cent "jump species" from other animals to people. Most described zoonoses happen indirectly, e.g. via the food system. 5. OUTBREAK FREQUENCY AND PREDICTABILITY: The frequency of pathogenic microorganisms jumping from other animals to people is increasing due to unsustainable

human activities. Pandemics such as the COVID-19 outbreak are a predictable and predicted outcome of how people source and grow food, trade and consume animals, and alter environments. 6. CONNECTIVITY AND COMPLEXITY: The links among the wider environment, biodiversity and emerging infectious diseases are complex. While wildlife is the most common source of emerging human disease, domesticated animals may be original sources, transmission pathways, or amplifiers of zoonotic disease. Such linkages—as well as the interconnectedness with issues such as air and water quality, food security and nutrition, and mental and physical health—should inform policies that address the challenges posed by current and future emerging infectious diseases, including zoonoses. 7. DISEASE DRIVERS: Seven human-mediated factors are most likely driving the emergence of zoonotic diseases: 1) increasing human demand for animal protein; 2) unsustainable agricultural intensification; 3) increased use and exploitation of wildlife; 4) unsustainable utilization of natural resources accelerated by urbanization, land use change and extractive industries; 5) increased travel and transportation; 6) changes in food supply; and 7) climate change. 8. IMPACT AND COST: Emerging zoonotic diseases threaten human and animal health, economic development and the environment. The greatest burden of zoonotic disease is borne by poor people, but emerging infectious diseases impact everyone, with monetary losses of emerging infectious disease much greater in high-income countries. Given that a single zoonotic outbreak can incur trillions of US dollars in costs across the globe, prevention is significantly more cost-effective than response. 9. POLICY OPTIONS: This assessment recommends ten policy response options to reduce the risk of future zoonotic pandemics and to 'build back better': (i) raise awareness of health and environment risks and prevention; (ii) improve health governance, including by engaging environmental stakeholders; (iii) expand scientific inquiry into the environmental dimensions of zoonotic diseases; (iv) ensure full- cost financial accounting of the societal impacts of disease; (v) enhance monitoring and regulation of food systems using risk-based approaches; (vi) phase out unsustainable agricultural practices; (vii) develop and implement stronger biosecurity measures; (viii) strengthen animal health (including wildlife health services); (ix) build capacity among health stakeholders to incorporate environmental dimensions of health; and (x) mainstream and implement One Health approaches. These policy options are discussed in detail in Section Five of this report. 10. ONE HEALTH: This report confirms and builds on the conclusions of the FAO-OIE-WHO Tripartite Alliance and many other expert groups that a One Health approach is the optimal method for preventing as well as responding to zoonotic disease outbreaks and pandemics. Adopting a One Health approach, which unites medical, veterinary and environmental expertise, will help governments, businesses and civil society achieve enduring health for people, animals and environments alike.

- ***Title:*** Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, chapter 07, Health, Wellbeing and the Changing Structure of Communities (AR6WGII)
- ***Year:*** 2022
- ***Organisation:*** IPCC
- ***Web Link:*** https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_Chapter07.pdf
- ***Knowledge gaps/future research:***

The experience of COVID-19 demonstrates that many warnings about the risks of the emergence of zoonotic transmission ('delay is costly', 'adapt early' and 'prevention pays') did not result in sufficient political attention, funding and pandemic prevention. In some countries, there has been an increased awareness of the risks and the real or perceived trade-offs associated with risk management (e.g., economy compared with health and impacts compared with adaptation). Building trust and participatory processes and establishing stronger relationships with communities and other civic institutions may enable a recalibration of how the government responds to crises and society–government relationships more generally (Amat et al., 2020; Deslatte, 2020). The management of the COVID-19 pandemic has highlighted the value of scientific (including medical and epidemiological) expertise and the importance of fast, accurate and comprehensive data to inform policy decisions and to anticipate and manage risk (high confidence). It emphasises the importance of effective communication of scientific knowledge (Semenza et al., 2021), decision-making under uncertainty and decision frameworks that navigate different values and priorities. Successful policy responses were based on the emerging data, medical advice and collaboration with a wider set of societal stakeholders beyond public health experts. For instance, experience in Aotearoa, New Zealand, highlights the importance of pandemic responses attuned to the needs of different sociocultural groups and Indigenous Peoples in particular. Their strengths-based COVID-19 response goes beyond identifying vulnerabilities to unlocking the resources, capabilities and potential that might otherwise be latent in communities (McMeeking and Savage, 2020). As far as the value of information for risk management is concerned, compared to the initial uncertainties regarding COVID-19, data about near- and longer-term climate-related hazards is generally very good; however, high-quality and dense meteorological data are often still lacking in lower income countries (Otto et al., 2020). Health data are particularly difficult to obtain in real time, as is the case for biodiversity data, which has a time lag of years before being made available and for which there is no coordinated monitoring, hampering effective risk management (Navarro et al., 2017). Therefore, both epidemiological and meteorological forecasts would benefit from more focus on (a) decision support, (b) conveying uncertainty and (c) capturing vulnerability (Coughlan de Perez et al., 2021). There is a considerable evidence base of specific actions that have co-benefits for reducing pandemic and climate change risks while enhancing social justice and biodiversity conservation (high confidence). The pandemic highlighted aspects of risk management that have long been recognised but are often not reflected in national and international climate policy: the value of addressing structural vulnerability rather than taking specific measures to control single hazards and drivers of risk and the importance of decision-making capacities and transparency, the rule of law, accountability and addressing inequities (or social exclusion) (reviewed by Pelling et al. (2021); see also Figure COVID.1). Comprehensive and integrated risk management strategies can enable countries to address both the current pandemic and increase resilience against climate change and other risks (Reckien, 2021; Semenza et al., 2021; Ebi et al., 2021b). In particular, given their immense scale, COVID-19 recovery investments may offer an opportunity to contribute to climate resilient development pathways (CRDPs) through a green, resilient, healthy and inclusive recovery (high confidence) (Sovacool et al., 2020; Rosenbloom and Markard, 2020; Lambert et al., 2020; Boyle et al., 2020; Bouman et al., 2020; UN DRR Asia-Pacific, 2020; Brosemer et al., 2020; Dodds et al., 2020; Hynes et al., 2020; Markard and Rosenbloom, 2020; Phillips et al., 2020; Schipper, 2020; Willi et al., 2020; Semenza et al., 2021; Pasini and Mazzocchi, 2020; Meige et al., 2020; Pelling et al., 2021). However, windows of opportunity to enable such transitions are only open for a limited period and need to be swiftly acted upon to effect change (high confidence) (Chapter 18; Weible et al., 2020; Reckien, 2021). Initial indications suggest that only USD 1.8 trillion of the greater than USD 17 trillion COVID-19-related stimulus financing by G20 countries and other major economies that was committed up until mid-2021 contributed to climate action and biodiversity objectives, with significant differences between countries and sectors (Vivideconomics, 2021). Moreover, responses to previous crises (e.g., the 2008–2011 global financial crisis) demonstrate that despite high ambitions during the response phase, opportunities for reform do not necessarily materialise (Bol et al., 2020; Boin et al., 2005). In addition, heightened societal and political attention to one crisis often comes at the cost of other policy priorities (high confidence) (Maor, 2018; Tosun et al., 2017), which could affect investments for climate resilient development (Hepburn et al., 2020; WHO, 2020a; Bateman et al., 2020; Meige et al., 2020; Semenza et al., 2021). In summary, the emerging literature suggests that the COVID-19 pandemic has aggravated climate-related health risks, demonstrated the global and local vulnerability to cascading shocks and illustrated the importance of integrated solutions that tackle ecosystem degradation and structural vulnerabilities in human societies. This highlights the potential and urgency of interventions that reduce pandemic and climate change risks while enhancing compound resilience, social justice and biodiversity conservation (see Figure COVID.1).

- ***Recommendations to decision-makers and proposed solutions:***

Solutions: Since AR5, the value of cross-sectoral collaboration to advance sustainable development has been more widely recognised, but despite acknowledgement of the importance of health adaptation as a key component, action has been slow (high confidence). Building climate-resilient health systems will require multi-sectoral, multi-system and collaborative efforts at all governance scales (very high confidence) (Sections 7.4.1, 7.4.2). Globally, health systems are poorly resourced in general, and their capacity to respond to climate change is weak, with mental health support being particularly inadequate (very high confidence). The health sectors of some countries have focused on implementing incremental changes to policies and measures to fill the adaptation gap (very high confidence). As the likelihood of dangerous risks to human health continue to increase, there is greater need for transformational changes

to health and other systems (very high confidence). This highlights an urgent and immediate need to address the wider interactions between environmental change, socioeconomic development and human health and well-being (high confidence). Targeted investments in health and other systems, including multi-sectoral, integrated approaches to protect against key health risks can effectively increase resilience (high confidence). Increased investment in strengthening general health systems, along with targeted investments to enhance protection against specific climate-sensitive exposures (e.g., hazard early warning and response systems, and integrated vector control programmes for VBDs) will increase resilience if implemented to at least keep pace with climate change (high confidence). • The future effects of climate change on VBDs can be significantly offset through enhanced commitment to and implementation of integrated vector control management approaches, disease surveillance, early warning systems and vaccine development (very high confidence) • Adaptation options for future climate risks associated with waterborne and food-borne diseasess include improving access to potable water, reducing exposure of water and sanitation systems to flooding and extreme weather events, and improved (including expanded) early warning systems (very high confidence) • Adaptation options for future extreme heat risks include heat action plans (HAPs) that incorporate early warning and response systems for urban and non-urban settings; tried, tested and iteratively updated response strategies targeting both the general population and vulnerable groups such as older adults or outside workers; and effective stakeholder communication plans (high confidence). These short-term responses can be complemented by longer-term urban planning and design, including nature-based solutions (NbS) that mitigate urban heat island (UHI) effects (high confidence) • Adaptation options to reduce the future risks of malnutrition include access to healthy, affordable, diverse diets from sustainable food systems (high confidence); health services including maternal, child and reproductive health (high confidence); nutrition services, nutrition and shock sensitive social protection (high confidence); water, sanitation and early warning systems (high confidence); and risk reduction schemes such as insurance (medium confidence) The COVID-19 pandemic has demonstrated the value of coordinated and multi-sectoral planning, social protection systems, safety nets and other capacities in societies to cope with a range of shocks and stresses (high confidence). The pandemic has posed a severe shock to many socioeconomic systems, resulting in substantial changes in vulnerability and exposure of people to climate risks (high confidence). The pandemic emphasises the inter-connected and compound nature of risks, vulnerabilities, and responses to emergencies that are simultaneously local and global (high confidence). Pathways to climate resilient development can be pursued simultaneously with recovering from the COVID-19 pandemic (high confidence). The COVID-19 pandemic has aggravated climate risks, demonstrated the global and local vulnerability to cascading shocks and illustrated the importance of integrated solutions that tackle ecosystem degradation and structural vulnerabilities in human societies (high confidence) Transitioning towards equitable, low-carbon societies has multiple benefits for health and well-being (very high confidence). Benefits for health and well-being can be gained from wide-spread, equitable access to affordable renewable energy (high confidence); active transport (e.g., walking and cycling) (high confidence); green buildings and nature-based solutions, such as green and blue urban infrastructure (high confidence); and by transitioning to a low-carbon, well-being-oriented and equity-oriented economy consistent with the aims of the SDGs (high confidence). Plant-rich diets consistent with international recommendations for healthy diets could contribute to lower GHG emissions while also generating health co-benefits, such as reducing ill health related to over-consumption of animal-based products (high confidence) Reducing future risks of involuntary migration and displacement due to climate change is possible through cooperative international efforts to enhance institutional adaptive capacity and sustainable development (high confidence). Institutional and cross-sectoral efforts to build adaptive capacity, coupled with policies aimed at ensuring safe and orderly movements of people within and between states, can form part of the CRDPs that reduce future risks of climate-related involuntary migration, displacement and immobility (medium confidence). In locations where permanent, governmentassisted relocation becomes unavoidable, active involvement of local populations in planning and decision-making increases the likelihood of successful outcomes (medium confidence). People who live on small island states do not view relocation as an appropriate or desirable means of adapting to the impacts of climate change (high confidence) Adaptation and sustainable development build peace in conflictprone regions by addressing the drivers of grievances that lead to conflict and vulnerability to climate change (high confidence). Environmental peacebuilding (EP) through natural resource sharing, conflict-sensitive adaptation and climate-resilient peacebuilding offer promising avenues for addressing conflict risk, but their efficacy is still to be demonstrated through effective monitoring and evaluation (high confidence). Formal institutional arrangements for natural resource management contribute to wider cooperation and peacebuilding (high confidence) and gender-based approaches provide under-utilised pathways to achieving sustainable peace (medium confidence). Inclusion, cross-issue and cross-sectoral integration in policy and programming, and approaches that incorporate different geographical scales and work across national boundaries can support climateresilient peace (high confidence)

- ***Title:*** EU Research Agenda for the Environment, Climate & Health 2021-2030
- ***Year:*** 2022
- ***Organisation:*** HERA
- ***Web Link:*** https://static1.squarespace.com/static/5d6d2b4f677cfc00014c7b53/t/620e8b6cee1c3961aea97483/1645120405039/HERA+Full+agenda+31.1.2022.pdf
- ***Knowledge gaps/future research:***

  A better understanding of the determinants of health is critical to select and implement rational and efficient policies, and above all, to improve health and wellbeing of citizens Research is needed to address global threats, such as climate change and biodiversity loss and their health consequences, but also to promote healthy and sustainable living in cities and rural communities. There are also fundamental knowledge gaps on the impact of different stressors on health and wellbeing. For example, only a fraction of commercially available chemicals has been sufficiently characterized with regard to their health hazards (Figure 3)18. There is a lack of information on both understanding current impacts and projected risks of recent and projected changes in the earth system, and on evidence-based solutions and policy measures and programs needed to prepare for and manage changing burdens of diseases (Ebi et al, 2021).

- ***Recommendations to decision-makers and proposed solutions:***

  Research goal 1 "Climate change and biodiversity loss – reduce effects on health and the environment" focuses on global interconnected issues. The consequences of climate change, biodiversity loss, disruption of food chains, emerging infectious diseases and decreased ecosystem services on health are not well understood despite evidence that they have major and persistent effects on life and the environment globally. The need to promote research for effective policies on mitigation and adaptation is identified as of paramount importance, as is the need to apply holistic approaches such as One-Health and Planetary health. Research goal 2 "Cities and communities – promote healthy lives in sustainable and inclusive societies" focuses on problem-based research. Living conditions in urban environments are of key concern as they impact the health and wellbeing of the majority of European citizens. The impacts of environmental factors may vary in different contexts, e.g. urban environment, workplace or polluted sites. Research should examine the complex relationships in these environments, and evaluate and promote positive interventions. Research goal 3 "Chemicals and physical stressors – prevent and eliminate harmful chemical exposures to health" focuses on chemicals, other stressors and environmental media. There are still many unknowns on the hazards and risks related to stressor families including chemicals and mixtures, physical stressors such as radiation, and the role played by the various environmental media carrying these stressors. Research should effectively address the challenges of a zero pollution paradigm and a sustainable future of mankind and our environment. Research goal 4 "Improve health impact assessment of environmental factors and promote implementation research" focuses on the need to develop new harmonized methodologies to evaluate the burden of environmental and climate change on health and to identify and assess the health benefits of human environmental interaction. Moreover, research should promote optimal ways to implement science-based decisions and policies as this is a limiting factor in many fields. Research goal 5 "Develop infrastructures, technologies and human resources for sustainable research on environment, climate change and health" focuses on the need of European research infrastructures to be strengthened and further developed in the environmental health field as they provide a basis for excellent research. The proposals include large cohort coordination, exposome characterization, data analysis and planetary monitoring tools. Research goal 6 "Promote research on transformational change in environment, climate change and health" focuses on the need of transformational change to address the intertwined environmental, social and health issues and reach critical global goals towards sustainability and equity. Societies will need to adapt to the challenges elicited by environmental stressors and climate change and this will require significant transformation of individual and collective behaviour and of policy making across the sectors and silos. Development of research approaches directed to finding and promoting workable solutions is necessary for achieving such transformations.

- ***Title:*** EU Biodiversity Strategy for 2030 Bringing nature back into our lives,
- ***Year:*** 2021
- ***Organisation:*** European Commission
- ***Web Link:*** https://op.europa.eu/en/publication-detail/-/publication/31e4609f-b91e-11eb-8aca-01aa75ed71a1
- ***Knowledge gaps/future research:***

  The fight against biodiversity loss must be underpinned by sound science. Research and innovation can develop and test 'green' solutions so that they can be prioritised over 'grey' infrastructure. It can also help authorities to support investments in nature-based solutions and green infrastructure, such as in old-industrialised, low-income or disaster-hit areas. The Horizon Europe programme includes a long-term strategic research agenda for biodiversity, including a science-policy mechanism for research-based options for ratcheting up the implementation of biodiversity commitments, with increased funding. Horizon Europe's Missions will significantly contribute to filling knowledge gaps and finding solutions to improve the health of ecosystems and their contribution to human health. In parallel, the Commission will promote and facilitate partnerships, including a dedicated Biodiversity Partnership, to make the bridge between science, policy and practice and to make nature-based solutions a reality on the ground. The Commission will also establish a new Knowledge Centre for Biodiversity in close cooperation with the European Environment Agency to underpin policy development and track progress on the implementation of biodiversity-related international instruments.
- ***Recommendations to decision-makers and proposed solutions:***

  The biodiversity crisis and the climate crisis are intrinsically linked. Climate change accelerates the destruction of the natural world through droughts, flooding and wildfires, while the loss and unsustainable use of nature are in turn key drivers of climate change. But, just as the crises are linked, so are the solutions. Nature regulates the climate, and nature-based solutions, such as protecting and restoring wetlands, peatlands and coastal ecosystems, or sustainably managing marine areas, forests, grasslands and soils, will be essential for emission reduction and climate adaptation. Because the biodiversity, climate and current economic crises are all interconnected, the actions undertaken to address each of these will need to be coherent and mutually supportive. Experience has shown that what is good for nature is also good for the economy. It is no longer a choice between nature on the one hand and the economy on the other, but an imperative of making the two work in partnership for the benefit of society as a whole.

- ***Title:*** Technical Information on Biodiversity and Pandemics, Note by the Executive Secretary
- ***Year:*** 2020
- ***Organisation:*** Convention on Biodiversity SBSTTA
- ***Web Link:*** https://www.cbd.int/doc/c/2abd/08b3/123a81e9d2b3b9d6eb0dd9b8/sbstta-sbi-ss-02-inf-01-en.pdf
- ***Knowledge gaps/future research:***

  Although research is still scarce, climate change is projected to cause shifts in host and vector ranges, alterations to life cycles of vectors and hosts under altered climatic conditions and migration of people and domestic animals. Climate change has already driven latitudinal and elevational shifts of biomes in boreal, temperate and tropical regions which has likely driven spread of certain diseases, or the expansion of some species (e.g. ticks and tick-borne disease). Temperature changes also allow occasional immigration of vectors to lead to persistence of disease. Land-use change, compounded with climate change will likely create novel wildlife communities, new relationships among wildlife, human and livestock populations and increased potential for cross-species transmission Given that less than 1 per cent of known species have been utilized by people, discovery of further compounds that help develop therapeutics and diagnostic agents is highly likely.60 Genomic advances are now bringing insights into how other species, such as bats, may resist or tolerate infections, potentially leading to mechanisms of infection control.61,62,63 Biodiversity is therefore a fundamental resource for health.
- ***Recommendations to decision-makers and proposed solutions:***

  Building 'green' and resilient economic systems in which the value of nature is included, will be a vital element for human health and well-being as well as environmental health. To achieve this, several international organizations and the Global Assessment Report on Biodiversity and Ecosystem Services issued by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services recognized the role of nature-based solutions for contributing to biodiversity conservation and overall climate change adaptation and mitigation effort in addition to providing other substantial benefits to people and nature. Policies that make the human-environment connection to zoonotic transmission and pandemics clear can increase support for biodiversity conservation, especially for emotive subjects like the commercial trade in wildlife and deforestation. Furthermore, reducing pandemic risks substantially through better management of environmental resources would cost 1-2 orders of magnitude less than estimates of the economic damages caused by global pandemics. Collaboration among conservation biologists and epidemiologists should be strongly encouraged to provide scientific guidance for measures to reduce risk in these cases, such as culling of non-native species that host zoonoses, or launching disease surveillance programmes. In addition, biotechnology, including synthetic biology could provide options to tackle challenges in many fields such as agriculture, health and environment. Considering the cross-cutting and integrated approach proposed through One Health, the Convention on Biological Diversity and its Cartagena Protocol have a key role to play on the safety assessment of potential solutions and technological developments that could be useful in tackling health and environmental issues. There is significant worldwide experience in conducting risk assessment for multiple purposes, including that of conducting risk assessment for the use of living modified organisms (LMOs) from many Parties to the Convention and to the Cartagena Protocol. This experience may be extremely useful in future evaluations or assessments of new developments targeting health and environmental challenges.

- ***Title:*** Policy Brief, Mending the Broken Relationship with Nature: Tackling the Biodiversity, Ecosystems, Health and Climate Change Nexus Post-COVID-19
- ***Year:*** 2021
- ***Organisation:*** UN ESCAP
- ***Web Link:*** https://www.unescap.org/kp/2021/mending-broken-relationship-nature-tackling-biodiversity-ecosystems-health-and-climate
- ***Knowledge gaps/future research:***
  What are the environmental issues that pose threats to human health and how are environmental and human health related? What are the approaches that can be used to understand these interactions? What are the concrete policy actions that can be implemented to mend the broken relationship between human societies and the environment and address, at the same time, the global biodiversity, climate and health crises? It is critical to generate knowledge to bring about change that emphasizes a shift away from current development trajectories characterized by biodiversity loss and ecosystem degradation, unsustainable production and consumption patterns, pollution, and climate change. A framework to address the nexus between the health of the natural world and human health within the limits of what nature can provide, in alignment with the 2030 Agenda for Sustainable Development, is imperative.
- ***Recommendations to decision-makers and proposed solutions:***

  With a framework addressing these linkages, specific institutional, structural economic, and behavioural change solutions are offered to ensure that environmental health and human health are protected, and offers perspectives on how to simultaneously address the causative factors of zoonoses in an integrated manner, focusing on the nexus between biodiversity, ecosystems, human health and climate change. Key institutional solutions include the adoption of a regional agenda that would bring in all relevant actors, strengthen environmental laws, regulations and their enforcement, and enhance monitoring capacity, with a focus on addressing the biodiversity and climate crises. Structural economic solutions look at how to render land management and urbanisation more sustainable, at reducing and managing pollution appropriately and at how putting nature at the economic paradigm can improve both human and environmental health. Finally, behavioural change solutions focus on better managing wildlife and wildlife trade, at promoting sustainable agri-food systems as well as overall sustainable consumption and production.

- ***Title:*** Biodiversity and international trade policy primer: How does nature fit in the sustainable trade agenda? UK Research and Innovation Global Challenges Research Fund (UKRI GCRF) Trade, Development and the Environment Hub
- ***Year:*** 2021
- ***Organisation:*** UNEP
- ***Web Link:*** https://tradehub.earth/wp-content/uploads/2021/11/Biodiversity-and-International-Trade-Policy-Primer-Document_05.pdf
- ***Knowledge gaps/future research:***
  Solutions to biodiversity loss will rely on closer attention to issues of fair trade, equity, and justice, and to the perspectives and solutions advanced by rural communities and indigenous peoples, who rely on nature for their livelihoods and are most directly impacted by land degradation. Solutions will furthermore require attention to critical political issues at the local level, ranging from land tenure to worker's rights.
- ***Recommendations to decision-makers and proposed solutions:***

  At the multilateral level, a new opportunity to advance policy dialogue, information-sharing and building knowledge on biodiversity and trade has emerged through the launch of Structured Discussions on Trade and Environmental Sustainability (TESSD) at the WTO. The statement launching the discussions explicitly mentions the CBD and the UN SDGs, and there is strong potential for a group of like-minded WTO members to ensure that biodiversity is one of the key work streams of attention. In TESSD discussions to date, for instance, biodiversity and ecosystem considerations have arisen in the context of discussions of sustainable agriculture, deforestation-free supply chains, plastic pollution, and the circular economy. There are also opportunities to advance dialogue and action on the intersection of trade and biodiversity issues in the context of ongoing work related to the Global Biodiversity Framework, the UN Food Systems Summit and the G7 and G20 Summits. Notably, across these forums, the potential framings and entry points most likely to achieve traction vary, and there are significant differences in their appeal to the diversity of governments and stakeholders. At the research level, there is considerable ongoing work on building knowledge on the impacts of trade on biodiversity and propose impactful policy interventions. To conclude this paper, following is a set of questions clustered under five themes that were identified through expert consultations and dialogue over the past year as especially worthy of further focused policy research, dialogue and action: biodiversity and trade policy, supply chain sustainability, standards and labels, trade in biodiversity, trade-related capacity building and investment, monitoring trade flows.

- ***Title:*** Covid-19, the Environment, and Food Systems: Contain, Cope, and Rebuild Better
- ***Year:*** 2020
- ***Organisation:*** UNEP
- ***Web Link:*** https://www.unep.org/resources/report/covid19-environment-and-food-systems-contain-cope-and-rebuild-better
- ***Knowledge gaps/future research:***
  "Rebuilding better" requires targeted investment in sustainable development. The UN framework for the immediate socio-economic response to COVID-19 places environmental sustainability and gender equality at the centre of the United Nations' response to COVID-19. The global response must build on the observed positive changes in people's behaviour and mindset during the crises, including how we travel, how we produce and consume food, and how we use environmental resources. It will require concerted action by governments, the private sector and everyone involved. The complex and globally interconnected nature of this transformation requires multilateral cooperation, monitoring the effects of the investments and sharing positive results. The crisis has created a new situation and requires new thinking and action. "Rebuilding better" must also be based on a global – not national – paradigm of aid and development assistance. The pandemic has shown that national borders are irrelevant to global issues like health, food security and sustainability. Landscapes, ecological zones and the nexus between health, environment and economic activities are key features that must be addressed working together.
- ***Recommendations to decision-makers and proposed solutions:***

  At the multilateral level, a new opportunity to advance policy dialogue, information-sharing and building knowledge on biodiversity and trade has emerged through the launch of Structured Discussions on Trade and Environmental Sustainability (TESSD) at the WTO. The statement launching the discussions explicitly mentions the CBD and the UN SDGs, and there is strong potential for a group of like-minded WTO members to ensure that biodiversity is one of the key work streams of attention. In TESSD discussions to date, for instance, biodiversity and ecosystem considerations have arisen in the context of discussions of sustainable agriculture, deforestation-free supply chains, plastic pollution, and the circular economy. There are also opportunities to advance dialogue and action on

the intersection of trade and biodiversity issues in the context of ongoing work related to the Global Biodiversity Framework, the UN Food Systems Summit and the G7 and G20 Summits. Notably, across these forums, the potential framings and entry points most likely to achieve traction vary, and there are significant differences in their appeal to the diversity of governments and stakeholders. At the research level, there is considerable ongoing work on building knowledge on the impacts of trade on biodiversity and propose impactful policy interventions. To conclude this paper, following is a set of questions clustered under five themes that were identified through expert consultations and dialogue over the past year as especially worthy of further focused policy research, dialogue and action: biodiversity and trade policy, supply chain sustainability, standards and labels, trade in biodiversity, trade-related capacity building and investment, monitoring trade flows.

- ***Title:*** Situation analysis on the roles and risks of wildlife in the emergence of human infectious diseases
- ***Year:*** 2022
- ***Organisation:*** IUCN
- ***Web Link:*** https://portals.iucn.org/library/sites/library/files/documents/2022-004-En.pdf
- ***Knowledge gaps/future research:***

Knowledge of the incidence of zoonosis from any source, in particular from wildlife or wildlife trade, is often weak on specifics and is highly data deficient globally, with a few important exceptions. The global burden of (human) disease database does not account separately for zoonosis, for example tuberculosis is recorded as a single disease, whether human or animal origin, whilst estimates of zoonotic tuberculosis are around 1% of global cases. Without human case data and confirmatory diagnostics on zoonotic and emerging infectious disease pathogens transmitted or derived from wildlife species, it is not possible to determine with certainty the importance or risk of these hosts, reservoirs, or genetic origins. Furthermore, there is no consistent surveillance of the disease and public health aspects of the wildlife trade, internationally or in many cases at national level. further confusion is in the use of the term "wildlife" in situations that cover diverse animal populations and animal use systems, some of which are not part of natural ecosystems, such as wildlife farming. This lack of specificity can lead to inappropriate focus on natural populations which, based on available evidence, we understand to have a negligible role in the general context of human disease, and which can result in inappropriate policies and interventions with potential negative effects to millions of people. Coronavirus disease 2019 (COVID-19) is a novel human disease caused by a new betacoronavirus strain named Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2), a human adapted coronavirus with as yet no evidence of zoonosis or animal reservoir. Although an animal reservoir or the immediate ancestor has not been found yet, there is an increasing body of evidence that report findings of related alpha- and betacoronavirus in Rhinolophus bats, demonstrating natural circulation of related betacoronavirus in Southeast Asia, highlighting the importance of cross-border surveillance. The human transmission may have been a single or repeated spillover events from wild, farmed, or domesticated animal(s) that could be both impossible to detect or to confirm at this stage, whilst also a laboratory origin of the virus cannot as yet be discounted.

- ***Recommendations to decision-makers and proposed solutions:***

Knowledge, quantity and quality of information 1. Seek cross-sectoral and interdisciplinary consensus on definitions related to zoonotic diseases and achieve common understanding. 2. Confirm and record zoonoses (in each case due to direct infection from an animal) in an open global human disease database to enable impact and risk factor analysis to prioritise research and mitigation measures. 3. Differentiate untested hypotheses from evidence-based conclusions in reporting and recommend evidence-based policy interventions for zoonosis and emerging pathogens. 4. Analyse diseases, disease processes, and risk contextually and specifically. Emergence of human pathogens and their risk 1. There is no evidence-based justification for interventions such as culling free ranging wildlife to prevent wildlife zoonoses or reduce the potential for emerging infectious diseases. An unintended consequence of culling "host populations" in a cordon sanitaire can be, perversely, more rapid spread through the perturbation caused and rapid reintroduction of cleared zones. However, culling of, for instance infected mink in farms or synanthropic wildlife such as rodents around human habitation might be an appropriate measure, where risk of a zoonosis is high, and control of vectors is commonly practised. 2. Biodiversity has a central role in disease regulation and must be conserved. Increased biodiversity can reduce the prevalence of infectious diseases (dilution effect) or increase it (amplification effect), depending on landscape features, community characteristics, and type of pathogen transmission. 3. Prevention and control of zoonoses and emerging infectious diseases are best achieved through infrastructural and health systems pathways. Rethinking the current production systems, exploitation practices of natural resources and animals (domestic, farmed, and wild), and systemic inequities in the access to healthcare will be fundamental to decrease the risk of future pandemics. New spillover events and outbreaks are inevitable but preventing increasing rates of these events and the rapid global spread are feasible goals, especially if they address primordial prevention issues (drivers) rather than just preparedness and rapid response. Wildlife trade 1. Preventive measures must be directed at specific practices and contexts. As with livestock (and other human-animal interactions like keeping companion animals), there is an intrinsic risk associated with wildlife trade whether legal or illegal (illegal trade likely has a higher risk than legal regulated trade). In the case of livestock trade, indiscriminate bans are not imposed unless there is a tangible health risk beyond pathogen detection. Rather institutions, such as European Food Safety Authority or the US Food and Drug Administration set up to regulate and control disease risk and exposure, and formulate appropriate regulations . Current best-practice guidelines for global livestock trade provide a framework to apply to wildlife trade. 2. Lack of data warrants improved surveillance of zoonosis cases attributed to wildlife and the wildlife trade, both legal and illegal, to at least the same standards applied to the domesticated animal trade. 3. Wildlife use and trade is often linked to the livelihoods of indigenous peoples and local communities, as well as local (and national) economies in developed and developing countries; the provision of alternative livelihood activities to replace wildlife trade needs to be carefully considered and evaluated to avoid perverse negative impacts on wildlife, natural resources, and local values. 4. Top-down regulations should account for multiple jurisdictions under unified policy instruments and in consultation with a broader range of regulatory instruments and local stakeholders. Participatory approaches and behavioural science could incentivise compliance with new measures by including relevant stakeholders along supply chains, generate understanding of what drives the use and consumption of wildlife, and develop inclusive measures, thereby increasing the likelihood of the long-term survival of wildlife populations, associated ecosystem services, and reducing risks to human health. 1. Human transformation of natural habitats facilitates pathogen transmission between domesticated animals, wildlife, and humans. Deforestation and landscape/land use change 1. Human transformation of natural habitats facilitates pathogen transmission between domesticated animals, wildlife, and humans. 2. Deforestation is one of the main drivers of biodiversity loss and it can negatively affect human health. Deforestation has been linked to an increase in zoonotic disease outbreaks and vector-borne disease affecting humans, but evidence to support a universal effect of deforestation is still missing. 3. Conservation and restoration of biodiversity is central to recovery of the planet and for a sustainable human future. This will reduce existential risk from diseases and other health threats such as climate change, pollution, and collapse of biological and environmental resources vital for life, such as soil organisms, water, and oxygen. 4. Further research and clearer understanding of the mechanisms for disease emergence driven by landscape change may allow for some mitigation and identify where trade-offs are possible in the short term. Intensified animal-based agriculture 1. A certain way to reduce risk of zoonosis and emerging infectious diseases globally, without affecting human nutrition, health, and well-being, is to reduce dependence on intensive animal-based food production systems. Human omnivory is well suited to a mostly plant-based diet and this would have added benefits of the potential release of land currently used for livestock food crops for reforestation, biodiversity, and ecosystems recovery. 2. Research on zoonotic disease risk especially from large-scale intensive wildlife and domesticated animal farming is urgently needed. Transport networks 1. Nations should implement health certifications, quarantine, and where feasible a reduction in human and animal movements as a component of disease regulation. 2. Societies and relevant authorities must improve current monitoring schemes of diseases along the animal trade supply chain, enhancing current human and animal health organisations' (World Health Organisation [WHO] and World Organisation for Animal Health [OIE]) practices for disease control in general. Translocation of animals for conservation and non-trade purposes 1. Wildlife disease risk analysis needs to be widely applied especially in rehabilitation and seizures. Actions should be regulated by the World Organisation for Animal Health (OIE) to reduce risk of zoonosis and zoonotically acquired emerging infectious diseases and this may require expansion of their mandate and capacities to address this. Climate change 1. Mitigation of climate change effects might be possible in some disease scenarios and these diseases should be identified and targeted. 2. It is unlikely mitigation will be possible in most vector-borne diseases as climate effects will disrupt the Earth's normal

ecological cycles. 3. Climate change will create novel human-animal interfaces, modify current ecological communities, and landscapes. Nations must take a proactive stance and focus on preventive measures to reduce future emergence and re-emergence of diseases. 4. Governments need to proactively prepare for epidemics, reflect on current surveillance and rapid response practices, and adapt to new endemic infection. 5. Ignoring the climate crisis will negatively impact the health of people, animals, and the environment. Tackling climate change ought to be a priority. Antimicrobial resistance (AMR) 1. Further research is required to investigate the use and disposal of antibiotics, how it contaminates the environment, and the role of naturally occurring antibiotic resistance cycles in wildlife. One Health approach 1. Move from reactive approaches to novel disease emergence to preventive approaches (e.g. act against the major environmental processes driving disease emergence, fund research, mitigate). 2. Prioritise the integration of international agencies addressing human, animal (domesticated and wildlife), and ecosystems health with broader sustainability agendas. 3. New agencies or agreements in global wildlife health may be needed if current animal health organisations such as OIE and UN's Food and Agriculture Organization (FAO) are not able to expand their mandates to evolving requirements. 4. Boost multidisciplinary collaboration to tackle zoonosis and emerging human and animal diseases, with a particular focus on improving knowledge of zoonosis burden, transmission risk, and its source. 5. Current bias in investment towards human and domesticated animal health should be addressed with a greater preventive focus on environmental and wildlife species health. 6. Institutional developments of ecosystems and wildlife health management systems are required. This will need intersectoral actions, capacity development, and systematic insertion of these systems into human development practices, global economies, health systems, and research agendas. 7. Global health (human) largely depends on the access to primary care and health systems. Global health initiatives ought to strive for equitable access to non-pharmaceutical interventions and pharmaceutical resources, such as vaccines, in a unified manner.

- ***Title:*** Common Approach to Integrating Biodiversity and Nature-based Solutions for Sustainable Development into United Nations Policy and Programme Planning and Delivery, CEB/2021/1/Add.1
- ***Year:*** 2021
- ***Organisation:*** United Nations System, Chief Executives Board for Coordination
- ***Web Link:*** https://unsceb.org/sites/default/files/2021-09/CEB_2021_1_Add.1%20%28Biodiversity%20Common%20Approach%29.pdf
- ***Knowledge gaps/future research:***

The General Assembly called upon the entities of the United Nations development system to: (a) adopt and mainstream a more climate- and environment-responsive approach into their programmes and strategic plans, where appropriate, as well as in cooperation frameworks; (b) advance the development of a system-wide approach, implement measures and report regularly to their respective governing bodies, through existing reporting and mandates, on their efforts to reduce their climate and environmental footprint, ensure consistency of their operations and programmes with low emissions and climate-resilient development pathways, stress the urgency of climate action and contribute to the post-2020 global biodiversity framework; and (c) fulfil their pledges made at the 2019 Climate Action Summit and follow-up on the 2020 summit on biodiversity.

- ***Recommendations to decision-makers and proposed solutions:***

Current status of and trends in biodiversity: it is time to restore the relationship with nature 1. Biodiversity underpins the lives and well-being of humans. It provides multiple essential benefits, including food security, clean water, prevention and cure of diseases, resilience in the face of climate change and changing societal demands and protection from extreme events and disasters, for all people. It ensures sustainable livelihoods and supports 1.2 billion jobs directly and many more indirectly, with half of the world's global economy being moderately to highly dependent on functioning ecosystems. It is also intrinsically linked with cultural diversity and spiritual, physical and psychological well-being. 2. From a scientific standpoint, it has been confirmed that countries have failed to implement the Strategic Plan for Biodiversity 2011–2020, including its 20 Aichi Biodiversity Targets, which suggests a lack of progress toward sustainability. Global ambition to address the three pillars of sustainable development is limited by siloed approaches, where the value of biodiversity and ecosystem services are largely unaccounted and disconnected from socioeconomic priorities. Biodiversity loss and ecosystem degradation jeopardize the effective enjoyment of human rights and progress towards achieving the 2030 Agenda for Sustainable Development. 3. The world is facing a complex crisis related to biodiversity loss, climate change and pollution. Biodiversity is in alarming decline around the world, with 1 million species at risk of extinction, 2 billion hectares of land degraded, two thirds of the ocean adversely affected by human disturbance and an estimated 420 million hectares of forests lost worldwide through deforestation since 1990. Human activities associated with unsustainable patterns of consumption and production are responsible for greenhouse gas emissions, pollution and biodiversity loss. The latest global scientific assessment identifies land- and sea-use change, caused particularly by agricultural expansion and rapid urbanization, as the key driver of biodiversity loss, together with direct exploitation of organisms, climate change, pollution and invasive alien species. 4. Environmental degradation affects individuals and groups in differentiated ways and typically places a disproportionate burden on women and girls, with more severe impacts felt by those in marginalized and vulnerable populations or locations. Unequal exposure occurs not only between, but also within, countries and at more granular scales such as among neighbourhoods in urban areas. Climate change and natural disasters can exacerbate threats that force people to flee within their countries or across international borders. The interplay between climate, conflict, hunger, poverty and persecution creates increasingly complex emergencies. For example, food insecurity may become a major driver of conflicts and displacement. 5. The realization of human rights, including the human right to a safe, clean, healthy and sustainable environment, support for sustainable development and protection of the environment go together. Efforts to reduce poverty, increase resilience and reduce displacement should leave no one behind, including those located in semi-arid and arid lands, small island developing States and landlocked developing countries. It is anticipated that failing to act now on long-term environmental risks will increase societal inequality and fragmentation and bring about dramatic consequences. 6. It is not too late to halt and reverse the decline of biodiversity and ecosystems. During the summit on biodiversity held in 2020, global leaders reiterated their commitments to develop an ambitious post-2020 global biodiversity framework to be adopted at the fifteenth Conference of the Parties to the Convention on Biological Diversity, in 2021. Bold leadership and urgent actions across the whole of government and society, together with an inclusive and networked multigovernance approach, are needed. Such actions can address the direct and underlying causes of biodiversity loss and the degradation of ecosystems, while shifting the course towards a nature-positive future. 7. Our economic recovery path must lead to a transformation of society's relationship with nature. The protection and sustainable use of biodiversity must be integrated into policies that will guide post-pandemic economic and development recovery and building-forward plans. The tools, instruments and knowledge are at hand, but will require clear and commensurate investments in nature. This means shifting investments and practices in all sectors to reflect and account for their impacts and dependencies on biodiversity and ecosystem services and prioritizing systemic transitions that work with and not against nature, and leave no one behind. An investment in the health of the planet is an essential investment in everyone's future. 8. The social consequences of the losses described above could be turned into opportunities to create decent jobs that enhance ecological integrity, economic prosperity and social well-being. The required economic transformation must include changing societal perceptions towards valuing and conserving biodiversity through public outreach and education, as societies cannot transform if what and how people learn remain the same. In the world of work, through which most people continue their learning and make their contribution to society, skills for a greener future remain a priority. This ranges from accelerating the transformation of the energy and other extractive sectors to creating resilience through natural resource management and ecosystem restoration. 9. The coming decade represents the last chance to take the measures needed to ensure a healthy and prosperous future for people and planet.

- ***Title:*** Workshop Report on Biodiversity and Pandemics of the Intergovernmental Platform on Biodiversity and Ecosystem Services
- ***Year:*** 2020
- ***Organisation:*** IPBES
- ***Web Link:*** https://ipbes.net/sites/default/files/2020-12/IPBES%20Workshop%20on%20Biodiversity%20and%20Pandemics%20Report_0.pdf
- ***Knowledge gaps/future research:***

Closing critical knowledge gaps on: • Supporting One Health scientific research to design and test better strategies to prevent pandemics. • Improving understanding of the relationship between ecosystem degradation and restoration and landscape structure, and the risk of emergence of disease. • Economic analyses of return-on-investment for programmes that reduce the environmental changes that lead to pandemics. • Key risk behaviours – in global consumption, in rural communities on the frontline of disease emergence, in the private sector, in national governments – that lead to pandemics. • Valuing Indigenous Peoples and Local Communities' engagement and knowledge in pandemic prevention programmes. • Undiscovered microbial diversity in wildlife that has potential to emerge in future, or to be used to develop therapeutics or vaccines. • Analysing the evolutionary underpinnings of host shifts that are involved in zoonotic disease spillover and the adaptation of emerging pathogens to new host species. • Climate change impacts and related extreme weather events (e.g. flooding and droughts) on disease emergence, to anticipate future threats. • Obtaining data on the relative importance of illegal, unregulated, and the legal and regulated wildlife trade in disease risk.

- ***Recommendations to decision-makers and proposed solutions:***

Enabling mechanisms: • Launching a high-level intergovernmental council on pandemic prevention, that would provide for cooperation among governments and work at the crossroads of the three Rio conventions to: 1) provide policy-relevant scientific information on the emergence of diseases, predict high-risk areas, evaluate economic impact of potential pandemics, highlight research gaps; and 2) coordinate the design of a monitoring framework, and possibly lay the groundwork for an agreement on goals and targets to be met by all partners for implementing the One Health approach (i.e. one that links human health, animal health and environmental sectors). Ultimately the work of the high-level council may lead to countries setting mutually agreed goals or targets within the framework of an accord or agreement. A broad international governmental agreement on pandemic prevention would represent a landmark achievement with clear benefits for humans, animals and ecosystems. • Institutionalizing One Health in national governments to build pandemic preparedness, enhance pandemic prevention programmes, and to investigate and control outbreaks across sectors. • Integrating ("mainstreaming") the economic cost of pandemics into consumption, production, and government policies and budgets. • Generating new green corporate or sovereign bonds to mobilize resources for biodiversity conservation and pandemic risk reduction. • Designing a green economic recovery from COVID-19 as an insurance against future outbreaks. Policies to reduce the role of land-use change in pandemic emergence: • Developing and incorporating pandemic and emerging disease risk health impact assessments in major development and land-use projects. • Reforming financial aid for land-use so that benefits and risks to biodiversity and health are recognized and explicitly targeted. • Assessing how, effective habitat conservation measures including protected areas and habitat restoration programmes can reduce pandemics, and trade-offs where disease spillover risk may increase. Developing programmes based on these assessments. • Enabling transformative change to reduce the types of consumption, globalized agricultural expansion and trade that have led to pandemics (e.g. consumption of palm oil, exotic wood, products requiring mine extraction, transport infrastructures, meat and other products of globalized livestock production). This could include modifying previous calls for taxes, or levies on meat consumption, livestock production or other forms of high pandemic risk consumption. Policies to reduce pandemic emergence related to the wildlife trade: • Building a new intergovernmental health and trade partnership to reduce zoonotic disease risks in the international wildlife trade, building on collaborations among OIE, CITES, CBD, WHO, FAO, IUCN and others. • Educating communities from all sectors in emerging infectious diseases hotspots regarding the health risks associated with wildlife use and trade that are known to pose a pandemic risk. • Reducing or removing species in wildlife trade that are identified by expert review as high-risk of disease emergence, testing the efficacy of establishing market clean-out days, increased cold chain capacity, biosafety, biosecurity and sanitation in markets. Conducting disease surveillance of wildlife in the trade, and of wildlife hunters, farmers, and traders. • Enhancing law enforcement collaboration on all aspects of the illegal wildlife trade.

- ***Title:*** Kunming-Montreal Global biodiversity framework
- ***Year:*** 2020
- ***Organisation:*** Convention on Biodiversity
- ***Web Link:*** https://www.cbd.int/doc/c/e6d3/cd1d/daf663719a03902a9b116c34/cop-15-l-25-en.pdf
- ***Knowledge gaps/future research:***

To take urgent action to halt and reverse biodiversity loss to put nature on a path to recovery for the benefit of people and planet by conserving and sustainably using biodiversity, and ensuring the fair and equitable sharing of benefits from the use of genetic resources, while providing the necessary means of implementation.

- ***Recommendations to decision-makers and proposed solutions:***

The framework has four long-term goals for 2050 related to the 2050 Vision for Biodiversity. GOAL A The integrity, connectivity and resilience of all ecosystems are maintained, enhanced, or restored, substantially increasing the area of natural ecosystems by 2050; Human induced extinction of known threatened species is halted, and, by 2050, extinction rate and risk of all species are reduced tenfold and the abundance of native wild species is increased to healthy and resilient levels; The genetic diversity within populations of wild and domesticated species, is maintained, safeguarding their adaptive potential. GOAL B Biodiversity is sustainably used and managed and nature's contributions to people, including ecosystem functions and services, are valued, maintained and enhanced, with those currently in decline being restored, supporting the achievement of sustainable development for the benefit of present and future generations by 2050. GOAL C The monetary and non-monetary benefits from the utilization of genetic resources, and digital sequence information on genetic resources, and of traditional knowledge associated with genetic resources, as applicable, are shared fairly and equitably, including, as appropriate with indigenous peoples and local communities, and substantially increased by 2050, while ensuring traditional knowledge associated with genetic resources is appropriately protected, thereby contributing to the conservation and sustainable use of biodiversity, in accordance with internationally agreed access and benefit-sharing instruments. GOAL D Adequate means of implementation, including financial resources, capacity-building, technical and scientific cooperation, and access to and transfer of technology to fully implement the Kunming-Montreal global biodiversity framework are secured and equitably accessible to all Parties, especially developing countries, in particular the least developed countries and small island developing States, as well as countries with economies in transition, progressively closing the biodiversity finance gap of 700 billion dollars per year, and aligning financial flows with the Kunming-Montreal Global Biodiversity Framework and the 2050 Vision for Biodiversity.

- ***Title:*** One Health Theory of Change
- ***Year:*** 2022
- ***Organisation:*** OHHLEP
- ***Web Link:*** https://www.who.int/publications/m/item/one-health-theory-of-change
- ***Knowledge gaps/future research:***

  For its initial term, the OHHLEP has been tasked to focus on: Providing policy relevant scientific assessment on the emergence of health crises arising from the human-animal-ecosystem interface, as well as research gaps; and Guidance on development of a long-term strategic approach to reducing the risk of zoonotic pandemics, with an associated monitoring and early warning framework, and the synergies needed to institutionalize and implement the One Health approach, including in areas that drive pandemic risk.

- ***Recommendations to decision-makers and proposed solutions:***

  Recognizing that the One Health approach embodies sustainable cross-sectoral collaboration at all levels, three Pathways of Change have been identified to provide a framework for the prioritization and implementation of high-level actions. The list of actions below while not exhaustive, provide detail to the Pathways of Change that will enable the translation of the high-level actions outlined in section 4 into practice. The detailed actions listed in this section are also intended to complement existing activities and synergize with existing efforts towards One Health (OH) implementation including those planned for the closely aligned One Health Joint Plan of Action. While some overlap of actions exist between the three pathways, most actions more obviously/substantively sit in one pathway versus the others and have therefore been categorized accordingly. PATHWAY 1 Actions related to policy development, political will, enabling regulatory frameworks, equitable investments and promoting institutionalization of intersectoral governance. 1. Advocate for adopting a One Health approach to tackle health threats in relevant global and regional fora and their funding instruments, including toward: Prevention and health promotion-oriented focus in international collaborations and investments (e.g. the One Health Joint Plan of Action, a potential international pandemic accord negotiations process, IHR reform, WHO/World Bank Global Preparedness and Monitoring Board (GPMB), and the Pandemic Prevention, Preparedness and Response Financial Intermediary Fund). Adequate safeguards through improved assessment of trade-offs and co-benefits. Value reinforcement for integrated and sustained surveillance systems. 2. Conduct stakeholder mapping and political economy analysis of One Health initiatives and policies and develop case studies. 3. Appraise existing assessment, evaluation and planning tools and outputs to identify critical gaps in architecture including supporting the review of existing Quadripartite health secuirty capacity assessment/building tools. 4. Provide advisory support regarding resource allocation - e.g. gaps in prevention, livestock biosecurity measures, animal welfare, and ecosystem management. Strengthen private sector engagement and private-public partnership for technology transfer and equitable access to common goods. 5. Establish a framework and models of One Health governance structures, legislation, and networks 6. Mainstream One Health into existing programs and plans (e.g. vector-borne diseases, plans for outbreak preparedness, prevention and response) and scale up monitoring and implementation of international conventions and related protocols (e.g. Convention on Biological Diversity, Nagoya protocol on Access and Benefit Sharing, Cartagena Protocol on Biosafety). 7. Advocate for community inclusion and engagement and sociopolitical parity including gender mainstreaming and inclusion of other disadvantaged groupings in One Health prioritization, programs and activities. 8. Promote co-design of top-down and bottom-up approaches, recognizing the needs of those most directly concerned, and ensuring the participation of women and other disadvantaged groups. 9. Establish a sustainable source of funding for systems and promote equitable resource allocation between sectors for effective implementation of global One Health strategies, through advocacy with financing institutions (Development Banks and foundations) to fill gaps and mobilize resources to support the "4Cs". 10. Develop an advocacy package tailored to political and opinion leaders at national and sub-national level. 11. Promote improved animal welfare standards and environmental protections across food and agricultural systems as well as across wider ecosystems including wildlife, terrestrial and aquatic habitats. 12. Support the investment in public, animal and ecosystem health infrastructure including appropriate WASH, IPC and clean air/water/energy initiatives through well planned urban and rural development programmes. PATHWAY 2 Actions related to implementation of One Health including scaling up of capacity development, community engagement and mobilization for action, multisectoral coordination, collaboration and communication, and equitable integration of sectors. 1. Develop metrics for One Health monitoring and evaluation frameworks, including for the One Health Joint Plan of Action implementation 2. Provide advisory support for implementation including priority setting, stakeholder identification and others as required. 3. Support the development of an overarching surveillance framework and strengthen surveillance and disease intelligence systems across the domains of human, animal and ecosystem health. 4. Develop and implement safeguards through improved One Health assessment of trade-offs and co-benefits for development projects 5. Conduct a detailed analysis of the challenges and constraints at community level for disease prevention and control to support the development and implementation of: A comprehensive social and community behaviour change strategy. Joint risk communication and community engagement plans and advocacy strategies that enable individuals and communities to protect their health, livelihoods and ecosystems. Community Knowledge, Attitude and Skills (KAS) to use information in assessing their own situations and to take actions to protect their own health, livelihoods and ecosystems against health hazards 6. Establish a global database and platform for identifying, curating, and signposting One Health networks and initiatives. 7. Integrate across sectors a wider expanse of knowledge systems including experiential learning, oral traditions, indigenous communities etc. into the data sets for evidence. 8. Integrate the One Health concept and elements across sectors including but not limited to: Key national assessment, capacity building and implementation tools. Equitable distribution of action plans and budgets between sectors, including wildlife and ecology, to ensure that their roles in relation to disease prevention and detection are understood and optimized. Workforce programs and career pathways for One Health specialists across disciplines and sectors. 9. Incentivize best practices for One Health operationalization. 10. Support implementation plans around the protection of natural habitats (both terrestrial and aquatic) from the excesses of unplanned urbanization, human encroachment, poor waste management and ecosystem pollution (air, land, water). PATHWAY 3 Actions related to strengthening the scientific evidence base, fostering knowledge exchange, technology transfer and continuing education, using better data and evidence to inform best practice, innovation and enabling access to new tools and technologies. 1. Assess the status of natural resources and biodiversity and their relevance to health 2. Review traditional/indigenous forms of knowledge and inputs of marginalized groups and ensure inclusive approaches 3. Assess spillover drivers and identify relevant risk reduction options 4. Identify core components and best practices for One Health surveillance systems 5. Create a global inventory of One Health initiatives, tools, guides, resources, and trainings to serve as a platform for providing reliable and authentic information and data sources.

- ***Title:*** Global Plan of Action on One Health. Towards a more comprehensive One Health, approach to global health threats at the human-animal-environment interface
- ***Year:*** 2022
- ***Organisation:*** AO, UNEP WHO, WOAH.
- ***Web Link:*** https://wedocs.unep.org/bitstream/handle/20.500.11822/40843/one_health.pdf?sequence=1&isAllowed=y
- ***Knowledge gaps/future research:***

  The OH JPA adopts One Health with a broader perspective, adopting a systems approach to support the health of humans, animals, plants and ecosystems, while identifying and addressing the factors underlying disease emergence, spread and persistence, and the complex economic, social and environmental determinants of health. By integrating the environmental dimension to gain a broader understanding of disease emergence and spread, as well as the role of ecosystems in disease regulation, One Health can unfold its entire capacity. It can thereby help to address the underlying drivers of disease emergence and ill health, improve disease prevention and preparedness, mitigate the impacts of health risks and threats, implement sustainable solutions and promote health for all in a holistic manner long term.

- ***Recommendations to decision-makers and proposed solutions:***

  The OH JPA is built around six interdependent action tracks that collectively contribute to achieving sustainable health and food systems, reduced global health threats and improved ecosystem management: • Action track 1: Enhancing One Health capacities to strengthen health systems • Action track 2: Reducing the risks from emerging and re-emerging zoonotic epidemics and pandemics • Action track 3: Controlling and eliminating endemic zoonotic, neglected tropical and vector-borne diseases • Action track 4: Strengthening the assessment, management and communication of food safety risks • Action track 5: Curbing the silent pandemic of AMR • Action track 6: Integrating the environment into One Health Each action track consists of a set of actions with specific activities, deliverables and a timeline to achieve the following objectives: i. Provide adequate guidance and tools for the effective implementation of multisectoral approaches to promote the health of humans, animals, plants and ecosystems and to prevent and manage risks at the human–animal–plant– environment interface. ii. Reduce the risk and minimize local and global impacts of zoonotic epidemics and pandemics by understanding the linkages and drivers of emergence and spillover, adopting upstream prevention and strengthening One Health surveillance, early warning and response systems. iii. Reduce the burden of endemic zoonotic, neglected tropical and vector-borne diseases by supporting countries in implementing community-centric, risk-based solutions, strengthening policy and legal frameworks from the local to the global level and across sectors, and increasing political commitment and investment. iv. Promote awareness, policy changes and action coordination among stakeholders to ensure that humans, animals and ecosystems achieve health and remain healthy in their interactions with and along the food supply chain. v. Take joint action to preserve antimicrobial efficacy and ensure sustainable and equitable access to antimicrobials for responsible and prudent use in human, animal and plant health. vi. Protect and restore biodiversity, prevent the degradation of ecosystems and the wider environment to jointly support the health of people, animals, plants and ecosystems, underpinning sustainable development. Lastly, the OH JPA promotes the adoption of cross-cutting principles, including systems thinking, advocacy, public-private partnerships, governance, institutional and legal frameworks, and traditional knowledge of local and indigenous communities, to build connections across the six action tracks and look at shared underlying issues.

Annex 3:
Ethical application

UNIVERSITY of STIRLING

Ethics Application Form

Applicant details

Are you a member of staff, a postgraduate research student, a postgraduate taught student or an undergraduate student?

- [x] Staff
- [ ] Postgraduate Research Student
- [ ] Postgraduate Taught Student
- [ ] Undergraduate Student

Please enter your job title: Professor

Applicant details

First Name: Nils

Surname: Bunnefeld

Division: Faculty of Natural Sciences

Faculty:

Email: nils.bunnefeld@stir.ac.uk

Type of application

27 January 2023

Reference #:

Does your application involve any of the following?

- [x] A new project with Human participants
- [ ] A new project with Animals
- [ ] A project that has already received ethical review
- [ ] An application or an amendment to a Project Licence
- [ ] None of the above

Additional factors

- [ ] Does the proposed project involve reproducing copyrighted work in published form (other than brief citation)?
- [ ] Does the proposed project involve activities which could temporarily or permanently damage or disturb the environment, or archaeological remains and artefacts?
- [ ] Does the proposed project involve a potential conflict of interest or raise ethical issues regarding the source of funding or where the publication of research data may be restricted?
- [x] None of the above

NHS Invasive or Clinical research

If your project involves NHS patients, staff, data or premises we would recommend using the HRA Decision Tool to determine whether NHS Research Ethics Committee approval will be required.

Please indicate those that apply to your study or select none of the above

- [ ] Requires approval by an NHS Research Ethics Committee (REC)
- [ ] Requires approval ONLY by NHS Research and Development (R&D) with an IRAS form
- [ ] Requires approval ONLY by NHS Research and Development (R&D) - no IRAS form is required
- [ ] Health care settings (in the UK or overseas)
- [ ] Clinical trial or an investigational medicinal product
- [ ] Clinical investigation and/or study of a medicinal product
- [ ] Human tissue samples or other human biological samples
- [ ] Imaging investigations (MRI, ultrasound)
- [ ] Physical examinations (blood pressure, pulse, respiratory rate)
- [ ] Physical tests (other than EEG, BioPac, fNIRS)
- [ ] Computer tests where there are potential health consequences (dementia, sleep apnoea, depression tests)
- [ ] Filming or photography (as part of a health research study or in a health setting/context)
- [ ] Sample-taking (urine, blood, hair, muscle biopsy)
- [ ] Ingestion of substances, fluids or alcohol
- [ ] Health related questionnaires, surveys or interviews where there is the potential to diagnose new health related conditions.
- [x] None of the above

Project details

Please enter the short title of your project (max 200 characters)

Policy relevant knowledge needs on Biodiversity and Pandemics

Please enter the full title of your project

Policy relevant knowledge needs on Biodiversity and Pandemics

Staff - If you have a Worktribe record for this project please make sure the titles are the same.

Please add the Worktribe reference for this project

Are there collaborators involved in the study?

☑ Yes ☐ No

You will be asked to add details of your collaborators later in the form.

Funding details

Project funder

European Commission

Please enter the type of funding

Government Funding

Project duration

Project start date

01/02/2022

Project end date

31/08/2023

If different from the project start and end dates

Expected start of data collection

01/03/2023

Expected end of data collection

30/04/2023

Health and Safety

If the proposed project poses any particular physical risks to the researcher(s) or research participants a risk assessment must be signed off by your supervisor or line manager prior to commencing fieldwork.

Has a health and safety risk assessment been successfully completed?

- ☐ Yes
- ☑ Not applicable
- ☐ In progress

Project description

Please provide a summary of your project (~half page, one page maximum) describing the topic, and main objectives, a summary of your proposed methodology (e.g. fieldwork, experimental procedures, surveys, interviews, focus groups, standardised testing, video or audio recording).

Topic

The COVID-19 crisis has revealed how fragile and vulnerable our societies are to pandemics and how challenging informed political and policy responses become when faced with such an emergency. The potential risk of zoonoses linked to unprecedented land degradation and conversion, unleashed consumption of natural resources, increasing livestock production, and acceleration of biodiversity loss had been identified and did not come as a surprise to the scientific community. The pandemic has revealed a broad range of science-policy challenges and knowledge gaps. Addressing these will better prepare us for the next crisis that emerges. The evidence needs to focus on improving our understanding and application of the science of pandemics to optimise coordination and coherence across policy sectors, building better resilience and response strategies (proactive and reactive approaches) in the context of the interface between Biodiversity and Pandemics. The knowledge synthesis process is overseen and facilitated by Eklipse. Eklipse was established in 2016 to help governments, institutions, businesses, and NGOs make better-informed decisions regarding Biodiversity in Europe. Eklipse was granted additional funding by the European Commission, under the Horizon 2020 Green Deal Call, as part of the EU response to the COVID-19 pandemic to answer policy-relevant needs for evidence related to Biodiversity and Pandemics. One of the evidence needs identified by a cross-sectoral group consisting of policy and science actors a consortium of policy relevance, wide-scale relevance, cross-sectoral approach, no duplication, and ethics was ensured, an Expert Working Group (EWG) was put in place to answer the need for evidence. The EWG was constituted by self-nominated experts through an open call disseminated widely through networks and social media, ensuring the cover in terms of disciplines as well as gender and geographical balance.

Main aims/objectives

1. Rapidly reviewing and summarising the current state of evidence and knowledge as reflected in peer-reviewed articles, reports from organisational websites and grey literature on the topic of Biodiversity and Pandemics via a scoping review.
2. Synthesising knowledge on the ongoing research initiatives related to the topic of the relationship between Biodiversity and Pandemics based on data collected by the Eklipse Scoping Group.
3. Contacting a large number of outside experts working on the topic of Biodiversity and Pandemics to validate and extend results collected in the first two steps and to prioritise research recommendations related to identified knowledge gaps via an online survey, targeted expert consultation, and a focus-group discussion.

Methods

The University has a number of pre-approved protocols for common research scenarios. If you will be following one of the University's protocols please indicate which one here.

To achieve the objectives formulated above, we are following three approaches:
1. Literature-based method, scoping review to summarise the current state of evidence and outline the knowledge gaps and address objective 1.
2. An Initiative scoping to analyse and summarise the current research recommendations relevant to "Biodiversity and Pandemics" and address objective 2.
3. People-based methods (online survey-based expert consultation, and at least one focus group) to consolidate and validate results on knowledge gaps obtained from methods 1 & 2 and prioritise the knowledge gaps and research recommendations, thus addressing objective 3.

These methods will be conducted in parallel, with an effective delayed start of the third method, in order to take into account the results of the first two methods (scoping review and initiative scoping) when formulating the questions in the online questionnaire (first of the two methods used for the objective 3). The use of the three approaches helps provide a more comprehensive answer to the request than a single method.

Please be aware that if your methodology changes during your research, it is your responsibility to submit an amendment to your approved application. See the Information button for further advice.

GDPR

Applicants must confirm that they have read and understood the University's guidance on GDPR and that the necessary steps have been considered to protect the data of your participants.

Review the University's guidance on GDPR

- [x] I have read and understood the University's GDPR guidance

Please indicate those that apply to your project

- [ ] Involves children or vulnerable adults
- [ ] Involves personal data that has been obtained without the knowledge of the data subjects
- [ ] Processing of bio-metric or genetic data
- [ ] Large scale processing of criminal convictions or special categories of personal data?
- [ ] Processing of personal data involving new technologies or novel applications of existing technologies
- [ ] Combining or matching personal data obtained from multiple sources
- [ ] Tracking geo-location
- [ ] Using personal data in a way that could significantly affect or have an impact on an individual
- [ ] Jeopardising the physical health or safety of individuals
- [ ] Systematic monitoring of publicly accessible areas
- [ ] Profiling or automated decision-making on a large scale where significant decisions are made impacting on people
- [x] None of the above

Participants, recruitment and location

Provide details of your participant population and the number of participants required

Include brief characteristics as well as principal inclusion and exclusion criteria.

Considering the people based-methods the following tools were chosen:

Wide expert consultation using an online survey in order to create a preliminary list of gaps in knowledge and research recommendations in a quantitative way (i.e., to get as many inputs of medium quality as possible). The online survey participants will be researchers and professionals working on the relationship between Biodiversity and Pandemics.
Online adapted focus group discussion (FGD) will be organised with the objectives to validate, consolidate and prioritise the items on the lists of gaps in knowledge and research recommendations developed based on interviews/survey and the literature-based (method 1).
We will exclude those under 18 from the survey, which will be done by requiring the participants to state that they are over 18 in the consent sheet, and making it clear that they must not complete it if they are younger.
We will not actively target any vulnerable groups, however it will be challenging to exclude them from the sample.

Describe how and from where participants will be recruited.

The online survey process will be disseminated by emailing targeted professionals with expert knowledge to ensure feedback quality. Participants will be selected using a structured approach, covering a wide range of disciplines, ecosystems and habitats and representing various organisational backgrounds and geographic regions. The list of targeted participants will be wide (with a target of between 300 and 400 individuals - the list already has more than 220 entries). In the list, contact details (name, email, city & country of residence), professional position and institution will be added with a column indicating if this participant could also have relevant experience to be involved in a focus group discussion. The list is populated from each Expert Working Group (EWG) member's existing network; other expert lists obtained through Eklipse; other working groups known to the EWG; and the academic readings and expertise of the EWG members obtained in method 1. It will include, therefore: i) Relevant persons who an EWG member knows personally (a column captures which EWG member knows this participant personally); ii) Relevant persons who we don't know personally but we "know" them (through reading articles, attending conferences etc.); iii) Authors of relevant articles that will be identified through the literature review. Attention will be given to the geographic coverage of the list that should be wide, as well as the thematic coverage (e.g., health, environment, social & sustainability sciences, as well as academic, public, private and voluntary sectors).

Describe where the research activities will take place

for example: online, in a classroom, in a sports facility

Online through zoom meetings and google forms (online survey).

Describe any incentive participants may receive for participation

For applications that will provide Psychology Undergraduate students with research tokens please ensure that your study follows the Undergraduate Student Participation in Research in the Psychology Division Research Tokens Protocol available from the approved protocol section of the website. You should make reference to the protocol in your answer here.

The participants' contribution will only be acknowledged if they select the option in the survey. In the survey, the participants will have the following options:
Be acknowledged in the final synthesis report as a participant in the survey.
Be personally contacted for the peer review of the final synthesis report.
Be personally contacted to attend a focus group to validate the results.
Be informed of the news related to the request Biodiversity and pandemics.
Be informed of any Eklipse news (open calls, outputs, events) through the newsletter.

Does your proposed study involve vulnerable groups?

- ☐ Yes
- ☑ No

Consent

Will you obtain consent from or on behalf of participants? When, where and how?

Remember to include how long you will allow participants to decide whether or not to take part.

Yes, the consent will be included as an item in the survey online form, which will be used to collect the participants' contributions.

How will consent be recorded?

If written consent will not be obtained, justify it here

The permissions will be recorded in the survey online form and then stored considering the standards defined in the Eklipse privacy policy and following the Eklipse privacy policy. https://eklipse.eu/ethical-framework/

Permissions

If any additional consent and permission procedures are required please provide details

For example, permissions to conduct field sampling or from local authorities to access schools

Ethical implications

Describe any ethical issues and how you will mitigate them

Regarding the online survey, the main ethical implications we face as a team are obtaining informed consent, ensuring the anonymity of the participants, and maintaining the confidentiality of the data. To minimise and mitigate any potential issues, the following measures are taken:

Participation in any stage of the study is entirely voluntary.
Efforts will be made to ensure informed consent is obtained for all participants.
Information on the objectives and purposes of the research and the rights of participants (i.e. to not take part, to remove their data) will be made available to all participants.
Participants will be kept anonymous throughout the process, and their names, and any other personal data, will not be used outside of the focus group setting.

Regarding the focus groups, each focus group will have members from the same stakeholder group to avoid confrontation and encourage a comfortable and safe environment. Equally, as in the case of the online survey, participants will be kept anonymous throughout the process, and their names, and any other personal data, will not be used outside of the focus group setting. In addition, core team members are all trained in aspects of mediation and facilitation and will be able to manage tensions if they do arise. Recordings of the focus groups will not be used by anyone outside of the core team, and they will be stored in an encrypted file using a code name. The core team will transcribe recordings, and only these transcriptions will be used for analysis. Any information in the transcriptions relating to specific names or personal data will be removed. Recordings will be securely deleted three months after the project's end date. Finally, anonymised data will be uploaded to encrypted servers and kept for one year to allow for further analysis and/or reporting to partners.

Are there risks of foreseeable harms that may be caused to participants and/or third parties

For example, landowners, institutions, carers and families

☐ Yes ☑ No

Methodologies

Will the proposed research involve the deception of participants?

☐ Yes ☑ No

Will the proposed research involve concealment or covert observation?

☐ Yes ☑ No

Is the project design emergent? e.g. will elements of the research be developed during the process of the research?

☐ Yes ☑ No

Dissemination

How will the results from this study (include feedback to participants) be disseminated?

The results of this study will be disseminated through different channels:
The anonymised results will be disseminated through the Eklipse website and social media.
Also, a policy brief and a podcast will be developed.
The anonymised results will also be disseminated through the institutions that are active as requesters of this evidence need. The institutions involved are: European Commission's Directorate-General for Research & Innovation (EC-DG RTD), European Commission's Directorate-General for Environment (EC – DG ENV), European Commission's Directorate-General for Agriculture and Rural Development (EC-DG AGRI), European Commission's Directorate-General DG Health Emergency Preparedness and Response Authority (EC – DG HERA), PREZODE (Preventing ZOonotic Disease Emergence), One Health High-Level Expert Panel (OHHLEP), Norwegian Veterinary Institute (NRI), Project HERA (Health Environment Research Agenda for Europe)
Also, the anonymised results will be disseminated through the experts part of the Eklipse Experts Working Group working on answering this question (https://eklipse.eu/request-biodiversity-pandemics/)

Data collection methods

Does the proposed work involved the remote acquisition of data from or about human participants using the internet and its associated technologies?

- ☐ Yes
- ☑ No

Does the proposed work involve collecting or accessing records of, personal or confidential information concerning individuals?

- ☐ Yes
- ☑ No

Does the proposed work involve the recording of participants through the use of audio visual methods?

- ☐ Yes
- ☑ No

Data analysis

Briefly describe the methods of data analysis

The online survey form should not request more than 15 to 20 minutes for reading and contributions. Tests will be run. The target would be to get a 10 to 20% response rate which with a list of 300 to 400 targeted individuals should come to between 30 to 80 respondents. The outputs of this online survey will be consolidated lists of gaps in knowledge and policy & research recommendations (later G&Rs) that will be synthesised by the EWG and the first layer of prioritisation of the items in these lists by the participants. Most of the responses will be close-ended responses. Respondents will be asked to contribute additional G&Rs (see proposed format below). The ranking of G&Rs will be synthesised across participants to identify which G&Rs are the most prioritised. Further analysis of results will be considered, such as differences/similarities between policy makers' and researchers' responses or associations between G&Rs (e.g., ecologists tend to prioritise items X & Y when human health practitioners prioritise W & Z). The new G&Rs submitted by respondents will be reviewed by EWG and merged with existing G&Rs, or existing G&Rs will be modified, taking these new G&Rs into consideration, or they will be added as a new contribution to the G&R lists.

In the case of the focus group, the objectives will be to validate, consolidate and prioritise further the lists of gaps in knowledge and research recommendations by key individuals. This focus group, not longer than half a day (2 to 3 hours), would be an online workshop using a facilitation board (e.g., Klaxoon; Cirad has a licence) and should gather between 15 and 25 participants. Their draft structure that will need to be adapted following the outputs of the other phases of the methods could be:

First, validation phase (45'): present to the participants the Eklipse request and the process that produced the list of gaps in knowledge and research recommendations synthesised after the online survey and literature-based Method 1 (some preliminary material that should facilitate this presentation will be sent to the participants beforehand); a 30mn discussion could then engage the participants to comment these lists;
Then, consolidation phase (30'): participants will be asked to contribute to the online board stickers with new contributions to these lists.
Finally, in the prioritisation phase (60'): participants will prioritise the gaps and recommendations by interacting with the online board.

The specific structure of the focus group will depend on the results from the online form and literature-based method (scoping review) and the number of external experts who agree to participate. The virtual format will increase the potential number here, and we have a professional zoom platform to enable multiple break-out rooms. We will take a professional approach to these sessions with experienced facilitators.

The final output of the entire process will be the prioritised lists of gaps in knowledge and research recommendations, synthesised and commented on by the EWG. Workshop participants will contribute in
writing through "post-its" allocated on the board, responding to the different questions prepared by the
EWG. One or two members of the facilitation team will take notes, and the discussions will be recorded after the consent of the respondents.

Data storage

Briefly describe the methods of data storage

The information will be stored in secured folders, considering the Eklipse Ethical Infrastructure.
https://eklipse.eu/ethical-framework/

Conflict of interest

Does the principal investigator or any other investigator/collaborator have any direct personal involvement (e.g. financial, share-holding, personal relationship etc.) in the organisations sponsoring or funding that research that may give rise to a potential conflict of interest?

☐ Yes ☑ No

Internal collaborators

Please enter details of University of Stirling co-applicants

First Name

Surname

Division

External collaborators

Please add details of any external co-applicants

First Name

Marie

Surname

Vandewalle

Organisation

Eklipse and Helmoltz Centre for Environmental Research, Germany

Documents

The University provides a range of template documents. We would strongly recommend that you use the templates that are available on the research ethics and integrity website.

Please upload your participant information sheet(s)

Documents

Type	Document Name	File Name	Version Date	Version	Size
Participant information sheet	Staff_PGR Participant Information Sheet	Staff_PGR Participant Information Sheet.docx	26/01/2023	1	75.8 KB

Please upload your consent sheet(s)

Documents

Type	Document Name	File Name	Version Date	Version	Size
Consent Form	(TEST) Eklipse Survey - Biodiversity and Pandemics - Google Forms	(TEST) Eklipse Survey - Biodiversity and Pandemics - Google Forms.pdf	26/01/2023	1	465.1 KB

Please upload copies of recruitment material(s)

Please attach copies of questionnaire(s), interview or focus group guides

If relevant, please attach copies of debrief information

If relevant, please attach other documentation

Signing the form will lock the form and prevent further editing. If you choose to unlock the form all signatures will be invalidated and requests will need to be made again.

Please sign your application

Signed: This form was signed by Nils Bunnefeld (nils.bunnefeld@stir.ac.uk) on 27/01/2023 14:46

Annex 4:
Ethical approval - University of Stirling

University of Stirling
Cottrell 3B1
Stirling
FK9 4LA

06/04/2023

Dear Nils

Ethics Application Form : Policy relevant knowledge needs on Biodiversity and Pandemics 13714

Thank you for your submission of the above ethics application.

The ethical approaches of this project have been approved and you can now proceed with your project.

Please note that should any of your proposal change, a further amendment submission will be necessary.

If you have any further queries, please do not hesitate to contact the Panel by email to ethics@stir.ac.uk

Yours sincerely,

General University Ethics Panel

Annex 5:
People-based method – Survey

Survey request “Biodiversity and Pandemics” - Identification of the key policy recommendations and knowledge research gaps -

Dear Experts,

We invite you to fill out the online survey organized by an Expert Working Group (EWG) in order to better understand the relationship between biodiversity and pandemics. This work was commissioned to Eklipse, an organization created in 2016 with the mission to bridge the gap between biodiversity policy and knowledge in Europe.

The survey is structured in two components: the first with policy recommendations (Section 2 of the survey) and the second with research knowledge gaps (Section 3 of the survey); both prepared based on an extensive review of scientific and institutional literature from 2018 to 2022 and a carefully crafted methodological protocol.

Your contribution and support will help us provide actionable knowledge that will feed into the Horizon Europe Work Program for the coming years, and the Long Term Strategic Agenda for Biodiversity.

Thank you for supporting this effort!

All the members of the Eklipse EWG on "Biodiversity and pandemics".

Completing this survey should take approximately 10-15 minutes and is open until March, 13th 2023.

IMPORTANT:

- Please note that the form does not save your answers after each section has been completed. In order to continue editing your form at a later date, you will need to add text to all mandatory fields and submit the form. Once the form has been submitted, you will be emailed instructions on how to edit your application.
- Please provide us with a working email address on your form, otherwise you will not be emailed details on how to edit your form.

Enquiries: Many thanks in advance for your input to this survey. If you have any question, please contact us at: emb@eklipse.eu

* Indicates required question

1. Email *

2. Last name *

3. First name *

Section 1: Eklipse privacy policy and GDPR agreement

Eklipse is a science-policy mechanism of the public interest. The lawful basis for processing your personal data under the EU's General Data Protection Regulation (GDPR) will be a public task. Our privacy policy (http://eklipse.eu/privacy-policy/) contains further information on the purpose and lawful basis for processing your personal data. It follows the rules of GDPR related to informed consent, anonymity, data storage, data protection and data use. If you have any question, please contact us at: emb@eklipse.eu

4. Please tick all boxes if you agree with the following items: *

Check all that apply.

- [ ] By answering the following survey, I agree with the collection, storage and use by the Eklipse team of the information provided by me. I retain the right to ask Eklipse to delete all my personal data at any moment. For further information: http://eklipse.eu/privacy-policy/
- [ ] I declare that the information provided is under my own personal capacity and does not involve my affiliation´s opinion.

Section 2: Policy Recommendations

INSTRUCTIONS:

- Before starting to answer this section, please read carefully the list of policy recommendations to identify **the three most important items** for you.
- If you think that this list has not covered an important policy recommendation, you will have the opportunity to add at the bottom of the list some items that will be considered as some of your priorities in the processing of the data. Please make sure your item(s) is well and concisely written, addresses a topic related to the link between Biodiversity and Pandemics and highlights a policy recommendation of importance for the future.

5. **In your point of view, what are the 3 most important policy recommendations (in no specific order) from the list below?** *

Check all that apply.

- [ ] GOVERNANCE: Promote responsible and inclusive governance systems in which policy makers take into account risk uncertainty, mitigation of environmental damage, and are accountable for bottom-up (or societal) requests
- [ ] COLLABORATION: Foster intersectionality at policy and practitioner levels, interdisciplinarity at practitioner and research levels and transdisciplinarity between all stakeholders including local communities/general public at risk of pandemics, as promoted by the One Health concept
- [ ] EDUCATION: Use adult and school education to increase understanding of the One Health (OH) approach and disease prevention in society and to build the future OH workforce
- [ ] AWARENESS: Build and strengthen awareness in societies and government from local to global about the need for transformative changes to mitigate risks and drivers that contribute to pandemic emergence, biodiversity loss, and the depletion of ecosystem/natural resources
- [ ] JUSTICE & EQUITY: Ensure that interventions in the context of pandemics and biodiversity account for and improve the situation of disadvantaged and marginalised groups within society, in particular regarding their access to health services and healthy ecosystems
- [ ] VALUES: Integrate local values and worldviews in the management of health issues, including pandemic prevention, preparedness and response
- [ ] FOOD SYSTEMS: Radically transform food and livestock production systems, trade, and their governance and policy, especially in their relation to nature and health
- [ ] CONSERVATION: Decrease the encroachment of human activities into natural habitats and better manage landscape to combine conservation and local development objectives while mitigating the risk of emergence and pandemics
- [ ] MONITORING: Develop long-term, robust, multi-faceted, open-data monitoring strategies for known and potential pathogens, infectious diseases and their systemic consequences along the anthropogenic gradient from natural to urban habitats, including pathogen genetic/genomic data, to enable prevention and early intervention against infectious disease emergence, including in post-disaster contexts
- [ ] WILDLIFE: Regulate wildlife use and trade in national and international regulatory frameworks
- [ ] BUSINESS: Strengthen and regulate links between business, investment and funding related to Pandemics and Biodiversity
- [ ] RESEARCH: Promote and invest in interdisciplinary research on the links between Biodiversity and Pandemics
- [ ] Other: _____

6. If you have answered “Other” above or you would like to add a comment, please elaborate in the box below.

Section 3: Research Knowledge Gaps

INSTRUCTIONS (same as previous):

- Before starting to answer this section, please read carefully the list of Research Knowledge Gaps
  to identify **the three most important items** for you.
- If you think that this list has not covered an important policy recommendation, you will have the opportunity to add at the bottom of the list some items that will be considered as some of your priorities in the processing of the data. Please make sure your item(s) is well and concisely written, addresses a topic related to the link between Biodiversity and Pandemics and highlights a policy recommendation of importance for the future.

7. **In your point of view, what are the 3 most important research knowledge gaps (in no specific order) from the list below?** *

Check all that apply.

- [ ] WILDLIFE-KEY SPECIES: Identify key wildlife species and their ecology and roles in infectious diseases emergence
- [ ] WILDLIFE-DOMESTIC-HUMAN INTERFACES: Identify drivers of contacts between wildlife, domestic and human animals
- [ ] DILUTION: Conduct more research on different contexts to investigate possible biodiversity-modulated mechanisms underlying changes to zoonotic risk from wildlife (e.g. biodiversity loss increasing or decreasing zoonotic risk)
- [ ] MICROBIAL DIVERSITY: Study microbial diversity, ecology and epidemiology in nature to identify potential future agents at risk of emerging and triggering pandemics, and how this diversity changes in response to environmental change and human activities
- [ ] PATHOGENS: Evaluate what characteristics of pathogens from wild animals make them most likely to cross the species barrier and spread in new hosts
- [ ] DIAGNOSIS: Develop and invest in rapid and validated diagnostic tools methodologies for emerging infectious diseases in wildlife
- [ ] MODELLING: Develop mathematical models regarding the links between Biodiversity and Pandemics including the impacts of environmental changes such as climate change
- [ ] WILDLIFE-TRADE: Collect, integrate and make available reliable data on wildlife trade pathways both legal and illegal and their compliance with regulations
- [ ] URBANISM: Identify and evaluate the risks posed by urban and peri-urban expansion and development in the context of biodiversity interactions and infectious disease emergence
- [ ] SOCIAL: Apply social science and humanities-driven methodologies to understand how perceptions, values and behaviours influence human interactions with wildlife and domesticated animals, and how to mitigate the ensuing risks regarding pandemics
- [ ] IMPACT: Develop integrated approaches to assess the societal and environmental impact of emerging infectious diseases, including potential prevention, response and recovery plans
- [ ] ECONOMICS: Study the return-on-investment for programmes that reduce the environmental changes and the human behaviours and activities that lead to pandemics.
- [ ] Other: _____

8. If you have answered “Other” above or you would like to add a comment, please elaborate in the box below.

Section 3: Next steps for the request process

Many thanks for your input to the Eklipse request “Biodiversity and pandemics” on:

"Building on existing relevant work on research agendas and knowledge gap analysis, identifying interdisciplinary research and action priorities, that contribute to a strategic research agenda on biodiversity and pandemics addressing the critical interlinkages between relevant sectors needed to make future actions more effective."

In the next weeks/months, the Eklipse Expert Working Group on “Biodiversity and pandemics” may organize experts consultations and will develop a knowledge synthesis report.

9. Please let us know by ticking the boxes below, if you would like to :

Check all that apply.

- ☐ Be acknowledged in the final synthesis report as a participant of the survey.
- ☐ Be personally contacted for the peer-review of the final synthesis report.
- ☐ Be personally contacted to attend a focus group to validate the results.
- ☐ Be informed of the news related to the request Biodiversity and pandemics.
- ☐ Be informed of any Eklipse news (open calls, outputs, events…) through the newsletter.
- ☐ Other: _____

10. Any additional comment?

Please don´t forget to finalize the survey by clicking on the button "submit" in the next page.

Annex 6:

Participants to the people-based method – Survey

Azat	Claudio
Barasa	Violet
Bastrup-Birk	Annemarie
Belsare	Aniruddha
Bilgen	Nüket
Blanc	Julian
Bonnet	Pascal
Breed	Andrew
Buholzer	Patrik
Cappelle	Julien
Capps	Benjamin
Chardonnet	Bertrand
Chardonnet	Philippe
Chochlakis	Dimosthenis
Cornelis	Daniel
De Garine-Wlichatitsky	Michel
De la Rocque	Stephane
Devos	Yann
Dobson	Andy
Drewe	Julian
Duboz	Raphaël
Erdem	Gul
Fagre	Anna
Fearnley	Lyle
Fevre	Eric
Fine	Amanda
Fritz	Herve
Gakuya	Francis
Giraudoux	Patrick
Goumou	Souana
Gozlan	Rodolphe
Guegan	Jean-Francois
Hamelin	Estelle
Hassell	James
Hayman	David
Hochman	Gilberto
Hofmeyr	Markus
Holmes	Edward
Jolma	Rosa
Kleitz	Gilles
Knight-Jones	Theo
Kocher	Arthur
Kock	Richard
Korukluoglu	Gulay
Leach	Melissa
Lynteris	Christos
MacGregor	Hayley
Machalaba	Catherine
Martel	An
Maudling	Rebecca
Mc Kay	Fernando
Mendoza	Hugo
Meredith	Anna
Mugabe	Prisca
Munyeme	Musso
Nguyen	Hung
Novaes	Roberto Leonan
Olson	Sarah
Petrini	Antonio
Petrovan	Silviu
Peyre	Marisa

Prins	Herbert
Randolph	Delia
Redding	David
Roche	Benjamin
Ruegg	Simon
Schmid	Boris
Sheath	Danny
Sizer	Nigel
Skotnes-Brown	Jules
Sokolova	Marina
Sommer, Prof Dr	Simone
Suu-Ire	Richard
Turkozan	Oguz
Valenzuela	Andres
Vora	Neil
Walzer	Christian
Wang	Linfa
Wilson	Nick
Wood	James
Woods	Rupert
Zambrana-Torrelio	Carlos
Zinsstag	Jakob
Participant to the survey 84	
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Participant to the survey 120	
Participant to the survey 121	

Annex 7:
List of focus group participants

The following table summarizes the names, position and expertise of the participants.

TITLE & NAME	ORGANISATION	POSITION
Dr. Bernadette Abela-Ridder	World Health Organisation (WHO)	Team leader, Neglected tropical diseases
Assoc. Prof. Nüket Bilgen	Ankara University, Faculty of Veterinary Medicine, Genetics Lab	Associated professor
Prof. Andy Dobson	Princeton University	
Prof. Eric Fèvre	ILRI / Uni. Of Liverpool	Researcher
Dr. Amanda Fine	Wildlife Research and Training Institute, Kenya	Director of One Health, Health Program
Dr. Francis Gakuya	Wildlife Research and Training Institute, Kenya	Director of field services
Dr. Richard Kock	Royal Veterinary College	Researcher (retd)
Prof. Christos Lynteris	St Andrews Uni	Professor
Rupert Woods	Wildlife Health Australia, WOAH Working Group on Wildlife	

Annex 8:
Points of discussion during the focus group discussion

Session 1: Introduction

The facilitator welcomed the participants and after presenting a few rules of conduct gave the floor to a member of the EWG to summarise the background, objective of the Eklipse request and of this focus group discussion. After this short introduction, participants and EWG members facilitating the focus group discussion (in one way or another) were provided a space on the virtual board followed by a minute or two to present themselves. Prior to the discussion, the results of the survey and basic instructions on how to use the online programs and the agenda of the meeting were shared with the experts.

Participants were asked if they had any question on the objectives or the process that listed below:

- *Participant question:* What is the outcome that you want to achieve?
- *EWG answer:* the objective is to feed the strategic agenda of different EC general direction (list different DGS) as well as of other requesters.
- *Serge Morand answer:* It is important to make the EC realize the importance to work interdisciplinary and open the silos and not only work on one level but in many levels
- *Participant question:* What kind of pandemics?
- *Serge Morand:* we are here concerned by human health but also animal health, but not really plant health. As the request focuses on biodiversity, it is taking into consideration ecosystem services.Participant question: is it only European wide or international?
- *EWG answer:* it is both.

Session 2: Policy recommendations

The session was driven by the facilitator asking a set of selected questions. During the first session the experts discussed the policy recommendations from the survey. The discussion started with one member of the EWG introducing the topics/thematics proposed in the survey and the survey prioritisation results. Then the experts were asked to discuss the proposed policy recommendations, highlighting any surprising results, adjustments needed and important items missing. Next in order, a discussion followed on the priorities given in the survey, captured by asking the experts what they thought the main criteria were for those priorities.

"**What were your first reactions to the proposed policy recommendations?**"

- *Participant 1:* These policy recommendations does not seem focused enough. For example, the CONSERVATION item seems an utopic recommendation. If we look at South Asia, the transformation has already happened, the encroachment story is already history. In the context of a pandemics, we have to recognize how the world is going and we are not going to stop this. It is not a reality to think that we can operate the changes requested in this recommendation. I think this is a very Western philosophy about protecting wildlife and trying to prevent the integration of humanity into nature.

- *Participant 2:* I wanted to say, effectively, a similar thought on the food systems policy item. The idea that food systems are so well organised and that we can change something by pushing the red button is also utopic. We have a multitude of things that we should do at small scales to be more realistic in the case of policy that we want to put in place. For example, one scale could be to look at each commodity and the details of the value chains and think of the different commodities partially. We need to be "commodity specific".

- *Participant 3*: many of these proposals can confuse policy makers, as they are complicated. They would need more policy adaptation. It seems that we should improve some blocks for example:

1. Wildlife and environmental health is given equal priority to animal and human health in policy development relevant to human, animal and environmental health.
2. That each EU country should have a wildlife health surveillance system that is integrated into their animal and human health arrangements.
3. That policy development and decision making should be evidence- and risk-based.

4. Another policy recommendation might be that all EU countries develop an all-hazards health protection framework.
5. All EU countries agree that wildlife health surveillance data should be shared between them.

› *Participant 4:* I think I have a general comment across the list, which is the lack of community-led approaches to any of these items, as the others are so well spotted, and they all seem to be very top- down items, and not really interested in engaging with local communities beyond the narrow framework of either educating them or making sure that they comply with whatever the "wise" people of Europe think. So, there is a lack of bottom-up answers, with community lead approaches/community knowledge involvement and production. The assumption is that knowledge comes from the experts, not from the local communities which we know is not true especially in epidemic contexts.

"**How would you go one step further and add some recommendations?**"

› *Participant 1:* I think it's important that we get the scope precise in relation to these policies because if it's too generic you know we're not going to progress. Coming back to pandemics and if we are restricting ourselves to human diseases, then we have to frame that there is a sort of top-down element to this in the context of understanding how pathogens evolve. We have these very commonly used statements about "60% of human pathogens that exist originated in animals". But actually, of those 900 odd pathogens that come from animals only about 200 emerged recently or are currently presenting a threat to human health. The rest, these 700 plus pathogens have evolved from animals and the emergence in humans happened over thousands of years. Therefore, we need to really focus our attention on how these rare but important emergence events (i.e., spillover) occur and ensure that our policies are directed towards understanding those events. In the end, solutions are with communities and how they understand and mitigate risk.

› *Participant 5:* I agree with Participant 1. It's important to determine what gives the ability to the organism to trigger a pandemic. Therefore, I think we have to use more genome analysis studies and determine which genes or which regions make them capable of causing a pandemic actually and in future, we might know which organisms could cause pandemic, so we can prevent it by making vaccines.

› *Participant 4:* I think there is a general mistake which is rather endemic to interdisciplinary discussions when social scientists are involved when it comes to policy. For example, all work social sciences are expected to do is basically behavioural science, related to risk understanding and risk averse behaviours. But in fact, as we know from actual studies and experiences in the field, this is not the most important aspect. We have endless studies that show that people are very well aware of the risks, but the political economy, the political system and the land economy will never allow them to living conditions which do not constantly catalyze actual risks for zoonotic spillovers. It's very important to have these aspects of political economy, of structural violence highlighted in the policy because here we imagining this liberal free completely economically independent individual who can take sovereign decisions on their life and on their contact with animals. This is almost never the case as we're all constrained by all these structural conditions especially in the global South. I have the feelings those recommendations are kind of addressing the global or national levels and not the local one. So maybe there is some question of breaking down to the right level what can be done in terms of policy so that for example.

› *Participant 7:* I actually need the clarification so I agree with Christo. I really believe we've got so many tools and different ways of making progress and but if communities are not engaged, this is useless

› *Participant 6:* The recommendations are quite vague and they are lacking focus. It does seem strange that any consideration of economics is not part of these items. If we look at the COVID-19 pandemic or foot-and-mouth disease or even HIV, most of the decisions were driven by economic considerations. And even some politicians looking for profits out of the epidemics. We need to have better ways of integrating the biological information and understanding of epidemics and the understanding of the economic benefits of biodiversity in order to integrate into a stronger framework. The politicians will never listen to CITES if the economics are not backing them.

- *Participant 8:* I agree, we have to look at it from different perspectives. I think politics should tackle the challenge of reducing the risk of zoonotic spillover. The ecological drivers, that are well known, and that are linked to anthropogenic drivers. They are people-centred and we have to look from the perspective of land use policies and the available space for conservation and human use. I'm not seeing away where we can just approach it within one one way and it has to be holistic. If there is no consideration of alternative sources of livelihood in those regions, the people cannot somehow be empowered to change practices. Which has more impact? Zoonotic diseases or the economic resource provided when taking the risk of exposing oneself to a disease.

"**What did you think of the prioritisation?**"

- *Participant 5:* considering the origin of the COVID-19 pandemic into wildlife and the consequences associated, the wildlife being a little down in the list is not acceptable. I think it should be higher and we should have more proposed policies about wildlife trade.

- *Participant 6:* I am asking myself if it was not just random. A statistician would say there is no pattern here.

- *Participant 1:* Just quickly to back up what Andy is saying. It is a pretty eurocentric view in the way priorities are falling out. Some of them aren't even priorities: for example, monitoring is irrelevant because everything depends on evidence, so you always need monitoring. The same applies to governance: we always need governance. Maybe some things may have been diluted as maybe it was not precise enough, as it includes many aspects. Another approach would be for known zoonosis, we should have a bottom-up approach because we know what it is and we want to know what reality on the ground is. When it comes to pathogen emergence, we don't know what it is, and so we need a different policy based on risk for example. As a policy, it would need maybe to have some feedback from policy actors from different levels. It would need to be reworked question by question.

In summary, participants suggested that policy recommendations were too broad as presented and needed to be simplified to provide more concrete policy recommendations for achieving broad aims. It was also noted that separate recommendations and research priorities may be needed for currently circulating versus emerging pathogens and zoonotic diseases. Participants generally agreed that the proposed policy recommendations lacked sufficient integration and reference to social sciences, community involvement, and economic and social drivers. A feedback from policy actors would probably be needed for this section.

Session 3: Knowledge gaps/research recommendation

The second session's discussion was on knowledge gaps and research recommendations. The discussion proceeded in the same way as the first session, starting with questions from the facilitator.

"**What are your thoughts related to this section?**"

- *Participant 1:* the biggest gap would be on zoonosis diagnosis in humans. Until we get
- that right, it is a huge gap. The tools do not exist for community level in LMICS for example.

- *Participant 3:* priority "research areas" (knowledge gaps) for us would be structures to rapidly provide: 1) risk assessment; 2) theory of change (issues based and to identify research needs), and; 3) value proposition (to aid with prioritisation).

- *Participant 2:* there is an issue of geographical scale. Tendency to draw pictures at continental scale of risks and priorities. For example, an urban environment consists of so many different niches and complexities. This kind of knowledge has to be generated at multiple different scales simultaneously to understand how these interactions are taking place socially, economically and ecologically. A real appreciation is the geographical scale at which there is this thinking.

- *Participant 4:* I will repeat myself from my comments on recommendations. What is missing is an approach which considers the broader political economic processes and forces which are shaping environments and human-animal interactions rather than just perceptions and values. And this should be surveyed/followed over a meaningful period of time rather than simply in the present. Anthropology is needed to understand how things have been shaping up in the last few decades in order for us to understand what is shaping these interactions which are not just the outcome of will or choice. The research gaps so far are very behaviorally focused. We really need proper social science and humanities involved here.

- *Participant 7:* First diagnostic techniques and recent studies are actually more focused on biosensors to detect microorganisms. We should have more research on these biosensors that could be really helpful for early diagnosis.

- *Participant 8:* at least social aspects have come out very clear as one of the main areas of research that you should focus on so that you can get those perspectives from communities and people who live with wildlife. When looking at drivers of spillover, if you look at social alone without the economics, then it becomes a major issue, so I tend to believe it should be a socio-economic approach. I also want to agree with Participant 1 about diagnostic techniques validated for wildlife.

- *Participatory 1:* I think a missing research area in the list is population sciences - impacts of changing demographies which determine risk of emergence and host vulnerabilities especially with human hosts.

- *Participant 9:* For the kind of transformation that we anticipated, it is required to address the drivers of infectious disease emergence. This really delves into the sort of cultural, economic and social drivers which the participants have just highlighted here. But I feel that it is just more than surveys but a deeper understanding, what economically and culturally is driving not only individuals but societies and industries in ways that is providing incentives to reflect on impact on the environment and biodiversity in particular. On ecology, I think in-depth studies of the ecology of these potential reservoir species link with the viral ecology and how these populations have been impacted To use the comment from Participant 1 about populations sciences more on the human side, the same applies to wildlife populations being impacted by changes and in their environment and natural and anthropomorphic interactions with humans as well as other species.

- *Participant 1:* “agriculturisation”, including of wildlife species is an area that deserves focal attention.

“How would you unfold it in a more relevant way?”

- *Participant 9:* from my experience working in Southeast Asia, you often can’t take this approach at a huge scale but at a specific location or site that really ensures that you have the full complement of research expertise, the ecological, the viral, some of the diagnostic approaches as well as really taking the time to have the full complement of stakeholders involved and allowing time for that process. Also to spend the time to explore and allow feedback to come from local communities, the local administrators and the scientific community and having those of ecologists as well as sociologists and people with political and cultural expertise. The design of the research study is built on a foundation of understanding the context very deeply that allows you to start to untangle some of these very complex interactions. This means having the funding and time for the co- development of the approaches.

- *Participant 3:* I don’t do research and our approach is very different and risk-based. We run the risk assessments, we look at the theory of change, we see what’s needed and then we apply it. I am struggling to see that the actions needed at a continental scale. I just wanted to make that comment just to be careful of endlessly doing research. I would let the action drive the research rather than the research drives the action, which is a terrible thing to say isn’t it? Our research is focused on developing systems on which we can make decisions because you need to take decisions regularly. We do need research strategies that can run in parallel. For the EU, you need systems to know how to get the job done on the ground. So somehow your research strategy is going to have to be agile, nimble,

> fit for purpose and context specific. As Participant 9 says, you need to bring that balance between activities that bring quick wins and long-term studies and how you balance that. If the purpose is to to develop and identify a strategic research agenda in order to make future action more effective, then you need those systems. For any sort of organisational structure, you will need governance, systems, documentation, capacity, capability and rehearsal. So an organisation should be interested in research to provide good governance, the good systems to identify the documentation to identify the missing capacity and capability and to help me with rehearsal and that's all about risk management.

In summary, focus group discussion participants identified a few specific items like: the need for better diagnostic for zoonotic diseases in humans and wildlife; the relevance of the scale of studies within habitat/study site and between them in order to be able to compare them; the need for changing the way social sciences are currently "manipulated" in health study in order to give their deserved space of study; or finally the need for more population sciences for humans and wildlife. An extensive discussion went on on the relevance of research and its impacts. In terms of relevance, in-depth studies addressing the multi-scale and multi-disciplinary approaches are needed to address the complex systems in which disease and health issues occur. Then, research should be woven into risk-management systems that lead to decision and action in order to be relevant for policy makers.

Session 4: Interdisciplinary priorities and possible projects

For the final session, participants were divided into two groups of 4-5 participants. The group members were pre-assigned and each group included participants from different disciplines to ensure interdisciplinary discussion. In this session, each group had to identify interdisciplinary research project ideas at the intersection of several research gaps and design together an interdisciplinary project taking into consideration at least 3 of the proposed research gaps. The groups were asked to provide a potential project including a title and a pitch, recommend length/amount of funding for such a project and give an example of how this could be done (ex. One Health approach). The objective of this session was to have a more concrete interdisciplinary discussion on priorities and moving from general themes to more concrete potential research projects. During the discussions, the facilitator moved between groups to ensure the instructions were clear and check how discussions went. Feedback from each group was presented by one of the experts of each group.

Group 1 feedback

Title: Integrating socio-economic-political science into technical solutions for disease diagnosis and management: addressing externalities for enhanced public health outcomes.

This title sets the interdisciplinary frame for the whole thing. We build into the project a core component of socio-economic-political science in relation to externalities. We have the technology developing particularly in relation to the interface, whether it be wildlife, whether it be public health, or zoonosis diagnosis, it's really trying to wrap this thing up so we're beginning to understand pathways and where things come from and go to.

A good example would be vaccines coming out of these management tools in relation to those sorts of pathogens that we see as a potential risk. The issue is communities are becoming more resistant to things like vaccines because people are not involved a lot in the decision-making process and the intervention is being imposed upon society in many ways through the political process. The community-based approaches are a key element to determine what is needed actually and what is acceptable to societies. There's always this danger with medicine which is a bit like developing weapons against microbial nature and there's an industrial complex that goes with these developments of drugs and vaccines. The socio-ecological systems research framework is a principle that would be very good and we need pilot sites, from high to low income settings because they provide very different contexts. A five-year time frame perhaps with a budget of 10M€. Isn't that modest?

Group 2 feedback

Title: Consortium to understand and mitigate public health threat that emerge from accelerating environmental changes in the tropics

It focuses on public health but is strongly linked to issues related to wildlife, livestock and ecosystem changes. We're looking at an initial period of 10 years potentially maybe eight with 12M€ of funding and then 20 year implementation period after that with monitoring and real-time actions with further potentially 20M€ or more. The focus here responds to the needs on the ground on encroachment and habitat loss and a

big element of this is understanding the social elements of why there is loss, how people are modifying their environment and why and what the economic and social drivers are to habitat loss and how policy meaning at a national level but also how communities manage themselves as a potentially unwritten policy at another level. Governance will be at all those multiple geographical scales. Secondly, this consortium would have a very specific focus on the biology of the pathogens at these encroached interfaces and a focus on wildlife, livestock and humans and the broader environment in which all of those things sit. We would have to deconstruct those parts of it much more before we would get the funding obviously. This is within a context of very strong Data Systems that support decisions and with kind of real-time policy feedback: tinkering with developing policy interventions at different scales and testing those policy interventions to see what real world impact they have which is why the timescale is so long, and then altering that policy very proactively to make sure that it's working in the most beneficial intended way. This speaks to_the priorities of national governments which signed up to the priorities of Africa CDC, WHO, WOAH, UNEP and FAO through the OHHLEP mechanism in particular.

Discussion on group work

- *Participant 3:* (referring to Group 2): it'll be successful because it's already building on work that's underway and it can serve as a proof of concept. These are low-hanging fruits. It directly supports objective 1 of the WOAH wildlife framework. It improves the countries' ability to manage a risk of pathogen emergency in wildlife and transmission at the human-animal-ecosystem interface whilst taking into account the protection of wildlife.

- *Participant 9:* the process and discussion and the representation of who was here in terms of expertise was relevant to build the collaborative interdisciplinary component. Having national scientists doing the work is critical. Even if it was very brief the involvement of practitioners in the group, it built the needed consensus around these issues. It translates to how will the work actually get done, what's the framework, what's the human infrastructure for getting that done. About them on there for this feedback.

- *Participant 1:* we have to ask questions. The focus is Africa (for group 2). Why don't we look at areas in the world where land transformation is very advanced? Why do we always go back to a continent where it's at an earlier stage of transformation. That could help to try to understand what has already happened in many other parts of the world. So for example India has the highest level of zoonosis globally and a huge population in a highly transformed landscape with a very integrated human-animal interface. We're always looking for the dark unknown whereas we should look at the obvious and try to learn what did they do, what were the societal, economic and social-cultural aspects which led to the situation with increased risk of zoonosis and in the context of emerging pathogens. It is just a question?

- *Participant 2:* interesting thought. The pace of change and the scale of change is so vast at the moment in Africa and in sub-saharan Africa specifically that we're dealing with the time scale and the scale of change is pretty unprecedented. If we look at areas where these changes have already become well embedded those changes may have happened over a 100-year period whereas in Africa that is happening over 20 years. The implications for the people who are living with those changes are within a generation.

- *Participant 3:* it's about going forward and what's the opportunity. Can we actually identify good people working on the ground already trying to do this because a lot of this stuff is already underway in many places all over the world, but what they don't have is the resources to either do it properly or to realise their vision or to apply the timeframe that they need to actually put the monitoring and evaluation to get the results.

Session 5: Wrap up and next steps

Feedback from EWG

After thanking the participants for their time and involvement, the following comments were made:

- In terms of policy, good governance is a key.
- In terms of knowledge gaps, the participants suggested many approaches and methods such as community-based, risk-based and theory of change.
- One of the things that really came up in both the policy as well as the research gaps was this focus on bottom-up approaches and having local communities being more involved to avoid top-down approaches.
- We found the social sciences were being brought in not just by the social scientists in the group. Recognizing the importance of a better integration of social sciences to address some of the biggest knowledge gaps is necessary because what's happening at the biological level cannot explain everything.
- We also heard the need to have more concrete policy suggestions. Our policies suggestions were very broad although this did come from the search of the scientific literature from which these policy recommendations came from.
- There was maybe a little bit of disagreement with the prioritisation of the policies. This comes back to this tension between a sort of trend towards the need for broad transformational transitions at global level versus the need to work more at a local scales
- We noted the tension between the need to use monitoring and predictions in early detections to follow what's happening and be able to react quickly versus the need to take into consideration these big recommendations of conservation and food systems transformation in order to make the systems a bit more resilient at the root. These two threads do have to work in parallels.
- The project sessions integrated that idea of local chain, local involvement and local context but also bringing in that a more global vision. Some of those tensions can also be resolved partially when we put things into practice because it seems one can't do one without the other.
- After the participants were offered a moment to reflect back on the focus group discussion during which they thank the facilitator and the organising team for a short but efficient workshop, then Serge Morand closed the meeting thanking all the guests that "permitted this very successful and useful focus group to conclude the scoping review and the survey process.", the EWG for their work and the facilitators, Estelle and Hugo.


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