Food and Agriculture Organization of the United Nations

UN environment programme

World Health Organization

World Organisation for Animal Health
Founded as OIE

Quadripartite One Health Intelligence Scoping Study

◆

Final Report

Supplementary Material 2: Characterizing the Risk Landscape (Riskscape) for Global One Health Intelligence

Contents

Executive summary

Objective: The scope of One Health is large and different sectors will approach it with different perspectives and priorities. The needs of One Health intelligence users will relate to the hazards and associated risk questions they must address. While this may be specific to certain jurisdictions and sectors, a shared understanding of the One Health riskscape will provide a foundation to improve intersectoral information exchange and build appropriate intelligence systems.

Method: As part of the One Health Intelligence Scoping Study (OHISS), key One Health hazard categories were identified and analysed using an all-hazards approach. Four example categories were then chosen from among those considered a high priority by the Quadripartite organizations, and a multidisciplinary method was tested for mapping risk pathways and associated drivers, impacts, vulnerabilities and critical monitoring points. In June 2022, 273 subject matter experts gathered for a series of workshops to provide a rapid and high-level illustration of this method using risk bowtie diagrams.

Results: The Quadripartite identified 17 categories of One Health hazard, including biological, chemical/radiological, meteorological/hydrological and environmental hazards. The categories were broad enough to include unknown hazards. Bowtie diagrams were completed for four categories: epidemic and emerging zoonotic diseases; antimicrobial resistant microorganisms; contamination of water and soil from chemical fertilizers/pesticides; and non-zoonotic animal diseases affecting food security. Many critical monitoring points (e.g. human/animal waste, wildlife health) and vulnerabilities (e.g. lack of biosecurity, poor vaccination) were identified along the pathways, as were links between bowties.

Conclusions: The ideal operational One Health intelligence system (OHIS) needs to have the flexibility to support multiple risk questions related to different types of hazards, including unknown hazards. Those looking to gather and use One Health intelligence should follow a risk-based, iterative process – defining the problem and determining critical monitoring points and associated data sources.

Abbreviations

EAG	External Advisory Group
OHHLEP	One Health High-Level Expert Panel
OHISS	One Health Intelligence Scoping Study
OHIS	One Health intelligence system
SARS-CoV-2	Severe Acute Respiratory Syndrome Coronavirus 2
UNEP	United Nations Environment Programme

Introduction

The scope of One Health is large and, as defined by the One Health High-Level Expert Panel (OHHLEP), includes a broad range of "threats to health and ecosystems" (OHHLEP, 2021, p. 13). In addition, the OHHLEP definition directly reflects many of the 17 Sustainable Development Goals: not just good health and well-being, but also zero hunger, clean water and sanitation, climate action, life below water and life on land, among others.

As a result, different sectors and jurisdictions will approach One Health with different perspectives and priorities. The ideal operational One Health intelligence system (OHIS) should, therefore, have the flexibility to support multiple risk questions related to different types of hazards, and to accommodate the range of drivers and impacts important to these hazards. The needs and goals of One Health intelligence users will relate to the hazards and associated risk questions they must address.

At the same time, a shared understanding of the risk landscape (i.e. riskscape) of One Health will provide a foundation to improve intersectoral information exchange and build appropriate intelligence systems.

The One Health Intelligence Scoping Study (OHISS) conducted a preliminary exploration of the One Health riskscape with the following objectives:

1. Identify key One Health hazard categories and determine which of them the Quadripartite[1] organizations would prioritize for an OHIS.
2. Test an approach for mapping risk pathways and associated drivers, impacts, vulnerabilities and critical monitoring points on a subset of hazard categories.
3. Start to develop a shared understanding of the scope of One Health intelligence and connections between hazards.
4. Use the examples to enhance understanding of how various datasets relate to the One Health hazards of concern, in order to inform operational prioritization of data.

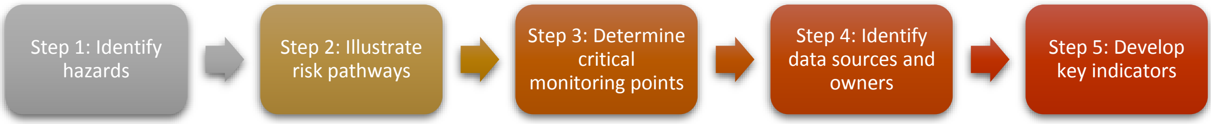
[1] The World Health Organization (WHO), the United Nations Environment Programme (UNEP), the Food and Agriculture Organization of the United Nations (FAO) and the World Organisation for Animal Health (WOAH, founded as OIE).

Methodologies

The approach

The OHISS proposes (and partially trialled) a risk-based approach to contribute to the development of a high-level framework for an operational OHIS. This approach includes a stepwise process of defining the problem and determining critical monitoring points and associated data sources (see Figure 1). The process, which can be tailored to the needs of different sectors or jurisdictions, starts with hazard identification (Step 1). The scope and specificity of the hazards identified will depend on the risk question under consideration.

Figure 1: A stepwise risk-based process for defining a problem to be addressed by One Health intelligence and determining critical monitoring points and associated data sources



Source: Authors' own elaboration.

Once the hazards within the scope have been clarified and described, illustrating the risk pathways (Step 2) (including causes/drivers, consequences, vulnerabilities and connections between hazards) will allow critical monitoring points to be mapped to the associated risks. The granularity of these pathways should match the specificity of the risk question. The risk pathways associated with many known One Health hazards have already been explored in detail within the literature.[2] However, for risk questions with broader scope and lower granularity (e.g. questions related to preparedness for the next pandemic), it may be useful to gather multidisciplinary expert input to elaborate on high-level pathways. This approach can identify critical monitoring points or data streams that are non-specific, and therefore could support a more holistic view of upstream drivers and downstream impacts.

In Step 3, critical monitoring points are identified along the various pathways. As in the previous step, the scope and specificity of these points can be geared to a particular risk question. The remaining steps of the process include, for each critical monitoring point, the identification of data sources and the owners of that data (Step 4), and the development of key indicators and methods to operationalize or report against indicators (Step 5).

[2] See Adipah, 2018; Islam *et al.*, 2020; Nielsen *et al.*, 2020; Oniciuc *et al.*, 2017.

Testing the approach with the Quadripartite

Within the OHISS, this approach was initiated with a high-level, global perspective in mind.

Step 1: Identify hazards

A hazard identification exercise was conducted with the Quadripartite organizations in May 2022 to explore the scope of One Health hazards and highlight key priorities for a global OHIS. The definition of hazard used for the exercise was that used by the United Nations General Assembly in 2017:

> "A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation" (United Nations Office for Disaster Risk Reduction, 2020, p. 9).

Although many human and animal health risk assessment disciplines use a more restricted definition of hazard that is focused on biological, chemical or physical agents, the "all-hazards" perspective of the United Nations definition is more inclusive of the range of potential One Health threats (United Nations Office for Disaster Risk Reduction, 2020).

An initial list of hazard categories was drafted, following a structure similar to that used by the United Nations Sendai Framework and illustrated by the United Nations Office for Disaster Risk Reduction (2020) and the World Health Organization (2020). Hazards were considered to be "One Health hazards" if their risk pathways (from drivers to impacts) would be expected to intersect human, animal, plant and ecosystem health. Examples of specific hazards within each category were given, but the exercise focused on categories (rather than individual hazards) to ensure that unknown and not-yet-emerged hazards would be included.

The initial list was shared with focal points from each of the Quadripartite organizations, who were asked to identify if any categories were missing. They were then given a chance to individually comment on whether their organization would consider any of the categories high or low priorities for a global OHIS. Focal points consulted internally as needed. The exercise aimed to identify common priorities across the organizations, as well as individual organizational priorities.

Steps 2-3: Illustrate risk pathways and determine critical monitoring points

From 7 to 10 June 2022, 273 subject matter experts gathered for a series of workshops using four One Health hazard categories chosen from among those considered a high priority by one or more of the Quadripartite organizations. The aim was to provide a rapid and high-level multidisciplinary illustration of risk pathways and associated critical monitoring points using a risk bowtie diagram approach. A call for expert participation was distributed widely, and all registrants were accepted. The call and workshops were provided in the English language only.

The risk bowtie diagram is a method of illustrating risk pathways, both before and after an adverse event, which has been used in various high-risk industries for decades (Culwick, Endlich and Prineas, 2020; Lindhout and Reniers, 2020; Wolters Kluwer, 2022). Drivers and causal pathways (i.e. a fault tree) are presented to the left of a central adverse/unwanted event, while cascading impacts (i.e. an event tree) are presented to the right.

A traditional application of a bowtie diagram focuses on identifying potential barriers (i.e. prevention and mitigation measures) along the risk pathways. When barriers are identified along a pathway, the effectiveness and potential failures of those barriers can be examined. In essence, bowtie diagrams traditionally identify vulnerabilities in the system. However, the aim of the workshops was to use a non-traditional application of a bowtie diagram, by identifying critical monitoring points along the pathways, rather than barriers. Nonetheless, the expert participants identified a number of failures/breakdowns of barriers to expand the risk pathways, as well as critical monitoring points associated with the barriers and vulnerabilities identified.

The workshops comprised three main parts, in which experts were asked to place Post-it notes on a Klaxoon whiteboard to: 1) add drivers or causes, positioning them horizontally relative to a scale ranging from "upstream driver" to "immediate cause", and add connections to form pathways; 2) add impacts/consequences, positioning them horizontally relative to a scale ranging from "immediate impact" to "long-term impact", and add connections to form pathways; and 3) identify critical monitoring points, placing them either along a pathway or in the appropriate general horizontal position.

Each of the four workshops was held at two different times, to accommodate participants from different time zones. Following the workshops, expert input from the two sessions was combined, and the OHISS team's early warning and risk modelling specialist clarified the risk bowtie diagrams by removing duplicates and combining similar concepts, adding connections to link steps in a pathway, distinguishing between drivers and barrier failures, removing recommendations to be separately noted, resizing/repositioning notes for readability, and linking critical monitoring points to the relevant pathways where required.

Step 4: Identify data sources and owners

The bowtie exercises conducted within the OHISS, on the four high-level hazard categories, were intended to test a multidisciplinary process and to start to develop a shared understanding of scope. Steps 4 and 5 were not conducted at this level of granularity for the hazard groupings identified by the Quadripartite organizations due to the limited timescale of the study.

As pointed out by the External Advisory Group (EAG), an important future step, once critical monitoring points are determined, is to figure out details, such as exactly what would be monitored (e.g. specific pathogens and ability to detect novel pathogens), where monitoring would occur, how often and the associated feasibility.

Step 5: Develop key indicators

Although not conducted as part of the OHISS, the development of key indicators (i.e. thresholds or markers that would suggest that the unwanted event potentially caused by the hazard might actually occur) is a crucial step for One Health intelligence. Research is needed to inform these indicators, especially at the boundary between sectors, such as understanding the interdependencies of natural ecosystems and health.[3]

[3] See Hambling, Weinstein and Slaney, 2011; Malecki, Resnick and Burke, 2008; Morris *et al.*, 2022; Subramanian and Payyappallimana, 2020.

Results/findings

Objective 1: One Health hazard categories and priorities

Since different sectors approach One Health with different perspectives and priorities, the co-identification of hazards and key concerns helps to ensure that the results of intelligence activities are useful to support decision-making and risk communications. This addresses the question: “What are we gathering intelligence on, and why?”

The 17 One Health hazard categories identified by the Quadripartite fall into four main types: biological, chemical/radiological, meteorological/hydrological and environmental (see Table 1). They were not categorized as human-induced versus natural as it becomes very difficult to distinguish the two, especially since human-induced drivers could be identified for each.

Many of the hazards listed in Table 1 could also be considered drivers and impacts of other hazards. Hazards were included if, from the One Health perspective, it might be useful to explore them as a central unwanted event with the development of risk pathways that would include various drivers and impacts. In addition, there is not an easy-to-define boundary between a One Health hazard and other hazard types, given the broad scope of One Health. The list is therefore not exhaustive. It is nonetheless a worthwhile exercise for collaborative purposes. Several other factors, such as social, political or infrastructural factors, although included as drivers, could also be explored as a central unwanted event (for example, exploring all the drivers and impacts of political unrest), but this type of analysis is likely being conducted within other fora.

Table 1: One Health hazard categories, by hazard type, identified by the Quadripartite organizations

Hazard type	One Health Hazard category	Example(s)	Why it falls within the scope of One Health
Biological	Epidemic and emerging zoonotic diseases, and human diseases with an animal origin	Rift Valley fever virus, SARS-CoV-2, Avian influenza virus, Ebola virus, monkeypox virus	Zoonotic diseases, which pass between animals and humans (including reverse zoonoses, from humans to animals) clearly lie at the interface of human and animal (domestic or wild) health, with many ecosystem health factors acting as drivers. The same is true of diseases that may have had an animal origin but then become predominantly transmitted among humans.
Biological	Epidemic and emerging arthropod-transmitted human diseases	Malaria	Some human vector-borne diseases may not be considered zoonotic if they rarely infect vertebrate hosts besides humans. Nonetheless, they require significant collaboration between environmental and human health disciplines.
Biological	Endemic zoonotic diseases affecting food/water safety	*Escherichia coli, Salmonella* spp.	Human and livestock/food sectors have a long history of collaboration related to endemic zoonotic diseases affecting food and water safety. Environmental factors also play a significant role in pathogen survival and spread.
Biological	Neglected endemic zoonotic diseases	Echinococcosis, leishmaniosis, rabies virus	Although they may not have the same ability to cause global outbreaks and pandemics as those hazards in the three categories above, neglected zoonotic diseases can have a large burden on low- and middle-income countries and clearly require a One Health approach to control.
Biological	Antimicrobial resistant organisms	Multidrug resistant bacteria (e.g. *Staphylococcus aureus*, *Escherichia coli*, *Klebsiella pneumoniae*), fungicide resistant fungi (e.g. mildews, leaf blight)	Resistance to antimicrobial treatments may develop in humans, animals (domestic or wild) or plants, and may spillover from one population to another. Resistant organisms may also be found in the environment.

Hazard type	One Health Hazard category	Example(s)	Why it falls within the scope of One Health
Biological	Non-zoonotic (endemic and epidemic) animal diseases with indirect effects on human health and well-being	African swine fever, bluetongue, foot-and-mouth disease virus, peste des petits ruminants	While non-zoonotic animal (domestic or wild) diseases do not infect humans, they may nonetheless have an indirect effect on human health and well-being by decreasing animal production, changing human behaviour, having an economic and environmental impact, affecting livelihoods and/or food security.
Biological	Plant pests/diseases with indirect effects on human or animal health and well-being	Cassava viruses, desert locusts	Similar to non-zoonotic animal diseases, significant plant pests/diseases may have indirect effects on human or animal (domestic or wild) health and well-being.
Chemical/radiological	Pollution/environmental contamination	Mercury, oil spills, air pollution	Chemical contamination of air, land or water can affect human, animal (domestic or wild), plant and/or ecosystem health.
Chemical/radiological	Chemical/radiological contaminants in food/feed/products	Pesticides, veterinary drugs	Chemical or radiological contaminants may be present in food, feed or other products, either through direct application/administration or via environmental contamination and may then affect human or animal (domestic or wild) health.
Meteorological/hydrological	Climate change	Increasing global temperatures, changes in precipitation and sea level	Climate change is an upstream driver of many of the other One Health hazards listed; however, it will also be considered a hazard on its own due to other direct and indirect impacts at the human-animal-ecosystem interface that are not captured within the other categories.
Meteorological/hydrological	Extreme temperatures	Heat stress	Extreme temperatures can affect the health and well-being of humans, animals (domestic or wild), plants and/or ecosystems.
Meteorological/hydrological	Increased frequency/severity of disasters (linked to climate change)	Floods, droughts, ice storm	The increased frequency or severity of natural hazards that result in disasters can affect the health and well-being of humans, animals (domestic or wild), plants and/or ecosystems.

Hazard type	One Health Hazard category	Example(s)	Why it falls within the scope of One Health
Environmental	Resource depletion/scarcity	Water scarcity, soil loss/degradation	Resource depletion and scarcity can affect crucial aspects of health and well-being for humans, animals (domestic and wild) and plants, such as availability of and access to clean water.
Environmental	Reduction/change in provisioning ecosystem services	Reduction of wild-sourced foods and fodder, loss of genetic resources for crops	Damage to ecosystems can affect the health and well-being of humans and animals (domestic or wild) through the reduction or change in provisioning services, such as wild food and medicines (including loss of diversity), water supply, sources of energy and construction materials, or genetic diversity.
Environmental	Reduction/change in habitats/supporting ecosystem services	Increased risk of human-wildlife conflict, loss of nutrient cycling	Damage to ecosystems can affect the health and well-being of humans, animals (domestic or wild) and plants through reduction or change in soil formation, nutrient cycling, and provision of habitat. Changes in distribution and habitat ranges of wildlife can increase human-wildlife conflict.
Environmental	Reduction/change in regulating ecosystem services	Increased erosion affecting water supplies, reduced filtering of pollutants	Damage to ecosystems can affect the health and well-being of humans, animals (domestic or wild) and plants through reduction or change in regulating services, such as regulation of floods, drought, land degradation, water quality and disease.
Environmental	Reduction/change of cultural ecosystem services	Reduced green space for recreation, exercise and mental well-being	Damage to ecosystems can affect the health and well-being of humans through reduction or change in cultural services, such as recreational, spiritual, religious and other non-material benefits.

Source: Authors' own elaboration.

Note: Examples are given within each category, but they are not intended to be exhaustive and would include unknown and not-yet-emerged hazards. A brief description of why the hazard category is considered to fall within the scope of One Health is also provided.

The two hazard categories identified as high priorities for One Health intelligence by most Quadripartite organizations were "epidemic and emerging zoonotic diseases/human diseases with an animal origin" and "antimicrobial resistant organisms". Other hazard categories were identified as priorities for One Health intelligence, but from the perspective of only one or two organizations, including “neglected endemic zoonotic diseases”, “non-zoonotic animal diseases with indirect effects on human health and well-being” and “pollution/environmental contamination”. The fact that these hazard categories were identified by only one or two organizations does not necessarily reflect their importance globally, but rather the organizational mandates and current strategic priorities within these organizations. In addition, the categories identified do not necessarily represent all the priorities of the four organizations since there was insufficient time for extensive internal consultations.

In addition to the focus on various hazards, it is important to remember that good health and well-being is not solely based on lack of ill-health. Ecosystems and the environment make significant positive contributions towards good health and well-being that need more attention (Subramanian and Payyappallimana, 2020).

Objective 2: Test an approach for mapping risk pathways and monitoring points

To test the risk bowtie method using a One Health approach, four example bowtie diagrams were created using expert opinion on drivers, impacts and critical monitoring points for the following hazard categories:

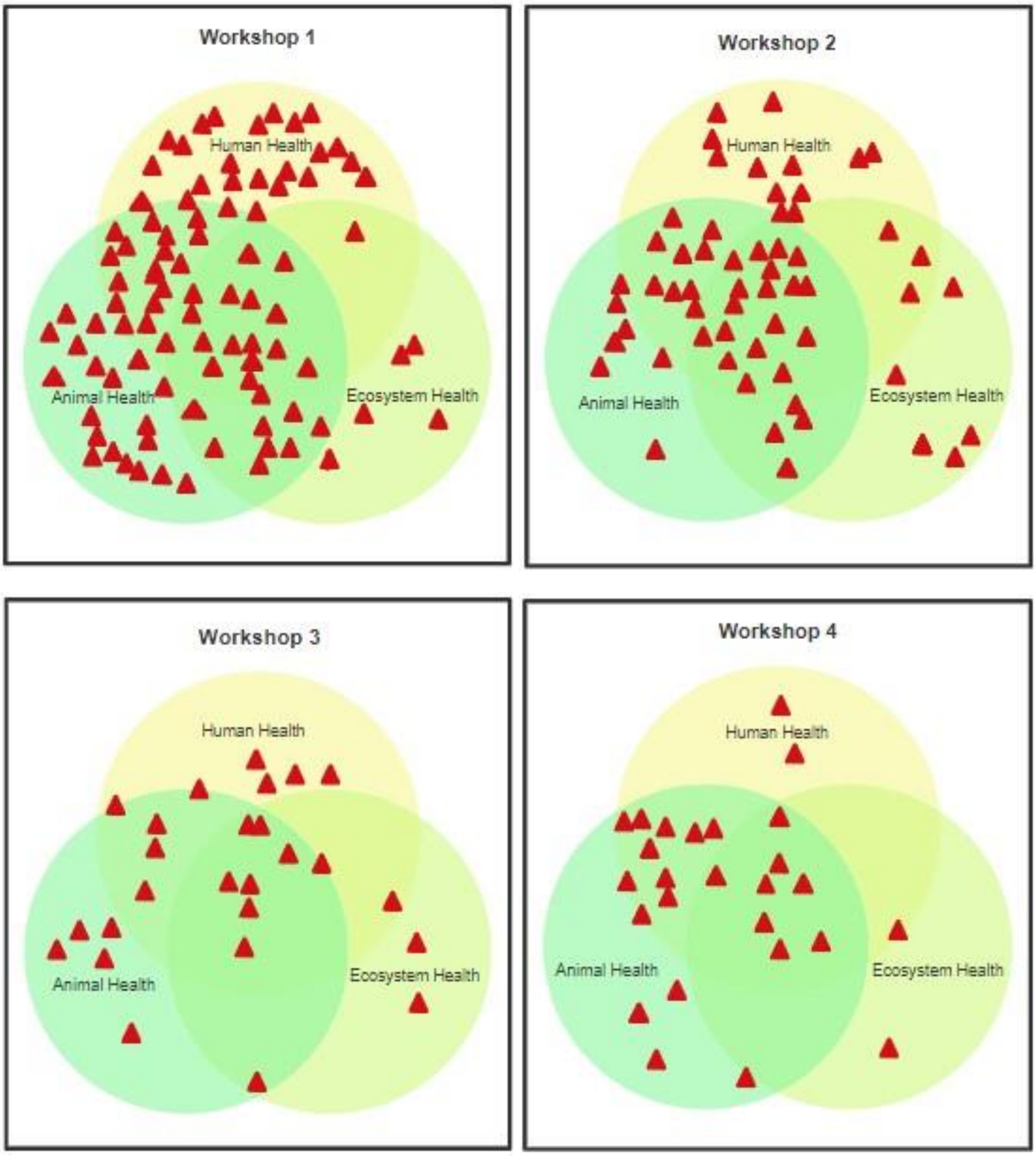
- epidemic and emerging zoonotic diseases;
- antimicrobial resistant microorganisms;
- contamination of water and soil from chemical fertilizers and pesticides; and
- non-zoonotic animal diseases affecting food security.

These four categories were chosen to ensure priorities from all four organizations were represented. Not all of the categories are necessarily priorities for all of the organizations, but they all benefit from looking at risk pathways from a multidisciplinary approach.

Only a subset of priority categories could be covered within the time frame of the OHISS. In addition, the “pollution/environmental contamination” hazard category was limited to contamination with fertilizers and pesticides. It was determined, in consultation with the United Nations Environment Programme (UNEP), that the original category was too broad for an effective risk bowtie exercise, and that it was broader than the other three examples. In the workshop, however, participants expressed the desire to examine other aspects of this category beyond fertilizers and pesticides. This would have to be done at a future stage.

Participating experts self-identified as being from all combinations of human health/animal health/ecosystem health sectors in Venn diagrams (see Figure 2). However, more were from human health, animal health or a combination with ecosystem health, than from the ecosystem sector alone.

Figure 2: Poll results for the question "Which sector best describes your primary area of expertise?"



Source: Screenshot from the results of the workshops, with input from participants gathered using Klaxoon boards (https://klaxoon.com/).

Note: Workshop 1: Epidemic and emerging zoonotic diseases; Workshop 2: Antimicrobial resistant microorganisms; Workshop 3: Contamination of water and soil from chemical fertilizers and pesticides; and Workshop 4: Non-zoonotic animal diseases affecting food security. Triangles placed in the overlapping sections of the Venn diagram are assumed to represent experts at the intersection of sectors.

Experts represented disciplines ranging from virology to social sciences, although the majority were epidemiologists and veterinarians (see Table 2). Other disciplines represented included legal, communications, conservation, bioethics, geography and toxicology fields. Additional disciplines suggested by the EAG for future inclusion in such exercises included the security sector, sociologists, anthropologists, bioinformaticians, legislators/policymakers, trade, disaster prevention/response, humanitarian response and indigenous communities.

A similar number of participants were from national authorities versus international organizations, but academia and research were also well represented. Some participants were also from other jurisdictions, including the private sector. The primary work location for most experts was North America and Europe, although some also participated from Africa, Asia, Central and South America, and Oceania. Holding the workshops in English only likely limited participation from regions outside North America and Europe.

Table 1: Percentages of each discipline, jurisdiction and geographic location of work represented at each workshop

Discipline	Workshop				Jurisdiction	Workshop				Geographic location	Workshop			
	1	2	3	4		1	2	3	4		1	2	3	4
Epidemiologist	32	36	32	37	**National authority**	28	22	52	32	**North America**	38	44	45	37
Veterinarian	29	25	36	35	**International organization**	23	31	20	36	**Europe**	34	23	23	23
Virologist/ microbiologist	12	16	0	2	**Academia**	22	18	12	13	**Africa**	10	11	9	23
Wildlife sector/ ecologist	10	3	3	12	**Research**	19	27	4	16	**Asia**	10	12	18	10
Medical practitioner	5	3	0	7	**Other**	8	2	12	3	**Central and South America**	5	8	5	4
Economist/ social scientist	4	4	0	0	Examples of other: NGO, private sector, consulting, wildlife health centre					**Oceania**	3	2	0	3
Climatologist/ hydrologist	2	2	0	2										
Entomologist	1	2	0	0										
Other	5	9	29	5										
Examples of other: legal, communication, conservation, bioethics, geography, toxicology, pathology, genomics, immunology, risk assessment, policy														

Source: Information reported directly by workshop participants.

Note: Choosing more than one discipline was acceptable. For geographic location, participants were asked to identify their primary physical work location, not their work remit. Workshop 1: Epidemic and emerging zoonotic diseases; Workshop 2: Antimicrobial resistant microorganisms; Workshop 3: Contamination of water and soil from chemical fertilizers and pesticides; and Workshop 4: Non-zoonotic animal diseases affecting food security.

Four risk bowtie diagrams were created from the expert input received during the workshops. Full visualization of these diagrams requires interactive viewing, with user control of the zooming. The full versions of the diagrams are available online at the following links:

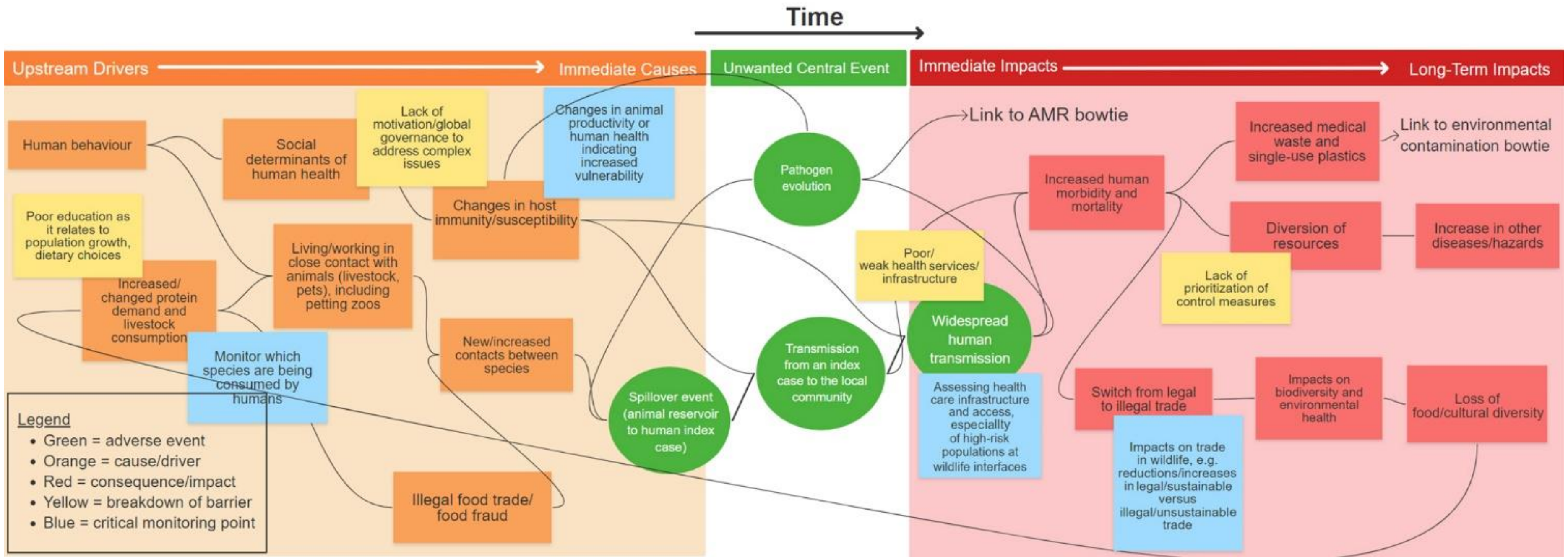
- Workshop 1: Epidemic and emerging zoonotic diseases: https://app.klaxoon.com/join/KQSEYMA
- Workshop 2: Antimicrobial resistant microorganisms: https://app.klaxoon.com/join/SHMF7XW
- Workshop 3: Contamination of water and soil from chemical fertilizers and pesticides: https://app.klaxoon.com/join/D8HTQKE
- Workshop 4: Non-zoonotic animal diseases affecting food security: https://app.klaxoon.com/join/JNJR8R6

Figure 3 shows a very simplified version of one of the bowtie diagrams, with the specific purpose of exemplifying the approach and allowing a description of what the reader can expect to see in the online versions.

The diagrams are complex, with many interlinked causal pathways (in orange on the left) leading to one or more unwanted central event(s) (in green), followed by many cascading and interlinked impacts (in red on the right). Feedback loops were identified, where an impact could become a driver in a cyclical pattern. It is presumed that not all possible connections are identified, especially between the various upstream drivers or long-term impacts, which are generally describing complex socioeconomic or environmental processes.

Many critical monitoring points (in blue) were identified by the experts in association with various pathways. In addition, many “barrier breakdowns” were identified (e.g. poor biosecurity, lack of vaccination) along with a strong social science/socioeconomic component (e.g. lack of education, mis/disinformation, market factors, inequity), highlighting vulnerabilities in the system (in yellow). Some of these vulnerabilities were associated with particular pathways, while others (shown clustered in the centre of the diagrams) are generally applicable to barriers throughout the bowtie diagram. In some cases, critical monitoring points were suggested for these vulnerabilities (e.g. monitoring public opinion).

Figure 3: Small and simplified excerpt from the risk bowtie diagram from Workshop 1: **Epidemic and emerging zoonotic diseases**, only for purposes of exemplifying the approach and giving an overview of the various components of the bowtie



Source: Authors' own elaboration using examples provided by participants during the workshop using Klaxoon boards (https://klaxoon.com/).

Although not specifically requested, many participants provided recommendations for potential barriers or otherwise (see annex 1). In some cases, potential benefits of the unwanted event were identified in addition to negative impacts, such as changes in attitudes and increases in funding, research and collaboration. Finally, in a few instances, the impacts identified were related to improper application of a barrier rather than the unwanted event itself, such as the impacts of inappropriate interventions.

These bowties provide a high-level view of broad categories of hazards. Different levels of granularity can be explored for these or other categories of One Health hazard in the future.

Objective 3: A shared understanding of One Health intelligence scope and connections

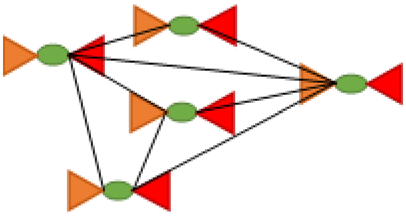
By creating a shared understanding of the One Health riskscape, individuals from different sectors and disciplines will be better placed to understand each other's perspectives and priorities. In addition, the process helps clarify the origin of drivers and impacts across the full One Health spectrum, capturing pathways more comprehensively than within a single sector alone. As a result, appropriate intelligence systems can be built that are capable of handling these different needs and incorporating the complexity of these risks.

Part of this understanding comes from embracing an all-hazards approach, with definitions, such as the hazard definition used in this exercise, that are inclusive of these different pathways and perspectives. In addition to the guidance of the Sustainable Development Goals and the OHHLEP definition of One Health, the range of One Health hazard categories identified by the Quadripartite organizations will increase awareness and understanding of the multitude of One Health intelligence needs and perspectives.

The assessments and scoping conducted by the OHISS reinforced that what might be identified as a driver or impact from one perspective, may be identified as the centre of a bowtie when examined from a different perspective. For example, all organizations identified "epidemic and emerging zoonotic diseases" as a priority, and when this was considered as the centre of a bowtie, the identified drivers and/or impacts included "pollution/environmental contamination", "climate change" and the various "reduction/change in ecosystem services". UNEP, however, identified these to be high priorities as One Health hazards in and of themselves – not only as drivers/impacts of infectious diseases, but also as their own bowtie centres, each with its own full list of causes and consequences that cross sectors. This was evidenced by the bowtie created in Workshop 3.

Although the riskscape workshops conducted within the OHISS focused on creating individual risk bowties, the system in which One Health exists is a complicated web of interconnected bowties linked by singular or multiple connection points (see Figure 4). Although it may never be possible to fully describe the system and all its connections, making some effort to identify where risk pathways connect will help identify areas of common priority that may benefit from increased cross-sectional working.

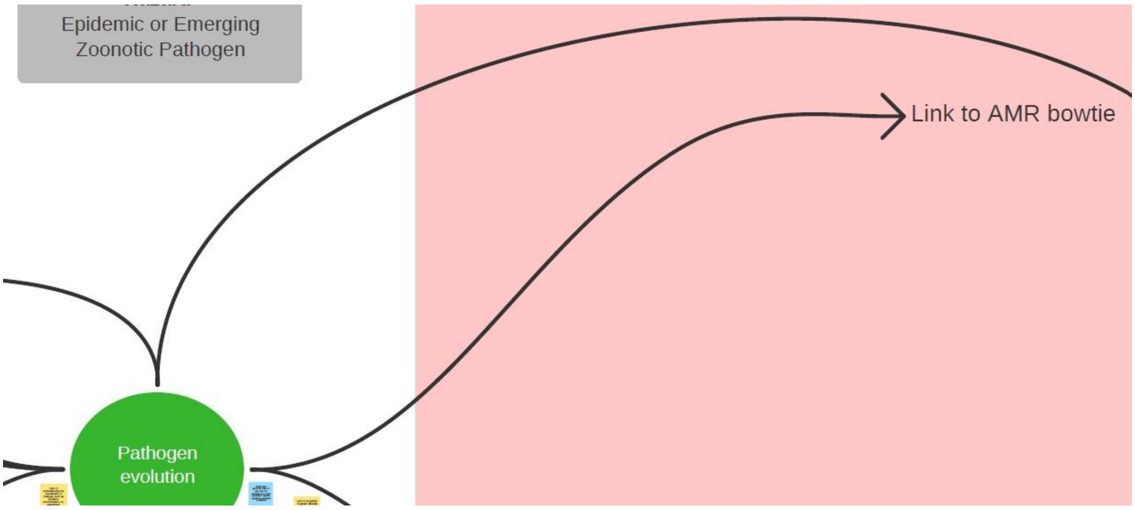
Figure 4: Representation of interconnected risk bowtie diagrams



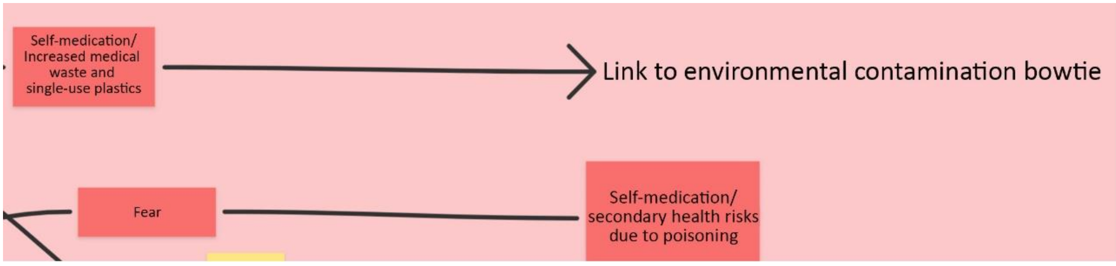
Source: Authors' own elaboration.

Examples of specific connection points identified during the workshops between the four example hazard categories included:

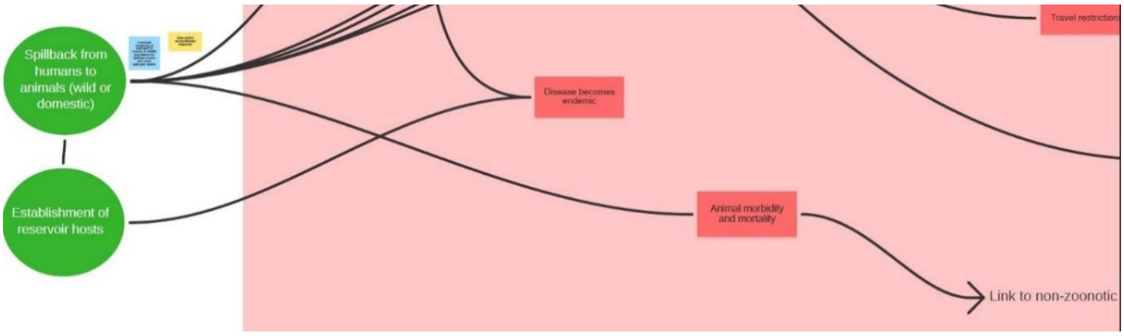
- a link between the pathogen evolution described for epidemic and emerging zoonotic diseases and antimicrobial resistant organisms;



- a link between increased medical waste and single-use plastics during epidemic and emerging zoonotic disease events to environmental contamination, and microplastics as vectors of pesticides and contaminants;

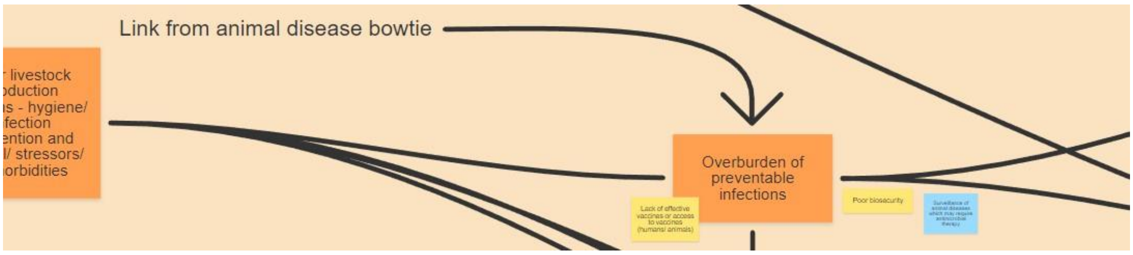


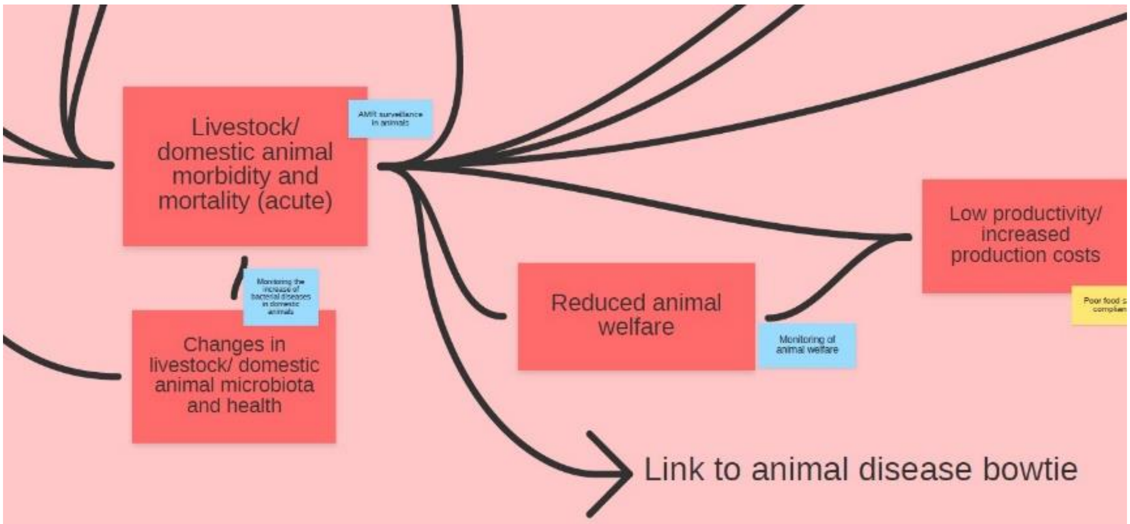
- a link from spillback of epidemic and emerging zoonotic diseases (from humans to animals) to non-zoonotic animal diseases with indirect effects on food security;



- a link from environmental contamination with pesticide/fertilizer to the development of antimicrobial resistance genes; and

- a link from non-zoonotic animal diseases to the overuse/misuse of antimicrobials in livestock and the development of antimicrobial resistance genes, and a feedback loop back to animal diseases from an outbreak with a resistant organism.





In addition to these specific connections, many of the upstream drivers and long-term consequences were shared among the hazards, such as:

- human behaviour
- population growth
- poverty
- conflict
- social inequalities
- globalization
- urbanization
- climate change
- habitat destruction
- change in biodiversity
- ecosystem degradation/disruption
- change in ecosystem services
- food insecurity
- mental health burden
- reduced quality of life/well-being

Many of these could be seen as both drivers and consequences in feedback loops within bowties as well as between bowties. They were also frequently discussed in relation to One Health intelligence within the literature review.[4]

Objective 4: Inform operational prioritization of data

Using the risk bowtie approach reveals certain attributes of a monitoring point, such as which/how many hazards it relates to, which/how many risk pathways it relates to and where on the pathway(s) it falls (including how upstream or downstream it is in relation to the event of interest). In the absence of detailed risk models, which exist for some specific hazards but not on an all-hazards scale, these factors can be used to inform decisions on the benefit that the data (if available) will provide in relation to risk. The cost/feasibility of acquiring and processing the data also needs to be taken into consideration.

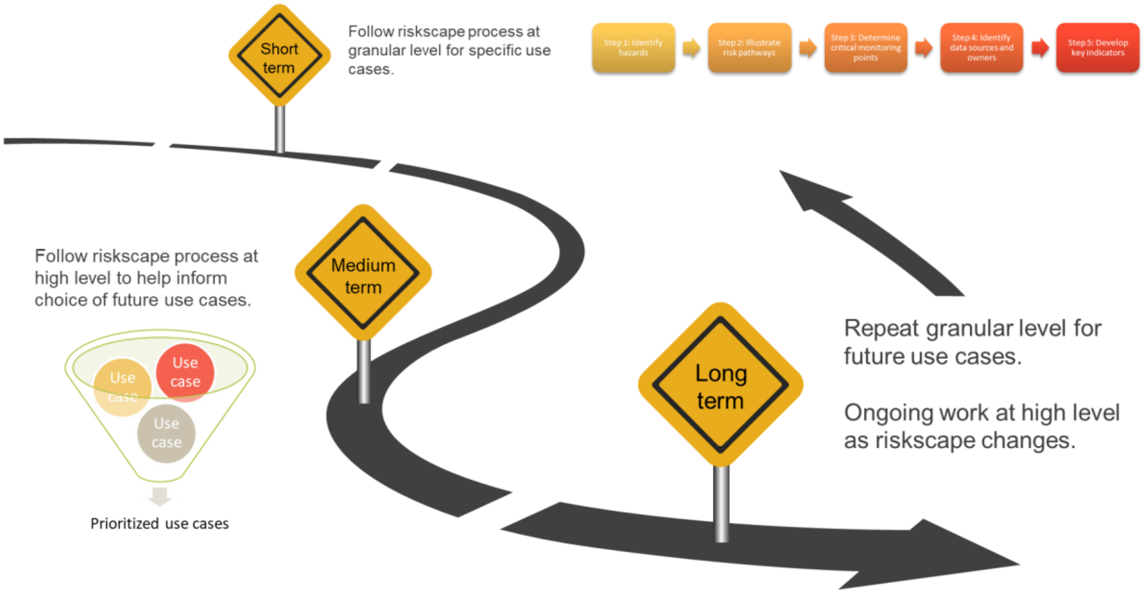
In the immediate-short term, the stepwise approach highlighted above can be employed within use cases chosen by the Quadripartite. For the decision points and associated risk questions supported by the use case, hazards should be identified and defined, risk pathways illustrated, critical monitoring points determined, data sources and owners identified, and key indicators developed.

An example of this process has already been conducted by the focal points from the UNEP World Conservation Monitoring Centre, who initiated Steps 1–3 (identify hazards, illustrate risk pathways, determine critical monitoring points) on more specific example hazards with the intention of exploring Step 4 (identify data sources and owners) for the data sources within their access. Nipah virus was used as an example zoonotic disease to understand how environmental and other relevant data could be sourced and possibly combined to evaluate risk and/or consequences. Water scarcity was used as an example environmental hazard, exploring drivers and consequences across the sectors, with a review of relevant datasets for the environmental drivers. Finally, land-use change (specifically deforestation due to agricultural expansion) was explored as a potential driver of several One Health hazards, along with a review of relevant datasets.

For the medium to longer term (i.e. the establishment of an umbrella framework for Quadripartite One Health intelligence), the identification and analysis of high-level One Health hazard categories started within the OHISS can be elaborated to determine priority risk questions for future use cases and identify gaps in operational One Health intelligence. The stepwise approach can then be repeated at a granular level for future use cases. In addition, and perhaps most importantly, an ongoing examination of the riskscape should continue so that priorities can be adjusted over time.

[4] See Aguirre *et al.*, 2021; Chatterjee *et al.*, 2021; Guégan *et al.*, 2020; Meurens *et al.*, 2021; Saylors *et al.*, 2021; Schurer *et al.*, 2016; Stevenson, Halpin and Heuer, 2021; Thumbi *et al.*, 2019; Woods *et al.*, 2019; Zaitchik *et al.*, 2016.

Figure 5: Road map for future use of the riskscape process, both at a granular level on specific use cases and at a high level to help inform choice of future use cases



Source: Authors' own elaboration.

The information provided in the high-level OHISS riskscape workshops was very extensive, even when restricted to the four example hazard categories. Clearly, more work could be done to assess this information (and further examples) for global Quadripartite organizations' priorities, and to further investigate information needs and data availability related to critical monitoring points.

For example, some critical monitoring points were identified across multiple bowties, and hence are potentially applicable to multiple risk questions. These included:

- Monitoring of upstream ecoclimatic risks (e.g. trends/changes in rainfall and temperature, Normalized Difference Vegetation Index)
  - The upstream nature of this monitoring point means it affects multiple pathways, but this may make it difficult to determine key indicators or thresholds for potential risk occurrence. Research on this is likely already under way for specific hazards but may not be available in a more general sense.
- Monitoring of human and animal waste (e.g. disposal, treatment, water quality, waste from health facilities)
  - The midstream position of this monitoring point on the risk pathways makes it applicable to fewer pathways but easier to determine key indicators. For epidemic and emerging zoonotic diseases, for example, the relevant pathways could be related to widespread transmission of an emerged pathogen or contamination of the environment and pathogen evolution.
- Monitoring of wildlife health (e.g. morbidity, mortality, pathogens of concern for spillover events, novel pathogen strains)
  - This monitoring point was fairly immediately related to the adverse events of interest, including the prevention of event escalation, immediate causes and immediate impacts. This would include, for example, surveillance of wildlife in transport hubs and markets, and peri-domestic wildlife.

- Monitoring of biodiversity/pollinator abundance and diversity through citizen science (e.g. public bird counts, pollinator diversity and number, indicator species)
    - This type of monitoring was related to mid- to long-term impacts. For example, in the bowtie related to pesticide/fertilizer contamination it was related to health impacts for wildlife of the various pathways of contamination (and as a potential indicator of contamination in the environment).

The risk bowtie diagrams identified causal pathways leading back to very upstream drivers. An important consideration when prioritizing critical monitoring points, as highlighted by workshop participants, is the question “At which point in the bowtie is it realistic to detect the first signal of a potential unwanted event?” This will depend, among other things, on the presence of accurate and reliable indicators.

Conclusions

The ideal operational OHIS needs to have the flexibility to support multiple different risk questions related to different types of hazards. During the OHISS, it became clear that the inclusion of environmental partners in discussions of One Health intelligence brings to the table not only the possibility of more data to support the previously established priority risk questions, but also the potential for new ones. Some One Health hazards may only currently be seen as priorities within a single organization's mandate but nonetheless require multisectoral collaboration to address. Understanding these differences in perspective is an important step towards a successful One Health approach to intelligence.

Those looking to gather and use One Health intelligence should follow a risk-based, iterative process of defining the problem(s) and determining critical monitoring points and associated data sources. Prioritization of critical monitoring points can then be based on factors related to benefit (including risk) and cost.

As pointed out during the workshops, logic models may be a good approach for organizing ideas and enhancing communication, but there are a number of caveats and limitations that must be kept in mind. The linear and static thinking associated with the traditional risk bowtie diagram has limitations within a system as incredibly complex and dynamic as One Health. This can be seen within the feedback loops and connections, only some of which could be captured within this high-level exercise. In addition, the bowtie is structured to describe a single, future, unwanted event, while in reality, many One Health hazards are ongoing, meaning that some "long-term" consequences may already be happening.

Some details of the pathways, not evident at first glance, may nonetheless be important in the consideration of risk. For example, the epidemic and emerging zoonotic diseases bowtie, as developed, does not clearly distinguish between the "origin" pathways, leading to an initial spillover of an emerging disease, and the "transmission" pathways, leading to transmission of an existing zoonotic disease. This is an important distinction because the dominant species involved in the two types of pathways may differ. Future exercises could include examining epidemics of established zoonotic diseases separately from new emerging diseases, and even, as suggested by the EAG, a specific focus on pandemics. Engering, Hogerwerf and Slingenbergh (2013) also suggest that drivers would differ between pathogens that are emerging in novel hosts, pathogens emerging novel traits in the same host and disease complexes moving into a novel geographic area.

It is important to remember that the development of risk bowtie diagrams is a method to illustrate risk pathways – it is not a risk assessment and therefore does not, in and of itself, involve the estimation of probabilities or magnitude of impacts. In addition to characterization of the riskscape, several other risk-related methods may be useful in relation to One Health intelligence. These include foresight exercises, risk-informed targeting of resources, risk-informed triaging of signals, risk modelling, and, of course, risk assessments. In addition to risk-based thinking, tools from system science can be used to help analyse this complex information and inform decision-making.

While the approach of rapidly gathering expert opinion allowed us to get a rapid multidisciplinary picture of complex problems, it should be acknowledged that experts tend to pull in the direction of their own expertise and no control of expert participation was applied for these exercises. The characteristics of participants should be taken into consideration when interpreting the results.

The elaboration of risk pathways primarily draws from experience with known risks but may also be extrapolated to “known unknowns” (i.e. unknown risks that can be anticipated based on similar experiences). However, the development of risk pathways may not help with “unknown unknowns” (i.e. completely unknown and unexpected risks). The best that can be done in advance for these risks is to iteratively update analyses to include new information.

Understanding One Health hazards in their context is key: Johnson, Hansen and Bi (2018) point out that without a larger picture and understanding of risk pathways, it is impossible to offer adequate and early interventions to reduce the spread of cases. This equally applies to the determination of critical monitoring points, which must be chosen and analysed within their associated risk landscape. One Health tries to apply this broader approach and takes into consideration underlying structural factors that include biological but also sociopolitical aspects (Queenan, Häsler and Rushton, 2016). Thus, regardless of the challenges, making some attempt to jointly review the One Health riskscape, using multidisciplinary input, is crucial in the development of an OHIS.

References

Adipah, S. 2018. The ecological effects of oil mitigation associated with environmental risk. *Journal of Environmental Science and Public Health,* 2(4): 160–167.

Aguirre, A.A., Gore, M.L., Kammer-Kerwick, M., Curtin, K.M., Heyns, A., Preiser, W. & Shelley, L.I. 2021. Opportunities for transdisciplinary science to mitigate biosecurity risks from the intersectionality of illegal wildlife trade with emerging zoonotic pathogens. *Frontiers in Ecology and Evolution*, 9: 7.

Chatterjee, P., Nair, P., Chersich, M., Terefe, Y., Chauhan, A.S., Quesada, F. & Simpson, G. 2021. One Health,"Disease X" & the challenge of "unknown" unknowns. *Indian Journal of Medical Research,* 153(3): 264.

Culwick, M.D., Endlich, Y. & Prineas, S.N. 2020. The bowtie diagram: A simple tool for analysis and planning in anesthesia. *Current Opinion in Anesthesiology,* 33(6): 808–814.

Engering, A., Hogerwerf, L. & Slingenbergh, J. 2013. Pathogen–host–environment interplay and disease emergence. *Emerging Microbes & Infections,* 2(1): 1–7.

Guégan, J.-F., Ayouba, A., Cappelle, J. & De Thoisy, B. 2020. Forests and emerging infectious diseases: Unleashing the beast within. *Environmental Research Letters,* 15(8): 083007.

Hambling, T., Weinstein, P. & Slaney, D. 2011. A review of frameworks for developing environmental health indicators for climate change and health. *International Journal of Environmental Research and Public Health,* 8(7): 2854–2875.

Islam, K., Ahsan, M., Chakma, S., Penjor, K., Barua, M., Jalal, M., Sabuj, A., Ani, Z. & Ahad, A. 2020. An assessment on potential risk pathways for the incursion of highly pathogenic avian influenza virus in backyard poultry farm in Bangladesh. *Veterinary World,* 13(10): 2104–2111.

Johnson, I., Hansen, A. & Bi, P. 2018. The challenges of implementing an integrated One Health surveillance system in Australia. *Zoonoses Public Health,* 65(1): e229–e236.

Lindhout, P. & Reniers, G. 2020. Reflecting on the safety zoo: Developing an integrated pandemics barrier model using early lessons from the Covid-19 pandemic. *Safety Science,* 130: 104907.

Malecki, K.C., Resnick, B. & Burke, T.A. 2008. Effective environmental public health surveillance programs: A framework for identifying and evaluating data resources and indicators. *Journal of Public Health Management and Practice,* 14(6): 543–551.

Meurens, F., Dunoyer, C., Fourichon, C., Gerdts, V., Haddad, N., Kortekaas, J., Lewandowska, M. *et al*. 2021. Animal board invited review: Risks of zoonotic disease emergence at the interface of wildlife and livestock systems. *Animal,* 15(6): 100241.

Morris, C.E., Géniaux, G., Nédellec, C., Sauvion, N. & Soubeyrand, S. 2022. One Health concepts and challenges for surveillance, forecasting, and mitigation of plant disease beyond the traditional scope of crop production. *Plant Pathology,* 71(1): 86–97.

Nielsen, S.S., Alvarez, J., Bicout, D.J., Calistri, P., Depner, K., Drewe, J.A., Garin-Bastuji, B. *et al*. 2020. Rift Valley Fever – epidemiological update and risk of introduction into Europe. *EFSA Journal,* 18(3): e06041.

One Health High-Level Expert Panel. 2021. *One Health High-Level Expert Panel Annual Report 2021*. Food and Agriculture Organization of the United Nations, World Organisation for Animal Health, United Nations Environment Programme, and World Health Organization.

Oniciuc, E.-A., Nicolau, A.I., Hernández, M. & Rodríguez-Lázaro, D. 2017. Presence of methicillin-resistant Staphylococcus aureus in the food chain. *Trends in Food Science & Technology,* 61: 49–59.

Queenan, K., Häsler, B. & Rushton, J. 2016. A One Health approach to antimicrobial resistance surveillance: is there a business case for it? *International Journal of Antimicrobial Agents,* 48(4): 422–427.

Saylors, K., Wolking, D.J., Hagan, E., Martinez, S., Francisco, L., Euren, J., Olson, S.H. *et al*. 2021. Socializing One Health: An innovative strategy to investigate social and behavioral risks of emerging viral threats. *One Health Outlook,* 3(1): 11.

Schurer, J.M., Mosites, E., Li, C., Meschke, S. & Rabinowitz, P. 2016. Community-based surveillance of zoonotic parasites in a 'One Health' world: A systematic review. *One Health,* 2: 166–174.

Stevenson, M., Halpin, K. & Heuer, C. 2021. Emerging and endemic zoonotic diseases: Surveillance and diagnostics. *Revue Scientifique et Technique,* 40(1): 119–129.

Subramanian, S.M. & Payyappallimana, U. 2020. Environment, biodiversity, and planetary health: Links between natural systems and human health. In R. Haring, I. Kickbusch, D. Ganten, & M. Moeti, eds. *Handbook of Global Health*, 1–14. Cham, Switzerland, Springer.

Thumbi, S.M., Njenga, M.K., Otiang, E., Otieno, L., Munyua, P., Eichler, S., Widdowson, M.A., McElwain, T.F. & Palmer, G.H. 2019. Mobile phone-based surveillance for animal disease in rural communities: Implications for detection of zoonoses spillover. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 374(1782): 20190020.

United Nations Office for Disaster Risk Reduction. 2020. *Hazard Definition and Classification Review*. Geneva, United Nations Office for Disaster Risk Reduction.

Wolters Kluwer. 2022. The bowtie method. In: *Knowledge Base*. Cited 26 July 2022. www.wolterskluwer.com/en/solutions/enablon/bowtie/expert-insights/barrier-based-risk-management-knowledge-base/the-bowtie-method

Woods, R., Reiss, A., Cox-Witton, K., Grillo, T. & Peters, A. 2019. The importance of wildlife disease monitoring as part of global surveillance for zoonotic diseases: The role of Australia. *Tropical Medicine and Infectious Disease*, 4(1): 29.

World Health Organization. 2020. *WHO technical guidance notes on Sendai Framework reporting for Ministries of Health*. Geneva, World Health Organization.

Zaitchik, B.F., Hayden, M.H., Villela, D.A., Lord, C.C., Kitron, U.D., Carvajal, J.J., Câmara, D.C. & dos Reis, I.C. 2016. Climate information for arbovirus risk monitoring: Opportunities and challenges. *Bulletin of the American Meteorological Society*, 97(5): ES107–ES111.

Annex I
Supplementary notes from riskscape workshops

In addition to input on the bowties, participants provided numerous recommendations, notes and potential benefits. A summary of these has been provided below.

Workshop 1: Epidemic and emerging zoonotic diseases

Recommendations

- Develop One Health national action plans and global One Health offices.
- Educate students and lay people, collaborate with journalists/news platforms, consider how to accurately communicate unknowns.
- Simultaneously focus on bottom-up (e.g. education) and top-down (e.g. policy) approaches to address One Health challenges.
- Develop and enforce policies and laws regarding environmental protection, sanitary measures for wildlife trade, monitoring and data sharing.
- Increase resources and monitoring in underserved areas, and global funding of health systems.
- Harmonize/standardize health care reporting and data collection, centralize and share data (especially on wildlife morbidity and mortality), use novel data sources but also novel sampling strategies with traditional surveillance.
- Better integrate wildlife ecologists and non-health disciplines into One Health approaches.
- Manage conflict between “invasive and non-native species” teams (managing invasive species) and “pathogen” teams (managing disease vectors).
- Invest in diagnostics and laboratory capacity (human, animal) with broad-based detection capacity for untargeted pathogens or pathogens for which we have little understanding (especially in low-resource settings).
- Establish portals or fora where countries can report morbidity/mortality events with unknown cause.
- Develop global/regional programmes on genomic surveillance, assess approaches used for screening pathogens (such as metagenomic approaches).
- Understand baseline levels, deviation from trends (using big data, data analytics and big trend analysis), indicators, high-risk populations/locations/viral families and high-risk spillover events.
- Implement disease forecasting (in collaboration with other fields).
- Establish a central repository of epidemiological information on known pathogens (host species, clinical signs, transmission routes).
- Research determinants of zoonotic potential, peri-domestic wildlife hosts, links between land-use change and disease, impacts of pesticides on vectors and disease emergence, adapting military surveillance technology (satellite imagery, drones), ways of getting data from areas that are not digitized, effectiveness of mitigating measures, impacts of control measures, long-term health impacts.
- Maintain biobanks/tissue banks for wildlife.

- Maintain control capability (e.g. vaccine banks, post-exposure prophylaxis).
- Have protocols in place for managing animals (companion, livestock and wildlife) in the event of disaster situations to limit the risk of disease emergence.
- Monitor and communicate successes to help encourage One Health sustainability.

Notes

- The monitoring of land-use change/biodiversity loss (e.g. where, how and focus areas) may vary significantly across different types of One Health concerns; also, changes in habitat/species and the risks posed will depend on the disease and species in question (i.e. risks could be increased or decreased).
- Many low- and middle-income countries have low levels of recording cause of death and issues with spotting increased mortality.
- Working with diseases in wildlife is challenging because centralized disease management is more effective, but nature management is often decentralized.

Potential benefits of unwanted events

- Increased public awareness, integration of One Health into curricular.
- Increased interdisciplinary, intersectoral and international collaboration, adoption of One Health approaches (including formation of the Quadripartite).
- Updated international health regulations (or "pandemic treaty").
- Increased funding/investment in research (preparedness, new technologies/vaccines/diagnostic assays).
- Behaviour changes that limit transmission.
- Increased interest in wildlife, commitment to wildlife conservation and focus on local conservation.
- In some cases, spillover may also be beneficial to the host immune system.

Workshop 2: Antimicrobial resistant microorganisms

Recommendations

- Increase public awareness and training of "paramedical" and other health workers.
- Increase regulation on the environmental release of contaminants with antimicrobial effects and non-prescription antibiotic access, and appropriate policy guidance.
- Adopt quality assurance/good animal husbandry practices.
- Increase investment in monitoring and surveillance, and using systems already in place.
- Address the issue that the risk of resistance is not limited to the same time frame as antimicrobial residues in food safety, since resistant bacteria can persist within livestock after treatment has finished.
- Implement proper diagnosis and antimicrobial sensitivity testing prior to treatment.
- Communicate and share data between sectors, establish standardized antimicrobial use metrics and harmonized protocols and platforms.

- Develop baseline data, epidemiological models, studies (source attribution, longitudinal studies in the environment, sociocultural drivers) and ensure findings are shared with policymakers.
- Research alternatives to antimicrobials.

Notes

- Risk pathways will be different for different types of resistance in different organisms (i.e. beyond antimicrobial resistance).
- In addition to resistance, antibiotic tolerance and persistence are sources of morbidity and mortality that require attention.
- The existence of antimicrobial resistant organisms is a problem regardless of infection/colonization of an individual.
- Although there is increasing evidence of antimicrobial resistance in wildlife, there is limited evidence of wildlife as reservoirs.

Potential benefits of unwanted events

- Changes occur in behaviours and practices (e.g. lower/more prudent use of antimicrobials).
- Opportunities arise for creating new knowledge about antimicrobial resistance and stewardship.
- More pressure to enable sound management of waste and wastewater.
- Increased research and development activities for alternatives to antimicrobials.

Workshop 3: Contamination of water and soil from chemical fertilizers and pesticides

Recommendations

- Improve professional and farmer education, access to information and safety training.
- Partner with indigenous communities to include indigenous knowledge.
- Improve regulatory framework, benchmarks and policies, including stronger requirements for proof of safety for new chemicals.
- Increase investment into green research and development.
- Evaluate national and community wastewater infrastructure.

Notes

- The risk pathways are highly dependent on the specific fertilizer/pesticide and the environment.
- Impacts are not only local – they can be global in relation to pesticide long-range transport.
- Chemicals in transboundary pollution and consumer/industrial products are overlooked in the context of health (effects on infectious diseases, non-communicable diseases and antimicrobial resistance).
- It should be recognized that the “pollution/environmental contamination” hazard category is wider than just fertilizers/pesticides.

Potential benefits of unwanted events

- Positive impacts on food security, nutrition and livelihoods.
- Organic farming and the market for organic produce increases.
- Boost to green chemistry research and development.

Workshop 4: Non-zoonotic animal diseases affecting food security

Recommendations

- Improve the efficiency of communication among stakeholders.
- Improve access to veterinary care, vaccines and diagnostics.
- Determine whether there are mechanisms in place for centralizing data.
- Build data-sharing agreements and a platform to share.
- Evaluate biosecurity and improve understanding of constraints at the farm level.
- Research animal trade networks and enhance effective animal quarantines at borders.
- Build wildlife health-related monitoring into existing ranger patrol systems (e.g. SMART).

Potential benefits of unwanted events

- Public recognition and funding of animal disease prevention research increases.
- Better data collection and reporting, and development of quick alert systems and disease forecasting.
- Broader scope of One Health collaboration, including with other fields such as genetics, math and physics.