Research Directions: One Health

www.cambridge.org/one

Impact Paper

Cite this article: Stephen C and Berezowski J (2025). Expectations of wildlife health surveillance systems and implications for system design. *Research Directions: One Health*. **3**, e2, 1–13. https://doi.org/10.1017/one.2025.4

Received: 23 September 2024
Revised: 19 February 2025
Accepted: 28 February 2025

Keywords:
Wildlife; surveillance; evidence; design; expectation

Corresponding author:
Craig Stephen;
Email: craigstephen.pes@gmail.com

Expectations of wildlife health surveillance systems and implications for system design

Craig Stephen[1,2] and John Berezowski[1,3]

[1]McEachran Institute, Nanoose Bay, Canada; [2]The University of British Columbia, Vancouver, Canada and [3]Scotland's Rural College, Edinburgh, UK

Abstract

Wildlife health surveillance is a rapidly evolving field. The goal of this commentary is to share the authors perspectives on the evolving expectations of wildlife health surveillance. We describe the basis for developing our opinions using multiple information sources including a narrative literature review, convenience samples of websites and conversations with experts. With increasing prominence of wildlife health, expectations for surveillance have increased. Situational awareness and threat or vulnerability detection were expected outputs. Action expectation themes included knowledge mobilization, reliable action thresholds and evidence-based decision making. Information expectations were broad and included the need for information on social and ecological risk drivers and impacts and evaluation of surveillance systems. Surveillance systems developers should consider: (1) What methods can equivalently and reliably manage the biases, uncertainties and ambiguities of wildlife health information; (2) How surveillance and intelligence systems support acceptable, ethical, efficient and effective actions that do not generate unintended consequences; and (3) How to generate evidence to show that surveillance and intelligence systems lead to decisions affecting vulnerability or resilience to endemic health threats, emerging diseases, climate change and other conservation threats.

Impact statement

As science and society increasingly recognize the role of wildlife health in health, economic and environmental security, the expectations for surveillance systems are also increasing. Expectations and goals are the foundations of surveillance system planning as they determine the information needs and methods required to support decision making. Wildlife health surveillance systems have historically focussed on threat detection, with an emphasis on detection of etiological agents or their effects on individuals. By triangulating different sources of information, this paper provides opinions on how changing expectations could influence surveillance systems design and therefore make the resulting surveillance outputs more broadly available and better suited to expanding expectations.

Introduction

The situation

High level political forums, academia and civil society organizations are advocating for reoriented approaches to more efficiently and effectively generate actionable wildlife health information suited to the current polycrisis (Guberti et al. 2014, Panel et al. 2023). International and national agencies are now expected to invest more in wildlife disease surveillance to better anticipate and prepare for a changing landscape of rapidly emerging, spreading and interacting health risks. The goal of this commentary was to share the authors perspectives for future-ready wildlife health surveillance.

There is a long history of wildlife surveillance helping to predict, manage and prevent infectious and non-infectious disease risks to people, economies, domestic animals and wildlife (Machalaba et al. 2021; George et al. 2023). It is increasingly seen as essential for prevention, early detection and containment of zoonotic epidemics and pandemics (Panel et al. 2023) as well as to address the growing influence of health impacts on wildlife conservation (Mazzamuto et al. 2022). Pandemic surveillance is expected to operate more collaboratively, faster and with more complete information than previously imagined (French et al. 2013), but some evidence suggests that wildlife health surveillance may not be up to the task.

A 2023 review identified an overall low level of capacity for wildlife disease surveillance globally, with marked variability between countries (Delgado et al. 2023). A 2021 report concluded that 58%, (62/107) of countries did not provide any evidence of a functional wildlife health surveillance program (Machalaba et al. 2021). Wildlife surveillance in Europe, for example, has been described as fragmented and incomplete (Lawson et al., 2021). While some countries routinely conduct wildlife disease surveillance many others only address disease events in post-outbreak scenarios (Schwind et al. 2014). There is growing dissatisfaction with the limited use of wildlife surveillance largely in reaction to adverse events (Stephen et al. 2018). Attempts to standardize and harmonize wildlife health surveillance at local, regional and global scales have had limited success to date (Barroso et al. 2024).

Surveillance and intelligence as foundations of the evidence ecosystem

An evidence ecosystem is the formal and informal linkages and interactions between different actors, capacity and information involved in production, translation and use of evidence for decision making (WHO 2022). It is embedded in the broader socio-political context within which evidence users and producers co-exist and influence each other (Gough et al. 2019).

Surveillance and intelligence are interconnected information systems that provide information components, structures and relationships in a disease management system (Figure 1). They provide timely information about changing health risks used to support decision making. Surveillance and intelligence systems must be designed with awareness of the services and functions needed to support health manager decisions, actions and expectations.

Surveillance is intended to assess and characterize the burden, distribution and change in health events, hazard or risks, thus helping identify priority problems, species, areas and actions. It should continuously generate information on where the problem is, who or what is affected, if the problem is getting better or worse and if interventions are making the desired change (Hasler et al. 2011, Panel et al. 2023). Where simple or complicated links exist between information, decision and action, surveillance information can be sufficient to achieve desired outcomes. But most new expectations being imposed on wildlife health surveillance involve complex and wicked problems with higher levels of uncertainty, conflicting goals and uncertain causal chains, such as pandemics and climate change. Addressing complexity requires intelligence systems to build a shared information commons by considering diverse sources of information and ways of knowing (Antoine-Moussiaux et al. 2019).

Intelligence comes from the systematic synthesis of different types and sources of information, from traditional and non-traditional sources, to generate actionable and meaningful signals of change, provide insight into future risk trajectories and characterize possible opportunities for intervention. Health intelligence collects, integrates and analyzes diverse data, information, knowledge, experience and other learning to make them understandable and usable for decision-making (Haby et al. 2023). Intelligence adds value to surveillance outputs by supplementing them with contextual understanding of a wildlife population and the prevailing social and ecological circumstances to better understand the risk and decision context. Intelligence products, therefore, consist of information and knowledge that have been refined to provide understanding that meets the needs of decision makers. Whereas the usual wildlife surveillance goal is early detection of harms to quickly minimize their effects, the goal of intelligence is to protect health by early actions in advance of harm (Figure 2).

Purpose

The purpose of this study was to develop a perspective on; 1) the expectations from the wildlife evidence ecosystem by international agencies, governments (public health, livestock health, wildlife conservation) and other stakeholders; 2) whether the wildlife evidence ecosystem produces sufficient scope of evidence to meet the expectations and 3) whether there are any guidelines or recommendations to assist or ensure that sufficient evidence is currently being produced or could be produced. We focussed on expectations and goals because they are the starting points for surveillance system design (Figure 3).

Information basis for the commentary

The intention of this paper was to create a high-level summary of a range of information sources to identify signals for change in how wildlife health surveillance needs be designed and used. There was no intention to determine the utility or return-on investment of surveillance, but rather to better understand what is being asked of wildlife surveillance systems. The following information is provided to help the reader understand the basis upon which the perspectives in this paper were generated.

We used different information sources to identify themes of expectations of wildlife surveillance, the breadth of evidence being produced and whether there were recommendations or regulations to ensure production of sufficient evidence of high quality.

Scanning operational goals and expectations

We began in 2023 by going to the home pages of websites of the World Organization for Animal Health (WOAH), International Union for the Conservation of Nature (IUCN), the Food and Agriculture Organization (FAO), the World Health Organization (WHO), World Bank, Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), Convention on Biological Diversity (CBD) and the non-government agencies the Wildlife Conservation Society, Animal Welfare Institute and World Wildlife Fund. We then went to the homepages of organizations hosting WOAH wildlife health collaborating centers working in themes relevant to wildlife health surveillance (Canadian Wildlife Health Cooperative, United States National Wildlife Health Center, Wildlife Health Australia and Centre for Environment, Fisheries and Aquaculture Sciences (United Kingdom)). These organizations were selected based on the authors personal understandings of their mandates and spheres of activity. On each site, we entered the term “wildlife health surveillance” and reviewed search outputs for explicit statements on the expectations, goals or purpose of surveillance systems. From this we developed a preliminary list of goals and expectations.

We next talked to 22 employees or members of working groups involved in wildlife health related work areas in the aforementioned organizations. People were selected if their job responsibilities involved wildlife health (based on webpage information or recommendations from others within the organization). Not all eligible people contributed to this portion of the study due to lack of time or interest. Some organisations had more than one person who fit this inclusion criteria. Respondents’ names and organizations were not recorded. Open-ended question focussed on their agencies’ evidence needs and expectations, their use of surveillance standards and other sources of international guidance upon which they relied. The draft findings were shared with two individuals

https://doi.org/10.1017/one.2025.4 Published online by Cambridge University Press

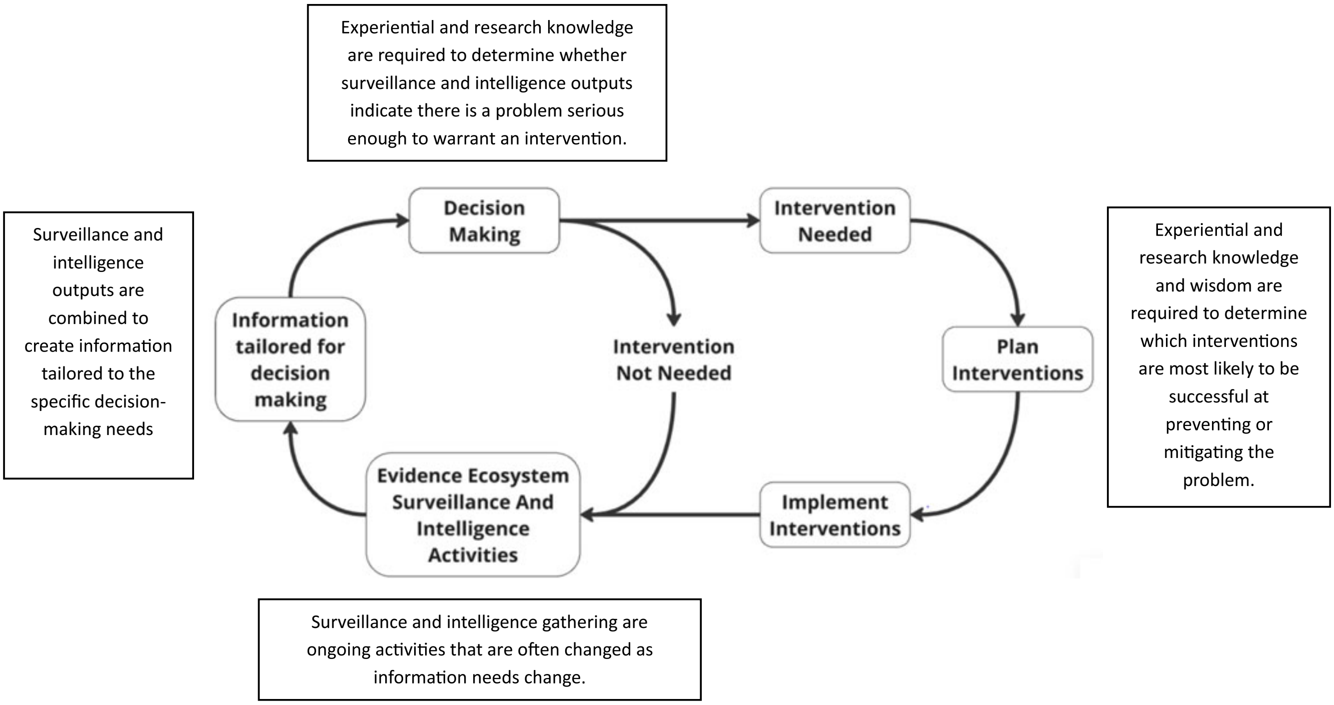

Figure 1. The basic surveillance-intelligence cycle illustrating the interdependence between surveillance activities, decision making and intervening. Different step in this cycle will have different needs and expectations for information and knowledge output.

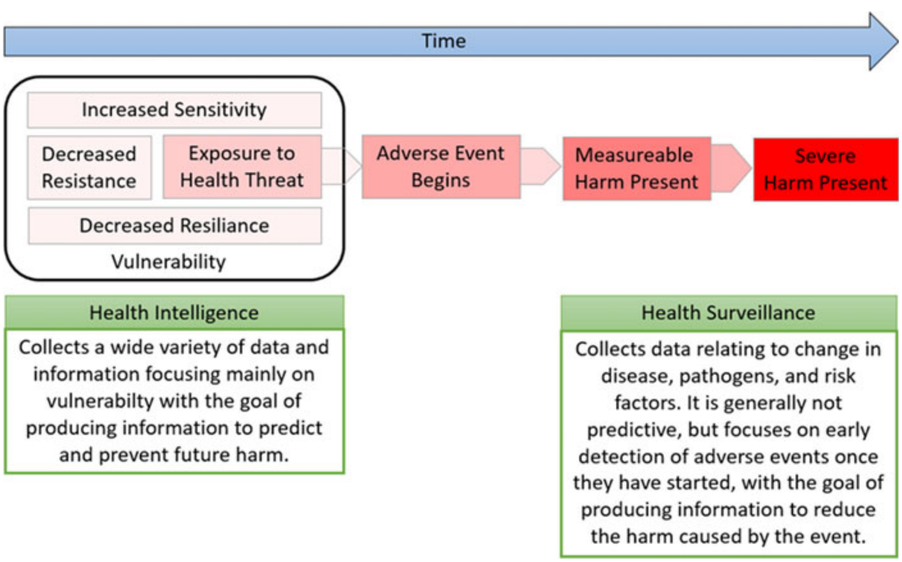

Figure 2. Timeline of the occurrence of harm in a population (shades of red) and the locations where health surveillance and health intelligence collect data and produce information (from Berezowski et al. 2020). Intelligence and surveillance are part of an integrated system of information acquisition Their outputs should both be considered in decision making.

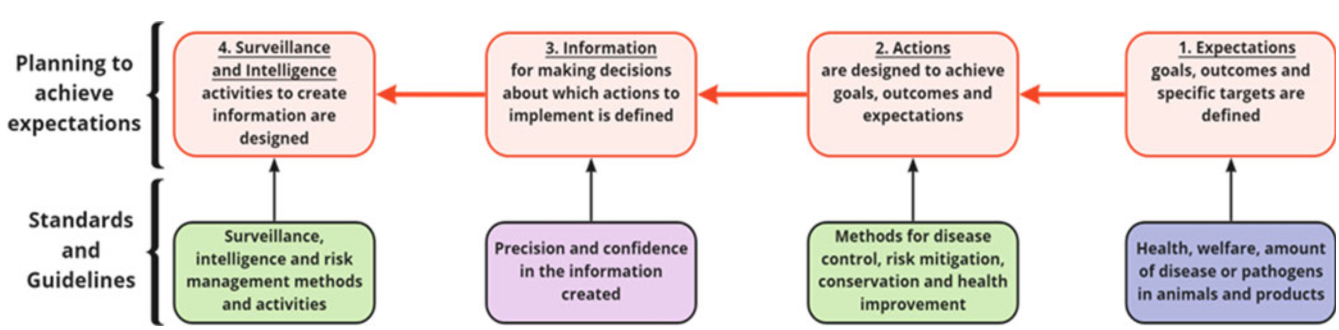

Figure 3. A conceptual illustration of the role of expectations as the conceptual foundation for planning and guidelines.

https://doi.org/10.1017/one.2025.4 Published online by Cambridge University Press

operating national wildlife health surveillance programs as a final attempt to assemble a list of operational surveillance goals and expectations. Ethical approval were not required as the Government of Canada guidelines on human subjects' research declares that research ethics approvals are not required when the information requested is within the mandate of the organization, or according to the terms and conditions of employment or when provisions of the information is normally administered in the ordinary course of the operation of an organization where participation is required (Anon, 2025).

Narrative literature review

We undertook a narrative literature review in 2023. Narrative reviews attempt to synthesize what has been written on a particular topic to provide the reader with a background for understanding of current knowledge rather than to seek generalization or cumulative knowledge (Pare and Kitsiou, 2017). Narrative reviews are unsystematic overviews, that provide a broad synthesis of previously published information. We began by seeking peer reviewed English language papers published between 2000 and 2023 in PubMed or Web of Science. This date range approximately covered the start of more common use of the term One Health until post-Covid increases in interest in wildlife health. We believed this to be a time with increased desire for wildlife health information and thus reflective of current expectations. We included analyses, commentaries and perspectives papers from the peer-reviewed literature. Papers that only described outputs of surveillance systems or did not discuss expectations or goals of knowledge users were excluded. We started with key words wildlife, health, disease, surveillance, intelligence, standards, guidelines, expectations. We examined references in these publications to find other papers with titles that suggested information about surveillance expectations or goals. Additional references were provided by colleagues aware of the project. Eighty papers were read for this project. Since narrative reviews do not aim to be inclusive of all literature, we recognize that this method will not include all literature on a topic but rather give an overview of common issues being discussed in the wildlife health surveillance community.

We organized the findings from this review using the guiding questions for wildlife health surveillance system design described in Berezowski at al (2022); (1) why are we doing this, (2) what needs to be kept under surveillance; (3) who needs to be involved; (4) how will we recognize a signal, (5) how do we know it works.

Information summary

Surveillance objectives

Objectives fell into 2 broad classes: those dealing with risks *from wildlife* to livestock, people and trade; and those dealing with risks *to wildlife* from disease and non-disease threats (Figure 4). Both classes expected consistent, reliable and timely sharing of information on infectious diseases and pathogen detection. Few were concerned with pollutants or non-infectious diseases. Where objectives were intended to help wildlife, both infectious and non-infectious harms of conservation, food safety and wildlife productivity importance were expected to be under surveillance. But not all programs were expected to cover this full range of harms. There was awareness of the role for social or environmental factors affecting wildlife fitness and sustainability but no clear or consistent pathway on how they would routinely be incorporated into surveillance activities. Some, but not all objectives recognized that the unique socio-ecological circumstances and knowledge gaps associated with wildlife complicate or preclude directly applying surveillance standards and guidelines developed for domestic animals.

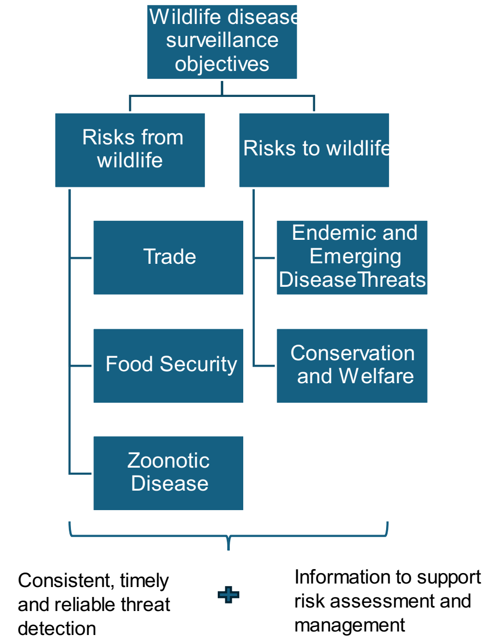

Figure 4. General taxonomy of objectives for wildlife health surveillance.

As *per* Rolka et al (2008 as cited in French et al. 2013) pandemic related expectations for wildlife fall into 3 categories; (1) pre-event/threat situations where a wide range of events and threats are assessed, 2) emergency situational awareness where detailed information on specific events or threats are monitored and 3) recovery operations where the impacts of interventions are monitored. Lawson et al (2021), concluded that national surveillance programs should have the objectives of (1) reducing "the social, human health, economic and ecological costs of pathogens carried by wild animals; and (2) [meeting] international obligations to detect and report important pathogens occurring in wild animals." This perspective neglects past and ongoing programs with objectives to track chemical contaminates in wildlife for public health, environmental health and wildlife health purposes. Some objectives were more ambitious such as in Sainsbury et al (2001) which were to; (i) define fully the inventory of diseases, disease-causing agents, host species and their geographic and temporal distributions; (ii) monitor changes in this inventory over time; (iii) detect new or emerging diseases and (iv) create accurate technical information on wildlife health and disease readily available to wildlife professionals and to the public.

We found no explicit logic models or theories of change that showed how information needed by decision makers was linked to the objectives, methods, or outputs of the surveillance system. In some cases, this logical relationship was implicit such as when detection of a listed pathogen resulted in banning movement of animals from that population because of pre-existing legal obligations. The actions and information types for the different expectations found in international standards, guidelines or stated goals are summarized in Figure 5.

The three most common surveillance goals were to provide situational awareness, establish baselines and threat detection.

https://doi.org/10.1017/one.2025.4 Published online by Cambridge University Press

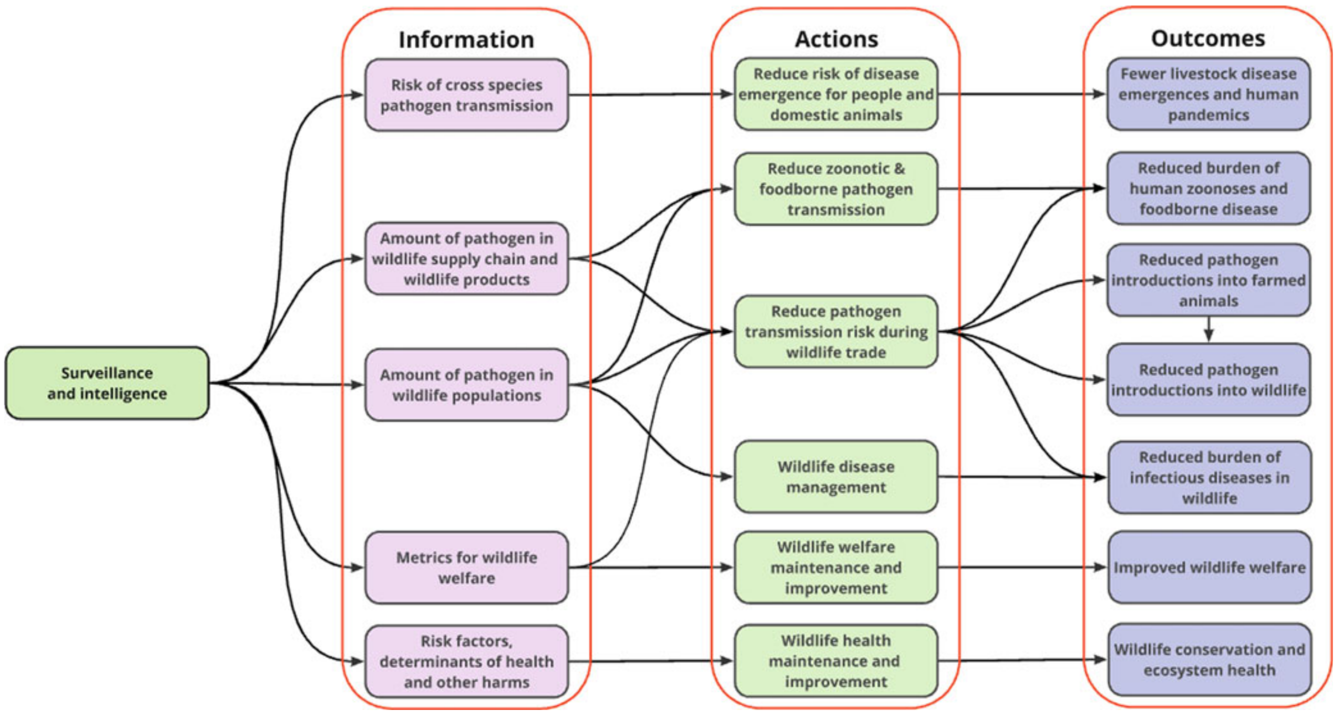

Figure 5. A summary of general relationships between information needs, actions and desired outcomes for wildlife health surveillance adapted from a 2023 online review of publicly available international standards, guidelines and goals.

Situational awareness

Situational awareness was a widely held expectation. Toner (2009) stated that situational awareness requires gathering the right information, analyzing it, understanding if the analyzed outputs are actionable and being able to do something with the information. We failed to find standards or guidance to fully operationalize Toner's (2009) view of situational awareness, nor did we find published evaluations of the utility of situational awareness produced by surveillance systems. This does not imply that situational awareness was not achieved. We did find intentions, sometimes implicit, that the surveillance system should address Regmi et al's (2016) proposed decision-makers needs included; (i) recognize priority problems and needs, (ii) track progress to evaluate the impact of interventions and (iii) make evidence-based decisions on policy, program design and resource allocation.

Establishing baselines

Some national goals or guidelines, such as those for Australia (WHA, 2020), advocated for the generation of the robust baseline information. WOAH and the International Union for the Conservation of Nature (IUCN) declared that baseline information was critical for epidemic detection (Jakob-Hoff et al. 2014). Historical records of threat or disease detections support declarations of disease freedom or changed epidemiological situations. Ryser-Degiorgis (2013) proposed that baseline data should; (i) establish the distribution of pathogens and appreciate their effects and epidemiology; (ii) assess temporal changes and understand the impacts on hosts and pathogens; (iii) provide signals for early detection and implementation of control measures; (iv) determine whether or not the emergence of a disease was due to the introduction of infected animals; and (v) assess causal associations between pathogen and disease. Problems with wildlife data quality and biases can necessitate the use of significant expert judgement to generate baseline data (Dorea et al 2013). Wildlife disease surveillance systems rarely generate or use baseline data on trends in population dynamics and demographics or changes in determinants of health in their surveillance outputs. Lack of these sorts of data can complicate interpretations of the changes from baseline for pathogens or diseases.

Threat detection

Threat detection was a regularly stated objective but largely biased towards the threat of pathogen spillover from wildlife to people or domestic animals. The Tripartite+ Guide to Preventing Zoonotic Disease in Countries expected that notifiable zoonotic diseases and events in wildlife to be reported to WOAH according to the Terrestrial and Aquatic Animal Health Codes (FAO, WOAH, WHO, 2019). The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (decisions 19.5–19.9) encouraged Parties to improve monitoring and reduce the risk of pathogen spillover along international wildlife trade supply chains. The United Nations Environment Program (UNEP/EA.5/Res.6 2002) expected actions to enhance data for the timely detection and responses to health risks linked to environmental factors. WOAH had guidelines, training materials and information management systems to actively encourage more widespread and effective monitoring of wildlife pathogens. The implications of some agreements were less clear. For example, the Sanitary and Phytosanitary Measures Agreement provides countries with a strong incentive to meet WOAH Standards for contagious disease management in livestock, aquaculture and poultry but it was less clear if it incentivized actions on wildlife diseases.

The IUCN March 2022 draft Guidelines for Prevention, Detection, Response and Recovery from Disease Risks in

Protected and Conserved Areas noted that surveillance is needed to protect wildlife from diseases that can affect their fitness and conservation status. When committing to One Health approaches for pandemic preparedness, G7 countries recognised the links between biodiversity loss and risks of zoonotic disease and committed to work to halt and reverse global biodiversity loss (ex. Anon, 2021). The role of accessible, safe and sustainable wildlife (including fisheries) was recognized by many organizations and experts as a foundation for food security and sustainable livelihoods for many of the most vulnerable people on the planet. UNEP (via Resolution UNEP/EA3/Res 4 2017) was concerned with many of the important threats to free-ranging wildlife health and welfare including chemical pollution, waste, habitat destruction and climate change but lacked explicit animal health guidelines for these threats.

Wildlife welfare surveillance

The Tripartite + Guide to Preventing Zoonotic Disease in Countries (FAO, WOAH, WHO, 2019) listed consideration of animal welfare as a best practice in emergency contingency planning. The WOAH Wildlife Health Framework acknowledged that wildlife management must deal with welfare (WOAH, 2021). The WOAH Global Animal Welfare Strategy established that animal welfare is closely linked to animal health, the health and well-being of people and the sustainability of socio-economic and ecological systems (WOAH, 2017). A case was made that welfare is an important component of any discussion or policy about wildlife trade, for the interests of wildlife and people (Wyatt et al. 2022).

Some guidance on welfare could be found but it mostly dealt with conditions of confinement or handling and not with conditions experienced by free-ranging wildlife populations. For example, WOAH and CITES provide guidelines for the welfare of wildlife in transit, but they did not deal with welfare of free-ranging wildlife. Welfare surveillance standards or guidelines were not found. We found no global agreement on criteria to measure or monitor wildlife welfare.

Populations considered

What was included as wildlife?

Wildlife, most broadly defined, includes all the native fauna and flora of a region that live independently and have a phenotype unaffected by human selection. But most surveillance standards, goals and expectations limited their concerns to animals, which variably could include feral domestic animals, captive wild animals and/or free ranging wild animals. Fish and aquatic invertebrates were rarely included in wildlife health surveillance objectives. They were more often included in separate aquatic animal health surveillance documents.

Captive wild animals include a wide suite of situations and species, such as endangered species in zoos, wild caught animals in the pet trade, animals in game farms and ranches, or animals held in captivity for conservation purposes. We found little guidance as to when captive animals originally derived from wildlife are no longer considered wildlife. Canada's 2005 Policy for Conservation of Wild Pacific Salmon (DFO, 2005) was one example. It stated that wild animals cannot be affected by captive rearing for two or more generations and still be considered wild. Some instances of wildlife farming have had multiple generations reared in captivity during which time selection pressures through breeding and husbandry substantially made these animals more like livestock and therefore more amendable to existing surveillance standards for domestic animals. Yet, farmed wildlife were often considered to be wildlife in many standards or guidelines we encountered. Captive populations that are sustained through captive breeding could be composed of groups with differing surveillance needs. For example, the endangered Vancouver Island Marmot (*Marmota vancouverensis*), is composed of three groups (free ranging, retained in zoos and captive released) each with different surveillance challenges and each with different disease patterns (McAdie, 2018). International standards and expectations for surveillance either inadequately, inconsistently or incompletely dealt with the implications of different life histories on surveillance system design and operation.

Animals in the wildlife trade

There was a preponderance of expectations for surveillance of species involved in the wildlife trade. A 2020 survey of WOAH Member Countries found virtually all (99%) believed Veterinary Services should be involved in monitoring wildlife trade supply chains (WOAH, 2021b). Multiple sectors expected that the legal wildlife trade should be treated equivalently to livestock trade in terms of surveillance for assurances of safe movement and use of wild animals and their products. Most of these concerns did not explicitly include capture fisheries as part of the wildlife trade, instead they were predominantly focussed on terrestrial wildlife and biased to charismatic megafauna and zoonotic pathogen hosts.

We found no guidance on how to include unintended consequences in surveillance activities intended to increase safety in the wildlife trade. For example, we found no instance where conservation standards were linked to health surveillance programs (i.e. conservations standards that exporting countries would have to adhere to if surveillance outcomes supported export of wildlife and wildlife products). Doing so could address UNEP expectations that "environmental sustainability is reflected in development and investment planning and provides countries with the necessary tools and technologies to protect and restore the environment" (UNEP, 2024).

Neglected populations

There were expectations for surveillance of species outside of the wildlife trade that could present risks to public health, livestock or wildlife. There was a bias toward tracking diseases in charismatic megafauna or species involved in recreational or commercial harvest. Fewer expectations involved animals that can be affected by diseases of conservation but not trade, harvest or public health significance (ex. invertebrates such as corals or fish not part of the seafood trade). This left many species, including the bulk of species at risk, being monitored by opportunistic surveillance rather than targeted efforts. This was especially pronounced for marine and aquatic species where interest, when present, was largely focussed on species of commercial fisheries importance or marine mammals.

Population sampling

Explicit and implicit goals for population coverage ranged from opportunistic samples to representative sub-samples of populations. While some surveillance systems, especially at the national and sub-national level, had authority to consider all wild animals in their jurisdiction, few have the resources, capacity, or sample supply system to provide equivalent surveillance for all wild animal populations in their jurisdiction.

Little guidance was given on accessing and incorporating information on the target population's size, demographics, heterogeneity in risk factor exposure or movements when designing sampling strategies. Some standards or guidelines acknowledged that representativeness can only be achieved if risk factors relevant to the issues under surveillance can be measured and weighted to show the relative differences in risk and proportion between the sample and the target population while also recognizing that the challenge in obtaining such information can bias wildlife health surveillance data. We found little guidance on how to account for or consider such biases apart from the use of expert opinion, experience, triangulation or accounting for biases when undertaking uncertainty assessment.

Surveillance programs mostly relied on non-probability sampling, negating the use of sample size estimation and tests of statistical inference. Much of the guidance for population sampling was general and inadequately considered practical limitations of sampling wildlife. For example, formula provided to estimate sample sizes in some wildlife-specific guidelines relied on information about the size of the population and the sensitivity and specificity of the tests used (information unknown for many wild species) and assumed representative or random sampling of the population (a situation rarely attainable for free ranging wildlife). Guidelines that used the statistical property that in large populations the number of samples needed does not increase as the population increases assumed large populations for sample size estimates and that the sample was a random sample of the population. Non-probability sampling can be used to establish the presence of a pathogen in population but cannot be used alone to accurately estimate the amount of disease or the absence of disease in a population.

Boundaries

Spatial boundaries for surveillance were often defined by a combination of political and ecological boundaries with more guidance for species with known transboundary disease concerns and for well-studied species. Less guidance was available for understudied species or species lacking economic or charismatic value. For example, in one case, where there were expectations for pathogens to be detected in aquatic animals in contiguous water bodies, guidance on what constitutes contiguous waters was not provided.

Legal or social status

Consideration of the legal or social status of animals was inconsistent. There are binding implications for population sampling where endangered species are involved or where aboriginal rights and claims may be affected. For example, the need to capture and sometimes kill wild animals (especially in fishes and invertebrates) for prospective sampling has welfare considerations as well as conservation and legal considerations for rare and endangered species. These aspects were rarely mentioned in the guidelines and standards we reviewed.

What health variables need to be under watch?

Disease cases and pathogens

Reviewed surveillance objectives primarily provided awareness of the presence and distribution of disease states or etiological agents to support risk communication regarding the threats posed to wild animal populations, people and the agricultural sector. Most wildlife health systems followed a "disease-by-disease" sequence, requiring the detection of adverse health outcomes (e.g., disease or death) or known threats (e.g., pathogen).

There was less interest in conducting wildlife surveillance to detect the environmental distribution of contaminants compared to contagious disease surveillance, especially for zoonotic diseases or diseases of agricultural significance.

Diagnostic criteria or case definitions

Well validated and field-tested diagnostic criteria were rare for wild populations, as were accurate disease prevalence estimates. The large numbers of wildlife species, the diversity of pathogens that infect them and the emergence of new diseases present unique challenges for test validation. "This creates important gaps in knowledge about the predictive value of surveillance case definitions" (Jia et al. 2020). Case definitions specifying the precise information to track will depend, in part, on the species being managed, the availability of contextual information and emerging research. Jai et al (2020) found that such information is often unavailable. Their review of diagnostic test validation studies for WOAH-listed diseases in wild mammals found most reports were concerned with one pathogen (*Mycobacterium bovis*) in one or more wildlife species and were affected by limited or missing information about sampled animals, criteria for positive and negative samples and representativeness of source and target populations. They could not determine if this reflected lack of information or lack or reporting but commented on how these deficits complicate the ability to determine diagnostic test performance.

The predictive value of a case definition is affected not only by the sensitivity and specificity of the diagnostic test or criteria used, but also by the prevalence of the disease (or problem or risk factor) in the population and the number of animals sampled (Martin et al. 1992). Given challenges in finding representative samples and often missing information on the source population size, it is rarely possible to provide prevalence estimates. For non-probability sampling, this problem is further compounded, because it is rarely possible to estimate how presence of the disease affects the detection of affected animals and their entry to a diagnostic system.

Health surveillance

Health was generally either left undefined or was, *de facto*, defined as absence of specific etiological agents. In recent decades, the interpretation of wildlife health has moved from the classical dichotomous state of "disease presence/absence" to a broader concept that integrates the interaction of biological, social and environmental health determinants (Stephen, 2014; Aleuy et al. 2022). Wildlife health surveillance programs tended not to track variables related to all three of these categories of determinants.

Standards or guidelines for the design and operation of surveillance systems tended to focus on independent threats or outcomes in the same population. We failed to find guidance on how to integrate different surveillance outcomes from different (or the same) surveillance program to develop a single integrated view of the population's health risk or outcome status.

Participants

Most often, wildlife health surveillance systems were designed and operated by national and sub-national government agencies, but international organizations and NGOs also delivered programs. Roles and responsibilities varied between programs resulting in different agencies having different roles in tracking or affecting determinants of wildlife health. Some guidance documents targeted specific audiences (ex. veterinary services) while others seemed not to be developed for a specific user group. Only a small number of programs considered multiple actors in the surveillance systems, with most of those looking at how citizen science or community collaborations can supplement sample acquisition.

Recognizing an actionable signal

The goal of surveillance is to find a change. Therefore, the first two questions to ask are, what signal of change is important to find and how much of a change warrants action? The first question could be answered in most cases by examining the purpose and objectives of the surveillance system and its associated case definitions.

As noted above, case definitions were relatively rare. A case definition should be meaningful, interpretable and understandable to those people whose decisions or actions are influenced by signals identified when monitoring cases. Given that most case definitions had a strong biomedical focus, it is implied that they are primarily for use by diagnosticians.

Some guidance was available on the detection of an unusual epidemiological situation. This could include factors such as a noteworthy occurrence of one or more sick or dead animals clustered in space and time, the involvement of a previously unknown etiology, occur of a disease outside it's known geographic-species distribution or host, or whether the circumstances surrounding an identified disease occurrence differed from historic norms.

The answer to the question, how much of a change warrants action, was more challenging to find. We found no gold standard or consensus on methods for identifying and calculating wildlife surveillance thresholds apart from declarations of the detected presence of an etiological agent or specific disease. Mandatory reporting for listed diseases was a commonly recognized action threshold. For welfare, evidence of cruelty was most often the threshold for action.

Despite recommendations to gather environmental data to support wildlife surveillance, there was no guidance on how to use such information in the analysis phase of surveillance. We found little evidence of risk factor surveillance that benefits wildlife, although periodic studies or surveys of factors affecting exposure or sensitivity to disease impacts on wildlife could be found.

System evaluation

We found little guidance on establishing performance standards specific to wildlife health surveillance programs. Some programs recommended, advised, or applied standards used in domestic animal surveillance. Nonrepresentative samples of the populations at risk, biased case ascertainment, the lack of adequately validated diagnostic tests, inaccurate or missing population denominator data, lack of standard case definitions and diagnostic protocols, regulatory restrictions, ecological complexities and fiscal constraints were but some of the factors complicating direct application of domestic animal or public health evaluation standards to wildlife surveillance.

We found no reports of systematic evaluation of a wildlife health surveillance system that examined all aspects of the system from data acquisition to knowledge translation or that looked at the full suite of factors recommended for surveillance system evaluation for domestic animals.

Implications for surveillance system design

Figure 6 is a synthesis of the expectations we derived from our information scan. Surveillance and intelligence systems can involve multiple purposes, stakeholders, components, infrastructure, processes, policies and regulations which are deployed differently depending on the surveillance context. As such the expectations in Figure 6 are generic and need to be adapted to the local capacity, questions and context.

Surveillance systems designers next need to consider the necessary attributes of their system's surveillance cycle (Figure 3) that can address these expectations. Goals and expectations dictate the necessary functions, services and boundaries of a surveillance system (Figure 1). These in turn determine the necessary structures, components, relationships.

Functions and services

A program designed to address the full evidence ecosystem would need to integrate and expand existing information across the multiple levels of decision-making to generate actionable, timely knowledge for stakeholders at the local, national regional and/or international levels. Its functions would need to help gather and understand new knowledge (cognition), access data and information from diverse sources to gain knowledge (cooperation) and do so in an efficient and broadly acceptable manner (coordination). This would be consistent with the concept of health intelligence which relies on information from multiple sources to provide a stream of information that can be inspected to support decisions about prevention, surveillance, or responses (Han and Drake, 2016). While intelligence seems to be a desirable outcome, most standards and guidelines focussed on surveillance.

Given that wildlife health has implications across multiple domains, it was not surprising that a single strategic objective was not common across surveillance programs, apart from the prevailing objective of creating situational awareness. Situational awareness is "the perception of elements in the environment with a comprehension of their meaning and a projection of their status in the near future," (Endsley and Garland, 2000). This requires a combination of the ability to accurately evaluate an existing situation and the ability to anticipate how an existing situation may develop in the future. We found most guidance on surveillance focussed more on detecting or perceiving a situation and less on how to acquire and use knowledge of the context, implications and consequences of a particular circumstance. There often was an expectation or assumption that threat detection will be sufficient to prompt actions without taking into consideration personal, psychosocial, organizational and methodological variables that can influence the translation of evidence to action. While detection of diseases or hazards that have associated legal obligations for reporting or action may be a sufficient action threshold, relying on hazard detection alone will unlikely be sufficient for non-regulated diseases or previously unknown diseases.

We found no published assessment of whether existing wildlife surveillance outputs provided sufficient cues to support decision making under the expected decision scenarios. The authors recognize the challenges of undertaking assessments of wildlife surveillance systems and the difficulty in attributing surveillance actions to health outcomes. The diversity of places, species and surveillance targets; the lack of investment in evaluation; and the difficulty in assigning causal relationships in complex socio-ecological situations make it challenging to declare if a surveillance system is working to meet its ultimate goal.

The expectations for wildlife disease surveillance to help predict threats was a commonly desired surveillance function for known wildlife diseases. Expectations for use of wildlife information for

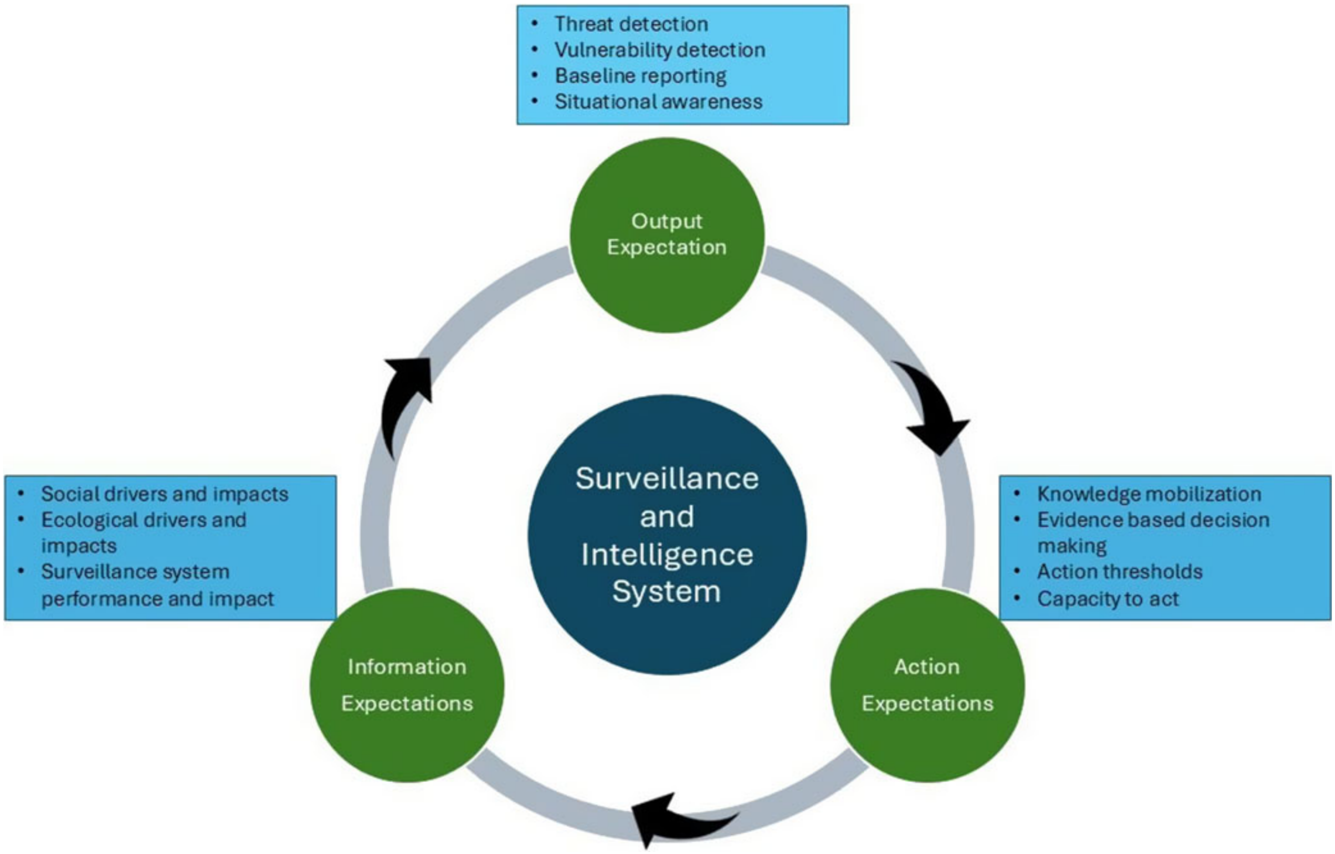

Figure 6. Summarizing expected outputs, information, and action themes for wildlife health surveillance and intelligence systems based on a non-systematic examination of trends in literature and operational goals for a selection of agencies involved in wildlife health management.

prediction of emerging threats seem more in the realm of research than surveillance. Whereas surveillance data can support research, surveillance for research should be designed to address specific hypothesis as opposed to surveillance for action which need to be designed to meet the information needs of decision makers.

The specific objectives of a health information system should be developed in part by research and in part by consensus to ensure fit with local needs and context but should consider; (i) what actions and interventions are available; (ii) who makes the decisions to act and what information they require; (iii) which indicators can provide the required information (iii) the biases inherent in the data collected and their impact on the validity of the information and (iv) the capacity to reliably and regularly generate information on a time line relevant for decision making. While the five requirements were woven into many surveillance programs, no explicit logic model was found that outlined the processes or procedures to meet these expectations. An explicit theory of change could transparently outline the design and operation of a surveillance system, thus increasing consistency and trust in the system.

Perhaps because there are very few means to alter the course of naturally occurring wildlife disease, few standards or guidelines made a clear link between a threat detection and a threshold for action apart from reporting listed diseases. More guidance was available on threat or hazard detection and much less on the analysis and information dissemination components of the surveillance cycle. Evidence is being sought to relate surveillance systems attributes to impacts on targeted health outcomes. But in the meantime, the wildlife health surveillance community is developing a series of guidelines and recommendations that combine expert experience, available literature and standard practice for surveillance used in the domestic animal sector and public health. Examples include IUCN and WOAH's General Guidelines for Surveillance of Diseases, Pathogens and Toxic Agents in Free-ranging Wildlife (WOAH and IUCN, 2024) or disease specific guidelines such as those developed for wildlife surveillance around mink farms during the SARS-CoV2 pandemic (ECCC, 2022).

Boundaries and relationships

There are three types of boundaries to consider, operational, spatial and species. Spatial boundaries based on political delineation can fail to account for the ecological reality of wildlife conservation (Thomson et al. 2013), yet most surveillance systems operated within political boundaries. As the number of species or populations increased in a system (species boundaries) the greater it seemed the reliance on opportunistic surveillance, most often focussed on game, traded and charismatic species. Guidance on operational boundaries often failed to consider the entire surveillance cycle from those who contribute to the funding or samples, to those undertaking all surveillance activities including analysis assessment, synthesis and dissemination, to those implementing surveillance outputs into practice. Disconnected operational boundaries can impede the smooth, timely, trusted flow of information from creation to implementation.

Wildlife health surveillance systems often require samples or observations from one sector (ex. wildlife managers or citizens) to be given to another sector (ex. veterinary services) who produce

https://doi.org/10.1017/one.2025.4 Published online by Cambridge University Press

outputs for different sector (ex. public health). To form a coherent information ecosystem, there must be value and reciprocity through the information conduit (Kunzler et al. 2024). We discovered many instances where requests were one-way such as when a veterinary service requested samples from an environment agency, but without due consideration of the value to the environment agency participating in the surveillance system.

The centrality of wildlife as sentinels in many surveillance programs runs counter to a One Health philosophy that seeks to protect ecosystem health or ensure intergenerational and interspecies health equity. The use of wildlife as sentinels re-enforces one-way movement of information from wildlife data providers to users in other sectors (e.g., public health or livestock health). Multi-way flow of information such that the wildlife sector also benefits from sentinel systems is critical to achieve the goals of One Health. This, in our view, is an underlying source of tension between aspirations and expectations for wildlife health surveillance for many international organizations and the reality of most surveillance programs. A healthy evidence ecosystem should cultivate positive feedback loops that mutually reenforce the goals of all its participants.

Components

Many wildlife surveillance systems track issues that effect a range of conservation, economic, human and ecological communities and geographic concerns. Evidence demand will grow as numbers of evidence users increases. As such, there can potentially be an exceptionally large number of information needs even for a single issue (Figures 5 and 6). The current norm emphasizes wildlife as a risk factor or sentinel for human and livestock contagious diseases, and to a lesser extent, chemical contaminants. There was less systematic and ongoing surveillance on the drivers of health in wildlife.

While there has been attention to ensuring surveillance systems produce scientifically robust outputs (Calba, 2016, Peyre et al. 2019), there seems to have been less attention on systematically determining whether the components of the programs produce useful outputs. Wildlife health surveillance is not receiving the same resources that public health or domestic animal surveillance receives. Therefore, any developments in wildlife surveillance needs to have a keen focus on eliminating outputs or efforts that are unusable or distract evidence users.

The lack of performance standards for wildlife surveillance negatively impacts attempts to show that activities are meeting the expectations of funder and knowledge users (Stephen et al. 2019). Reasons why it can be hard to systematically evaluate a wildlife health surveillance system included; study design limitations (ex. researchers use no control, use historical controls, reliance on ecological design {in the epidemiological sense}); lack of a random or representative sample, assumptions that lack of negative events is proof of effectiveness or absence; lack of sufficient time to follow-up to establish medium-to-long term benefits; using surrogates of risk or benefits rather than directly measuring the impacts on health outcomes; using socially irrelevant end-points; unaccounted confounding variables and/or responses to surveillance outputs are influenced by other social or ecological pressures such as land use management decisions or demands for wildlife products. Without evidence-based design and evaluation, programs can produce inefficient, ineffective or harmful outcomes and limited knowledge exchange opportunities (Milner-Gulland et al. 2018).

Structures

"Wildlife surveillance techniques are necessarily very different from those for domestic animal surveillance" and creative surveillance designed for a particular context is needed to overcome such constraints (Cameron, 2010). Giacinti et al (2022) proposed four areas to improve wildlife surveillance for future needs, (i) improvements in representativeness in terms of the sampling of populations and the breadth of species under surveillance, (ii) harmonization of methods for design, implementation and assessment of surveillance systems (iii), expanded and diversified collaborations to access the necessary scope of information to detect and understand wildlife health trends and (iv) a shift to a solutions-focussed surveillance program design. Points iii and iv align with Toner's (2009) assertion that situational awareness requires analysis of the right types and breadth of information, to allow outputs to be actionable.

Wildlife health standards or guidelines can specify what needs to be achieved but will need flexibility in how it is achieved due the variability in the circumstances, species and threats under consideration. Outcome based standards and guidelines may be most appropriate in that they establish what must be achieved rather than what must be done. The idea is not to standardize methods used for surveillance system design, but to build systems that allow the comparison of outputs from one surveillance system in one region to a different surveillance system for the same disease in a different region. It would be up to the surveillance and intelligence system operators to defend the validity of assertions that their target population was representatively sampled. This would allow the use of methods that work the best for the given circumstances and decision needs.

Conclusions

This paper shows a mismatch between the evidence ecosystem envisioned to support international expectations and the capacity to meet those expectations. The non-systematic nature of this project coupled with the restriction to English language literature and English or multi-language organization constrains the viewpoint we used to scan this topic. While evidence suggests that English is the most common language of science and that major discrepancies in literature reviews using English only compared to using languages other than English are rare in conventional medicine and epidemiological studies (Morrison et al. 2012, Nussbaumer-Streit et al. 2020), we cannot make conclusions on the impact of this bias in affecting the perspectives we developed.

Wildlife health surveillance is a rapidly evolving field. New technologies, new obligations and new threats are resulting in rapidly changing surveillance systems components. It is without doubt that some of the challenges and deficits we have detected, or opportunities identified will have been addressed to some degree by the time of publication of this paper. However, it is equally without doubt that these changes will not be equitable distributed around the world, will be sustained or will be adequately implemented, therefore, retaining the relevance of the insights we developed through this project.

We recognize the contradiction between our suggestions to grow wildlife health surveillance systems into intelligence systems for more effective situational awareness and the findings of Delgado et al (2023) and Machalaba et al (2021) of low global capacity for wildlife disease surveillance. Expectations for wildlife health have increased at the multilateral level, especially after the SARS-CoV pandemic. Yet most surveillance is implemented at the national and sub-national level where capacities can be highly variable. While the perspectives offered in this paper have relevance to setting expectations and information design, we do not offer solutions to the challenges of implementing or scaling up global surveillance capacity. A global discussion is needed about what can realistically be done to achieve the desired objectives.

Information and knowledge gaps featured prominently in our scan of expectations and knowledge. A research agenda supporting wildlife health surveillance and intelligence development should be centered on four core issues:

1. Equivalency– What methods can equivalently be used to reliably acquire wildlife health information and/or how can the biases, uncertainties and ambiguities of wildlife health information be effectively accounted for in risk assessment and decision making? Issues of non-representative and biased wildlife population sampling were pervasive problems in our scan, needing considerable guidance to ensure information generated from wildlife is appropriately assessed.
2. Equity – Do the current approaches ensure that all wildlife can reach their full health potential and are not disadvantaged from the actions taken in response to surveillance and intelligence outputs. Systems designed to protect one group (ex. livestock) should not adversely affect another group (ex. wildlife). The harms and benefits of wildlife risk management should be equally borne by wildlife users and non-users.
3. Effectiveness – Do we know that surveillance and intelligence systems support decisions that are acceptable, ethical, efficient and effective and do not generate unintended adverse consequences? The decisions on what to monitor will influence what can be done with surveillance outputs. For example, the decision to focus on diseases that affect livestock trade can reduce the resources available to track diseases of concern to local threatened species. The need for a disease to be known to cause significant impacts could preclude proactive management targeting distal risk factors for yet unknown diseases, making it hard for wildlife health surveillance to support very early warning against future pandemics. Integrating traditionally distinct knowledge, skills and perspectives for game-changing purposes is a growing expectation of universities and governments (Halloun 2020), but guidance on how to achieve this in the wildlife health sector was either lacking or aspirational.
4. Welfare - Systems intended to promote wildlife resilience require a shift from an exclusive focus on disease, distress and cruelty to health promotion strategies that support animals in all ways, as individual and as groups, to humanely fulfill their evolved roles and needs. Wildlife population welfare surveillance needs to not only address how we protect wildlife from the direct effects of diseases but also the indirect effects on the environmental and social change that impede welfare and thereby increase vulnerability and reduce resilience to emerging diseases, climate change and other conservation threats. Welfare exists when animals have the capacity for unimpaired flourishing, free of obstacles, to live in a way that conforms with expectations, opportunities and abilities (Stephen and Wade, 2018). There will be a need for considerable consultation, applied research and partnerships to support efforts to identify variables that influence wildlife welfare protection.

Data availability statement. All information used in this analysis were described in the paper and can be found through the references cited.

Acknowledgements. We thank the professionals who provided their time, experience and insight to help provide the necessary context to complete this commentary.

Author contributions. CS conceived the study. CS and JB both extracted information from online, literature and key informant source. CS drafted the initial analysis while both JB and CS prepared the final document.

Financial support. This work was supported in part from finding provided by the World Organization for Animal Health.

Competing interests. Neither author had any conflicts of interest.

Ethics statement. No animal subjects were used in this analysis. Human participants provided information were not subject to Canadian guidelines for research on human subjects.

Connections references

Lawson B, Neimanis A, Lavazza A, López-Olvera JR, Tavernier P, Billinis C, Duff JP, Mladenov DT, Rijks JM, Savić S, Wibbelt G (2021) How to start up a national wildlife health surveillance programme. *Animals* 30;**11**(9):2543.

Stephen C (2023). How do the practical and pragmatic limitations in the design or implementation of wildlife disease surveillance systems bias our understanding of the drivers, epidemiology and impact of pathogen traffic between wildlife and people or domestic species, or within wildlife host populations?. *Research Directions: One Health*, *1*, p.e4. https://doi.org/10.1017/one.2022.5.

Barroso P, López-Olvera JR, wa Kiluba TK. Gortázar C (2024). Overcoming the limitations of wildlife disease monitoring. *Research Directions: One Health*, *2*, p.e3. https://doi.org/10.1017/one.2023.16.

References

Aleuy OA, Kutz S, Mallory ML and Provencher JF (2022) Wildlife health in environmental impact assessments: are we missing a key metric? *Environmental Reviews* **31**(2), 348–359. https://doi.org/10.1139/er-2022-0023.

Anon (2021) GY Carbis Bay Health Declaration. G7 Cornwall UK 2021. https://www.consilium.europa.eu/media/50362/g7-carbis-bay-health-declaration-pdf-389kb-4-pages.pdf (Accessed September 16, 2024).

Anon (2025) Navigating the ethics of human research. Panel on Research Ethics. Government of Canada. https://ethics.gc.ca/eng/home.html (Accessed Feb 14, 2025)

Antoine-Moussiaux N, Vandenberg O, Kozlakidis Z, Aenishaenslin C, Peyre M, Roche M, Bonnet P and Ravel A (2019) Valuing health surveillance as an information system: interdisciplinary insights. *Frontiers in Public Health* **13**(7), 439416. https://doi.org/10.3389/fpubh.2019.00138.

Barroso P, López-Olvera JR, wa Kiluba TK and Gortázar C (2024) Overcoming the limitations of wildlife disease monitoring. *Research Directions: One Health* **2**, e3. https://doi.org/10.1017/one.2023.16.

Berezowski J, Carmo LP and Stephen C (2020) Building health surveillance for decision support at the animal, human, environment nexus. In C Stephen (ed.), *Animals, Health and Society: Health Promotion, Harm Reduction and Health Equity in a One Health World.* Boca Raton: CRC Press.

Calba C (2016) Surveillance systems evaluation: a systematic review of the existing approaches. *BMC Public Health* **15**(1), 448. https://doi.org/10.1186/s12889-015-1791-5.

Cameron A (2010) Surveillance needs, tools and options: Experiences between developed and developing worlds. Challenges of Animal Health Information Systems and Surveillance for Animal Diseases and Zoonoses. In *Proceedings of the international workshop organized by FAO, Rome, Italy FAO Animal Production and Health Proceedings*, pp. 91–94, 23-26 November

Delgado M, Ferrari N, Fanelli A, Muset S, Thompson L, Sleeman JM, White CL, Walsh D, Wannous C and Tizzani P (2023) Wildlife health surveillance: gaps, needs and opportunities. *Revue Scientifique et Technique-Office International Des Epizooties* **42**, 161–172. https://doi.org/10.20506/rst.vol.42.3342.

DFO (2005) Canada's Policy for the Conservtion of Wild Pacific Salmon. Fisheries and Oceans Canada. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/315577.pdf (Accessed September 19, 2024)

Dórea FC, Revie CW, McEwen BJ, McNab WB, Kelton D and Sanchez J (2013) Retrospective time series analysis of veterinary laboratory data: preparing a historical baseline for cluster detection in syndromic surveillance. *Preventive Veterinary Medicine 1* **109**(3–4), 219–227.

ECCC (2022) Wildlife Surveillance Guidelines in Response to the Detection of SARS-CoV-2 in Farmed Mink in Canada. Government of Canada. https://www.cwhc-rcsf.ca/docs/covid/EN_WildlifeSWG_Wildlife-Surveillance-Guidelines-v2_17Feb2022.pdf. (Accessed Feb 14, 2025)

Endsley MR and Garland DJ (2000) Theoretical underpinnings of situation awareness: a critical review. *Situation Awareness Analysis and Measurement* **1**(1), 3–21.

FAO, WOAH, WHO (2019) Taking a multisectoral, one health approach: a tripartite guide to addressing zoonotic diseases in countries. https://iris.who.int/bitstream/handle/10665/325620/9789241514934-eng.pdf?sequence=1. (Accessed Sept 19, 2024)

French M and Mykhalovskiy E (2013) Public health intelligence and the detection of potential pandemics. *Pandemics and Emerging Infectious Diseases: The Sociological Agenda* **3**, 8–20. https://doi.org/10.1002/9781118553923.

George SE, Smink M, Sangkachai N, Wiratsudakul A, Sakcamduang W, Suwanpakdee S and Sleeman JM (2023) Stakeholder attitudes and perspectives on wildlife disease surveillance as a component of a *One Health* approach in Thailand. *One Health 1;* **17**, 100600.

Giacinti JA, Jane Parmley E, Reist M, Bayley D, Pearl DL, Jardine CM and Creed I (2022) Canadian wildlife health surveillance—patterns, challenges and opportunities identified by a scoping review. *Facets* **7**(1), 25–44. https://doi.org/10.1139/facets-2021-0027.

Gough D, Thomas J and Oliver S (2019) Clarifying differences between reviews within evidence ecosystems. *Systematic Reviews* **8**(1), 1–5. https://doi.org/10.1186/s13643-019-1089-2.

Guberti V, Stancampiano L and Ferrari N (2014) Surveillance, monitoring and survey of wildlife diseases: a public health and conservation approach. *Hystrix* **25**(1), 3–8.

Haby MM, Chapman E, Barreto JO, Mujica OJ, Cinnamond AR, Caixeta R, Garcia-Saiso S and Reveiz L (2023) Greater agreement is required to harness the potential of health intelligence: a critical interpretive synthesis. *Journal of Clinical Epidemiology* **163**, 37–50. https://doi.org/10.1016/j.jclinepi.2023.09.007.

Han BA and Drake JM (2016) Future directions in analytics for infectious disease intelligence: toward an integrated warning system for emerging pathogens. *EMBO Reports* **17**(6), 785–789. https://doi.org/10.15252/embr.201642534.

Häsler B, Howe KS and Stärk KD (2011) Conceptualising the technical relationship of animal disease surveillance to intervention and mitigation as a basis for economic analysis. *BMC Health Services Research* **11**(1), 1–10. https://doi.org/10.1186/1472-6963-11-225.

Jakob-Hoff RM, MacDiarmid SC, Lees C, Miller PS, Travis D and Kock R (2014) – Manual of Procedures for Wildlife Disease Risk Analysis. World Organisation for Animal Health, Paris, 160 pp. Published in association with the International Union for Conservation of Nature and the Species Survival Commission. https://portals.iucn.org/library/sites/library/files/documents/2014-007.pdf (Accessed Sept 19, 2024)

Jia B, Colling A, Stallknecht DE, Blehert D, Bingham J, Crossley B, Eagles D and Gardner IA (2020) Validation of laboratory tests for infectious diseases in wild mammals: review and recommendations. *Journal of Veterinary Diagnostic Investigation* **32**(6), 776–792. https://doi.org/10.1177/1040638720920346.

Kunzler AM, Iannizzi C, Burns J, Metzendorf MI, Voigt-Radloff S, Piechotta V, Schmaderer C, Holzmann-Littig C, Balzer F, Benstoem C and Binder H (2024) Informing pandemic management in Germany with trustworthy living evidence syntheses and guideline development: lessons learned from the COVID-19 evidence ecosystem. *Journal of Clinical Epidemiology* **173**, 111456. https://doi.org/10.1016/j.jclinepi.2024.111456.

Lawson B, Neimanis A, Lavazza A, López-Olvera JR, Tavernier P, Billinis C, Duff JP, Mladenov DT, Rijks JM, Savić S and Wibbelt G (2021) How to start up a national wildlife health surveillance programme. *Animals* **11**(9), 2543. https://doi.org/10.3390/ani11092543.

Machalaba C, Uhart M, Ryser-Degiorgis MP and Karesh WB (2021) Gaps in health security related to wildlife and environment affecting pandemic prevention and preparedness, 2007-2020. *Bulletin of the World Health Organization* **99**(5), 342–350B. https://doi.org/10.2471/BLT.20.272690.

Martin SW, Shoukri M and Thorburn MA (1992) Evaluating the health status of herds based on tests applied to individuals. *Preventive Veterinary Medicine* **14**(1–2), 33–43. https://doi.org/10.1016/0167-5877(92)90082-Q.

Mazzamuto MV, Schilling AK and Romeo C (2022) Wildlife disease monitoring: methods and perspectives. *Animals* **12**(21), 3032. https://doi.org/10.3390/ani12213032.

McAdie ML (2018) Indicators of Individual and Population Health in the Vancouver Island Marmot (Marmota Vancouverensis)(Doctoral dissertation, Thompson Rivers University). Available at https://arcabc.ca/islandora/object/tru:2737, (Accessed March 26, 2025).

Milner-Gulland EJ, Cugniere L, Hinsley A, Phelps J and Veríssimo D (2018) Evidence to action: Research to address illegal wildlife trade. https://ideas.repec.org/p/osf/socarx/35ndz.html (Accessed Sept 19, 2024)

Morrison A, Polisena J, Husereau D, Moulton K, Clark M, Fiander M, Mierzwinski-Urban M, Clifford T, Hutton B and Rabb D (2012) The effect of english-language restriction on systematic review-based meta-analyses: a systematic review of empirical studies. *International Journal of Technology Assessment in Health Care* **28**(2), 138–144. https://doi.org/10.1017/S0266462312000086.

Nussbaumer-Streit B, Klerings I, Dobrescu AI, Persad E, Stevens A, Garritty C, Kamel C, Affengruber L, King VJ and Gartlehner G (2020) Excluding non-english publications from evidence-syntheses did not change conclusions: a meta-epidemiological study. *Journal of Clinical Epidemiology 1;* **118**, 42–54.

Panel OHHLE, Hayman DT, Adisasmito WB, Almuhairi S, Behravesh CB, Bilivogui P, Bukach SA, Casas N, Becerra NC, Charron DF and Chaudhary A (2023) Developing one health surveillance systems. *One Health* **17**, 100617. https://doi.org/10.1016/j.onehlt.2023.100617.

Paré G and Kitsiou S (2017) Chapter 9 Methods for literature reviews. In Lau F and Kuziemsky C (eds.), *Handbook of eHealth Evaluation: An Evidence-Based Approach [Internet]*. Victoria (BC): University of Victoria, Available from: https://www.ncbi.nlm.nih.gov/books/NBK481583/., (Accessed Sept 19, 2024)Feb 27

Peyre M, Hoinville L, Njoroge J, Cameron A, Traon D, Goutard F, Calba C, Grosbois V, Delabouglise A, Varant V, Drewe J, Pfeiffer D and Häsler B (2019) The RISKSUR EVA tool (Survtool): a tool for the integrated evaluation of animal health surveillance systems. *Preventive Veterinary Medicine* **173**, 104777. https://doi.org/10.1016/j.prevetmed.2019.104777.

Regmi K, Bendel N and Gee I (2016) Public health intelligence: an overview. In Regmi K and Gee I (eds.), *Public Health Intelligence*. Springer International Publishing Switzerland, pp. 1–18, 2016

H Rolka, O' Connor J and Walker D (2008) Public health information fusion for situation awareness. In Zeng D, Chen H, Rolka H and Lober W (eds.), *Biosurveillance and Biosecurity: Lecture Notes in Computer Science*. Berlin: Springer.

Ryser-Degiorgis MP (2013) Wildlife health investigations: needs, challenges and recommendations. *BMC Veterinary Research* **9**(1), 1–17. https://doi.org/10.1186/1746-6148-9-223.

Sainsbury AW, Bennett PM, Cunningham AA and Kirkwood JK (2001) Status of wildlife health monitoring in the united Kingdom. *Veterinary Record* **148**(18), 558–563. https://doi.org/10.1136/vr.148.18.558.

Schwind JS, Goldstein T, Thomas K, Mazet JAK, Smith WA and PREDICT Consortium (2014) Capacity building efforts and perceptions for wildlife surveillance to detect zoonotic pathogens: comparing stakeholder perspectives. *BMC Public Health* **14**, 1–8.

Stephen C (2014) Toward a modernized definition of wildlife health. *Journal of Wildlife Diseases* **50**(3), 427–430. https://doi.org/10.7589/2013-11-305.

Stephen C, Sleeman J, Nguyen N, Zimmer P, Duff JP, Gavier-Widén D, Grillo T, Lee H, Rijks JM, Ryser-Degiorgis MP and Tana T (2018) Proposed attributes of national wildlife health programmes. *Revue*

Scientifique et Technique-Office International Des Epizooties **37**(3), 925–936. https://doi.org/10.20506/rst.issue.37.3.2884.

Stephen C, Wade J (2018) Wildlife population welfare as coherence between adapted capacities and environmental capacities: a case study of threatened lamprey on Vancouver Island. *Frontiers in Veterinary Science* **5**, 227. https://doi.org/10.3389/fvets.2018.00227.

Stephen C, Zimmer P and Lee M (2019) Is there a due diligence standard for wildlife disease surveillance? A Canadian case study. *The Canadian Veterinary Journal* **60**(8), 841–847.

Thomson GR, Penrith ML, Atkinson MW, Atkinson SJ, Cassidy D and Osofsky SA (2013) Balancing livestock production and wildlife conservation in and around southern Africa's transfrontier conservation areas. *Transboundary and Emerging Diseases* **60**(6), 492–506. https://doi.org/10.1111/tbed.2013.60.issue-6.

Toner ES (2009) Creating situational awareness: A systems approach.. Institute of Medicine (US) Forum on Medical and Public Health Preparedness for Catastrophic Events. Medical Surge Capacity: Workshop Summary. Washington (DC): National Academies Press (US). https://www.ncbi.nlm.nih.gov/books/NBK32848/ (Accessed Sept 19, 2024). https://www.ncbi.nlm.nih.gov/books/NBK32848/.

UNEP (2024) About the united nations environment program. (Accessed Sept 19, 2024).https://www.unep.org/about-un-environment.

WHA (2020) National guidelines for management of disease in free-ranging Australian wildlife, wildlife health Australia, Sydney NSW. https://wildlifehealthaustralia.com.au/Portals/0/ResourceCentre/BiosecurityMgmt/National_Guidelines_Management_Disease_Freeranging_Aust_Wildlife_Nov_2020.pdf, (Accessed Sept 19, 2024).

WHO (2022(. Evidence, policy, impact: WHO guide for evidence-informed decision-making. *World Health Organization*, (Accessed Sept 19, 2024), https://www.who.int/publications/i/item/9789240039872.

WOAH (2017) OIE global animal welfare strategy. World organization for animal health. Available at https://www.woah.org/app/uploads/2021/03/en-oie-aw-strategy.pdf, (Accessed Sept 19, 2024).

WOAH (2021) OIE wildlife health framework. World organization for animal health. Available at https://www.woah.org/fileadmin/Home/eng/Internationa_Standard_Setting/docs/pdf/WGWildlife/A_Wildlifehealth_conceptnote.pdf, (Accessed Sept 19, 2024).

WOAH (2021b) Wildlife health survey report. World organization for animal health. Available at https://www.woah.org/app/uploads/2021/03/wildlife-health-survey-report.pdf, (Accessed Sept 19, 2024).

WOAH and **IUCN** (2024) – *General Guidelines for Surveillance of Diseases, Pathogens and Toxic Agents in Free-Ranging Wildlife: An Overview for Wildlife Authorities and Others Working with Wildlife*. Paris: Gland, 56, Licence: CC BY-SA 3.0 IGO, https://doi.org/10.20506/woah.3509.

Wyatt T, Maher J, Allen D, Clarke N and Rook D (2022) The welfare of wildlife: an interdisciplinary analysis of harm in the legal and illegal wildlife trades and possible ways forward. *Crime, Law and Social Change* **77**(1), 69–89. https://doi.org/10.1007/s10611-021-09984-9.