Wildlife health surveillance: gaps, needs and opportunities

M. Delgado (1), N. Ferrari (2), A. Fanelli (3), S. Muset (1), L. Thompson (1), J.M. Sleeman (4), C.L. White (4), D. Walsh (4, 5), C. Wannous (1) & P. Tizzani* (1)

(1) World Organisation for Animal Health, 12 rue de Prony, 75017 Paris, France

(2) Department of Veterinary Medicine and Animal Sciences, Università degli Studi di Milano, Via dell'Università, 6, 26900 Lodi, Italy

(3) Department of Veterinary Medicine, University of Bari, Strada Provinciale per Casamassima Km 3, 70010 Valenzano, Metropolitan City of Bari, Italy

(4) United States Geological Survey, National Wildlife Health Center, 6006 Schroeder Road, Madison, WI 53711, United States of America

(5) Present address: United States Geological Survey, Montana Cooperative Wildlife Research Unit, University of Montana, Natural Science Building 205, Missoula, MT 59812-1120, United States of America

*Corresponding author: p.tizzani@woah.org
ORCID: https://orcid.org/0000-0003-2603-4172

Summary

Disease emergence represents a global threat for public health, economy, and biological conservation, most of the emerging zoonotic diseases have an animal origin of which the majority of these are from wildlife. To prevent their spread and to support the implementation of control measures, disease surveillance and reporting systems are needed, and due to globalisation, these activities should be carried out at the global level. To define the main gaps effecting the performances

of wildlife health surveillance and reporting systems globally, we analysed data from a questionnaire sent to National Focal Points of the World Organisation for Animal Health that inquired on structure and limits of wildlife surveillance and reporting systems in their territories. The response from 103 Members, covering all world areas, showed that 54.4% of them have a wildlife disease surveillance programme and 66% implemented a strategy to manage disease spread. The lack of dedicated budget affected the possibility of outbreak investigations, sampling collection, and diagnostic testing. Although most Members maintain records relating to wildlife mortality or morbidity events in centralised databases, data analyses and disease risk assessment are reported as priority needs. Our evaluation of surveillance capacity showed an overall low level with marked variability between Members that was not restricted to specific geographical area. Increased wildlife disease surveillance globally would help in understanding and managing risks to animal and public health. Moreover, consideration of the influence of socio-economic, cultural, and biodiversity aspects could improve disease surveillance under a One Health approach.

Keywords

Data quality – Global survey – One Health – Wildlife Health Framework – Wildlife health surveillance.

Introduction and objective

About 60% of emerging infectious diseases are zoonotic, and of those that have emerged over the past two decades approximatively 72% have a wildlife source [1, 2]. Wildlife diseases are a growing concern at the global level, not only because of the threat they pose for the health of wild and domestic animal populations in terms of economic losses, food insecurity, and biodiversity conservation, but also because of the potential effect on public health [3]. This is especially true when considering the increasing trend in global, regional, and sub-regional movement of wild animals and their products. As examples, between 1996 and 2018 the global market of reptile leather for fashion rose from United States dollar (USD) 140 million to USD 600 million, and the fish market trade rose from USD 40 billion to USD 180 billion [4]. The

legal and illegal trade of wildlife were estimated to be worth around USD 6 billion per year in 2005 [5], and in 2022 illicit wildlife trafficking by itself is estimated between USD 7.8 billion and USD 10 billion per year globally [6]. It is noteworthy that between 2000 and 2006, in the United States of America (USA) alone, approximately 1.5 billion live wild animals were legally imported into the country and that an average of over 25 million kilograms of dead wildlife and wildlife products enter the USA each year [7].

Anthropogenic activities affecting climatic conditions and the environment, including habitat destruction and fragmentation, which increase the interactions at the human–livestock–wildlife interface have deeply modified several pathogen dynamics with an increasing risk of disease emergence and re-emergence [8, 9]. A review analysing mass mortality events in wildlife highlighted that 26.3% of the events were due to infectious diseases [10]. This indicates a growing need for effective and reliable surveillance and reporting systems for appropriate prevention, situational awareness, and assessment of the effectiveness of management actions to prevent wildlife health events. Early detection and rapid response are critical when new health threats emerge and grow. Early detection and timely sharing of information is key to prevent and control zoonotic disease spread and to avoid long-term economic, social, and environmental costs [11].

Wildlife disease surveillance provides important information that can allow organisations to take action to control and prevent these diseases in wildlife populations. In turn, these disease management actions contribute to enhanced wildlife management/conservation and provide information to protect human and livestock health. In the context of animal health, wildlife disease surveillance may provide valuable information on domestic and wild animal morbidity and mortality, identify changes in patterns of disease occurrence over time, and assist in early detection of disease outbreaks, including those linked to emerging diseases. Many of the pathogens on the World Organisation for Animal Health (WOAH, founded as OIE) list of reported diseases an infect and be maintained for long or short periods of time in wild animals. Because there is a wide array of species of wild animals, risks

of multi-directional disease transmission vary in different regions or areas, dictated by the species and types of livestock interfaces present. Thus, national wildlife disease surveillance programmes are crucial for understanding local risks to animal health and potential zoonotic disease transmission and for preserving wildlife.

Sharing animal health findings from wildlife collected at the national level with other countries faces multiple challenges, including high variability amongst countries in their capacity to conduct wildlife surveillance, ability to collect and share information, and capacity to support international reporting [11]. The World Animal Health Information System (WAHIS) is the international reference system that collects and shares data on animal health gathered by the Veterinary Services from WOAH Members and non-Member countries and territories on listed diseases in domestic animals and wildlife, as well as on emerging diseases and zoonoses. All this information can be publicly accessed and visualised. Information is collected on 117 WOAH-listed diseases (https://www.woah.org/en/what-we-do/animal-health-and-welfare/animal-diseases) plus emerging diseases in domestic animals and wildlife and on 53 non-WOAH listed diseases of specific importance for wildlife. The role and mission of WOAH in collecting wildlife health information has been reinforced by the adoption of WOAH Wildlife Health Framework (https://www.woah.org/fileadmin/Home/eng/Internationa_Standard_Setting/docs/pdf/WGWildlife/A_Wildlifehealth_conceptnote.pdf) in May 2021 by WOAH 88th General Session of the World Assembly of Delegates. The Framework identifies two main priorities:

1) to improve WOAH Members' ability to manage the risk of pathogen emergence in wildlife and transmission at the human–animal–ecosystem interface, whilst taking into account the protection of wildlife;

2) to support WOAH Members to improve surveillance systems, early detection, notification, and management of wildlife diseases.

These factors place WOAH and its WAHIS system in a unique position to provide an international reference database on wildlife health.

In 2021, the WOAH Collaborating Centre for 'Research, Diagnosis and Surveillance of Wildlife Pathogens' located in Madison, USA, developed, in collaboration with WOAH, a questionnaire to gather data and information from WOAH National Focal Points (NFPs) for Wildlife. The purpose of this questionnaire was to gain knowledge of in-country governance in charge of wildlife disease surveillance systems to identify gaps and needs to improve global surveillance, as well as to better assess the quality of the wildlife disease data reported to WOAH through the WAHIS system.

The purpose of this paper is to use the results of the questionnaire to identify the global gaps, needs, and opportunities of wildlife health data collection and sharing, and to inform future capacity building activities for WOAH Members across the five WOAH regions.

Materials and methods

World Organisation for Animal Health questionnaire

The Wildlife Disease Surveillance Survey (WDSS) questionnaire was composed of seven sections with a total of 54 questions designed to collect information on wildlife disease surveillance activities in countries. The following five out of the seven sections were considered for this paper:

1) Background information
2) Partner wildlife disease reporting network
3) Wildlife disease diagnostics
4) Wildlife disease information management
5) Wildlife disease management

Sections 6 and 7 were not included as they pertained specifically to the WAHIS system (Section 6) or legal aspects of surveillance (Section 7).

The full questionnaire is available as supplementary material upon request from the corresponding author.

Some of the questions were only available to respondents depending on answers to a preceding question; therefore, not all respondents answered the same number of questions.

The questionnaire, available in the three WOAH official languages (English, French, and Spanish), was distributed by WOAH to 182 WOAH Members of NFPs for Wildlife using the Microsoft Forms platform in September 2021, allowing a one-month period to respond to the questionnaire. Reminders were sent out to encourage participation.

Study area

The study area includes 182 WOAH Members, which are grouped in five regions to express and address specific problems faced by its Members in the different areas of the world. The list of regions is provided in Figure 1, and includes:

- Africa
- Americas
- Asia and the Pacific
- Europe
- Middle East

Although a Member can belong to more than one WOAH's region from an administrative point of view, for the objective of this paper each Member was assigned to only one region.

Analysis of the questionnaire

For the purpose of this paper, 18 of the 54 questions, linked to in-country surveillance activities referring to wildlife diseases, were selected in order to describe, and analyse the following aspects:

1) **Who** oversees wildlife disease surveillance and monitoring, and how the networks are composed in the different countries from field sampling to data analysis?

2) **How** are surveillance and monitoring systems organised (planning/testing/number of samples/priority diseases)?

3) **Diagnostic capacity** (from collection of samples to diagnosis): what is the WOAH Members' capacity in term of pathogens identification?

4) **Management** and response to wildlife disease events (from the field to data storage and follow-up)

5) **Categorise** countries according to their surveillance capacity. For this categorisation, 11 questions were selected to evaluate and score the surveillance capabilities of each Member. The selected questions reflected the country's capacity to perform the various steps to accomplish disease surveillance. Each question was assigned a qualification of 0 or 1, with 0 being absence and 1 being presence of disease surveillance capacity. The final score for each country was therefore out of a maximum of 11 points.

All the responses were exported into and processed using Microsoft Excel and analysed using R, version 3.2 [12] to obtain a descriptive distribution of frequencies for the questions. Visualisation of data and data manipulation were done using the following packages: ggpubr [13], ggplot2 [14], VennDiagram [15] and Tidyverse [16].

Results

One-hundred and three (103) of the 182 WOAH Members submitted the WDSS; i.e., a response rate of 56.6% (Figure 2). All responses were provided by WOAH NFPs, and the time required to complete the survey averaged 3.7 hours (around 223 minutes).

1) **Who** oversees wildlife disease surveillance and monitoring, and how the networks are composed in the different countries from field sampling to data analysis?

The Veterinary Services were the national authority solely in charge of wildlife health management in 49.5% of the respondents' countries. However, 87.8% of respondents mentioned that Veterinary Services jointly oversee wildlife health events in collaboration with the Wildlife Services, Protected Areas, and Environmental Services. In addition, 12.1% of respondents stated that wildlife disease management is performed by other authorities, including the Environmental Services (which is in charge for 4.04% of respondents), the Wildlife Services (2.02%) and different combinations of the National Parks and Protected Areas with the Environmental and Wildlife Services (6.06%) (Figure 3).

2) **How** are surveillance and monitoring systems organised (planning/testing/number of samples/priority diseases)?

The majority (54.4%) of the respondents indicated having a National Wildlife Disease Surveillance programme in place. Of these, 94.6% of them included investigation of wildlife morbidity and mortality events (general surveillance, also called 'passive surveillance'), while 85.7% included testing of opportunistically collected and/or apparently healthy wildlife for specific diseases (targeted surveillance, also called 'active surveillance') and 71.4% collected information on wildlife intended for commercial or non-commercial use or consumption (Figure 4).

The main source of information about wildlife diseases used at the national level came from the National Environmental Agency for 39.3% of the respondents and from the National Agriculture Agency for 32.1%. Academia was also a non-negligible source of information and mentioned by 7.1% of the respondents.

The three most monitored priority wildlife diseases were avian influenza (17.3%), African swine fever (11.1%), and rabies (11.1%). Of the diseases monitored, 90% had zoonotic potential or can affect

domestic animals. The diseases mentioned affecting only wildlife were Chronic wasting disease, White-nose syndrome, and European brown hare syndrome, with 0.4% of respondents listing these diseases.

The most important need for the wildlife disease surveillance programmes mentioned by respondents was the ability to conduct outbreak investigation (41% of respondents). The second most important need was increasing their ability to collect samples during outbreak investigations (16.8% of the respondents). The European region was the only one indicating that the highest current need for their wildlife disease surveillance programme was for increased data visualisation and geographic information system (GIS) applications. The most important needs for wildlife disease surveillance programmes, split by region, are represented in Figure 5.

3) **Diagnostic capacity** (from collection of samples to diagnosis): what is the WOAH Members' capacity in term of pathogens identification?

The majority of respondents (63.1%) indicated impediments when collecting, handling, or transporting wildlife samples for diagnostic testing and/or the diagnostic testing itself; of these, 75% indicated that a lack of a dedicated budget was a very important impediment to collecting, handling, or transporting wildlife samples for diagnostic testing.

Additional factors considered very important impediments to this activity included having proper equipment for the field (64%), accessing carcasses or sick animals due to remote locations (62%), and shipping and storing samples (55%). When asked about impediments for the diagnostic testing on wildlife samples, respondents indicated that testing costs (68%), access to species-specific protocols (65%), and access to proper testing equipment and material (63%) were very important impediments.

4) **Management** and response to wildlife disease events (from the field to data storage and follow-up)

For the purpose of managing wildlife diseases, 62.1% of the respondents maintain records and data relating to wildlife mortality or morbidity events that have occurred in their territories. More than half (56.2%) of the respondents indicated that they use a centralised database as a method for maintaining at least a portion of their wildlife disease information. However, around a quarter (28.1%) still use paper records to manage at least a portion of their wildlife disease information. The main purpose of collecting and storing data is to provide wildlife disease information to the government at the national level and to use them as epidemiological data to respond to wildlife health events.

Two-thirds (66%) of the respondents indicated that their country has implemented a response to manage a wildlife health event. The principal management strategies focused on protecting domestic animals and humans and preventing the transmission to domestic animals or humans of the transboundary animal diseases and zoonoses.

5) **Categorise** countries according to their surveillance capacity

Using WOAH definition of epidemiological surveillance, the countries were evaluated according to their responses and received a score (out of 11 points) reflecting their capacity to conduct wildlife epidemiological surveillance.

The overall average score for all regions was 5.3/11, with Asia and the Pacific and Europe being the two regions with the highest scores (both with 5.5/11); however, the variability of results from Europe was less polarised. The region with the lowest average surveillance capacity was the Americas, having an average of 4.8/11. The Middle East, Africa, and Asia and the Pacific also represented a particular case having higher heterogeneities with bimodal distribution of scores (Figure 6).

Discussion

In this study we analysed the WDSS for WOAH Members in order to identify the main gaps in wildlife health surveillance at the country level. WOAH received responses from 103 out of 182 Members. The

survey highlighted high heterogeneity around the needs, level of capacity, and organisation of wildlife disease surveillance systems.

In addition to the Veterinary Services, other agencies often are involved in surveillance, thus warranting good coordination for disease surveillance at the country level. Outbreak investigation is the most common wildlife disease surveillance activity reported by WOAH Members. The majority of the Members stated having some type of wildlife disease surveillance system and associated database, which provides a basis for further capacity building.

Wildlife diseases can cause economic losses and represent a threat to the health of wild and domestic animals, food security, and biodiversity conservation [3]. Zoonotic disease in particular can represent a risk to humans, affecting public health investments [17]. To reduce these impacts, adequate wildlife health surveillance systems would be needed for early detection of any potential health threat and to aid in a rapid response such as applying proper control measures. Moreover, because the world is increasingly interconnected by global movement of humans, animals, and animal products, surveillance systems at country level would ideally be optimised to reduce disease occurrence and spread both at national and international levels. In this context, WOAH established a Wildlife Health Framework (https://www.woah.org/fileadmin/Home/eng/Internationa_Standard_Setting/docs/pdf/WGWildlife/A_Wildlifehealth_conceptnote.pdf), and the WDSS was designed to identify gap points where global wildlife disease surveillance could be improved.

With a 56.6% response rate that included representatives from all five regions, the WDSS covered a homogeneous geographic distribution. However, the risk of emergence of zoonotic diseases from wildlife is concentrated in disease outbreak hotspot areas [18, 19], where epidemiological surveillance in wildlife could be overlooked. Some WOAH Members belonging to these hotspots such as Central and East Africa, Southeast Asia, and Central and South American countries who did not participate in the survey and, therefore, left some important information gaps in the geographic coverage of responses that may be

needed for a comprehensive picture of the current wildlife disease surveillance system landscape. In addition, only half of the respondents reported having an ongoing wildlife disease surveillance programme, further highlighting the risk of having hotspot areas not covered by surveillance.

From the survey results, the Veterinary Services seemed to be the main, but not the only, national authority in charge of the management of wildlife health. In fact, Veterinary Services interact with other authorities to collect relevant information (reported by 87.8% of all responding Members); this highlights the presence and importance of multisectoral collaboration in wildlife disease surveillance. For example, National Parks and Protected Areas, are responsible for wildlife surveillance in 6% of the responding countries. For these latter countries, survey responses did not indicate whether surveillance plans existed at the national level and could be an important gap in surveillance coverage. Although surveillance in protected areas play a fundamental role for biodiversity conservation, if surveillance is only performed in protected areas, the limited spatial coverage might miss some emerging diseases such as those related to higher human densities. As the efficiency of wildlife health surveillance is influenced by both cross-sectoral and multidisciplinary actions, these collaborations would ideally be coupled with harmonisation of national responsibilities toward wildlife and health management [20, 21]. These collaborations would benefit from being monitored, encouraged, and supported by central authorities.

Surveillance programmes mainly consisted of general and targeted surveillance [22], but some Member countries also performed surveillance for commercial and non-commercial use and consumption of wildlife. Despite the existence of these surveillance programmes, most of the Members highlighted budget limitations affecting their capacity to detect and respond to wildlife health events. The limitations in surveillance capacities due to lack of budget and/or investment in wildlife health programmes can result in greater spending by governments to address consequences of an outbreak or a spillover event. For example, the White-nose syndrome in bats led to agricultural

losses estimated at more than USD 3.7 billion per year in the USA alone [23]. Therefore, wildlife disease surveillance using both passive and active surveillance for monitoring of wildlife health at a national level would help to address some of the gaps and needs identified in this questionnaire [18, 24, 25]. Prioritising the diseases to be surveilled would be helpful so that specific diseases receive sufficient means to reach effective performances and to avoid resource dispersion over a too wide range that could result in inefficient surveillance [24].

Regarding data management from the field and laboratories, half of WOAH Members (56.2%) reported data storage in digital databases. Given the importance of national digital databases to improve the speed of analysis, more investment in data management would be useful. Moreover, members mentioned the need for adequate data analysis, suggesting that training and capacity building would increase interpretation and analysis of the existing and future data. The development and validation of diagnostic tests for wildlife, and research on rapid tests for using in-field may be considered; the latter will preclude the need to ship and store samples. This would be useful for early identification of signals that warrant actions to prevent disease outbreaks and resilience to respond to new and ongoing epidemiological events [11, 24].

In general, the low capacity to conduct wildlife health surveillance, coupled with logistic constraints and limitations, resulted in a prioritisation from the Veterinary Services of surveillance toward diseases with recognised higher impacts on livestock or human health (such as avian influenza, African swine fever, and rabies). An evidence-based examination of the relationship between zoonoses and emerging wildlife-related pathogens indicates that both represent risk factors for public health [26]. The results of the WDSS indicate that wildlife disease surveillance efforts are primarily directed toward known diseases of wildlife origin that could affect humans or livestock. Because international wildlife trade is also a contributing factor to zoonotic disease risk and represents a public health problem, trade would ideally be part of the surveillance programmes for wildlife diseases [27, 28]. Due to the wide spectrum of possible diseases

originating from wildlife, the prioritisation of diseases according to the specific needs of the territory is required to allocate efforts [29]. Addressing wildlife diseases that affect domestic livestock and public health is important, but it is also important to pay attention to wildlife diseases for biodiversity and conservation purposes, which concomitantly affect disease emergence and spread [30].

Overall, heterogeneity was founded among Members in their capacity to conduct wildlife disease surveillance. Clusters of countries with similar surveillance scores were detected in all regions, strongly reflecting differences within a single region (Figure 6). In Africa, Asia and the Pacific, the Americas, and the Middle East, two clusters of responses were observed for surveillance capacity. A tendency to have one group with a high mark related to epidemiological surveillance and another group with a very low capacity could be explained by the fact that the questions were related to each other and caused an automatic deletion of the ensuing questions. They could also be related by the classification of countries within regions by income and/or political understanding of the needs and importance of wildlife health – affecting investment and allocation of budgets to wildlife health. The Middle East represents a unique case because although it has the most marked clustering, this region is influenced by the factor of a minor biodiversity. The European region has the least score variability; this region obtained the best average surveillance capacity score among all the regions and identified a need to build capacity of GIS programmes, indicating the better capacity to collect data. Asia and the Pacific also obtained a high overall score; however, Asia and the Pacific Members were very polarised with either very high or very low scores, highlighting a high heterogeneity. The overall score for capacity was low in all regions. Increased recognition of the value of wildlife disease surveillance by national governments could make wildlife disease surveillance systems more functional and sustainable. Systems could then be more integrated into comprehensive One Health surveillance and therefore contribute to better animal, human, and environment health under the One Health approach.

Finally, factors such as socio-economic, cultural, environmental, and biodiversity variability of each country were not measured in this study; these have the potential to play an important role in the responses obtained. Future studies could explore the relationship between capacity of wildlife health surveillance and biodiversity hotspots. Moreover, several countries prioritise climate- and environment-sensitive diseases (notably echinococcosis, leptospirosis, yellow fever, and Rift Valley fever), but climate is poorly represented in evaluations and plans [31].

Our study identified a core foundation for wildlife disease surveillance at the national and international level; however, considerable variability in national-level capacity exists. Survey respondents identified several challenges in implementation of wildlife disease surveillance, especially the lack of adequate budget. Finally, given the complex nature of wildlife disease emergence and the multiple sectors and stakeholders involved, this study identified the importance of an interdisciplinary, or One Health, approach to disease surveillance.

Conclusions

Wildlife health surveillance is crucial to better understand and manage risks to animal and public health, yet wildlife health may be lacking in health security programmes. The challenges of disease surveillance in wildlife involve different factors that could be addressed in a multidirectional way through the One Health approach.

Taking into account the gaps, needs, and opportunities identified through this WDSS, WOAH – under the strategic advice of its Working Group for Wildlife and through the implementation of its Wildlife Health programme, involvement of its Collaborating Centres' network for wildlife, solid international partnerships and integration with the One Health approach – is working to improve the health of wildlife, and therefore contribute to improving global health.

Respondents to the questionnaire identified the need for national-level capacity assessments to prioritise investments. Our findings indicated that wildlife and environmental considerations remain absent from even

the most recent health security capacity assessments and plans and that wildlife is not a priority in the context of health security frameworks. However, dedicated international commitment would be important to support countries in building wildlife health capacity.

The importance of a One Health multisectoral and collaborative approach – one that recognises the connection between the health of humans, animals, and ecosystems was highlighted in our study to ensure improved coverage and effectiveness of wildlife disease surveillance systems.

The adoption of digital surveillance systems to optimise data flow and efficiency of data collection, analysis, reporting and data sharing may facilitate intersectoral, national, and international collaborations and data interpretations. This would allow the inclusion of enhanced competencies for risk reduction, particularly those related to disease emergence. Increased consideration of wildlife and environmental changes as the major source of emerging zoonoses could help in understanding and managing risks to animal and public health.

Acknowledgements

Data are available from the funding organisation WOAH. Contact WOAH for further information. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the United States Government.

References

[1] Taylor L.H., Latham S.M. & Woolhouse M.E. (2001). – Risk factors for human disease emergence. *Philos. Trans. R. Soc. B Biol. Sci.*, **356** (1411), 983–989. https://doi.org/10.1098/rstb.2001.0888

[2] Woolhouse M.E. (2002). – Population biology of emerging and re-emerging pathogens. *Trends Microbiol.*, **10** (Suppl. 10), S3–S7. https://doi.org/10.1016/s0966-842x(02)02428-9

[3] Cupertino M., Resende M.B., Mayers N., Carvalho L.M. & Siqueira-Batista R. (2020). – Emerging and re-emerging human infectious diseases: a systematic review of the role of wild animals with a focus on public health impact. *Asian Pac. J. Trop. Med.*, **13** (3), 99–106. https://doi.org/10.4103/1995-7645.277535

[4] Hughes A.C. (2021). – Wildlife trade. *Curr. Biol.*, **31** (19), R1218–R1224. https://doi.org/10.1016/j.cub.2021.08.056

[5] Wyatt T., Maher J., Allen D., Clarke N. & 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 Soc. Change*, **77** (1), 69–89. https://doi.org/10.1007/s10611-021-09984-9

[6] Wildlife Conservation Society (2022). – Why should we care about wildlife trafficking? Available at: https://wildlifetrade.wcs.org/Wildlife-Trade/Why-should-we-care.aspx (accessed on 27 September 2022).

[7] Rostal M.K., Olival K.J., Loh E.H. & Karesh W.B. (2013). – Wildlife: the need to better understand the linkages. *Curr. Top. Microbiol. Immunol.*, **365**, 101–125. https://doi.org/10.1007/82_2012_271

[8] Zell R. (2004). – Global climate change and the emergence/re-emergence of infectious diseases. *Int. J. Med. Microbiol.*, **293** (Suppl. 37), 16–26. https://doi.org/10.1016/S1433-1128(04)80005-6

[9] El-Sayed A. & Kamel M. (2020). – Climatic changes and their role in emergence and re-emergence of diseases. *Environ. Sci. Pollut. Res. Int.*, **27** (18), 22336–22352. https://doi.org/10.1007/s11356-020-08896-w

[10] Fey S.B., Siepielski A.M., Nusslé S., Cervantes-Yoshida K., Hwan J.L., Huber E.R., Fey M.J., Catenazzi A. & Carlson S.M. (2015). – Recent shifts in the occurrence, cause, and magnitude of animal mass mortality events. *Proc. Natl Acad. Sci. USA*, **112** (4), 1083–1088. https://doi.org/10.1073/pnas.1414894112

[11] Machalaba C., Feferholtz Y., Uhart M. & Karesh W.B. (2020). – Wildlife conservation status and disease trends: ten years of reports to the Worldwide Monitoring System for Wild Animal Diseases. *Rev Sci Tech*, **39** (3), 991–1001. https://doi.org/10.20506/rst.39.3.3191

[12] R Core Team (2021). – R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: https://www.R-project.org (accessed on 27 September 2022).

[13] Kassambara A. (2020). – ggpubr: 'ggplot2' based publication ready plots. R package version 0.4.0. Available at: https://CRAN.R-project.org/package=ggpubr (accessed on 27 September 2022).

[14] Wickham H. (2016). – Data analysis. *In* ggplot2: elegant graphics for data analysis. 2nd Ed. Springer, Cham, Switzerland, 189–201. https://doi.org/10.1007/978-3-319-24277-4_9

[15] Chen H. (2021). – VennDiagram: generate high-resolution Venn and Euler plots. R package version 1.7.1. Available at: https://CRAN.R-project.org/package=VennDiagram (accessed on 27 September 2022).

[16] Wickham H., Averick M. […] & Yutani H. (2019). – Welcome to the Tidyverse. *J. Open Res. Softw.*, **4** (43), 1686. https://doi.org/10.21105/joss.01686

[17] Häsler B., Gilbert W., Jones B.A., Pfeiffer D.U., Rushton J. & Otte M.J. (2012). – The economic value of One Health in relation to the mitigation of zoonotic disease risks. *In* One Health: the human-animal-environment interfaces in emerging infectious diseases (J. Mackenzie, M. Jeggo, P. Daszak & J. Richt, eds). *Curr. Top. Microbiol. Immunol.*, **365**. Springer-Verlag, Berlin Heidelberg, Germany, 127–151. https://doi.org/10.1007/82_2012_239

[18] Jones K.E., Patel N.G., Levy M.A., Storeygard A., Balk D., Gittleman J.L. & Daszak P. (2008). – Global trends in emerging infectious diseases. *Nature*, **451** (7181), 990–993. https://doi.org/10.1038/nature06536

[19] Allen T., Murray K.A., Zambrana-Torrelio C., Morse S.S., Rondinini C., Di Marco M., Breit N., Olival K.J. & Daszak P. (2017). – Global hotspots and correlates of emerging zoonotic diseases. *Nat. Commun.*, **8** (1), 1124. https://doi.org/10.1038/s41467-017-00923-8

[20] Fanelli A., Awada L. […] & Tizzani P. (2022). – Sensitivity of an international notification system for wildlife diseases: a case study using the OIE-WAHIS data on tularemia. *Zoonoses Public Health*, **69** (4), 286–294. https://doi.org/10.1111/zph.12916

[21] Wentholt M.T.A., Cardoen S., Imberechts H., Van Huffel X., Ooms B.W. & Frewer L.J. (2012). – Defining European preparedness and research needs regarding emerging infectious animal diseases: results from a Delphi expert consultation. *Prev. Vet. Med.*, **103** (2–3), 81–92. https://doi.org/10.1016/j.prevetmed.2011.09.021

[22] Cameron A., Mariner J.C., Paisley L., Parmley J., Roger F., Scott A., Willeberg P. & Wolhuter M. (2015). – Guide to terrestrial animal health surveillance. World Organisation for Animal Health, Paris, France, 108 pp.

[23] Boyles J.G., Cryan P.M., McCracken G.F. & Kunz T.H. (2011). – Economic importance of bats in agriculture. *Science*, **332** (6025), 41–42. https://doi.org/10.1126/science.1201366

[24] Guberti V., Stancampiano L. & Ferrari N. (2014). – Surveillance, monitoring and surveys of wildlife diseases: a public health and conservation approach. *Hystrix It. J. Mamm.*, **25** (1), 3–8. https://doi.org/10.4404/hystrix-25.1-10114

[25] Sleeman J.M., Brand C.J. & Wright S.D. (2012). – Strategies for wildlife disease surveillance. *In* New directions in conservation medicine: applied cases in ecological health (A. Alonso Aguirre, R.S. Ostfield & P. Daszak, eds). Oxford University Press, New York, United States of America, 539–551. Available at: https://digitalcommons.unl.edu/usgsstaffpub/971 (accessed on 27 September 2022).

[26] Kock R. & Caceres-Escobar H. (2022). – Situation analysis on the roles and risks of wildlife in the emergence of human infectious diseases. International Union for Conservation of Nature, Gland, Switzerland, 112 pp. https://doi.org/10.2305/IUCN.CH.2022.01.en

[27] Kruse H., Kirkemo A.M. & Handeland K. (2004). – Wildlife as source of zoonotic infections. *Emerg. Infect. Dis.*, **10** (12), 2067–2072. https://doi.org/10.3201/eid1012.040707

[28] Borsky S., Hennighausen H., Leiter A. & Williges K. (2020). – CITES and the zoonotic disease content in international wildlife trade. *Environ. Resour. Econ.*, **76** (4), 1001–1017. https://doi.org/10.1007/s10640-020-00456-7

[29] McKenzie J., Simpson H. & Langstaff I. (2007). – Development of methodology to prioritise wildlife pathogens for surveillance. *Prev. Vet. Med.*, **81** (1–3), 194–210. https://doi.org/10.1016/j.prevetmed.2007.04.003

[30] Deem S.L., Karesh W.B. & Weisman W. (2001). – Putting theory into practice: wildlife health in conservation. *Conserv. Biol.*, **15** (5), 1224–1233. https://doi.org/10.1111/j.1523-1739.2001.00336.x

[31] Machalaba C., Uhart M., Ryser-Degiorgis M.-P. & Karesh W.B. (2021). – Gaps in health security related to wildlife and environment affecting pandemic prevention and preparedness, 2007–2020. *Bull. World Health Organ.*, **99** (5), 342–350B. https://doi.org/10.2471/BLT.20.272690

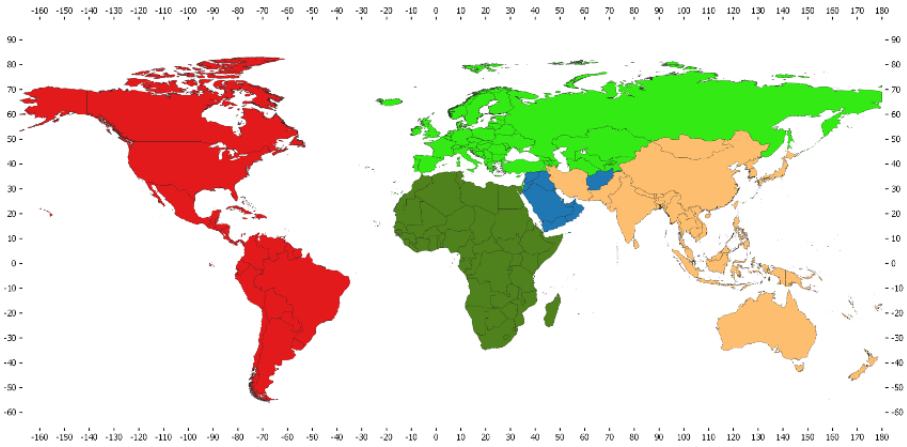

Figure 1

World Organisation for Animal Health Members grouped by region

Africa (dark green), Americas (red), Asia and the Pacific (orange), Europe (light green) and the Middle East (blue)

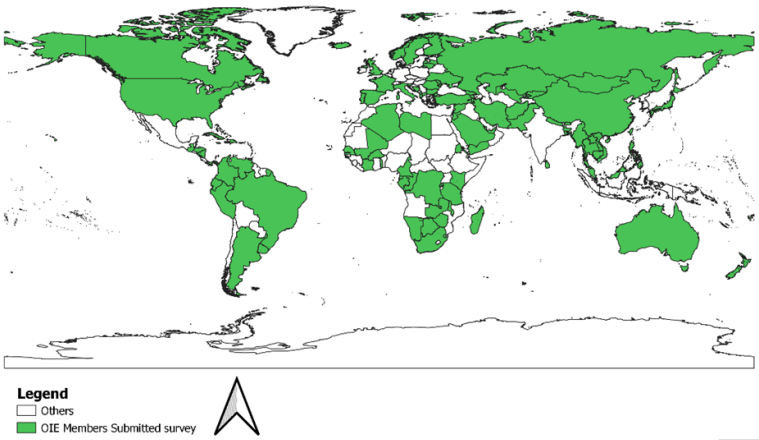

Figure 2

World Organisation for Animal Health Members who submitted responses to the in-country Wildlife Disease Surveillance Survey (WDSS)

Others include countries of Members who did not respond to the WDSS and Non-Members

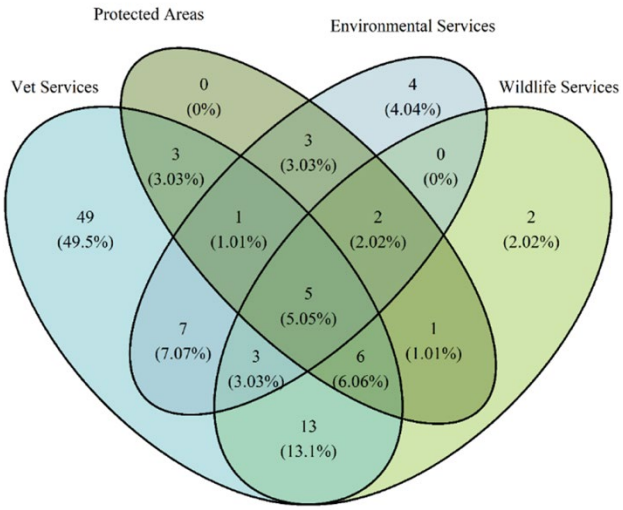

Figure 3

National authorities mentioned by the Members for overseeing Wildlife Health Management

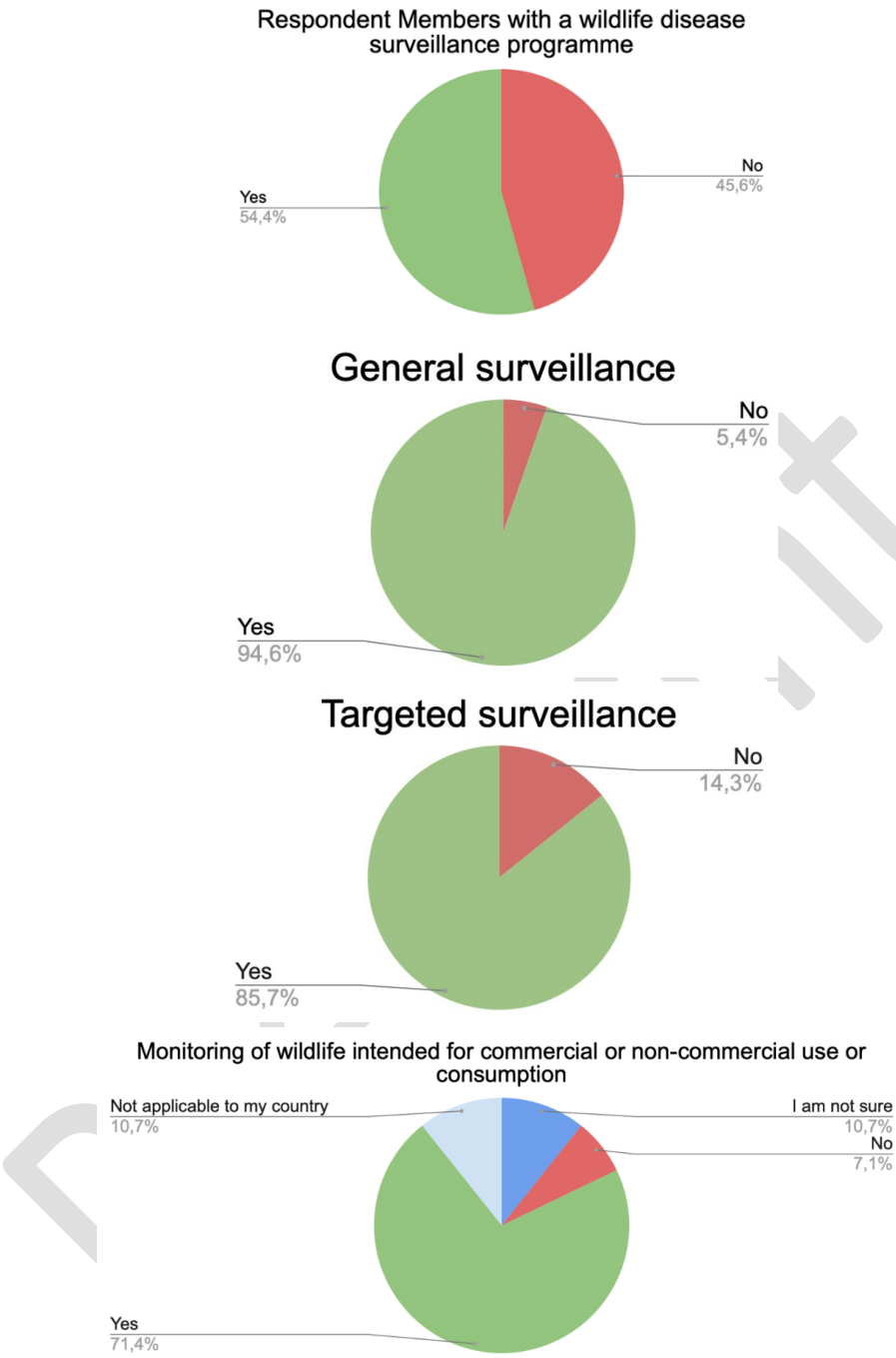

Figure 4

Percentage of National Focal Points for Wildlife mentioning if they have a wildlife disease surveillance programme and for what purpose

The lower three pie charts are showing data only for those responding members that said ‘yes’ in the top pie chart

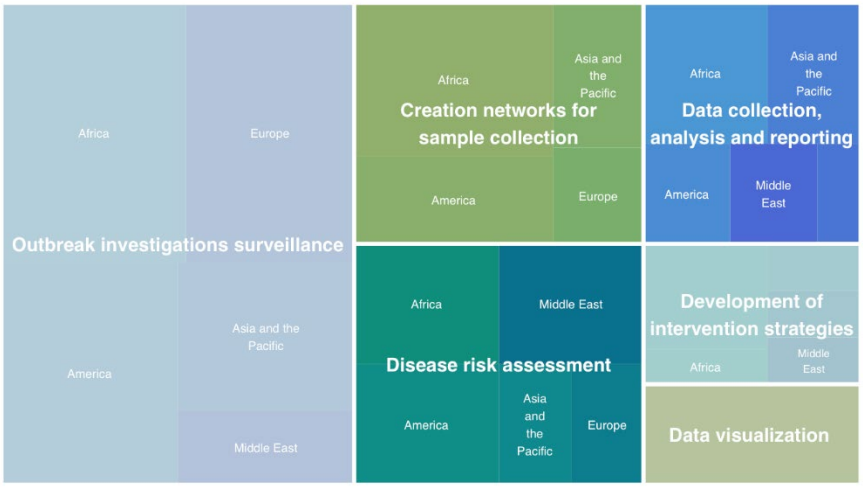

Figure 5

Rank of the most important needs of wildlife disease surveillance programmes, by World Organisation for Animal Health regions

The size of the square is proportional to the number of responses

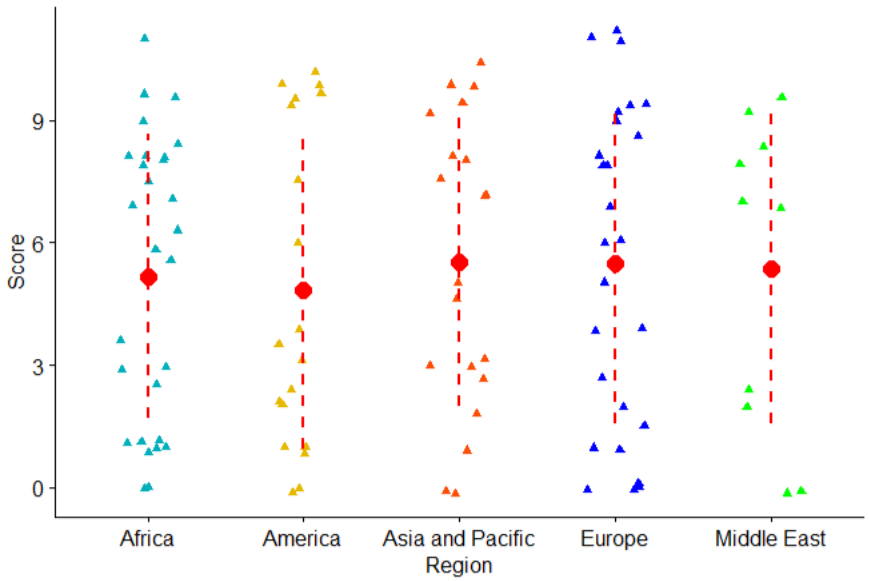

Figure 6

Distribution of country surveillance capacity scores, by region

Each triangle represents the score of wildlife surveillance capacity obtained by the countries. The red circle illustrates the average score for each region. The vertical dashes represent the standard deviation