Wildlife health perceptions and monitoring practices in globally distributed protected areas

Authors: Diego Montecino-Latorre[1*], Mathieu Pruvot[1,2], Sarah H Olson[1]

Affiliations: [1] Wildlife Conservation Society, Health Program, Bronx, NY, USA
[2] University of Calgary, Faculty of Veterinary Medicine, Calgary, AB, Canada

Keywords: conservation, protected areas, wildlife disease, wildlife health, wildlife health monitoring, wildlife health surveillance

Corresponding author name: Dr Diego Montecino-Latorre

Corresponding author address: 2300 Southern Boulevard, Bronx, New York 10460

Corresponding author email: dmontecino@wcs.org

Acknowledgments: Thanks to all responders to our survey and the SMART Partnership (https://smartconservationtools.org) for distributing the survey across the community of SMART users, especially to Mōnica Barcellos. Special thanks to Jonathan Palmer, Executive Director of the Wildlife Conservation Society's Conservation Technology Department.

Abstract

Deficits in wildlife health (WH) monitoring at protected areas (PAs) can weaken the detection of infectious diseases; physical, and chemical threats; rapid response; and assessment of health management practices, threatening biodiversity conservation and global health. However, there is a lack of baseline information regarding the local perception of wildlife, human, and livestock health relevance at these sites. Current WH monitoring practices and WH data collection and management in PAs are also unknown. To address these gaps, we conducted a survey targeting globally distributed protected area data managers (PADMs). Eighty-six valid responses were considered for analysis.

PADMs considered WH as relevant to the conservation goals of PAs and >90% of them confirmed that non-healthy wildlife (injured, sick, and dead) are encountered. However, >50% and >20% of PADMs claimed that these animals were not recorded, respectively. When these animals were documented, the recording methods and information collected differed. Although domestic animal presence was common and considered a conservation concern, these animals and their health status were not always recorded. Health data were often stored in a database, but paper forms and spreadsheets were also used.

Responses suggest that valuable syndromic WH surveillance data from PAs are being lost due to non-collection or inadequate management and their value could be limited by unstandardized recording. Rangers could become a globally distributed "One Health workforce" but these flaws must be addressed first.

Introduction

Despite the growing recognition that the health of animals, people, and their shared environment are inseparably linked, effective surveillance systems collecting, analyzing, and responding to wildlife health (WH) data remain uncommon or deficient (Machalaba et al. 2021; One Health High-Level Expert Panel et al. 2022; World Organization for Animal Health [WOAH] 2023; Delgado et al. 2023). Human encroachment and land-use change (Laurance et al. 2012; Vicente et al. 2021; Meng et al. 2023) are associated with extraction, pollution, the creation of human-wildlife-livestock interfaces, and ecosystem degradation (Plowright et al. 2021; Vicente et al. 2021; Reaser et al. 2023). These processes expose wildlife and people to physical (e.g., snaring, fire), chemical (e.g., poisoning events), and biological hazards (e.g., pathogens) with the capacity to impact biodiversity conservation and global health (De Vos et al. 2016; Vila et al. 2019; Wolf et al. 2019; Hacon et al. 2020; Machalaba et al. 2020; Becker et al. 2023; Groenenberg et al. 2023; Porco et al. 2023).

Ebola virus disease is an illustrative example. Index cases of several human outbreaks of this disease have included hunters who contacted wildlife (Judson et al. 2016). Outbreaks in wildlife have decimated populations of western gorillas and chimpanzees (Whitfield 2003; Leroy et al. 2004; Bermejo et al. 2006) and have preceded outbreaks in humans (Rouquet et al. 2005).

Protected areas (PAs), nature's last strongholds, are increasingly facing anthropogenic pressures becoming key human-wildlife interfaces for disease emergence and prevention (Mittermeier et al. 2011; Machalaba et al. 2021; IUCN & EcoHealth Alliance 2022; WOAH 2023; Hayman et al. 2023; Hopkins et al. 2024). WH monitoring at these sites can strengthen the detection of infectious diseases, physical, and chemical threats; rapid response; and assessment of health management practices. However, there is a lack of baseline information regarding the perception of wildlife, human, and livestock health relevance for biodiversity conservation. Current WH monitoring practices and WH data collection and management at these sites are also unknown. To address these gaps, we conducted a survey targeting protected area data managers (PADMs) to assess: i) their perceptions regarding WH and pathogen transmission between wildlife, humans, and livestock, ii) the detection and documentation of dead, sick, or injured wildlife, and domestic animals in PAs, and iii) health data management in PAs.

Methods

The "Spatial Monitoring and Reporting Tool" (SMART) is a technology platform designed to support the administration of PAs (Cronin et al. 2021) through the collection, management, assessment, and communication of PA data. SMART technology is distributed globally in more than 1,000 conservation sites by the time of the study.

We developed a web-based questionnaire aimed at these PADMs SMART-users. First, respondents were asked if their job roles and responsibilities matched the definition "a person directly responsible for managing SMART data in one or more PAs or a general manager or administrator of one or more PAs that uses SMART data". Respondents who did not identify as a PADM were considered outside our target population and excluded. The survey had five sections. Section 1 assessed the perception of PADMs on the importance of WH in achieving conservation goals, the role of human and livestock pathogens in affecting WH, and the role of wildlife pathogens in affecting public and livestock health. Section 2 requested PADMs to rank the overall frequency of encounters with dead, sick, or injured wildlife in PAs and their documentation when found during patrols. Section 3, asked about the presence of domestic animals in the PA(s), the documentation of their health status, and the perceived threats of domestic animals to conservation goals. Likert scales were used to answer questions in Sections 1-3. Section 4 addressed health data storage practices when collected and Section 5 assessed the current state of SMART deployment in PAs.

An introductory web page explained that the survey was voluntary, anonymous, aimed at PADMs, and that clicking the "Start the survey" button constituted consent. A tutorial was provided for the language-translation tool of this survey built on Google Forms (Supporting Information). The survey did not request any personal information or demographic characteristics and, consequently, it was exempt from full ethics review [placeholder for Institutional Review Board to keep authors' anonymity during peer review].

The survey was distributed globally to the SMART Community Forum users by the SMART Partnership (https://smartconservationtools.org) via email in October 2022 and remained open for three months. A reminder was sent to the SMART Community three weeks before the closing date.

Responses by PADMs could represent single or multiple PAs. For our analysis, we focused on what we considered to be "local" responses which included one or two PAs, and assumed they provided insights into specific local realities. "Non-local" responses represented more than two PAs, which were assumed to help understand perceptions at the decision-making level and were analyzed separately (see Supporting Information). We discarded responses that only included marine PAs based on the World Database on Protected Areas (https://www.protectedplanet.net/en/thematic-areas/wdpa?tab=WDPA) as marine PA management, species, and patrol logistics are markedly different. The descriptive analysis of survey responses was conducted in R v4.3.1. The responses dataset can be found here https://figshare.com/s/36513db82ac5dfa8e71d?file=49682265. Descriptive analysis can be found at [placeholder for github repository to keep authors' anonymity during peer review].

Results

We received 128 responses. Forty-two were removed because either the PA name(s) were not provided, only marine PAs were listed, or the respondents did not match the target audience (8, 7, and 27 responses, respectively). The final dataset contained 86 respondents from 23 countries. Seventy-three were local responses from 19 countries and 13 were non-local responses from 10 countries (the descriptive analysis of non-local responses is provided in the Supporting Information). The specific countries are not provided to protect the identity of the respondents, but local responses were from North, Central, and South America; West, Central, East, and Southern Africa; Southeast and South Asia; and a Balkan country in Europe, with most coming from South America. Non-local responses were from West, Central, and East Africa, Central and South America, and Southeast and South Asia.

Perceptions regarding wildlife health importance in conservation and potential consequences of pathogen transmission among wildlife, domestic animals, and people

Most respondents either strongly agreed or agreed with the affirmations "Wildlife health, including infectious and non-infectious diseases, is important to achieve the conservation goals of the protected areas where I work" and "human or livestock pathogens can affect wildlife populations inhabiting the protected area(s) I work in" (92%; and 81%, respectively). Regarding the affirmation "pathogens carried by wildlife inhabiting the protected area(s) where I work in can affect livestock health", most respondents strongly agreed or agreed (48%) although the proportion of neutral respondents was more prominent (29%). Across respondents, 63% strongly agreed or agreed that "pathogens carried by wildlife inhabiting the protected area(s) where I work in can affect human health". Detailed response distributions are shown in Figure 1. Non-local responses followed similar trends (Figure S1).

Overall frequency of encounters with dead, sick, or injured wildlife in protected areas and their documentation when found during patrols

Most local PADMs (97%) reported the encounter of dead animals in the PAs (e.g., "Very rarely" or more frequently), and 76% of them reported documenting these encounters if found during patrols. Similar to dead animal encounters, 93% of local PADMs reported encounters with sick or injured animals in the PAs (e.g., "Very rarely" or more frequently), but only 35% and 48% confirmed their documentation, respectively. In general, the documentation of injured, sick, or dead animals tend to be higher as the encounter frequency increased (Figure 2). All non-local PADMs reported the encounter with dead and injured or sick wildlife ("Very rarely" up to "Very frequently"). The proportions of non-local PADMs reporting the documentation of these animals were larger compared to the proportions from local responses (92, 62, and 85%, for dead, sick, and injured wildlife respectively, Figure S2).

All 17 local PADMs who ranked encountering dead wildlife "Very rarely" or more frequently but answered that these animals were not documented, either agreed or strongly agreed with the importance of WH to achieve conservation goals. Similarly, 91 and 94% of local PADMs who ranked encountering sick or injured wildlife "Very rarely" or more frequently but answered that these animals were not documented either agreed or strongly agreed with this statement. The corresponding percentages for non-local PADMs were 0, 80 and 50% for dead, sick and injured wildlife).

The documentation method of dead, sick, or injured wildlife, varied among the 58 local PADMs that reported the recording of one or more of these groups. Most often, each animal was documented individually ("Individual observation"). The second most common method involved a complete inventory of healthy, sick, injured, or dead animals for each species ("Part of the full count"). Reporting their presence or absence was the third most common method ("Present or absent"; Table 1). For non-local responses, the predominant method was "each animal is an individual observation" across health categories (Table S1).

The data collected from each observation were not consistent. Across health categories and documentation method, photographs and the species were the main item collected. Anomalies observed in non-healthy wildlife and the condition of carcasses were not always recorded (Table 1). In non-local responses the trend was relatively similar, however, items were reported to be recorded more consistently (e.g., age, anomalies, and condition in the three health categories; Table S1).

Presence of domestic animals in protected areas, the documentation of their health status, and the perceived threats of domestic animals to conservation goals

Fifty-two local PADMs (71%) responded that domestic animals were found in the corresponding PAs. Among them, 67% reported that domestic animals were documented if observed during patrols, but only 26% reported recording their health status (Figure 3). Forty-two local respondents reporting domestic animals in the PAs (81%) either agreed or strongly agreed that domestic animals are a conservation concern (Figure 3). Twenty-seven of them (64%) answered that these animals were documented. Most respondents claiming that domestic animals are not found in the corresponding PAs also either agreed or strongly agreed that they are a conservation concern.

Eight non-local PADMs (62%) responded that domestic animals were found in the PAs. Among them, seven (88%) reported that domestic animals were documented if observed during patrols, of which only two (29%) reported recording their health status (Figure S3).

Health data storage practices in protected areas

Seventy-two, 54, and 65% of local PADMs reporting the documentation of either injured, sick, or dead wildlife stored all these data in a SMART database. Paper forms, reports, and spreadsheets were employed when non-healthy wildlife were documented but their data was not stored in a SMART database.

Thirty-one of the 35 local respondents (89%) recording domestic animals during patrols indicated that this information was stored in a SMART database. The health status of domestic animals, when documented, was also stored in a SMART database.

Discussion

We developed a web-based questionnaire aimed at globally distributed PADMs to learn about their perceptions regarding WH; the monitoring of dead, sick, and injured wildlife and domestic animals in PAs; and health data storage practices. Regardless of any geographic biases in this study, the responses suggest that valuable syndromic WH and, consequently, One Health surveillance data are being lost due to non-collection or inadequate management. Even when WH data are collected and properly managed, the usefulness for surveillance is likely limited by the diversity of methods employed to record them.

PADMs largely considered WH as relevant to the conservation goals of PAs and most of them confirmed that dead, sick, or injured wildlife were encountered “Very rarely” or more frequently. However, the documentation of these animals was not always conducted, and it was less common in responses from local data managers. This contradiction could be explained by recent global pathogen-driven crises such as SARS-CoV-2 and H5N1 Highly Pathogenic Avian Influenza virus (Nicola et al. 2020; Leguia et al, 2023) that might have sensitized our audience by the time the survey was distributed but before health-associated monitoring objectives could be planned and rolled out. These findings could also suggest a lack of knowledge or resources to act on their understanding of the importance of WH for conservation goals. Although only 13 non-local responses were included in the final dataset, the larger proportion of non-local responses reporting the documentation of non-healthy wildlife could suggest differences between the expectations of managers in an administrative role and field realities in PAs. Protected area management agencies should take a more active local role to identify and correct weaknesses in WH data collection.

We noted a general agreement among PADMs regarding the conservation threat that domestic animals (e.g., dogs, cats, cattle) present. Although we did not explicitly ask why domestic animals are a conservation concern, most PADMs also agreed with the statement "human and wildlife pathogens can impact wildlife health" either when these animals were found in the PAs or not (Figure S4 and S5). This finding might imply that pathogens are part of the reason why domestic animals are considered a conservation concern. Pathogen transmission from domestic animals to wildlife can seriously harm biodiversity conservation efforts including in PAs (e.g., del Valle Ferreyra et al. [2022]) and they add to the direct and indirect pressures on wildlife from domestic animals, such as predation, competition, disturbance, and land-use change in- and out-side of PAs (du Toit 2011; Gompper 2013). While most local PADMs reported the presence of domestic animals in PAs, their documentation was not consistent and only a minority responded that their health status was recorded. The contradiction between perceived conservation risk of domestic animals and documentation of their presence and health status could be explained by the same drivers mentioned above.

Adequate management of data and harmonization are foundational pillars for WH monitoring (WOAH 2010, 2015, 2018; Sleeman et al. 2012; Ryser-Degiorgis 2013; Stephen 2018; Lawson et al. 2021; Machalaba et al. 2021; Giacinti et al. 2022; Stephen & Berezowski 2022; Hayman et al. 2023; Heiderich et al. 2023). However, we found that paper forms and Excel sheets are used to store data from sick, injured, or dead wildlife even when SMART was available. Also, we found diverse structure and attributes in WH data that was collected. The lack of harmonization across PAs within and beyond country boundaries can limit the value of collected health data as regional, national, or across border health assessments could be unfeasible. Similarly, the longitudinal assessment of wildlife health trends in a single PA is not possible when data is recorded differently over time. These findings are aligned with historical pitfalls in WH surveillance's data governance (e.g., Avery-Gomm et al. 2016; Lawson et al. 2021; Heiderich et al. 2023; WOAH 2023).

Recommendations

Leveraging existing PA human resources that can detect morbidity and mortality in animals offers a sound and cost-effective strategy to establish a minimal baseline of WH monitoring. Rangers can detect injured, sick, and dead animals in PAs and the few documented initiatives that explicitly report ranger participation in WH monitoring have demonstrated their potential to provide data to assess health risks and trends or trigger responses to disease outbreaks of global and conservation concern (Kuisma et al. 2019; Vila et al. 2019; Wolf et al. 2019; Montecino-Latorre et al. 2020; Orozco et al. 2020; Porco et al. 2023). Rangers also have contributed to a healthier planet through emergency medical assistance, contact tracing, and public health education (Singh et al. 2021; Stolton et al. 2023). Currently, there are approximately 280,000 rangers worldwide and it is estimated that 1.5 million will be needed by 2030 to adequately protect 30% of the planet (Appleton et al. 2022). The present and projected number of rangers reveal their unique potential as a worldwide distributed "One Health workforce" that could drastically improve the general global absence of WH and One Health surveillance (Machalaba et al. 2021; Worsley-Tonks et al. 2022; Delgado et al. 2023; Hopkins et al. 2024).

Our recommendation is to include WH monitoring within the remit of rangers. The global integration of this workforce into WH monitoring could be supported by SMART or the World Commission of Protected Areas (WCPA) of the International Union for Conservation of Nature, all of which support best practice management of PAs. Indeed, the WCPA has established a two-year Task Force to integrate One Health in PAs and vice versa which includes WH surveillance activities in PAs (Hopkins et al., 2024). This Task Force makes explicit the contemporaneous relevance to develop WH surveillance policy in PAs to support the conservation of biodiversity and global health.

Technology can enhance ranger integration into WH surveillance systems. The engagement of a large community of SMART-using rangers to document "health incidents" in PAs represents a promising opportunity to create a technology-supported worldwide network of WH sentinels (Worsley-Tonks et al. 2022). Other platforms such as EarthRanger could also support the integration.

However, there are key issues that must be addressed before. First, a definition of a health event optimized for rangers must be established. The minimal set of variables to be recorded from each health event and their documentation method must be harmonized across jurisdictions. Specific variables and options can then be tailored to individual PA realities. Second, rangers need to be trained to recognize and document health events encountered during their patrols. Third, a database to guarantee the governance of ranger-documented health events must be available. SMART technology is ready to support the management of harmonized syndromic health data, provided that adequate resources for planning, training, and expert support are available. PADMs working with fully implemented SMART should have the capacity to properly manage and query health data and coordinate their distribution with other relevant parties, such as environmental agencies and organizations, veterinary services, and public health managers.

Efforts to address the issues mentioned above and build this workforce have already started. WildHealthNet, a Wildlife Conservation Society (WCS) initiative, focuses on creating national surveillance networks and codifying their Standard Operating Procedures (Denstedt et al. 2021; Porco et al. 2023; Pruvot et al. 2023). Currently, WCS is supporting the integration of rangers into WH monitoring using the same standards in Lao, Peru, Cambodia, Guatemala, and Madagascar. Additional efforts are underway through the Wildlife Health Intelligence Network (Noguera et al. 2024) whose objectives include building a larger community of practice that supports the scaling of local WH surveillance globally, and the establishment of WH data collection and management standards. We strongly recommend taking steps towards the global adoption of ranger-based WH monitoring in PAs, utilizing a unified methodology and standards to support biodiversity conservation and improve the health of all.

References

Appleton, M.R., Courtiol, A., Emerton, L., Slade, J.L., Tilker, A., Warr, L.C., Malvido, M.Á., Barborak, J.R., de Bruin, L., Chapple, R., Daltry, J.C., Hadley, N.P., Jordan, C.A., Rousset, F., Singh, R., Sterling, E.J., Wessling, E.G. & Long, B. (2022). Protected area personnel and ranger numbers are insufficient to deliver global expectations. *Nature Sustainability*, 5, 1100–1110.

Avery-Gomm, S., Valliant, M., Schacter, C.R., Robbins, K.F., Liboiron, M., Daoust, P.-Y., Rios, L.M. & Jones, I.L. (2016). A study of wrecked Dovekies (*Alle alle*) in the western North Atlantic highlights the importance of using standardized methods to quantify plastic ingestion. *Mar. Pollut. Bull.*, 113, 75–80.

Becker, D.J., Eby, P., Madden, W., Peel, A.J. & Plowright, R.K. (2023). Ecological conditions predict the intensity of Hendra virus excretion over space and time from bat reservoir hosts. *Ecol. Lett.*, 26, 23–36.

Bermejo M, Rodríguez-Teijeiro JD, Illera G, Barroso A, Vilà C, Walsh PD. 2006. Ebola outbreak killed 5000 gorillas. *Science* 314,1564.

Cronin, D.T., Dancer, A., Long, B., Lynam, A.J., Muntifering, J., Palmer, J., Bergl, R.A., Wich, S.A. & Piel, A.K. (2021). Application of SMART software for conservation area management. In: *Conservation Technology*. Oxford University Press Oxford, UK, pp. 201–224.

Delgado, M., Ferrari, N., Fanelli, A., Muset, Thompson L., Sleeman, J. M., White, C. L., Walsh, D., Wannous, C. & Tizzani, P. (2023). Wildlife health surveillance: Gaps, needs and opportunities. *Rev. Sci. Tech.*, 42, 161-172.

Denstedt, E., Porco, A., Hwang, J., Nga, N.T.T., Ngoc, P.T.B., Chea, S., Khammavong, K., Milavong, P., Sours, S., Osbjer, K., Tum, S., Douangngeun, B., Theppanya, W., Van Long, N., Thanh Phuong, N., Tin Vinh Quang, L., Van Hung, V., Hoa, N.T., Le Anh, D., Fine, A. & Pruvot, M. (2021). Detection of African swine fever virus in free-ranging wild boar in Southeast Asia. *Transbound. Emerg. Dis.*, 68, 2669–2675.

De Vos, A., Cumming, G., Cumming, D., Ament, J., Baum, J., Clements, H., Grewar, J., Maciejewski, K. & Moore, C. (2016). Pathogens, disease, and the social-ecological resilience of protected areas. *Ecol. Soc.*, 21.

del Valle Ferreyra, H., Rudd, J., Foley, J., Vanstreels, R. E. T., Martín, A. M., Donadio, E., & Uhart, M. M. (2022). Sarcoptic mange outbreak decimates South American wild camelid populations in San Guillermo National Park, Argentina. *Plos One,* 17, e0256616.

Giacinti, J.A., Jane Parmley, E., Reist, M., Bayley, D., Pearl, D.L. & Jardine, C.M. (2022). Canadian wildlife health surveillance—patterns, challenges and opportunities identified by a scoping review. *Facets (Ott)*, 7, 25–44.

Gompper, M.E. (2013). *Free-Ranging Dogs and Wildlife Conservation*. OUP Oxford.

Groenenberg, M., Crouthers, R., Yoganand, K., Banet-Eugene, S., Bun, S., Muth, S., Kim, M., Mang, T., Panha, M., Pheaktra, P., Pin, T., Sopheak, K., Sovanna, P., Vibolratanak, P., Wyatt, A.G. & Gray, T.N.E. (2023). Snaring devastates terrestrial ungulates whilst sparing arboreal primates in Cambodia's Eastern Plains Landscape. *Biol. Conserv.*, 284, 110195.

Hacon, S. de S., Oliveira-da-Costa, M., Gama, C. de S., Ferreira, R., Basta, P.C., Schramm, A. & Yokota, D. (2020). Mercury Exposure through Fish Consumption in Traditional Communities in the Brazilian Northern Amazon. *Int. J. Environ. Res. Public Health*, 17.

Hayman, D.T.S., Adisasmito, W.B., Almuhairi, S., Behravesh, C.B., Bilivogui, P., Bukachi, S.A., Casas, N., Becerra, N.C., Charron, D.F., Chaudhary, A., Ciacci Zanella, J.R., Cunningham, A.A., Dar, O., Debnath, N., Dungu, B., Farag, E., Gao, G.F., Khaitsa, M., Machalaba, C., Mackenzie, J.S., Markotter, W., Mettenleiter, T.C., Morand, S., Smolenskiy, V., Zhou, L. & Koopmans, M. (2023). Developing One Health surveillance systems. *One Health*, 100617.

Heiderich, E., Keller, S., Pewsner, M., Origgi, F.C., Zürcher-Giovannini, S., Borel, S., Marti, I., Scherrer, P., Pisano, S.R.R., Friker, B., Adrian-Kalchhauser, I. & Ryser-Degiorgis, M.-P. (2023). Analysis of a European general wildlife health surveillance program: chances, challenges and recommendations. *bioRxiv*.

Hopkins, S. R., Olson, S.H., Fairban, H. T., Redford, K. H., Adams, J., Mitchell, B. A., Nova, N., Muylaert, R. L., Morand, S., Miller, A. & Rao M. (2024). Protected areas and One Health. *Parks,* 30, 6 – 13.

IUCN & EcoHealth Alliance. (2022). *Healthy people and wildlife through nature protection: Guidelines for prevention, detection, response, and recovery from disease risks in and around protected and conserved areas*.

Judson S.D., Fischer R., Judson A., Munster V.J. (2016). Ecological contexts of index cases and spillover events of different ebolaviruses. *PLoS Pathog*., 12, e1005780.

Kuisma, E., Olson, S.H., Cameron, K.N., Reed, P.E., Karesh, W.B., Ondzie, A.I., Akongo, M.-J., Kaba, S.D., Fischer, R.J., Seifert, S.N., Muñoz-Fontela, C., Becker-Ziaja, B., Escudero-Pérez, B., Goma-Nkoua, C., Munster, V.J. & Mombouli, J.-V. (2019). Long-term wildlife mortality surveillance in northern Congo: a model for the detection of Ebola virus disease epizootics. *Philos. Trans. R. Soc. Lond. B Biol. Sci.*, 374, 20180339.

Laurance, W.F., Useche, D.C., Rendeiro, J., Kalka, M., Bradshaw, C.J.A., Sloan, S.P., Laurance, S.G., Campbell, M., Abernethy, K., Alvarez, P., Arroyo-Rodriguez, V., Ashton, P., Benítez-

Malvido, J., Blom, A., Bobo, K.S., Cannon, C.H., Cao, M., Carroll, R., Chapman, C., Coates, R., Cords, M., Danielsen, F., De Dijn, B., Dinerstein, E., Donnelly, M.A., Edwards, D., Edwards, F., Farwig, N., Fashing, P., Forget, P.-M., Foster, M., Gale, G., Harris, D., Harrison, R., Hart, J., Karpanty, S., Kress, W.J., Krishnaswamy, J., Logsdon, W., Lovett, J., Magnusson, W., Maisels, F., Marshall, A.R., McClearn, D., Mudappa, D., Nielsen, M.R., Pearson, R., Pitman, N., van der Ploeg, J., Plumptre, A., Poulsen, J., Quesada, M., Rainey, H., Robinson, D., Roetgers, C., Rovero, F., Scatena, F., Schulze, C., Sheil, D., Struhsaker, T., Terborgh, J., Thomas, D., Timm, R., Urbina-Cardona, J.N., Vasudevan, K., Wright, S.J., Arias-G, J.C., Arroyo, L., Ashton, M., Auzel, P., Babaasa, D., Babweteera, F., Baker, P., Banki, O., Bass, M., Bila-Isia, I., Blake, S., Brockelman, W., Brokaw, N., Brühl, C.A., Bunyavejchewin, S., Chao, J.-T., Chave, J., Chellam, R., Clark, C.J., Clavijo, J., Congdon, R., Corlett, R., Dattaraja, H.S., Dave, C., Davies, G., Beisiegel, B. de M., da Silva, R. de N.P., Di Fiore, A., Diesmos, A., Dirzo, R., Doran-Sheehy, D., Eaton, M., Emmons, L., Estrada, A., Ewango, C., Fedigan, L., Feer, F., Fruth, B., Willis, J.G., Goodale, U., Goodman, S., Guix, J.C., Guthiga, P., Haber, W., Hamer, K., Herbinger, I., Hill, J., Huang, Z., Sun, I.F., Ickes, K., Itoh, A., Ivanauskas, N., Jackes, B., Janovec, J., Janzen, D., Jiangming, M., Jin, C., Jones, T., Justiniano, H., Kalko, E., Kasangaki, A., Killeen, T., King, H.-B., Klop, E., Knott, C., Koné, I., Kudavidanage, E., Ribeiro, J.L. da S., Lattke, J., Laval, R., Lawton, R., Leal, M., Leighton, M., Lentino, M., Leonel, C., Lindsell, J., Ling-Ling, L., Linsenmair, K.E., Losos, E., Lugo, A., Lwanga, J., Mack, A.L., Martins, M., McGraw, W.S., McNab, R., Montag, L., Thompson, J.M., Nabe-Nielsen, J., Nakagawa, M., Nepal, S., Norconk, M., Novotny, V., O'Donnell, S., Opiang, M., Ouboter, P., Parker, K., Parthasarathy, N., Pisciotta, K., Prawiradilaga, D., Pringle, C., Rajathurai, S., Reichard, U., Reinartz, G., Renton, K., Reynolds, G., Reynolds, V., Riley, E., Rödel, M.-O., Rothman, J., Round, P., Sakai, S., Sanaiotti, T., Savini, T., Schaab, G., Seidensticker, J., Siaka, A., Silman, M.R., Smith, T.B., de Almeida, S.S., Sodhi, N., Stanford, C., Stewart, K., Stokes, E., Stoner, K.E., Sukumar, R., Surbeck, M., Tobler, M., Tscharntke, T., Turkalo, A., Umapathy, G., van Weerd, M., Rivera, J.V., Venkataraman, M., Venn, L., Verea, C., de Castilho, C.V., Waltert, M., Wang, B., Watts, D., Weber, W., West, P., Whitacre, D., Whitney, K., Wilkie, D., Williams, S., Wright, D.D., Wright, P., Xiankai, L., Yonzon, P. & Zamzani, F. (2012). Averting biodiversity collapse in tropical forest protected areas. *Nature*, 489, 290–294.

Lawson, B., Neimanis, A., Lavazza, A., López-Olvera, J.R., Tavernier, P., Billinis, C., Duff, J.P., Mladenov, D.T., Rijks, J.M., Savić, S., Wibbelt, G., Ryser-Degiorgis, M.-P. & Kuiken, T. (2021). How to Start Up a National Wildlife Health Surveillance Programme. *Animals (Basel)*, 11.

Leguia, M., Garcia-Glaessner, A., Muñoz-Saavedra, B., Juarez, D., Barrera, P., Calvo-Mac, C., Jara, J., Silva, W., Ploog, K., Amaro, L. & Colchao-Claux, P. (2023). Highly pathogenic avian influenza A (H5N1) in marine mammals and seabirds in Peru. *Nat. Comm.*, 14, p.5489.

Leroy EM et al. 2004. Multiple Ebola virus transmission events and rapid decline of central African wildlife. Science 303:387–390.

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, 991–1001.

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, 342–350B.

Meng, Z., Dong, J., Ellis, E.C., Metternicht, G., Qin, Y., Song, X.-P., Löfqvist, S., Garrett, R.D., Jia, X. & Xiao, X. (2023). Post-2020 biodiversity framework challenged by cropland expansion in protected areas. *Nature Sustainability*, 1–11.

Mittermeier, R.A., Turner, W.R., Larsen, F.W., Brooks, T.M. & Gascon, C. (2011). Global Biodiversity Conservation: The Critical Role of Hotspots. In: *Biodiversity Hotspots: Distribution and Protection of Conservation Priority Areas* (eds. Zachos, F.E. & Habel, J.C.). Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 3–22.

Montecino-Latorre, D., Napolitano, C., Briceño, C. & Uhart, M.M. (2020). Sarcoptic mange: An emerging threat to Chilean wild mammals? *Perspect Ecol. Conserv*, 18, 267–276.

Nicola, M., Alsafi, Z., Sohrabi, C., Kerwan, A., Al-Jabir, A., Iosifidis, C., Agha, M. & Agha, R. (2020). The socio-economic implications of the coronavirus pandemic (COVID-19): A review. *International Journal of Surgery*, *78*, 185-193.

Noguera Z., L. P., Kappel, C., Uhart, M. M., Diaz, F., Cayol, C., Cox-Witton, K., Death, C., Joly, D. O., Brown, K., Gardner, E. G., Suwanpakdee, S., Bett, B., Pepin, K. M., Yellowbird, K., Saulo, D., Morgan, O., Olson, S. H., & Pruvot, M. (2024). Theory of change for building stronger wildlife health surveillance systems globally. *Preprints*. https://doi.org/10.20944/preprints202407.1055.v2

One Health High-Level Expert Panel (OHHLEP), Adisasmito, W.B., Almuhairi, S., Behravesh, C.B., Bilivogui, P., Bukachi, S.A., Casas, N., Cediel Becerra, N., Charron, D.F., Chaudhary, A., Ciacci Zanella, J.R., Cunningham, A.A., Dar, O., Debnath, N., Dungu, B., Farag, E., Gao, G.F., Hayman, D.T.S., Khaitsa, M., Koopmans, M.P.G., Machalaba, C., Mackenzie, J.S., Markotter, W., Mettenleiter, T.C., Morand, S., Smolenskiy, V. & Zhou, L. (2022). One Health: A new definition for a sustainable and healthy future. *PLoS Pathog.*, 18, e1010537.

Orozco, M.M., Argibay, H.D., Minatel, L., Guillemi, E.C., Berra, Y., Schapira, A., Di Nucci, D., Marcos, A., Lois, F., Falzone, M. & Farber, M.D. (2020). A participatory surveillance of marsh deer (Blastocerus dichotomus) morbidity and mortality in Argentina: first results. *BMC Vet. Res.*, 16, 321.

Plowright, R.K., Reaser, J.K., Locke, H., Woodley, S.J., Patz, J.A., Becker, D.J., Oppler, G., Hudson, P.J. & Tabor, G.M. (2021). Land use-induced spillover: a call to action to safeguard environmental, animal, and human health. *Lancet Planet Health*, 5, e237–e245.

Porco, A., Chea, S., Sours, S., Nou, V., Groenenberg, M., Agger, C., Tum, S., Chhuon, V., Sorn, S., Hong, C., Davis, B., Davis, S., Ken, S., Olson, S. & Fine, A. (2023). Case Report: Lumpy skin disease in an endangered wild banteng (Bos javanicus) and initiation of a vaccination campaign in domestic livestock in Cambodia. *Frontiers in Veterinary Science*, 10.

Pruvot, M., Denstedt, E., Latinne, A., Porco, A., Montecino-Latorre, D., Khammavong, K., Milavong, P., Phouangsouvanh, S., Sisavanh, M., Nga, N.T.T., Ngoc, P.T.B., Thanh, V.D., Chea, S., Sours, S., Phommachanh, P., Theppangna, W., Phiphakhavong, S., Vanna, C., Masphal, K., Sothyra, T., San, S., Chamnan, H., Long, P.T., Diep, N.T., Duoc, V.T., Zimmer, P., Brown, K., Olson, S.H. & Fine, A.E. (2023). WildHealthNet: Supporting the development of sustainable wildlife health surveillance networks in Southeast Asia. *Sci. Total Environ.*, 863, 160748.

Reaser, J.K., Chitale, R.A., Tabor, G.M., Hudson, P.J. & Plowright, R.K. (2023). Looking Left: Ecologically Based Biosecurity to Prevent Pandemics. *Health Secur*.

Rouquet P et al. 2005. Wild animal mortality monitoring and human Ebola outbreaks, Gabon and Republic of Congo, 2001-2003. Emerging infectious diseases **11**:283–290. Centers for Disease Control and Prevention (CDC).

Ryser-Degiorgis, M.-P. (2013). Wildlife health investigations: needs, challenges and recommendations. *BMC Vet. Res.*, 9, 223.

Singh, R., Galliers, C., Moreto, W., Slade, J., Long, B., Aisha, H., Wright, A., Cartwright, F., Deokar, A., Wyatt, A., Deokar, D., Phoonjampa, R., Smallwood, E., Aziz, R., Koutoua Benoit, A., Cao, R., Willmore, S., Jayantha, D. & Gosh, S. (2021). Impact of the COVID-19 pandemic on rangers and the role of rangers as a planetary health service. *Parks & Recreation*, 119–134.

Sleeman, J.M., Brand, C.J. & Wright, S.D. (2012). Strategies for Wildlife Disease Surveillance. USGS Staff -- Published Research.

Stephen, C. (2018). Evolving Urban Wildlife Health Surveillance to Intelligence for Pest Mitigation and Monitoring. *Frontiers in Ecology and Evolution*, 6.

Stephen, C. & Berezowski, J. (2022). Wildlife Health Surveillance and Intelligence. Challenges and Opportunities. In: *Wildlife Population Health* (ed. Stephen, C.). Springer International Publishing, Cham, pp. 99–111.

Stolton, S., Timmins, H.L., Dudley, N., Biegus, O., Galliers, C., Jackson, W., Kettunen, M., Long, B., Rao, M., Rodriguez, C.M., Romanelli, C., Schneider, T., Seidl, A., Singh, R. & Sykes, M. (2023). Essential planetary health workers: Positioning rangers within global policy. *Conserv. Lett.*

du Toit, J.T. (2011). Ecology. Coexisting with cattle. *Science*.

Vicente, J., Vercauteren, K.C. & Gortázar, C. (2021). *Diseases at the Wildlife - Livestock*

Interface: Research and Perspectives in a Changing World. Springer Nature.

Vila, A.R., Briceño, C., McAloose, D., Seimon, T.A., Armién, A.G., Mauldin, E.A., Be, N.A., Thissen, J.B., Hinojosa, A., Quezada, M., Paredes, J., Avendaño, I., Silva, A. & Uhart, M.M. (2019). Putative parapoxvirus-associated foot disease in the endangered huemul deer (Hippocamelus bisulcus) in Bernardo O'Higgins National Park, Chile. *PLoS One*, 14, e0213667.

Whitfield J. 2003. Ape populations decimated by hunting and Ebola virus. Nature 422, 551.

Wolf, T.M., Annie Wang, W., Lonsdorf, E.V., Gillespie, T.R., Pusey, A., Gilby, I.C., Travis, D.A. & Singer, R.S. (2019). Optimizing syndromic health surveillance in free ranging great apes: the case of Gombe National Park. *J. Appl. Ecol.*, 56, 509–518.

World Health Organization, Food and Agriculture Organization of the United Nations, United Nations Environment Programme & World Organisation for Animal Health. (2023). *A guide to implementing the One Health Joint Plan of Action at national level*.

World Organisation for Animal Health. (2010). *Training Manual on Wildlife Diseases and Surveillance*. World Organisation for Animal Health.

World Organisation for Animal Health. (2015). *Training Manual on Surveillance and International Reporting of Diseases in Wild Animals*. World Organisation for Animal Health.

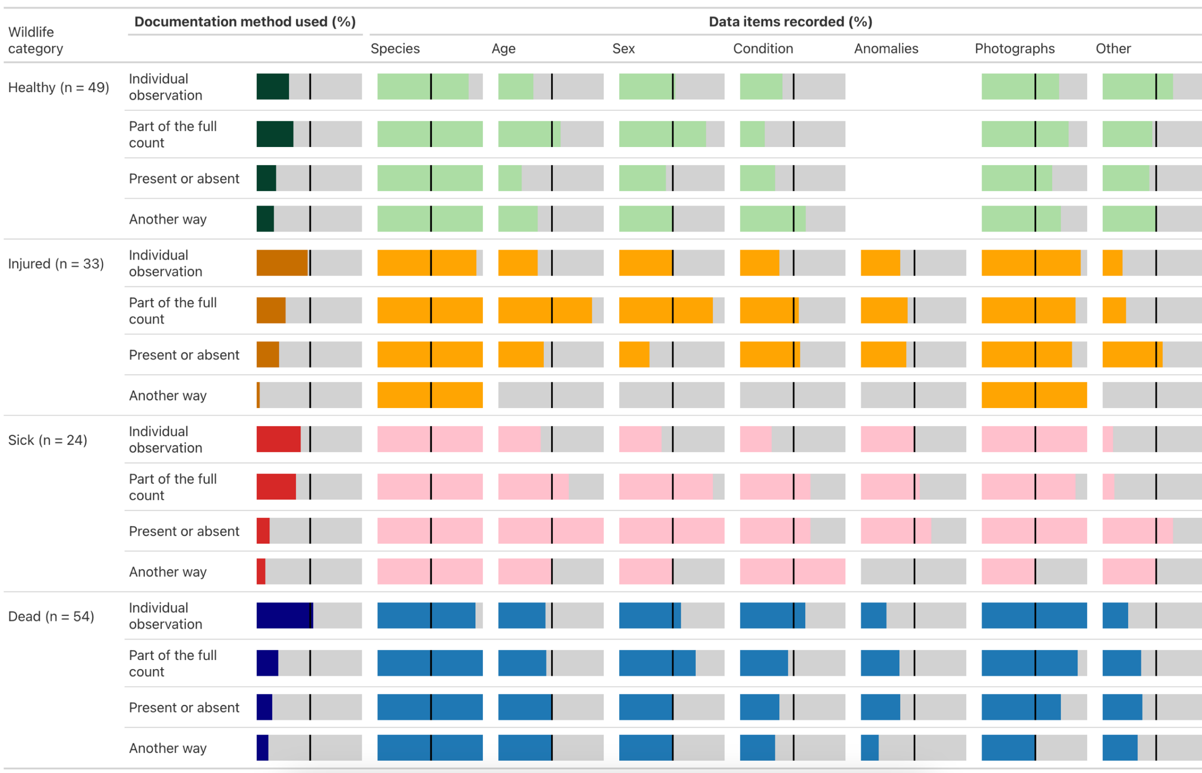
World Organisation for Animal Health. (2018). *Training Manual on Wildlife Health Information Management - Fifth Cycle*. World Organisation for Animal Health.

World Organization for Animal Health. (2023). *In-country Wildlife Disease Surveillance Survey Report*.

Worsley-Tonks, K.E.L., Bender, J.B., Deem, S.L., Ferguson, A.W., Fèvre, E.M., Martins, D.J., Muloi, D.M., Murray, S., Mutinda, M., Ogada, D., Omondi, G.P., Prasad, S., Wild, H., Zimmerman, D.M. & Hassell, J.M. (2022). Strengthening global health security by improving disease surveillance in remote rural areas of low-income and middle-income countries. *Lancet Glob Health*, 10, e579–e584.

Tables and Figures

Table 1. Distribution of the method of documentation to register either healthy, sick, injured, or dead wildlife found during ranger patrols reported by local protected area data managers ("Individual observation", "Part of the full count", "Present or absent", "Another way") and the recording of specific data items for each wildlife health status across documentation methods.



** The black line shows the 50% reference.*

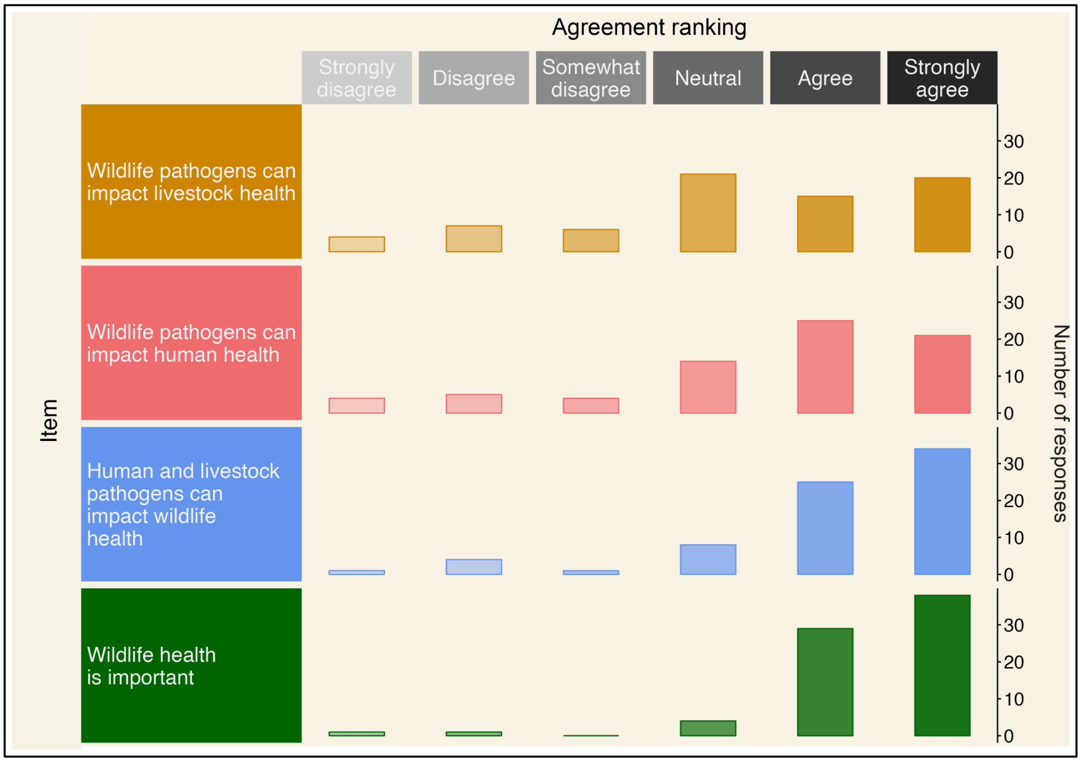
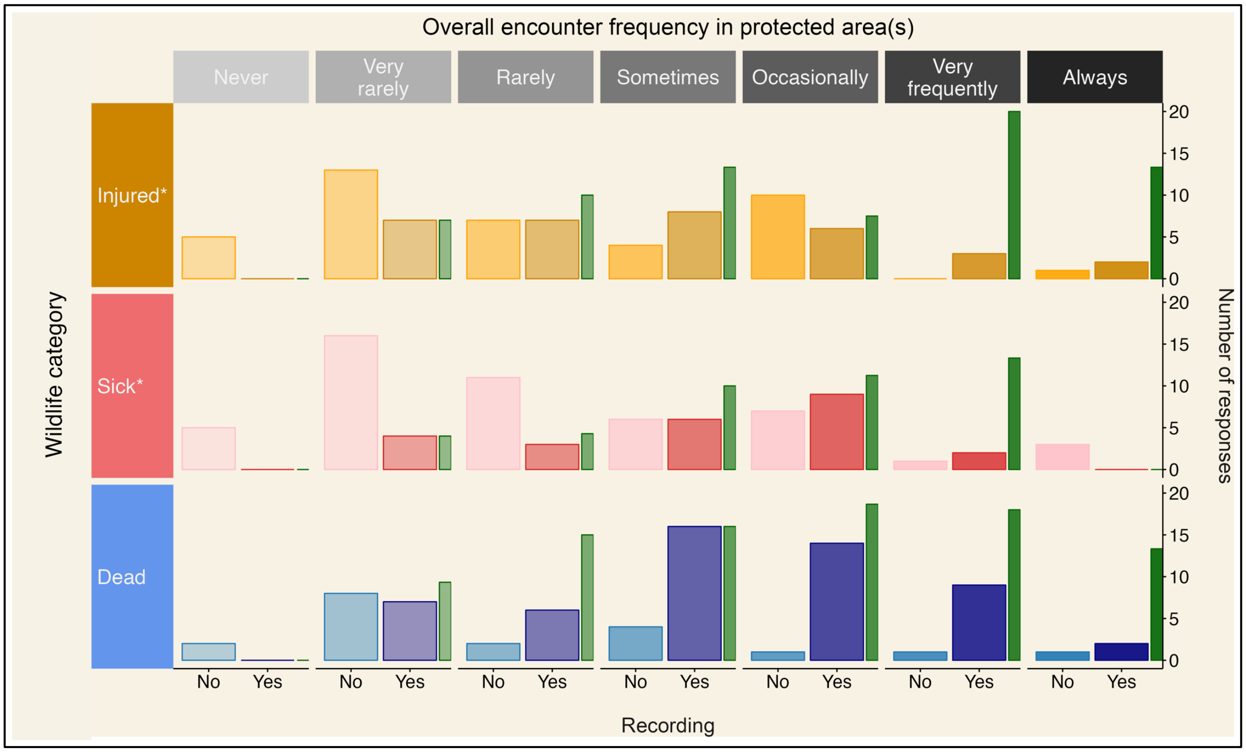


Figure 1. Distribution of the level of agreement (grey scale) among local protected area data managers with statements: 'Pathogens carried by wildlife inhabiting the protected area(s) where I work in can affect livestock health' (brown), 'Pathogens carried by wildlife inhabiting the protected area(s) where I work in can affect human health' (red), 'Human or livestock pathogens can affect wildlife populations inhabiting the protected area(s) where I work in' (blue), and 'Wildlife health is important to achieve the conservation goals of the protected area(s) where I work' (green).



* The overall encountering frequency for sick and injured wildlife was requested in a unique question, therefore, rows one and two show the same total number of responses per encountering frequency.

Figure 2. Distribution of local protected area data manager responses regarding the encounter of or injured (brown), sick (red), dead (blue) wildlife in the protected area(s) where they work and the recording (bright color) or non-recoding (pale color) of these animals when encountered. Green bars represent the proportion of responses that reported the recording of wildlife per wildlife category and encounter frequency.

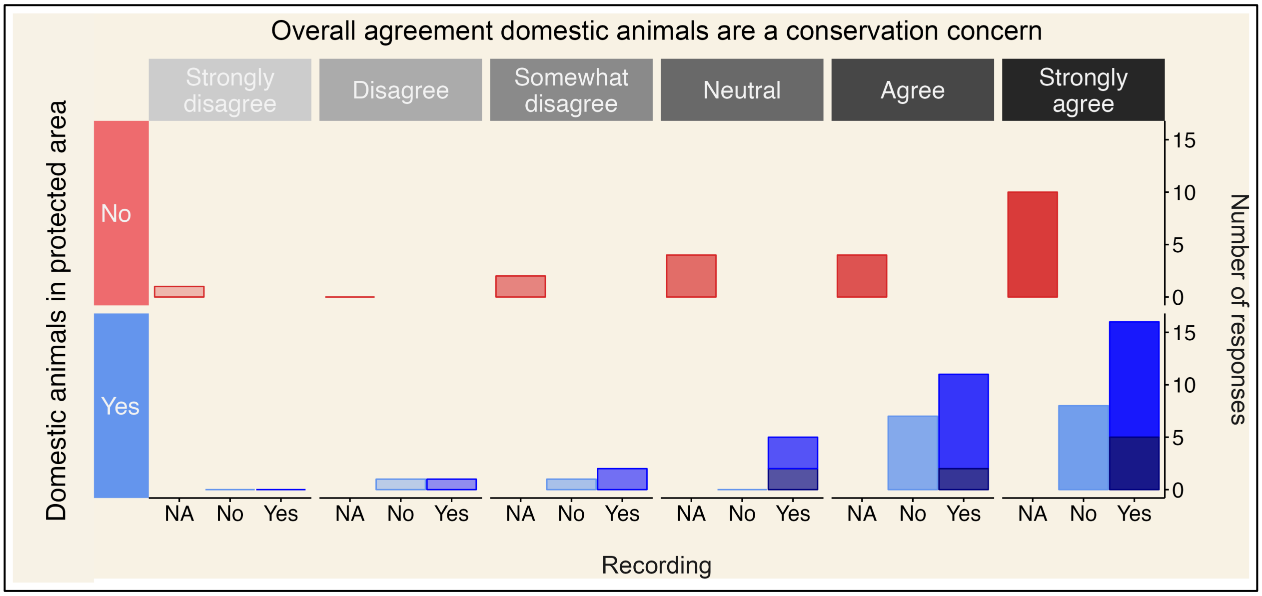


Figure 3. Distribution of the level of agreement among local protected area data managers with the statement: 'Introduced domestic animals (e.g., dogs, cats, cattle, pigs, cows) are a concern for the conservation goals of the protected areas where I work' for the groups that reported the absence (red) and presence (blue) of domestic animals in the protected area(s) and their recording of the latter. Darker segments in the bars within the "Domestic animal in protected area > Yes response" category (x-axis) represent the number of responses that documented health status as part recording the presence of domestic animals.