December 12, 2020

OPPORTUNITIES FOR INTERDISCIPLINARY SCIENCE TO MITIGATE BIOSECURITY RISKS FROM THE INTERSECTIONALITY OF ILLEGAL WILDLIFE TRADE WITH EMERGING ZOONOTIC PATHOGENS

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Abstract: Existing collaborations among public health practitioners, veterinarians and ecologists do not sufficiently consider illegal wildlife trade in their surveillance, biosafety, and security (SB&S) efforts even though the risks to health and biodiversity from these threats are significant. We highlight multiple cases to illustrate the risks posed by existing gaps in understanding the intersectionality of the illegal wildlife trade and zoonotic disease transmission. We argue for more integrative science in support of decision-making using the One Health approach. Opportunities abound to apply interdisipinary science to sustainable wildlife trade policy and programing, such as combining on-the-ground monitoring of health, environmental, and social conditions with an understanding of the operational and spatial dynamics of illicit wildlife trade. We advocate for (1) a surveillance sample management system for enhanced diagnostic efficiency in collaboration with diverse and local partners that can help establish new or link existing surveillance networks, outbreak analysis, and risk mitigation strategies; (2) novel analytical tools and decision support models that can enhance self-directed local livelihoods by addressing monitoring, detection, prevention, interdiction, and remediation; (3) enhanced capacity to promote joint SB&S efforts that can encourage improved human and animal health, timely reporting, emerging disease detection, and outbreak response; and, (4) enhanced monitoring of illicit wildlife trade and supply chains across the heterogeneous context within which they occur. By integrating more diverse scientific disiplines, and their respective scientists with indigenous people and local community insight and risk assessment data, we can help promote a more sustainable and equitable wildlife trade.

Keywords: biosafety**,** biosecurity, COVID-19, emerging infectious diseases, illegal wildlife trade, One Health, spatial analytics, zoonosis

Introduction

The contemporary scope and scale of the illegal wildlife trade (IWT) is unprecedented (Goldenberg et al., 2017; UNODC, 2020). This transnational environmental crime includes harms against tens of thousands of vertebrates (Scheffers et. al., 2019) as well as species of flora and fauna and generates an estimated $5-$23 billion annually (May, 2017). IWT threatens species, ecosystems and societies both locally and globally (Hinsley et al., 2017; May, 2017). IWT is linked to the spread of zoonotic diseases (Gomez and Aguirre, 2008; Pavlin et al., 2009) and is associated with kleptocracy, corruption, money laundering, degradation of the rule of law, national insecurity, undercutting of sustainable development investments, erosion of cultural resources, and convergence with other serious crimes (Shelley, 2018). IWT-related risks are reinforced by the cross-border and transboundary nature of wildlife crime, diversity of wildlife populations, community-based management regimes, and rural-urban connectivity (Hübschle, 2017; Gore et al., 2019). Efforts to reduce risks associated with IWT may generate new risks. For example indigenous peoples and local communities (IPLCs) have long been seen as either cultprits of biodiversity decline or as “unseen sentinels” effectively managing and monitoring their territories. A binary approach to IWT solutions can exclude IPLC cultural and livelihood dimensions of risk management, provoke existing or new environmental injustices. It may also preclude informed consent of people who will be directly affected by decision making (Mataias et al., 2020).

Interdisciplinary science can support efforts to promote sustainable and equitable trade of wildlife because IWT involves both overt and covert human behaviors. These behaviors create new biosecurity risks, including spaces, exposure pathways, and transmission routes for emerging and resurgent pathogens. For example, Mountain hawk-eagles (*Spizaetus nipalensis*) smuggled from Thailand to Belgium were infected with H5N1 highly pathogenic avian influenza. Although screening indicated no dissemination occurred, officials expressed great concern that illegal movement and trade of birds are a major threat for the introduction of this disease (Van Borm et al., 2005). Humans across all stages of the IWT supply chain—from IPLCs to law enforcement officials to conservation biologists-- are at risk from exposure to trafficked wildlife and their pathogens, regardless of their intention in interacting with wildlife (Gomez and Aguirre, 2008). Despite the overall human health risks associated with exposure to pathogens with pandemic potential, the connections of IWT with zoonotic pathogens and vector spread, the intersectionality of the issue has not received sufficient attention from the scientific community (UNODC, 2020, WWF Global Science, 2020). Widespread infection and pandemics are potential outcomes of the trafficked wildlife and as seen most recently with COVID-19, a disproportionate risk from pandemics falls on already vulnerable human populations.

A serious problem confronts decision-makers who seek to support decision-making with evidence because the intersectionality can create new, significant, or modified biosecurity and environmental risks that remain unquantified. Failing to understand the impact in unmodeled, unmanaged, and unmitigated human health risks can have serious impacts as the following discussion of the biosecurity risks associated with pathogens of pandemic potential and IWT illustrates.

Conversely, opportunities abound to leverage collaborative research and innovative analytic approaches to expand our undersanding of IWT and manage future risks in an equitable and sustainable manner (Aguirre and Nichols, 2020). After our discussions of the risks, we then identify four scientific opportunities for the use of interdisciplinary science to mitigate biosecurity risks associated with pathogens of pandemic potential and IWT.

Past as Prologue and the Repeating Biosecurity Risks of Zoonotic Transmission

Several ‘stuttering’ events occurred over decades before HIV crossed over to humans in about the 1920s and was first detected in the 1980s; wildmeat hunting and subsequent consumption is thought to be the primary human-wildlife interaction that enabled the spillover of AIDs from chimpanzees to humans (Wolfe et al. 2007; Ordaz-Nemeth et al. 2017). The scope and scale of human-wildlife interactions has geometrically increased since the appearance of HIV. During this period there has been a dramatic increase of habit loss and degradation.These interactions often occur when animals are under stress or in poor sanitary conditions with minimal attention to animal welfare. Such stress increases wildlife susceptibility to emerging pathogens, and reactivation of existing infections.

Human-wildlife interactions enable zoonotic infections in at least two ways. First, infections can move from animals to humans. This infection pathway is most common in geographies where wet markets, wildmeat hunting, and trade in nonnative species are common, driven by legitimate and illegitimate motivations, because these interactions increase the spatial and temporal likelihood of transmission. Second, infections may transfer from humans to other animal species through a process known as zooanthroponosis (Messenger et.al. 2014). This less common pathway of transmission can still generate substantial risks. For example, the first case of SARS-CoV-2 in animals was reported in a Pomeranian dog on February 28, 2020, in Hong Kong. Subsequently, positive test results were reported in two dogs, two domestic cats, four tigers, and three lions (Gönültas et al., 2020; Wang et al., 2020). Spillover of SARS-CoV-2 from humans to mink was first reported in the Netherlands in April, and then found in Spain, Italy, the USA, Sweden, and Greece. Infected mink farms were identified through contact tracing by confirming COVID-19 in symptomatic humans. As a result millions of mink have been culled globally (Kevany, 2020; Koopmans, 2020).

Notable pandemics including SARS in China, 2003; MERS in the Middle East, 2012; Chikungunya in the Americas, 2013; Ebola in West Africa, 2014-2016; Zika in the Americas, 2015; and Ebola in DRC and Uganda, 2018, underscore the intersectionality of environmental and animal wellbeing with maintenance of human health. These outbreaks not only caused the death of hundreds of thousands of people, they increased risks from comorbidity factors such as diabetes, negatively impacted economies, and caused tensions among decision-makers (Khubchandani et al., 2020; Madhav et al., 2017).

For COVID-19 in 2020, the large number of initial patients of COVID-19 associated with a wet market in Wuhan, China originally suggested that the locale, where people closely interacted with legally (and potentially illegally) traded wildlife, was key in its transmission among humans. Some scientists have speculated that the market could have been a focus of human-to-human rather than animal-to-human spread (e.g., Mckenzie amd Smith 2020). SARS-CoV-2 may have resulted from zoonotic transmission from bats to humans (Aguirre et al., 2020; Dhama et al., 2020) as the virus is 96.3% similar to Bat-CoV-RaTG13 previously detected in horseshoe bats (*Rhinolophus affinis*) from China's Yunnan Province. As horseshoe bats were hibernating at the time when COVID-19 appeared, there is general consensus that SARS-CoV-2 could have an ancestral origin in Bat-CoV-RaTG13 (Wong et al. 2019; Andersen et al. 2020). More recently, SARS-CoV-2 was not detected in Sunda pangolins (*Manis javanica*) confirming that this species is an incidental host (Lee et al. 2020). At the time we wrote this manuscript, zoonotic transmission of COVID-19 had not been determined, and ultimately, scientists may never be able to determine a specific animal host and whether it was linked to legally or illegally traded wildlife.

A One Health Approach to Surveillance, Biosefety and Security

Existing collaborations among medical personnel and veterinarians seldom consider the role of IWT in zoonotic transmission of pathogens in surveillance, biosafety, and security (SB&S) efforts (Graham et al. 2013). This observation is striking within the context of One Health (OH), or “the collaborative effort of multiple disciplines—working locally, nationally, and globally—to attain optimal health for people, animals and our environment” (AVMA 2008). A OH approach is well suited for globally distributed challenges such as IWT and pandemics. These problems are situated within the larger context of landuse change (e.g., urbanization, deforestation), human migration, and climate change. Globalization and connectivity force new and reapeated human-animal interactions (Aguirre and Tabor 2008).

OH can accommodate dynamic changes in the relationship between humans and wildlife; for example the open and dark web, social media, smart phones and mobile banking enable IWT as ever before (IFAW 2012, Lavorgna, 2014). Virtual platforms for buying and selling products blur the lines between the legal and illegal wildlife trade, and the lack of monitoring and regulation of virtual “ecosystems” complicate efforts to reduce biosafety risks and promote sustainable trade. The ability to engage in IWT anonymously has increased access to wildlife for diverse stakeholders while at the same time obfuscating some options for pandemic-related contact tracing (FATF 2020; Siriwat and Nijman 2018).

Integrating theories, methods, and analytical techniques from diverse disciplines with different skill sets can serve as a force multiplier for the policy-relevance of science focused on the threats to human security and global health posed by pathogens of pandemic potential. Pandemic-related impacts such as those associated with COVD-19 (e.g., human death and illness, economic declines, polititization of science) and the increasing sophistication, impact, and economic value of IWT combine to demonstrate that future collaborations incorporating OH approaches may be most effective at advancing sustainable and equitable objectives if they engage diverse experts across domains such as conservation criminology, transnational crime, and corruption, supply chain analytics, operations research, and data science. Such interdisciplinary science can at least help clarify a common vision for sustainable use, establish shared values and goals, prioritize equitable allocation of limited resources, guide response protocols, support scalability of decision making tools, and enhance communication.

Opportunities to Mitigate Biosecurity Risks Using Interdisciplinary Science

Populating a data landscape with analytically relevant variables will enable tracking of trends over time, facilitate aggregation and disaggregation of data, support monitoring and evaluation efforts, enhance transparency in decision making, and promote accountability to donors. At present, the data landscape is devoid of many of these characteristics, to the detriment of sustainable wildlife use and human well being. We propose actionable opportunities to address these shortcomings.

Daszak et al. (2020) recognized that one strategy to help mitigate the pandemic potential of zoonotic disease outbreaks already exists, but needs to be brought to scale: SB&S. We propose four collaborative initiatives to help scale, extend and enhance SB&S efforts in support of more sustainable and equitable treatment of IWT. The OH framework accommodates the range of interdisciplinary perspectives involved in assessing existing SB&S efforts and detection networks for zoonotic pathogens that pose disease burdens for humans and animals. Beyond leveraging existing capacity, technology, and health systems identified through an OH assessment, bespoke, cutting-edge, and locally-sensitive decision and location science-based surveillance and response models can be incorporated to support more effective policy-making and sustainable use of wildlife (Hyatt et al., 2015). There are multiple opportunities for interdisciplinary science teams to contribute new knowledge that enhances SB&S decision making, some of which we discuss here.

One pathway for improving detection of pathogens in trafficked wildlifeis through enhanced technical capacity for effective detection networks, outbreak analysis, and surveillance. Such capacity can generate inferences and inform efforts to decrease the risk of transmission of these pathogens to people and animals. Endemic and cross-boundary zoonotic pathogens (e.g., Ebola, Marburg, bovine tuberculosis, anthrax, mycobacterium) are often underreported or were reported late, due to a lack of local diagnostic capacity and missing data on disease prevalence (Halliday et al, 2012; Tambo et al., 2014). A surveillance system focusing on specific pathogens by country or region along supply chain components of trafficked wildlife requires an understanding of the factors promoting emergence. Identifying approaches for prevention, rapid control, and mitigation is key (https://www.unodc.org/documents/Advocacy-Section/Wildlife_trafficking_COVID_19_GPWLFC_public.pdf). The health, societal, economic, and geopolitical impacts caused directly and indirectly by the COVID-19 pandemic, for example, illustrate the range of risks associated with leaders or public officials who are unable (or unwilling) to identify and respond promptly and adequately to emerging zoonotic pathogens.

First, decision makers, civil society, and partner sectors may leverage enhanced SB&S to respond in an appropriate and timely manner to emerging infectious diseases (EIDs) and strengthen national and local response capacities to prevent future outbreaks. A range of relevant activities includes:

- Comprehensive and co-created prevention education component for at-risk populations.
- A surveillance sample management system for enhanced diagnostic efficiency in collaboration with local partners to further establish or link existing surveillance networks (e.g., Rhinoceros DNA Index System in South Africa https://erhodis.org/).
- Integration of systems analysis and decision science methods within an economic, environmental, social ecosystem and IPLC perspective.
- Integrate transport industry such as aviation into enforcement efforts to prevent zoonotic transmission and wildlife trade (https://routespartnership.org/industry-resources/publications/animalsmuggling)
- Consideration of the spatiality and intersectionality of wildlife trafficking and biosafety from cross-boundary zoonotic transmission.

Many stakeholders around the world already have the ability to create and manage highly efficient systems and networks across domain areas including logistics, commerce, and health care. SB&S can use those same tools to weaken illicit networks having negative outcomes including health risks, corruption, or abuse (Wood, 1993; Guo et al., 2016). That said, these methods require not only data regarding the nature of disease risk, but also need information on the behaviors of people who participate in those networks that lead to pathogen spillover (Alexander and McNutt, 2010). This requires a multi-cultural perspective and sensitivities.

Second, there exists an opportunity to leverage insights from IPLCs using community-based participatory methods and combining such knowledge with expert assessments, inducing the development of novel analytical tools and approaches that decision-makers can use to respectfuly and equitably support local livelihoods by addressing the following enduring challenges: monitoring, detection, prevention, interdiction, and remediation. Improved decision-making for these challenges can be achieved with insights from IPLCs, through a clearer understanding about the operational environment and the economic and societal drivers that motivate local community members to participate in IWT.

Third, decision support models informing behavioral change policies can dramatically enhance local capacity to prevent, detect, and respond to pathogen risks. Supporting compliance with existing rules and enhancing crime analysis and prevention capacity of law enforcement authorities can help address the needs of community members who may otherwise resort to participation in IWT. Participatory methods can help ensure that local populations inform the development of solutions and these strategies are more likely to be consistent with cultural needs and priorities.

At the same time decision-support tools also need to be based on broad systematic evidence appropriate for long term sustainability—and it is imperative that these tools provide ease-of-use and interpretability for implementation by local stakeholders unfamiliar with sophisticated models and diagnostic tools. Can you provide a past example? Community outreach and engagement can produce accurate and reliable information about the prevalence of wildlife trafficking and EIDs that would otherwise not be konwn; community engagement will support the sustainability of detection and prevention strategies. We know that poverty, deforestation, urbanization, and human behavior are comorbidity factors underlying EID emergence that may progress into a pandemic (Patz et al., 2004; Hassell et al., 2017). These variables influence epidemiology of pandemics in dynamic ways. Even without the benefit of hindsight on the pandemic, past responses to pandemics reveals that local capacity building, integrative research and transdisciplinary collaborations using the social ecological systems and resilience approach (Wilcox et al. 2019) will be prerequisites to untangle these complex issues that may result in severe harm across large populations. These efforts can be combined and integrated with our understanding of the illicit wildlife trade. Best practices from efforts to combat other elements of the illicit economy such as study of supply chains, corruption and illicit financial flows is crucial (Aguirre et al. 2020).

Finally, more can be done to harmonize a "network of networks"—including local communities--- with enhanced capacity to promote joint SB&S efforts that encourage improved human and animal health, timely reporting, emerging disease detection, and outbreak response along with reporting on IWT. We already have global structures in place to support such a network of networks through science diplomacy, such as The One Health Tripartite Agreement between the Food and Agricultural Organization, World Health Organization and World Organization for Animal Health, supported by the World Bank Group (Vandersmissen and Welburn, 2014).

We can promote resilience in ecosystem function by enhancing education for justice, promoting legislative science advice, and funding multidisciplinary research teams. Science teams can help increase awareness and data integration capacity to facilitate new threat information that can be used strategically and tactically in both responsive and proactive ways. Such information could be particularly useful when it intentionally captures local community knowledge and integrates datasets to dramatically decrease the biosafety security gap between urban and rural areas (OECD, 2020).

Prevention Produces Sustainable Outcomes Relative to Reactive Approaches

PREDICT, a multi-country wildlife surveillance and training project funded by U.S. Agency for Internaitonal Development, strengthened global capacity for detection and discovery of zoonotic viruses with pandemic potential. Over 160,000 animals and people in over 30 countries were sampled yielding more than 1,166 viruses, most new to science (PREDICT 2014). Although 949 novel and 217 known viruses were identified in what can be seen as a successful surveillance effort, it is unclear if this type of effort alone can contribute to preventing disease outbreaks at their origin. Although this was a $220M, 10-year (2011-2019) effort, this sum is a small fraction of the trillions of dollars now spent globally to mitigate risks associated with the COVID-19 pandemic and the large-scale economic losses resulting from the pandemic. The PREDICT effort helps demonstrate that although many potentially threatening viruses can be found if we look for them (Anthony et al. 2017), a broader and trans-disciplinary approach will be needed to mitigate the risks they pose.

Future efforts for containing zoonotic disease of pandemic potential may require a significant shift from scientific prediction to prevention, interdiction, and remediation strategies to deliver any practically beneficial outcomes (Dobson et al. 2020). It also requires efforts to reduce habitat destruction. The COVID-19 pandemic demonstrates that finding a virus, and managing the virus from a public health perspective, are two very different things. The world population and its many different cultures constitutes a complex system within which the virus circulates. Across the social, biological, and engineering sciences there is knowledge, and there are methods that can individually be brought to bear to more fully understand this complex system. More importantly, when diverse disciplines and their resources are brought together to address a complex challenge, they can answer questions and gain insights that no single discipline could generate in isolation.

Conclusions

Supporting SB&S efforts by government agencies and authorities (i.e., 1972 Biological Weapons Convention, 2004 UN Security Council Resolution 1540, 2005 World Health Organization International Health Regulations, Biosafety Level 4 containment laboratories (BSL-4)) from the local to the international levels, is critical for sustainable use of wildlife. These SB&S efforts can create new -- and enhance existing – collabotations and capacity to address security issues at the intersection of human and animal health, wildlife trafficking, and infectious pathogens. This intersectionality is well-situated within the OH approach, parytioularly with the context of current consumption rates of animals for food, culture, traditional medicine, or the exotic pet trade. These activities have persisted for millennia and are highly likely to persist in a post-COVID-19 world. If there are wildlife consumption or trade bans in countries where wildlife products are consumed, what will the impact of these be on curbing disease transmission? How successful would a ban of limited scope be in reducing the risks to human health and well-being from zoonotic transmission? In reality, banning wet markets is unlikely to wholly eliminate or even significantly reduce the disease transmission risks associated with IWT. It may, for example, help drive IWT underground, decrease nutritional options for vulnerable populations, degrade social and cultural identity or alter expressions of power and status. These are phenomena with policy implications that can be most accurately addressed by interdisciplinary scientific research with policy analysis (Alves and Rosa, 2007; Aguirre et al., 2019). A more integrated interdisciplinary approach can help inform this needed. Attention can be focused on the supply chains that allow zoonotic pathogens to be so rapidly distributed around the globe. Local capacity building is an essential element of global prevention, and local capacity can be combined with resourceful and well-trained networks at the global level to encourage diverse approaches to sustain biodiversity. This requires unprecedented cooperation by those in the OH world with the specialists in illicit trade in wildlife and illicit supply chains. This also requires multidisciplinary teams spanning science and enginerring, environmental studies and social science as well as NGOs and corporations.

We need to ensure that businesses are not complicit in shipping animals with harmful diseases around the world. We need interdisciplinary research to address illicit supply chains. More work is needed with the tech sector to ensure that online platforms and social media are not facilitators of illicit sales of endangered species of poached animal, and illicitly obtained flor and fauna. . By involving participants at all levels and in all sectors of society we can encourage policies that improve environmental conditions in local communities and at the regional level. Habitat conservation, wildlife protection and a focus on the diverse skill sets of communities is key to accomplishing these objectives. By integrating more diverse scientific disiplines, and their respective scientists with indigenous people and local community insight and risk assessment data, we can promote more sustainable and equitable wildlife trade.

Acknowledgements: The views expressed in this article are those of the authors and do not necessarily reflect the views of their professional or personal affiliations.

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