

Editorial — Links between biodiversity and health: consequences and opportunities for collaboration

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The relationships between biodiversity and the health of people, livestock, and wildlife have been increasingly recognized and documented in recent decades (Millennium Ecosystem Assessment, 2005; Myers *et al.*, 2013; Hough, 2014; WHO, 2015). In attempting to understand the practical implications of these links, one inevitably stumbles on their complexity and sometimes contradictory nature. One consequence of this is difficulty in aligning the policy agendas and activities of the conservation and health sectors (Chivian & Bernstein, 2008; Hough, 2014). In the interests of promoting beneficial collaborations between these sectors, we briefly illustrate the diversity of these relationships using examples from Cambodia, and highlight the complementary nature of conservation and health initiatives through examples of ongoing projects and potential opportunities.

Strong economic growth in Cambodia, with a stable 7% GDP growth over the past six years, has led to improvements in several development and health indicators (World Bank, 2016). However, rapid rates of deforestation, agricultural growth, and urbanization represent major challenges to ecosystem and biodiversity conservation, and offer mixed prospects for animal and public health (NBSC, 2014).

One of the most obvious connections between biodiversity and health is through *provisioning services* (Millennium Ecosystem Assessment, 2005). Many of Cambodia's rural communities still rely heavily on wildlife and non-timber forest products for their subsistence and nutritional needs, similar to other parts of Southeast Asia and the world (Golden *et al.*, 2011; Johnson *et al.*, 2012). However, wildlife consumption has also caused major infectious disease outbreaks (e.g., SARS, HIV, Ebola) and continues to be a driver of disease emergence (Karesh & Noble, 2009; Greatorex *et al.*, 2016). Overfishing and over-

hunting are also driving biodiversity declines in many of Cambodia's landscapes (Valbo-Jørgensen *et al.*, 2009; Gray *et al.*, 2012), further affecting food chains in these ecosystems and compromising the nutritional status and survival of wildlife (O'Kelly *et al.*, 2012). Conversion of biodiverse areas to monocultures and agriculture intensification have increased chemical pollution with severe health consequences for wildlife, livestock, and humans (Monirith *et al.*, 1999; Neufeld *et al.*, 2010; Wang *et al.*, 2011; WCS, 2016). Smoke from forest fires used to clear land also cause significant respiratory issues, particularly in children (Jayachandran, 2009). When natural habitats are destroyed, the vegetal and microbial diversity that have allowed many biomedical discoveries supporting human and animal health (e.g., anti-microbial drugs) are also lost. These biota also support the health of rural and indigenous communities through traditional medicine (Hout *et al.*, 2006; Chea *et al.*, 2007). Although conservation of medicinal plants can be used to promote sustainable use and forest protection (e.g., Laval *et al.*, 2011), some of the beliefs and practices involving the use of animal parts for traditional medicine pose a considerable threat to wildlife (Sodhi *et al.*, 2004; Starr *et al.*, 2010) and will likely continue to result in species extinctions (Courchamp *et al.*, 2006).

A wide range of *regulating and supporting ecosystem services* (Millennium Ecosystem Assessment, 2005) are related to wildlife, livestock, and human health. Intact ecosystems may help in regulating pests and infectious diseases (WHO, 2015). However, the relationships between biodiversity and infectious diseases are complex, highly context-dependent, and much debated (Johnson & Thielges, 2010; Randolph & Dobson, 2012; Ostfeld, 2013). In some circumstances, diversity of host species plays a regulating role through the combined

action of host competition and differential host susceptibility to pathogens (i.e. the dilution effect) (Keesing *et al.*, 2010), while in others, it can be a source of pathogens and result in their amplification (Randolph & Dobson, 2012). Higher biodiversity often results in higher pathogen diversity, but a pathogen-rich ecosystem may not necessarily be an issue; rather it is the loss of ecosystem integrity and increased contact with invasive hosts (including humans and livestock) that may increase disease emergence risks (Patz *et al.*, 2004). For instance, the overall richness of infectious diseases in the Asia-Pacific region is positively correlated with the richness of birds and mammals, but the number of zoonotic disease outbreaks are positively correlated with the number of threatened wildlife species, while vector-borne disease outbreaks are negatively correlated to the percentage of forest cover (Morand *et al.*, 2014). Encroachment into natural areas, logging and road development, increased contact between wildlife, livestock and humans, and modification of host and vector communities are some of the factors linking ecosystem disturbance to disease emergence (Horby *et al.*, 2013; Jones *et al.*, 2013). Threats of disease emergence are by no means limited to humans and livestock, and their consequences for wildlife conservation can be dire. Large epidemics of chytrid fungus in amphibians and canine distemper virus in wild carnivores, for instance, are driving declines in many species (Hatcher *et al.*, 2012; Kolby & Daszak, 2016). In Cambodia, there is still much to learn about how infectious diseases may challenge conservation efforts, and the current interest in wildlife farming (intended to reduce hunting pressure on wild populations) is likely to create more interfaces that increase the risk of disease emergence (WCS & FPD, 2008). Finally, most regulating or supporting ecosystem services have direct or indirect impacts on animal and human health at various scales. Water and nutrient cycles, carbon sequestration, and pollination all have complex relationships with factors that influence pathogen transmission, nutrition and other health outcomes. Exposure of humans to biodiverse environments has also been linked to the ability to mount adequate immune response and prevent autoimmune diseases (WHO, 2015). The social and psychological impact of habitat degradation on society is also increasingly documented (Speldewinde *et al.*, 2009), as is the positive effect of experiencing nature on mental and physical well-being (Bratman *et al.*, 2012).

Given the diverse relationships between biodiversity and health, any policy or intervention directed to one sector will inevitably affect the other (Walther *et al.*, 2016). In recognition of the complex connections between the environment, wildlife, livestock, humans and pathogens, the concepts of “One Health”, “EcoHealth” and “Plan-

etary Health” have emerged to promote integrative and trans-disciplinary approaches to their study (Roger *et al.*, 2016). These are all initiatives and frameworks that foster collaboration between the livestock, human and wildlife health sectors, and encourage an ecosystem approach to health. Although these efforts have improved coordination between public and animal health, much more can be done to increase collaboration between health sectors and conservation initiatives.

Field personnel in protected areas and individuals that directly work with wildlife (e.g., law enforcement, wildlife monitoring) are typically at the forefront of unusual events in wildlife and constitute an important interface with wild animals and the pathogens they carry. Such field capacity is invaluable for wildlife health surveillance. Biodiversity monitoring is in many cases a powerful indicator of health-related factors (e.g., lichens and air quality, arthropods and soils, aquatic organisms and aquatic systems) (WHO, 2015). Disease outbreak and mass mortalities in wildlife can also provide a warning sign for health issues in livestock and humans, irrespective of whether the origin is infectious (e.g., West-Nile virus, Yellow fever, Ebola) or non-infectious. The latter is illustrated by the recent detection of wildlife deaths in Preah Vihear Province from pesticide contamination of the environment, also affecting livestock and humans (WCS, 2016). An important consequence is that staff working in protected areas need to understand the risks of zoonotic disease transmission and other health risks, and to adopt adequate protective measures in their activities. Collaboration between conservation and health organizations could do much to improve detection of these events and ensure prompt identification of the underlying issues and appropriate responses. This is currently being done under a EU-funded LACANET (Lao PDR – Cambodia One Health Network) project which links field capacity and wildlife health expertise (within the Wildlife Conservation Society) with animal and public health partners, and trains staff in Cambodia’s protected areas to organize wildlife health surveillance (LACANET, 2016). The project is also conducting research on the factors that are driving biodiversity loss and disease emergence (e.g., land-use change, wildlife trade). This presents an opportunity to address conservation challenges in a new way, as health is a value broadly shared across cultural and socio-economic groups, and can be used to generate support for conservation initiatives when overlapping objectives are identified. In addition, many conservation NGOs have long-standing relationships with local communities and particular landscapes, which makes them particularly well-positioned to facilitate health-related projects and interven-

tions. Engagement on health issues could also strengthen these ties. Conservation organizations should include health as one of their conservation tools, and reach out to health organizations to identify potential collaborations. In a resource-limited context, it is also imperative to optimize the use of resources, and take advantage of these potential synergies. This includes the appropriate use of wildlife by limiting the use of lethal sampling for health studies, and collaborating with local collections (such as the zoological collection of the Centre for Biodiversity Conservation at the Royal University of Phnom Penh [RUPP]) and bio-banking efforts (such as the RUPP Conservation Genetics laboratory) when wildlife mortality is beyond the control of project implementers.

The complementarity of the conservation and health sectors should be better utilized as part of the multiple projects that follow the “One Health” framework (i.e. multi-disciplinary ecosystem approach to health), and could improve assessments of the respective impacts of health and conservation interventions on conservation and health outcomes. For instance, when community access to wildlife is critical to maintain nutrition in protected areas, but no longer acceptable due to population declines, conservation organizations could seek the support of animal production and animal health partners to find alternative strategies addressing such issues. Similarly, disease risks related to wildlife consumption, when appropriately documented, may also be a strong argument to encourage reductions in wildlife hunting and trade, and the health sectors should work closely with conservation partners to translate findings into useful outreach material. Additionally, because strategies used by conservationists in Cambodia are diversifying (e.g., the Wildlife Conservation Society and Fauna & Flora International support the recovery of wild populations of Mangrove Terrapin (*Batagur affinis*) and Siamese crocodile (*Crocodylus siamensis*) through headstarting, captive breeding and reintroduction, whereas BirdLife International use livestock to perform the ecological roles once played by large ungulate populations in Western Siem Pang), needs for expertise in veterinary care, animal health and husbandry must be appropriately assessed to ensure the health and well-being of the animals, and ultimately the success of these efforts. Consultation with appropriate animal health expertise at the planning stage is therefore essential, as reactive measures usually come too late to adequately identify and address underlying issues. Similarly, although many wildlife health projects in Cambodia in recent years have been implemented under the One Health umbrella, their links to conservation have often been an after-thought. Maintaining a dialogue between wildlife health and conservation actors

is essential to ensure that the wildlife health activities also meet questions and needs related to species conservation, and identifies these during the onset of projects.

In short, improving collaboration between conservationists and practitioners from the human, livestock and wildlife health sectors is critical. Joint planning should aim at identifying complementarity and aligning objectives, and organize coordinated activity implementation and integrated actions. This is not only a morally responsible use of resources, but is also necessary to harness synergies that already exist in nature.

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