# Spatializing zoonotic disease dynamics from a political ecology perspective: Reconceptualizing spillover as structure

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## Abstract

Estimates that 60% of emerging infectious diseases are zoonotic in origin, combined with recent high-profile zoonotic outbreaks like the COVID-19 pandemic, have the world scrambling to understand, predict, and prevent zoonotic disease risks and outbreaks. Scientists and public health officials draw attention to anthropogenic processes understood to contribute to these risks, such as the wildlife trade, climate change, deforestation, and urbanization. Rightly understood as a joint public health and human-environment challenge, what is being lost is an appreciation for the structural, systemic drivers of zoonotic disease risks, outbreaks, their spatialities, and related interventions. In this article, we articulate the need for this research and how political ecology can respond to it. Complementing existing work on political ecologies of health and disease, we develop a specific political ecology approach to examine the structural processes shaping the spatialities of zoonotic disease dynamics. This framework is intended to: 1. give critical attention to spatialities of animal-human-pathogen relations; 2. examine how and what political-economic, socio-cultural and other structural processes drive changes in these spatialities; and 3. investigate how changes in these spatialities intensify (or de-intensify) animal-human-pathogen relations and zoonotic risks. We use this framework to reconceptualize taken-for-granted and key components of zoonotic disease outbreaks – reservoirs, interfaces, and spillovers. We reframe reservoirs as bodies and landscapes that are spaces of zoonotic hazard; and interfaces as spaces of interspecies intimacy. From here, we explain why it is important to think about spillover not just as an event preceding an outbreak, but as a structured process that unfolds across space, time, and scale. Our intention is for others to enrich and advance this framework through application in different zoonotic disease contexts to critically examine how spaces of hazard, intimacy and spillover are shaped, and what this means for differentiated risks, vulnerabilities, and interventions.

**Key words:** Zoonosis, political ecology, disease, animal-human interfaces, health

## Résumé

Les estimations selon lesquelles 60% des maladies infectieuses émergentes sont d'origine zoonotique, combinées aux récentes épidémies zoonotiques très médiatisées comme la pandémie de COVID-19, ont poussé le monde à se démener pour comprendre, prédire et prévenir les risques et les épidémies de maladies zoonotiques. Les scientifiques et les responsables de la santé publique attirent l'attention sur les processus anthropogéniques dont on sait qu'ils contribuent à ces risques, tels que le commerce des espèces sauvages, le changement climatique, la déforestation et l'urbanisation. Considéré à juste titre comme un défi commun à la santé publique et à l'environnement humain, ce qui se perd, c'est l'appréciation des moteurs structurels et

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systémiques des risques de zoonoses, des épidémies, de leurs spatialités et des interventions qui y sont liées. Dans cet article, nous soulignons la nécessité de cette recherche et la manière dont « political ecology » peut y répondre. En complément des travaux existants sur « political ecology » de la santé et de la maladie, nous développons une approche spécifique « political ecology » pour examiner les processus structurels qui façonnent les spatialités de la dynamique des maladies zoonotiques. Ce cadre est destiné à: 1. accorder une attention critique aux spatialités des relations entre l'animal et l'homme et les agents pathogènes; 2. examiner comment et quels processus politico-économiques, socioculturels et autres processus structurels entraînent des changements dans ces spatialités; 3. étudier comment les changements dans ces spatialités intensifient (ou désintensifient) les relations entre l'animal et l'homme et les agents pathogènes ainsi que les risques zoonotiques. Nous utilisons ce cadre pour reconceptualiser les éléments clés des épidémies de maladies zoonotiques: les réservoirs, les interfaces et les débordements. Nous recadrons les réservoirs comme des corps et des paysages qui sont des espaces de danger zoonotique, et les interfaces comme des espaces d'intimité inter-espèces. À partir de là, nous expliquons pourquoi il est important d'envisager les débordements non seulement comme un événement précédant une épidémie, mais aussi comme un processus structuré qui se déploie dans l'espace, le temps et l'échelle. Nous souhaitons que d'autres enrichissent et fassent progresser ce cadre en l'appliquant à différents contextes de maladies zoonotiques afin d'examiner de manière critique la façon dont les espaces de danger, d'intimité et de propagation sont façonnés, et ce que cela signifie pour des risques, des vulnérabilités et des interventions différenciés.

**Mots-clés:** Zoonose, political ecology, maladie, interfaces animal-homme, santé

## Resumen

Las estimaciones de que el 60% de las enfermedades infecciosas emergentes son de origen zoonótico, junto con los recientes brotes zoonóticos de gran repercusión como la pandemia de COVID-19, hacen que el mundo se esfuerce por comprender, predecir y prevenir los riesgos y brotes de enfermedades zoonóticas. Científicos y funcionarios de salud pública llaman la atención sobre los procesos antropogénicos que se entiende contribuyen a estos riesgos, como el comercio de animales salvajes, el cambio climático, la deforestación y la urbanización. Entendido correctamente como un reto conjunto para la salud pública y el medio ambiente, lo que se está perdiendo es la apreciación de los impulsores estructurales y sistémicos de los riesgos de enfermedades zoonóticas, los brotes, sus espacialidades y las intervenciones relacionadas. En este artículo articulamos la necesidad de esta investigación y el modo en que la ecología política puede responder a ella. Complementando los trabajos existentes sobre ecologías políticas de la salud y la enfermedad, desarrollamos un enfoque específico de ecología política para examinar los procesos estructurales que conforman las espacialidades de la dinámica de las enfermedades zoonóticas. Este marco pretende: 1. prestar una atención crítica a las espacialidades de las relaciones entre animales, humanos y patógenos; 2. examinar cómo y qué procesos político-económicos, socioculturales y otros procesos estructurales impulsan cambios en estas espacialidades; 3. investigar cómo los cambios en estas espacialidades intensifican (o desintensifican) las relaciones entre animales, humanos y patógenos y los riesgos zoonóticos. Utilizamos este marco para reconceptualizar los componentes clave de los brotes de enfermedades zoonóticas: reservorios, interfaces y spillovers. Reformulamos los reservorios como cuerpos y paisajes que son espacios de peligro zoonótico; y las interfaces como espacios de intimidad interespecífica. A partir de aquí, explicamos por qué es importante pensar en la propagación no sólo como un acontecimiento que precede a un brote, sino como un proceso estructurado que se desarrolla a través del espacio, el tiempo y la escala. Nuestra intención es que otros trabajos enriquezcan y hagan avanzar este marco mediante su aplicación en diferentes contextos de enfermedades zoonóticas para examinar críticamente cómo se configuran los espacios de peligro, intimidad y propagación, y qué significa esto para los riesgos, vulnerabilidades e intervenciones diferenciados.

**Palabras clave:** Zoonosis; ecología política; enfermedad; interfaces animal-humano; salud

## 1. Introduction

Over the past century, there has been a notable increase in zoonotic disease outbreaks – infectious diseases that jump from animals to humans (UNEP, 2016).[2] Some estimates suggest that 60% of all emerging

[2] We recognize that humans are also animals, but for ease of discussion refer to humans and animals to distinguish between humans on the one hand and nonhuman animals like livestock, pets, wildlife, etc. on the other. It is also important to

infectious diseases are zoonotic in origin (UNEP, 2016), with recent high-profile outbreaks pushing zoonotic disease into the global spotlight. This includes Severe Acute Respiratory Syndrome (SARS, 2002), Avian Influenza (Bird Flu, 2004, 2025), H1N1 (Swine Flu, 2009), Middle East Respiratory Syndrome (MERS, 2012), Ebola (2013–2016), Zika Virus (2015–2016), and West Nile Virus (2019). Most recently, the SARS-CoV-2 (COVID-19) pandemic of 2020–2011 made zoonotic disease a global priority and a matter of everyday concern for billions of people around the world.

Mainstream scientific discourse often attributes increased zoonotic disease outbreaks to processes of agricultural expansion and intensification, deforestation, industrialisation and infrastructure development, and urbanisation. These processes cause large-scale habitat loss and ecosystem fragmentation, which can increase proximity and alter interactions between humans and animals that may harbor disease pathogens (Hassell *et al.*, 2017; White & Razgour, 2020; Keesing & Ostfield, 2021; Plowright *et al.*, 2021; Rulli *et al.,* 2021; Santini, 2021). Since the COVID-19 pandemic, the trade and consumption of wildlife has also come under greater scrutiny, with the harvesting, transportation, storage, and sale of wild animals and meat condoned by many environmental and public health experts as a zoonotic risk (Enns *et al.,* 2021; Roe *et al*., 2020; Peros *et al*., 2021).

Understanding how these and other proximate socio-environmental processes factor into zoonotic disease outbreaks has become a global priority for many natural science disciplines and public health bodies. On a near daily basis, high-level quantitative and geospatial data is being produced showing where zoonotic disease outbreaks are most likely to occur and which zoonotic diseases represent the greatest global public health threats (Grange *et al.,* 2021; Leach & Scoones, 2013). This data is made accessible to policymakers and public health officials devising interventions that aim to prevent diseases from spilling over from animals to humans where risk is perceived to be greatest. While important epidemiologically, this data is limited when it comes to understanding the societal and political-economic factors that drive socio-environmental change that shapes zoonotic disease risk and vulnerability in different contexts and among different people. It also falls short in explaining the systemic changes that may be needed to prevent future outbreaks, epidemics and pandemics (Dzingirai *et al*., 2017b; Hinchliffe, 2022; Leach *et al*., 2017). Such knowledge requires a focus on the structural forces that shape the spatialities – intersections of space, power, and socio-ecological life – of zoonotic relations and associated risks, outbreaks, and intervention processes at all scales.

We position our contribution in this article within existing geographical and political ecology work that draws attention to infectious disease spatialities and spread as being much more than biological or epidemiological processes. Some of this research grapples with zoonoses, although not always specifically (Connolly, 2017; Connolly *et al*., 2021; Dzingirai *et al.*, 2017a, 2017b; Enns & Bersaglio, 2024; Enticott, 2008; Gandy, 2022, 2023; Hinchliffe *et al*., 2013; Leach *et al.*, 2017). We build on this work, stitching it together to develop a political ecology framework to critically examine the spatialities of zoonotic disease dynamics, namely reservoirs, interfaces, and spillover. We argue that these zoonotic spatialities are structural, and we demonstrate why this matters for understanding these specific components and the uneven dynamics of zoonotic risk and vulnerability. While all infectious diseases involve spatial, relational, and structural dynamics, the animal-human-pathogen relationship underpinning zoonoses makes it unique and worthy of a separate political ecology framework. As structural processes at and traversing various scales alter landscapes, ecosystems, habitats, and the ways in which human and nonhuman bodies interact with and move within and through them, the spatial dynamics of animal-human-pathogen relations can also shift. This leads to changing and possibly greater zoonotic disease risks. Political ecology thus has a valuable role to play in understanding and researching the processes that shape key elements of zoonotic spatialities. In doing so, it can also help shed light on how structural inequalities, injustices, and power relations make certain human and nonhuman animals and spaces more vulnerable to zoonotic risks than others.

To illustrate this, we incorporate mainstream scientific and political ecology perspectives to develop a framework for examining the structural processes that contribute to shaping spatialities of zoonotic relations,

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acknowledge that zoonotic diseases can jump from humans to animals, even though we tend to use the language of animal-human transmission throughout this article for the sake of simplicity.

disease risk, and outbreaks. We bring together three main threads of analysis to underpin this political ecology of zoonosis:

1. the spatialities of animal-human-pathogen relations;
2. how and what political-economic, socio-cultural, and other structural processes drive changes in these spatialities;
3. how changes in these spatialities intensify (or de-intensify) animal-human-pathogen relations and related zoonotic risks.

We use this framework to reconceptualise taken-for-granted and key components of zoonotic disease outbreaks – reservoirs, interfaces, and spillovers (Table 1). We reframe reservoirs as bodies and landscapes that have been rendered hazardous spaces, and interfaces as spaces of intensifying intimacies between species. From here, we explain why it is important to think about spillover not just as a singular event preceding an outbreak, but as a structured process that unfolds across space, time, and scale. This has implications for the nature and the scope of interventions that need to be prioritised in the (post-)pandemic era.

The article begins by reviewing relevant literature in political ecology, bringing together existing work on health and disease, zoonotic disease, and their spatialities. This informs our framework and guides our illustrative analysis in the following sections. Before concluding the article, we discuss how our analysis requires a fundamental shift in thinking about the very nature of zoonotic spillover as a structural process. In developing this framework, our hope is that others will enrich it analytically and theoretically, while advancing it empirically through applications in different geographical and socioecological contexts.

## 2. Political ecology, spatiality, and zoonotic disease

*Political ecology, health and disease*

Within political ecology, studies on disease and health focus on a range of empirical contexts – particularly where health-related inequalities may be experienced along the lines of class, gender, race, sexuality, and other categories. This includes efforts to understand the politics and ecologies of: infectious and communicable disease (Brenner & Ghosh, 2022; Chung *et al*., 2020; Connolly *et al*., 2021; Eaves & Al Hindi, 2020; Harris, 2019; Neely, 2015; Nyantakyi-Frimpong *et al*., 2016; Rose-Redwood *et al*., 2020); non-communicable disease, including reproductive health (Guthman & DuPuis, 2006; Harper, 2004; Nichols & Casino, 2021); and health-related inequalities associated with certain economies, labor regimes, and livelihood systems (Brisbois *et al.*, 2017, 2018; Sultana, 2012). Collectively, this work productively approaches health and disease as "a nature-society question" (Mansfield, 2008) and contributes to advancing emancipatory and action-oriented research agendas to understand and transform health-related environmental injustices (Brisbois *et al*., 2017; Richmond *et al*., 2005).

Political ecology demonstrates that many public health challenges are not strictly epidemiological, but the product of structural inequalities, injustices, and power relations that intersect with disease and medical ecologies to produce certain health-environment connections and outcomes (De Ver Dye *et al*., 2020; Guthman & DuPuis, 2006; Mayer, 1996). While Turshen (1977) was among the first explicitly to carry out a study termed the "political ecology of disease", examining how class shaped exposure to disease and access to health services during the industrial revolution in England, it has long been recognised that health and disease need to be understood in relation to broader socio-ecological systems. In the late 1800s, Rudolf Virchow coined the term "social medicine", positing medicine as a social science with epidemics as social in origin, and disease more the result of poverty and socio-economic conditions rather than of germs or microbes (also see Adams *et al*., 2019). This approach has influenced more contemporary approaches to understanding infectious disease in the context of the structural violence of neoliberal policies and market forces that erode or shape access to social and economic rights. This is what Farmer eloquently captures with "pathologies of power" as a "broad biosocial

approach" to disease (Farmer, 2004, p. 19).

As it relates to political *ecologies* of disease, the field of disease ecology takes centre stage. Disease ecology seeks to understand how the interconnections between people and environment (including social and environmental change and/or disruption) lead to disease redistribution and emergence (see Anderson, 2004). Drawing on the words of Burnet, a pioneer of disease ecology, Anderson writes "Infectious disease was, he [Burnet] claimed, nothing more or less than 'a manifestation of the interaction of living beings' in a changing environment" (Anderson 2004, p. 49). Some disease ecologists also look at social processes like migration, urbanisation, demographic change, and labor dynamics as factors shaping disease distribution and emergence. However, disease ecology largely falls short of accounting for and analysing the power dynamics and structural processes that underpin or shape socio-environmental change, and how these occur unevenly across space, time, and different groups of people. Disease ecology, has, for example, been termed the "natural history of infectious disease" (Anderson, 2004; Burnet & White, 1972), with some prominent disease ecologists being Malthusian, provoking familiar critiques about apolitical analyses of socio-ecological interactions and processes. As Turshen (1977, p. 48) explained, while disease ecology and medical ecology recognised a connection between the environment, health, and disease, they selected "only biological and sociocultural factors as relevant."

Post-structural approaches in political ecology – often through engagement with Science and Technology Studies (STS) – are also useful in examining how scientific discourses and systems of knowledge production are shaped by power relations and reproduce structures of power in the public health arena (Connolly *et al*., 2017; Forsyth, 2004; Richmond *et al*., 2005; Robinson, 2017). This focus on discourse is also seen in allied fields like political epidemiology, demonstrating how health discourses, and therefore interventions, are shaped by environmental narratives and vice-versa (Brownlea, 1981).

A political ecology of infectious disease merges the focus on structural dynamics of social medicine and related approaches with the analysis of relations between pathogens, human and nonhuman animals, and environmental change of disease ecology. In doing so, it also foregrounds Hinchliffe *et al*.'s (2017) understanding of pathogenicity as the relational processes or conditions (rather than microbes) that produce infectious disease, a point we return to below.

*The political ecology of zoonotic disease*

Even though zoonotic disease sits squarely at the human-environment nexus, there has been relatively little sustained engagement with the issue in political ecology until recently, and no overarching framework for a political ecology of zoonosis. The subject remains dominated by animal and veterinary science, epidemiological, and One Health disciplines. This trend has begun to change in the last decade, thanks to work by Hinchliffe and Lavau (2013); Leach and Scoones (2013); Lorimer (2017); Dzingirai *et al.* (2017a, 2017b); Kaup (2018); Connolly and colleagues (Connolly, 2017; Connolly *et al*., 2021); Gandy (2022, 2023); Enns and Bersaglio (2024) and Fernando (2020a; 2020b), among others.

Political ecology work on zoonotic disease tends to adopt similar perspectives to that on health and disease more broadly. For example, in seeking to understand the dynamics of zoonotic disease risk, vulnerabilities, and outbreaks, there has been a focus on how and why different actors within different livelihood systems or trade networks experience varied forms of risk and vulnerability (Dzingirai *et al*., 2017b; Enns *et al*., 2023; van Vliet *et al*., 2022). Rather than approaching these economies as intrinsically risky or irresponsible, this work focuses on how biological, cultural, ecological, economic, epidemiological, microbial, political, social, and spiritual processes intersect and interact across space with implications for zoonotic disease risk and vulnerability in specific contexts (Braun, 2007; Dizingirai *et al*., 2017a). There are also efforts to examine how power-laden discourses and systems of knowledge production concerning zoonoses shape and are reproduced through public health interventions (Hinchliffe & Lavau, 2013; Hinchliffe, 2015; Jackson & Neely, 2015; Leach & Scoones 2013).

More-than-human thought is also being applied and advanced in innovative ways through increased engagement with zoonotic disease through what may be understood as a political ecology orientation. Some

advocate for a microbial scale of analysis, suggesting that zoonotic diseases be understood as more-than-human relations consisting of microbes, viruses, animals, plants, and humans, as well as technologies and other actants (Andrews, 2019; Braun, 2007; Lorimer, 2017). Adopting a more-than-human perspective informs more nuanced, comprehensive understandings of how and where diseases emerge and pathogenic spillovers occur; why different populations of humans and nonhumans experience zoonoses so differently in terms of risk and vulnerability; and, similarly, why experiences with zoonotic disease prevention and response efforts may also differ from one population to the next (Eaves & Al-Hindi, 2020; Enns & Bersaglio, 2024; Fernando 2020a; Gandy, 2023; Lunstrum *et al*., 2021).

*Political ecology and the spatialities of (zoonotic) disease*

Spatiality and geography in the health-environment nexus features prominently in political ecology. For example, specific work on infectious disease, which sometimes includes a focus on zoonoses, takes a landscape approach to understand the "everyday lived experience" of the socio-natural production and transformation of (urban) space and environments and what this means for health outcomes (Connolly, 2017, p. 434). This landscape approach informs and complements analyses of the political, demographic, and economic dynamics that influence the spatial factors of infectious disease spread, especially in contexts of extended and planetary urbanisation (Ali *et al.* 2022; Connolly *et al*., 2021; Gandy, 2022, 2023; Kaup, 2018). The theme of space cuts across much of the political ecology and human-environment geography literature on zoonotic disease specifically. This work engages with a range of physical spaces at different scales, from global arenas of knowledge production and policymaking (Hinchliffe, 2022; Hinchliffe & Lavau, 2013; Leach & Scoones, 2013), to landscapes of extraction, livestock production, and resource-based livelihoods (Atkins & Robinson, 2013; Dzingirai *et al*., 2017b; Enticott, 2008; Hinchliffe *et al.*, 2013; Leach *et al*., 2017), global and local infrastructures (Enns & Bersaglio, 2024), bodies and microbial-level sites of interaction (Andrews, 2019; Braun, 2007; Hinchliffe, 2022; Lorimer, 2017), and the variegated processes of urbanization (Ali *et al*., 2022; Connolly, 2017; Connolly *et al*., 2021; Gandy, 2023). Analytical engagement focuses on how landscapes, ecosystems, and bodies have been rendered hazardous, risky, or vulnerable spaces across time because of (neo)colonial violence, environmental injustice, exploitative political economies, and human-induced environmental change (Brown & Kelly, 2014; Fernando 2020a, 2020b; Gandy 2023; Lunstrum *et al*., 2021).

What emerges as pivotal in this work for a political ecology approach to zoonoses is the *intensity of relations* between animal, human, and pathogen bodies in a context of changes in relations between these bodies and the environments in which they are situated in and move through. This is what Hinchliffe *et al*. (2016) argue with their relational and multispecies approach to disease (not necessarily zoonotic). While agreeing "diseases are made from host-pathogen and environmental interactions", they move beyond this "epidemiological 'matter of fact'" to argue that these interactions exist within a network of other socio-material relations, like labor relations, market relations, governmental relations and so on. It is the intensity of these relations and their spatial configurations that shape the emergence and distribution of disease, or as they say, "contribute to pathogenicity" (2016, p. xiv; also see Lorimer, 2017). They capture these processes of relational "socio-material intensities that generate pathogenicity" and their spatialities with the term "disease situations" (2016, p. xv). Focusing on viral haemorrhagic fevers, Brown and Kelly (2014, p. 281) similarly use "hotspot" as a spatial metaphor and site of study for "material proximities" or "mundane interactions that create the conditions of pathogenic possibility". Dixon and Jones III (2015, p. 226) develop the concept of "tactile topologies" to understand the material connections between and among bodies and how they are always being reassembled in ways that change and reshape the "intensity and substance of relations" between human, animal, pathogen and object bodies. Similarly, in pushing geographers to think beyond border*lines* and to think of disease border*lands*, Hinchliffe *et al*. (2013) argue human-nonhuman bodily arrangements, their intensifications, and rearrangements "are expressed through spatial *intension* rather than spatial extension; that is, they emerge through the *intensity* of the relationships that compose the spaces of which they are a part, rather than through their extended distribution in networked space" (Hinchliffe *et al*. 2013, p. 538. emphasis added).

Insights into the intensity of material relations and their recalibration within specific spaces also inform interventions to reduce zoonotic spread, such as biosecurity interventions for bovine tuberculosis that focus on managing the intensity of human-animal-pathogen relations in a single space, or in a particular reservoir landscape, such as on the farm (Enticott, 2008).

Drawing on this body of work, when spatiality is understood as the intersection of space, power relations, and social (including socio-ecological) organisation, the concept's influence in political ecology literature on zoonotic disease becomes clear. Spaces of zoonotic disease can and must be understood as multi-scalar, temporal, and relational more-than-human processes. Moreover, these relations between bodies and their environments, their increasing or decreasing intensities, and thus the level of disease risk not only occur within and across space; they are shaped by the spatialities of socio-ecological arrangements and dynamics in specific contexts. These arrangements are mediated and re-shaped political-economically, culturally, and environmentally, both internally and externally to the immediate spaces of animal-human-pathogen relations. It is that engagement with the structural spatialities of zoonotic disease that remains largely implicit, and that our framework seeks to develop further and make explicit. As the political ecology subfield devoted to the study of zoonotic disease continues to grow in response to one of the most pressing threats to life on Earth, the time is right for greater dialogue about what systematic engagement with the structural and structured natures of the spatialities of zoonotic disease in political ecology could and should look like, and how to approach this.

In what follows, we offer one approach to developing a political ecology framework for examining the structural nature of zoonotic disease spatiality. As a starting point, we adopt a political ecology perspective to spatialise key components of a zoonotic disease outbreak that are taken-for-granted in mainstream public and scientific discourse. These components are reservoirs, interfaces, and spillovers (Table 1). Through our analysis and discussion, we suggest that reservoirs can be understood as bodies and landscapes that have been rendered hazardous spaces, and that interfaces represent spaces of intimacies between bodies, populations, species, and pathogens. Importantly, these spaces are not intrinsically risky, but are instead shaped by structures that operate across scale to embed injustices, inequalities, and power relations into the more-than-human fabric of society that then alter and intensify animal-human-pathogen relations. Similarly, spillover is not a singular event or moment that can be prevented merely through technical policy and public health measures, as it is so commonly understood (also see Hinchliffe, 2022; Plowright *et al.,* 2021). Spillover is a complex spatio-temporal phenomenon that is shaped by historical legacies, structural forces, and ongoing socio-ecological processes.

| Component | Common mainstream definition | Definition adapted with PE insights | Useful PE concepts and literature |
|---|---|---|---|
| **Reservoirs** | **Definition**: Animals harboring at least one zoonotic pathogen in their bodies<br><br>**Emphasises**: (Bio-)physical properties intrinsic to individuals, animals, and species (e.g. genetic traits, immunology, etc.)<br><br>*May refer to wider systems of reservoirs, vectors, and novel hosts* | **Definition**: Animals and spaces rendered zoonotic hazards and harboring at least one zoonotic pathogen<br><br>**Emphasises**: Power relations and structural violence embodied by animals; unique attributes of spaces occupied by reservoirs; political-economic drivers of spatial transformation, with implications for animal behavior, distribution, ecology, health, etc.<br><br>*May refer to individual bodies or populations* | Political ecology of/on hazards and disasters<br><br>Structural political ecology |
| **Interfaces** | **Definition**: Spaces where contact between animals, vectors, and humans could lead to the transfer of pathogens (e.g. farms and ranches, butcheries and markets)<br><br>**Emphasises**: Demand (e.g. economic, cultural) for certain animal products and the activities required to meet demand; also, human-induced environmental change, including biodiversity and species loss<br><br>*May include spaces of interaction with companion species, though this is less common in the literature* | **Definition**: Spaces of interspecies intimacy with contact between animals, vectors, and humans shaped by broader forces in ways that expose certain animal and human populations to greater risk of zoonotic transmission.<br><br>**Emphasises**: Structural forces (e.g. power relations, socio-economic status, historical injustices) that shape (i) where interfaces are, (ii) who occupies them, and (iii) the type of animal-human interactions they entail<br><br>*E.g. capitalist and/or masculinist political economies may lead to both widespread habitat loss and shape intimate, mundane contact between people and animals in unequal ways.* | Feminist political ecology<br><br>Intersectional approaches<br><br>Multispecies and more-than-human approaches |

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|---|---|---|---|
| **Spillovers** | **Definition**: The transmission of pathogens from animals to humans, with the potential to circulate in the novel host population (i.e. cause an outbreak)<br><br>**Emphasises**: Inherent risk of certain animals, interactions, and spaces, including certain consumption habits, economies, cultural practices, etc.<br><br>*Understood as distinct events or moments of transmission in discrete spaces, which can be prevented with targeted policy and practical interventions* | **Definition**: Structural forces and processes unfolding spatially over time, creating the conditions needed for pathogens to transfer from certain animals to certain humans and potentially circulate in a novel host population<br><br>**Emphasises**: Changing, relational risk dynamics due to (legacies of) past and present structural forces on ecosystems, landscapes, and more-than-human relations.<br><br>*Understood as a spatio-temporal phenomenon with differentiated implications for different groups and populations; requires widespread radical change to political-economic and socio-ecological systems* | Structural political ecology |

Table 1: Spatializing reservoirs, interfaces, and spillovers with insights from Political Ecology (PE). Source: Authors

## 3. The spatialities of zoonotic disease reservoirs and interfaces

*Reservoirs as spaces of embodied hazard*

In scientific discourse, 'reservoir' describes an animal that harbors zoonotic pathogens with the potential to spillover to humans. 'Hyperreservoirs' harbor two or more zoonotic pathogens, with 'special' reservoirs harboring a disproportionate share relative to others (Mollentze & Streicker, 2020). Reservoirs differ from vectors, such as fleas, mosquitos, sandflies, and ticks, which transmit vector-borne diseases from reservoirs to novel hosts through reservoir systems that maintain pathogens (Otranto *et al*., 2009; Woolhouse & Gowtage-Sequeria, 2005).[3]

Most research into reservoirs occurs within the disciplines of (micro)biology, ecology, epidemiology, and virology, where there is interest in understanding the intrinsic properties of reservoirs – genetic factors (Han *et al*., 2015) and immune functions (Brook *et al*., 2020) – that make species susceptible to certain pathogens. Different theories have emerged as to why some species are more likely to be reservoirs. The proximity of a species' evolutionary development to humans could matter, making primates more hazardous than other species

[3] We recognise there is debate about whether vector-borne diseases are zoonoses. For the purposes of this article and our framework, we include vector-borne zoonoses as part of zoonotic diseases. This is keeping in line with EU, CDC, and WHO, among others as well as research on emerging zoonotic diseases resulting from climate change and other processes of environmental change we discuss in the article (see for example Jánová, 2019). Pathogen refers to an organism (living or non-living), such as viruses, bacteria, fungi, protozoa and helminths, that can cause disease (Woolhouse & Gowtage-Sequeria, 2005).

for example (Olival *et al.,* 2017). A reservoir hazard could have more to do with the species richness of a particular reservoir group than evolutionary development or physiology (Mollentze & Streicker, 2020); meaning taxa or reservoir groups with a higher diversity of species, like bats and rodents, may be more likely to harbor greater numbers of pathogens with zoonotic potential.

While this knowledge can help explain how reservoirs and reservoir systems function biophysically, questions remain about why some spaces are uniquely abundant or lacking abundance in reservoir species, and therefore why certain *spaces* are more hazardous to (certain) humans than others when it comes to zoonoses. A hazard is generally understood as a "process, phenomenon or human activity that may cause loss of life, injury, or other health impacts, property damage, social and economic disruption or environmental degradation" (UNDRR, 2023, para 1). Zoonotic diseases represent biological hazards – "of organic origin or conveyed by biological vectors" (UNDRR, 2023, para 6) – determined by the "relative number of available zoonotic infectious agents at a given space and time acting as potential sources of harm (e.g. zoonotic disease outbreak) to a human population" (Gibb *et al.,* 2020, p. 1). Importantly – and qualifying this definition in line with political ecology and related understandings of hazards and risks – hazards, and reservoirs are not intrinsically harmful, but have the potential to cause harm. It is also not necessarily the sheer number of potential or existing pathogens within a given reservoir space that defines the level of hazard, potential harms in the form of illness, infection, spillover, or outbreak, or risk. Rather, it is when the environment and relations between humans, animals, and pathogens change that potential harm and risks related to zoonotic illness increase and occur. What then are the processes that make some spaces more or less abundant in reservoir species, and that alter socio-ecological relations in a way that renders such spaces more hazardous, and heighten the risk for the jump from animals to humans to occur?

Understanding the (bio-)physical properties of reservoirs as well as their behaviors, distributions, and quotidian rhythms is essential to the mitigation and prevention of pathogenicity and zoonotic disease risk. But when it comes to understanding, mitigating, and preventing zoonotic disease hazard, the level of reservoir is about as 'deep' as most scientific and policy interventions go. From a political ecology perspective there is a need to go deeper and further across time to ask how some *spaces* become more hazardous to certain humans in terms of zoonoses. Without denying that the (bio-)physical properties of reservoirs matter, responding to and understanding these questions requires further consideration for the relationship between reservoirs, space, and zoonotic disease. Political ecology provides the conceptual tools needed to critically examine the political-economic dynamics at and across multiple scales that shape both the physical and relational space of reservoirs, and thus of zoonotic hazards. Thinking on hazards can help shift much needed attention to the external socio-ecological relations and their intensification that shape reservoir abundance and their relations with people, rather than focus merely or predominantly on a specific species' or body's internal and intrinsic properties, and the internal spatialities of a specific animal-human-pathogen relation.

Political ecology would approach the amount and type of reservoirs "at a given space and time acting as a potential source of harm" (Gibb *et al*., 2020, p. 1) as emerging from more-than-human spatialities that recalibrate relations between animals, humans, and pathogens, and draw reservoirs and novel hosts into pathogenetic entanglements. For example, large-scale spatial transformations alter the demographics and distributions of notorious reservoirs, such as bats, rats, and primates (Brook *et al*., 2020; Dzingirai *et al.,* 2017a; Kaup, 2018). Deforestation, ecosystem fragmentation, habitat loss, and (peri-)urbanisation reposition reservoirs, and thus the pathogens they carry, cartographically and spatially in relation to novel hosts. This renders these species and spaces as greater biological hazards to certain humans, other novel hosts like domestic animals, and societies at large. This can be seen in how policies on housing finance and government subcontracting "propelled the growth of large-lot suburbs south of Washington D.C. and resulted in the creation of a landscape in which ticks, tick-hosts, and tick-borne disease thrive" (Kaup, 2018, p. 381; also see Connolly *et al*., 2021; Gandy, 2023; Treffers *et al*., 2021 for more on urban political ecologies and zoonoses). And while certain livelihoods in spaces where reservoirs are more abundant may intensify zoonotic risk, political ecology necessarily asks how histories of underdevelopment and related political-economic processes broadly shape resource and labor market access and local ecosystem-livelihood dynamics that push people into more or less hazardous spaces and activities (Dzingirai *et al*., 2017b; Leach *et al*., 2017).

Yet, a political ecology perspective encourages even deeper inquiry than this. One of the most significant drivers behind the spatial transformations outlined above is persistent economic expansion for industrial agricultural, energy, and mineral production mainly fuelled by demand for agricultural and natural resource commodities in Europe, North America, and increasingly Asia. Present-day capitalist systems were set in motion during the era of imperial expansion, when colonial powers spread around the world stealing land, exploiting resources, and systematically altering biodiversity, ecosystems, and the socioecological systems that previously sustained them (Grove, 1996; Moore, 2015). Human-environment, and thereby animal-human-pathogen relations were re-shaped and intensified in the process.

Thus, while focusing on the genetics, life histories (i.e. evolution), and richness of species is important, it leaves the story of why certain reservoirs, and the spaces in which they exist, become hazardous for humans as incomplete. A focus is also needed on how structural forces and related processes of socio-ecological change and spatial transformation can slowly change species and pathogen distribution and disrupt their quotidian rhythms over time. As a result, certain spaces, via changing relations between reservoir bodies and other human and nonhuman animals, are rendered increasingly hazardous and even risky for humans. As the next section discusses, socio-ecological change and spatial transformation can in turn alter and intensify how animals and humans interact in certain types of spaces.

*Interfaces as spaces of interspecies intimacy*

For zoonotic pathogens to successfully transfer from reservoirs to humans, there needs to be contact and/or exchange of bodily fluids or aerosols (Magouras *et al*., 2020). The spaces where these interactions occur are known as animal-human interfaces. Wild-domestic animal interfaces are also uniquely risky from a zoonotic perspective, as they can bridge pathogens in wild animals to humans. Zoonotic transmission can also occur through indirect contact, namely through airborne transmission or pathogens that can survive for long periods in the environment. While indirect and distended from direct animal-animal or animal-human contact, these are still interfaces that occur through intermediate and less proximate human-animal spaces. If there were no interfaces, disease pathogens would circulate in host reservoir populations, posing a hazard, but without much risk of spillover.

Natural science disciplines are increasingly interested in understanding where interfaces are changing and new interfaces are emerging in ways that heighten the pathogenic risks associated with animal-human, and animal-animal contact (Neff, 2021). This work tends to focus on changing interface dynamics resulting from climate change, deforestation, human population growth, the rise of disposable incomes and middle classes, and (peri)urbanisation, including land use change and landscape fragmentation (Di Marco *et al*., 2020; Gibb *et al*., 2020; Hassel *et al.*, 2017; McMahon *et al*., 2018; Keesing & Ostfield, 2021; Morand & Lajaunie, 2021; Naguib *et al*., 2021; Plowright *et al.*, 2021; Rulli *et al*., 2021; White & Razgour, 2020). These processes are said to increase the proximity and frequency of contact between animals – including between wild and domestic animals – and humans, and thereby animal-human-pathogen relations. Due to the origins of COVID-19, there is also renewed interest in wild meat interfaces, such as markets where wild animals and products are sold, and areas of high biodiversity where wild meat hunting is more common and less regulated (Peros *et al*., 2021). This work feeds into efforts to monitor, manage, and regulate interfaces deemed especially risky.

Most current research into interfaces is focused on the frontlines of zoonotic disease and feeds data into public health policies and programming, prioritizing descriptive and quantitative data for high-level analysis of zoonotic disease hotspots. As a result, we have an increasingly better sense of where and how interfaces are changing in line with the processes stated in the previous paragraph. However, contextualised analysis of the underlying drivers behind these same processes, and what shapes the needed body-to-body, fluid-to-body, or indirect contact remains limited. Our understanding of changing interface dynamics is also overly anthropocentric, placing humans and human activities at the centre of analysis. Questions remain about the political-economic ideologies, systems, and structures that shape interfaces and the power relations that influence bodily animal-human and pathogen-human interactions.

From a political ecology perspective, interfaces are far more than just containers or moments where animals and humans (or wild and domestic animals) interact with the potential for spillover. Recent work in the

field demonstrates how political-economic histories and developments create and reproduce landscape-level interfaces (Dzingirai *et al*., 2017a; Leach *et al*., 2017), for example, by "intensifying and altering patterns of settlement, human movement and land use" (Dzingirai *et al*., 2017b, p. 4). Focusing on three different zoonotic diseases in three different sub-Saharan African countries, Dzingirai *et al*. (2017b) offer insights into how broader forms of social differentiation shape "who gets sick, and why?" within zoonotic disease landscapes. This work serves as an excellent foundation for further inquiry into the political ecology of zoonotic disease landscapes and spatiality.

Leaving analyses of interfaces at the level of landscape change does, however, risk missing out on important understandings of how one body or its fluids encounters another within the context of broader socio-ecological change (or no change at all). There is thus a need for research into the intimate spaces and scales of animal-human interaction where different bodies, fluids, and aerosols come into contact in unequal ways. Feminist and multi-species approaches in political ecology and geography can further help address this gap and understand the "tactile topologies" (see Dixon & Jones, 2015) and intimate and/or intermediate spatialities of zoonotic interfaces.

Feminist political ecology is well-regarded for accounting for material and embodied effects of gendered divisions of labor, resource use and access, discourses, and norms as a variable in understanding changing socio-ecological and political-ecological relations (Elmhirst, 2011; Ndi, 2019). Feminist approaches can also become particularly important for understanding zoonotic interfaces by re-scaling the lens of analysis to the intimate spaces and realities of the household, the individual, and the body to understand how effects of broader political-ecological dynamics are embodied, experienced, and how this varies across individuals and groups (Elmhirst, 2011; Massé *et al*., 2021; Sultana, 2021a). Intersectional feminist approaches focus on how dynamics of class, race, ethnicity and other markers of identity intersect with gendered and other discursive and material power structures (Mollett & Faria, 2013; Sultana, 2021a). In bringing these feminist geographical approaches on intersectionality together with multi-species approaches, Hovorka (2012) demonstrates how local and household social, economic and political dynamics shape different and unequal spatialities of gender-species relations. In her case, given structures of patriarchy and broader political-economic histories in Botswana, "women's lives and circumstances are necessarily intertwined with chickens, and likewise men with cattle" (p. 875). While Hovorka does not look at concerns of disease or zoonosis, her gender-species intersectional analysis provides a powerful framework for examining and understanding how different groups of people come into different, intimate, and proximate relationships with different animal species. We also see this in the wild meat trade and value chain where men and women occupy different roles, resulting in different interactions with wildlife and their bodily fluids, and thus differential exposure to zoonotic diseases (van Vliet *et al*., 2022). There is no one interface along the wild meat value chain, but many interfaces affecting different people as brought about by the (gendered) divisions of labor that create specific interspecies spaces of intimacy.

The dynamics in industrialised meat and fur supply chains during the COVID-19 pandemic further underscore these intersectional-interspecies relations. Slaughterhouses were spaces of intertwined animal and racialised violence (Struthers Montford & Wotherspoon, 2021). Employing some of the most disadvantaged and marginalised workers, slaughterhouses were the locations of the largest individual COVID-19 outbreaks globally. Interspecies dynamics in the pandemic echo Blanchette's (2020) conclusion that industrial meat production is a gendered affair relying on a low-paid workforce from low-income geographies. Meatpacking facilities in the US implemented a punitive attendance system and workers were required to work even if they showed COVID-19 symptoms or were waiting for test results (Schlitz, 2020). It was reported that 87% of the confirmed cases were among economically insecure Hispanic, Black, and Asian workers (Waltenburg, Gabel, Honein, *et al*., 2020). The global agribusiness creates what Segata *et al*. (2021) refer to as unhealthy ecologies. These ecologies are predicated on intimate interrelations between precarious humans, animals, toxic chemicals, and waste, and are underpinned by infection, risk, and death (Segata *et al*., 2021). A recent body of work similarly examines and calls for further research on how dynamics of social difference across space shape livelihoods, interactions with one's environment, and the resultant interfaces of and exposure to zoonoses (Dzingirai *et al*., 2017a, 2017b; Leach *et al*., 2017). Industrial mink production is another example of an unhealthy ecology. In April 2020, a COVID-19 spillover from humans to minks and back from minks to humans was detected in the Netherlands and later in Italy, Spain, Sweden, Greece, Denmark and the US (Voelkner,

2021). More than 450 industrial mink farms in Europe and North America were affected by COVID-19, leading to the culling of over 20 million animals. This happened because high numbers of live minks, exposed to humans with the virus, were stored in crowded conditions and treated like commodities. This is an example of a well-known reservoir species being subjected to commodification, exploitation, and violence in ways that allowed COVID-19 to spread rapidly and mutate among this reservoir population.

What is key in these examples is that spaces such as meat packing facilities, fur farms, and the wild meat trade embody how humans understand and relate to animals in wider society – where the hazards and violence they are subjected to get 'fetishized' (concealed) by the final commodity form of their rendered bodies. Researching these intimate spaces of interspecies relations and how they come about is necessary for understanding how specific zoonotic interfaces materialize, and the differing vulnerabilities to zoonoses across space, species, and gendered, classed, and racialized lines that result. Drawing on feminist political ecology to critically examine who is exposed to interspecies spaces of intimacy and related zoonotic outcomes thus builds on and complements recent work advancing feminist political ecologies of health by considering how social and ecological differences matter for health (Senanayake & King, 2019; Senanayake, 2023). More-than-human/posthuman political ecology literature also becomes useful for analysing and reconceptualizing zoonotic disease interfaces as power-laden spaces of more-than-human entanglements (Ejsing, 2023). That is, political ecology can offer critical insights into how societal inequalities intersect to reproduce zoonotic disease interfaces at different spatial scales. These critical insights are necessary for understanding why certain types of animals and humans find themselves entangled within the intimate spatialities needed for zoonotic disease spread. Understanding such local, intimate relations and spatialities does, however, require the use of local, situated knowledge, especially of ecosystem and resource users (see for example Leach *et al*., 2017) and those who are otherwise in contact with spaces of zoonotic hazard. It is in this way that grounded, contextualized, and targeted interventions based on an understanding of how and why people interact with reservoirs or zoonotic hosts can be crafted.

## 4. Spillover: A structure, not an event

Spillover is commonly used to describe the moment a pathogen overcomes naturally occurring barriers to spill over from one species to another (Kenney *et al*., 2021). While emphasis is often placed on the physical event or moment of transmission, there is growing interdisciplinary recognition that spillover is far more complex. Spillover has been described as an "infect-shed-spill-spread cascade" (Plowright *et al*., 2021, e237) that plays out through a series of events: "pathogen infection in wildlife, shedding of the pathogen from wildlife, transmission of the pathogen to people (sometimes through other animals that act as intermediate pathogen hosts), and further spread of the pathogen by person-to-person transmission" (Plowright *et al*., 2021, e238). Before a zoonotic disease hazard and risk to humans and public health materializes as spillover, pathogens need to succeed in each of these steps which are often protracted across space and time.

Greater awareness of how many actions, interactions, conditions, and variables are at play in spillover makes the task of preventing it appear increasingly daunting. However, this has not stopped scientists from trying. As we have discussed, concerted efforts are underway to map specific geographical hot spots where the risk of a zoonotic disease outbreak with epidemic and pandemic potential is perceived to be highest. Since the COVID-19 pandemic, an open access online platform, SpillOver, has been developed to help scientists quantitatively rank zoonotic diseases according to their spillover risk. Using information uploaded by researchers, SpillOver "calculates a comparative 'risk score' for each virus, much like a credit report" to create a global watch list accessible to policymakers and public health officials (Grange *et al.*, 2021, p. 3). SpillOver is designed to complement spatial data on zoonotic disease hotspots, providing further insight into where disease monitoring and pandemic risk-reduction interventions should be targeted and investment in vaccines directed (Grange *et al*., 2021). This type of data and knowledge is rapidly emerging and evolving, providing policymakers and public health officials with real-time data on how to mobilize and utilize resources to prevent outbreaks (Galaz *et al*., 2015).

Such data and knowledge have an integral role to play in pandemic prediction and prevention. However, the contributions it can make to dislodging zoonotic disease risk and vulnerability from the very fabric of society

– particularly with a concern for equity and justice – are far more limited (see Brierley *et al*., 2016). This is partly because problematic assumptions are often built into the models, risk maps, and scoring systems used to generate and operationalise knowledge for pandemic prevention, including the tendency to treat animal-human interactions as homogeneous and predictable. There is also the risk that assumptions about which zoonotic diseases are highest priority for dominant political and economic global actors will be privileged over those of high priority among other actors and localized populations. Thus, alongside initiatives like SpillOver, there is a need for more normative, justice-oriented discussions about which diseases should be prioritized, where and among what populations, and which intervention styles may be available and most appropriate.

Recent empirical insights underscore the importance of further contextualized, nuanced, and justice-orientated inquiry into spillover risk and vulnerability. One study from the Democratic Republic of Congo demonstrates that, within wild meat trade networks, risk of pathogen transmission is highest at the level of hunters and porters, who tend to be men, compared to others in the wildmeat trade chain, such as vendors and consumers, because contact with live animals happens in hunting camps where hunters butcher and smoke wild animals (van Vliet *et al*., 2022). Comparatively, in Guyana exposure to transmission risk is higher for women who are responsible for butchering wild meat once it is brought back to the village than it is for hunters or consumers (Milstein *et al*., 2020). Great differentiation can also exist within the same geographical context. For example, in Sierra Leone, housing styles – which overlap with socioeconomic status – make households more or less vulnerable to Lassa Fever (Dzingirai *et al*., 2017a).

These examples illustrate the structured nature of spillover. On the one hand, spillover is structured in the sense that structural forces in society act on reservoirs, interfaces, and other variables within the infect-shed-spill-spread cascade to alter the spatialities of animal-human-pathogen relations and make spillover a possibility, and reality. This is seen in the examples of industrial meat processing, wild meat trade, and patterns of resource use and housing mentioned above. On the other hand, patterns of risk and vulnerability to spillover among human populations also map onto much broader – and at times global-level – patterns of inequality, injustice, and power. This is evident in how demand for resources in the Global North often produces landscape change and re-shapes animal-human-pathogen spatialities and intensities in already vulnerable areas elsewhere, and how the global hyper mobility of goods and bodies among certain classes and for the purposes of capital accumulation circulates zoonotic pathogens, thereby extending animal-human-pathogen spatialities in an interconnected global web (see for example Braun, 2007). As Dzingirai *et al*. explain, spillover is "as much a social, institutional and political phenomenon, as it is a biological one" (2017a, p. 10).

Building on this, we argue that spillover is shaped by structural forces and processes that unfold spatially over time and across scale, creating the conditions – spaces of hazard and intimacy – for pathogens to transfer from certain animals to certain humans, and potentially to circulate among novel host populations. It is important to recognize that structural forces and processes are not strictly anthropocentric, but are shaped by and in turn shape ecological systems and processes of environmental change (Figure 1). The effects of these forces and processes – which intersect and interact across spaces, time, and scale – risk being amplified as the world enters deeper into a state of biodiversity, climate, and ecological crisis. Until spillover is recognized and approached structurally rather than as an isolated or singular event, efforts to mitigate and prevent zoonotic disease outbreaks will remain extrinsic, superficial, uneven, and unjust.

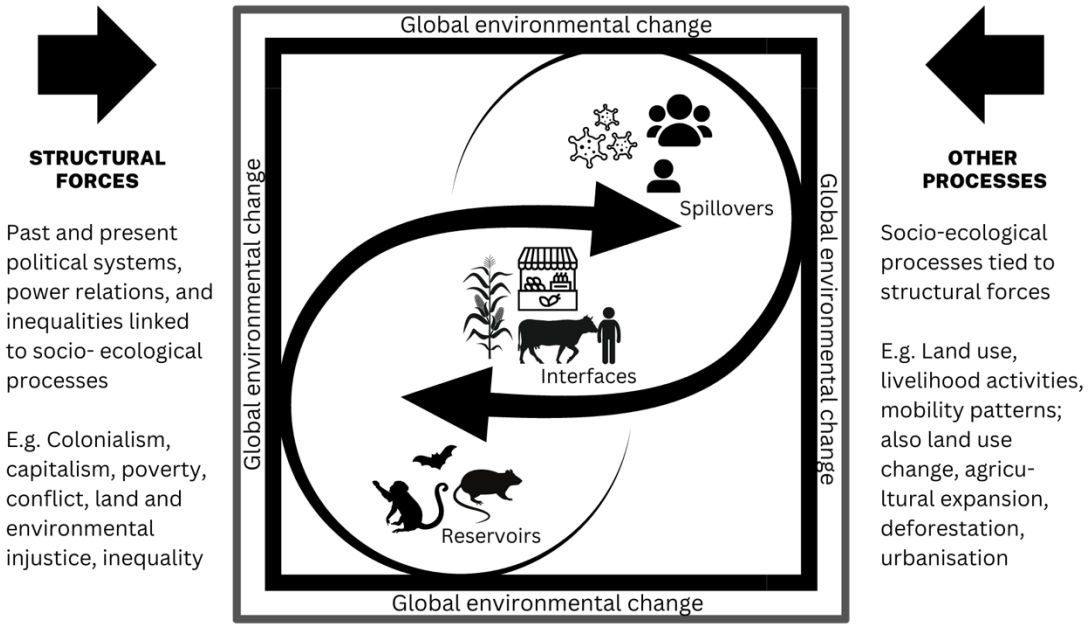


Figure 1: The spatialities of zoonotic disease outbreaks from a political ecology perspective. Source: Authors. This figure illustrates the dynamic relationship between structural forces linked to socio-ecological processes – past and present political-economic systems, political relations, and inequalities, e.g. colonialism, conflict, poverty, land and environmental injustice – and socio-ecological processes tied to structural forces – e.g. land-use, livelihood activities, and mobility patterns, among others – that produce environmental change and shape the spatialities of reservoirs, interfaces, and spillovers.

Before concluding, we wish to clarify that understanding how spillovers work, structurally, does not require a lack of focus on the agency of people within these structures. For centuries, all around the world people have developed creative solutions for coexisting with animals in ways that minimize zoonotic disease risks. While animals and humans have always shared pathogens and been bound together by processes that play out from the microbial to global scale, humans have developed defences and immunities (as have many animals), as well as practices and treatments, norms, and rules that support coexistence.

Tragically, much of this customary and tacit or traditional knowledge has been lost with the expansion of modernized, western conceptions of health and disease. Nevertheless, it would be used to fill gaps in and supplement mainstream knowledge and high-level or quantitative data on zoonotic disease risk (Barnett *et al*., 2020; Fairhead *et al*., 2021; Paige *et al*., 2015). These other knowledge systems could also be supported and strengthened to serve as first prevention strategies and responses at the frontlines of zoonotic disease, with the potential to support struggles for justice, rights, and tenure among many Indigenous Peoples and Local Communities (WHO, 2021). For example, we know that giving Indigenous Peoples control over their territories can help reduce the risk of zoonotic disease epidemics and pandemics (Vittor *et al*., 2021). It is here where structures of epistemic violence that are tangled up with colonial and capitalist expansion (Gandy 2023; O'Lear *et al*., 2022; Sultana, 2021b) also shape zoonotic disease risk and vulnerability globally, and risk erasing and replacing knowledge that could be vital to predicting, mitigating, and preventing future outbreaks and pandemics.

## 5. Conclusion

In mainstream scientific discourse, zoonotic disease outbreaks have long been understood primarily as moments of spillover, with much of the increased risk of spillover attributed to environmental and landscape change like agricultural expansion and intensification, deforestation, industrialisation and infrastructure development, and urbanisation. While rightly pointing to zoonoses and related risks as a human-environment challenge, and not merely an issue of medical or public health, common understandings and approaches to zoonoses are limited in their understanding of political-economic and socio-cultural factors that drive such environmental change, and ultimately shape zoonotic disease hazards, risks, vulnerability, and related dynamics in different contexts and among different people. Political ecology thus has an important role to play in furthering critical understandings and examinations of zoonotic dynamics and how to reduce risks and prevent future outbreaks.

In this article, we argue for a political ecology approach to zoonoses to address this gap. We develop this approach to a political ecology of zoonoses by drawing on existing work in political ecology of health and disease, and work that draws on broader political ecology and critical geographical approaches, to examine zoonoses. We argue that the strength of a political ecology approach lies not only in its attention to how structural power dynamics across space, time, and scale shape human-environment relations that underpin zoonotic dynamics; the strength is in understanding how these structural processes – from the global to the body – re-configure the spatialities and intensities of animal-human-pathogen relations that amplify zoonotic risk and vulnerability in unequal ways. We demonstrate this by using political ecology to reconceptualize taken-for-granted and key components of zoonotic disease outbreaks, namely reservoir, interface, and spillover.

In unpacking the spatial and political-ecological dynamics of animal-human-pathogen relations that constitute each of these components, we come to understand zoonotic reservoirs as spaces of zoonotic hazard, with interfaces being understood as spaces of interspecies intimacy. By giving critical attention to the processes that reconfigure spaces of zoonotic hazard and interspecies intimacy, and related animal-human-pathogen relations, a broader, more complex conceptualisation of spillover emerges. Far from an event or moment in time preceding an outbreak, zoonotic spillover is a structured process unfolding across space, time, and scale, with said processes rendering certain animals, people, and spaces more vulnerable to zoonotic risks than others. Understanding zoonotic spillover as structure enables a deeper, nuanced, and more holistic understanding of the broader processes, including those related to inequalities, injustices, and power relations, shaping the spatialities of animal-human-pathogen relations, and thereby zoonotic drivers, risks, and vulnerabilities, across time and scale. The implications of this are multiple and significant. We can understand broader processes that lead to spillover, how broader inequalities, injustices, and power relations play out in the context of spillover, and where to target interventions.

Importantly, a turn to focus on zoonoses as one of the most pressing human-environment challenges also challenges political ecology and what can sometimes be seen as an over-reliance on capital and political economy as an explanatory variable, including with regards to the re-calibrating of animal-human-pathogen relations and their spatialities. What is needed is more contextual, nuanced, and justice-oriented research into the structures of spillover and the spatialities of zoonotic hazard, risk, and interspecies intimacy that make spillover possible, but with a view to how these structures transcend capital. For this reason, in addition to political ecological work on health and disease, we provided examples of existing literature and frameworks in political ecology, such as feminist and intersectional political ecologies, more-than-human approaches, and the political ecologies of hazards, that underpin our own analyses and can help guide and inspire further research. These, however, are just a starting point as other approaches within political ecology are sure to be productive in developing emancipatory agendas and methods, such as those that focus on gendered aspects of zoonosis or link zoonotic prevention to poverty transformation, account for existing local knowledge about zoonotic disease management (Milstein *et al*., 2020), and supporting Indigenous Peoples and Local Communities in obtaining sovereignty over their territories and food systems. In proposing and developing the foundations for this political ecology of zoonosis framework, our hope is that others will enrich it analytically and theoretically, while advancing it empirically through application in different geographical and socioecological contexts to critically examine how spaces of hazard, intimacy, and spillover of different zoonotic disease realities are shaped, and what this means for risk, vulnerabilities, and interventions.

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