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Moving Target(s):
One Health at changing human-livestock-wildlife interfaces in tropical ecosystems

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Abstract

One Health approaches currently conceptualized for Western landscapes require fundamental rethinking for tropics, where human-livestock-wildlife interfaces exist as variegated mosaics rather than discrete zones. This overview examines why tropical ecosystems involve (i) Human mobility patterns shifting continuously through rural-urban migration and globalization (ii) Livestock health infrastructure concerns, creating dependencies on informal practitioners and perpetuating practices like diclofenac use cascading into public health disasters; and (iii) Environmental conditions that transform rapidly through agricultural intensification, habitat fragmentation, and climate change, while wildlife populations adapt to anthropogenic subsidies that fundamentally alter behavior and disease dynamics. Each component—human, livestock, environmental—changes independently while influencing the others, creating dynamic complexity amplified by economic inequities that shape health-seeking behaviors and risk perceptions. I argue that tropical One Health must embrace co-cultural frameworks recognizing interspecies cultural transmission, acknowledge how political-ecological forces structure disease interfaces, and develop context-appropriate interventions grounded in local social-ecological realities rather than imposing incompatible models.

Keywords: tropical ecosystems, zoonotic spillover, human-wildlife interfaces, co-cultures, migration ecology, veterinary infrastructure, Global South, health equity, disease emergence

Movement is fundamental to survival and fitness across the animal kingdom, including humans (Goossens et al. 2020). Organisms move to secure resources, find mates, escape predators, and respond to environmental changes (Sergio et al. 2014). Yet anthropogenic pressures are transforming movement paradigms for all life forms in ecosystems across the globe at unprecedented rates (Gaynor et al. 2018, Doherty et al. 2021). Over the past century, technological advances have enabled humans to traverse vast distances rapidly and to homogenize landscapes across multiple continents (Anonymous 2016). Modern transportation networks now connect the most remote corners of the globe within hours, facilitating not only human movement but also the inadvertent dispersal of pathogens, invasive species, and novel ecological interactions (Bhagwat et al. 2012, Robertson et al. 2013, Theodosopoulos et al. 2021). Despite this expansion, ~65% of the human population occupies <4% of terrestrial space, primarily concentrated in urban and peri-urban areas (UNO 2018). But paradoxically, human activities now impact roughly >70% of Earth's land surface that extends into marine ecosystems through resource extraction, agriculture, infrastructure development, and pollution (Lim and Sodhi 2004, Cox et al. 2018, Bobiec et al. 2021, Myers 2021). Collectively, these create facilitative impacts on a select set of species by providing new resources or habitats, e.g., (Galushin 1971, Angel et al. 2011, Kumar et al. 2018a, Beatley 2020), and reductive impacts for the majority of biodiversity by removing or degrading natural systems (e.g., Dunne et al. 2002, Angel et al. 2011, McCallum 2015, Anonymous 2016). The resulting spatial disconnect in ecosystem processes generates novel challenges for nonhuman species, whose movements increasingly encounter anthropogenic barriers, altered resource distributions, and modified environmental cues (Rutz et al. 2020). When movement patterns evolved over millennia collide with rapidly changing landscapes, ecological mismatches emerge between organismal fitness needs and environmental realities. These lead to nonhuman settlements in apparently suitable but suboptimal habitats, called ecological traps (Schlaepfer et al. 2002, Robertson et al. 2013), a topic I explore subsequently. These environmental challenges and associated struggles are central to conflicts and poor health, which facilitate cross-vector transmission, spreading diseases that compromise health and creating a vicious cycle (Jones et al. 2008, Oro et al. 2013, Becker and Hall 2014, Allen et al. 2017, Cunningham et al. 2017).

Dynamics of environmental alterations are not unique to tropical regions. Agricultural intensification, urbanization, and infrastructure development affect ecosystems globally (Grimm et al. 2008, Angel et al. 2011, Abu Hatab et al. 2019, Boonman et al. 2024). However, tropical regions present a particularly complex confluence of factors that warrant distinct and focused attention within the One Health framework. Recent pandemic and epidemic events, including COVID-19, Ebola, Nipah virus, and highly pathogenic avian influenza, have highlighted the urgent need to understand the dynamic interplay between humans and nonhuman animals in disease emergence (Plowright et al. 2017, Altizer et al. 2018, Becker et al. 2018, Glidden et al. 2021a). Increasing scrutiny is directed toward anthropogenic impacts that facilitate novel host-pathogen interactions, which are pivotal in driving zoonotic spillover (Krystosik et al. 2020). These impacts are shaped by, and, in turn, further shape our interactions with nature through infrastructure development, resource manipulation, and human activities, practices, and beliefs

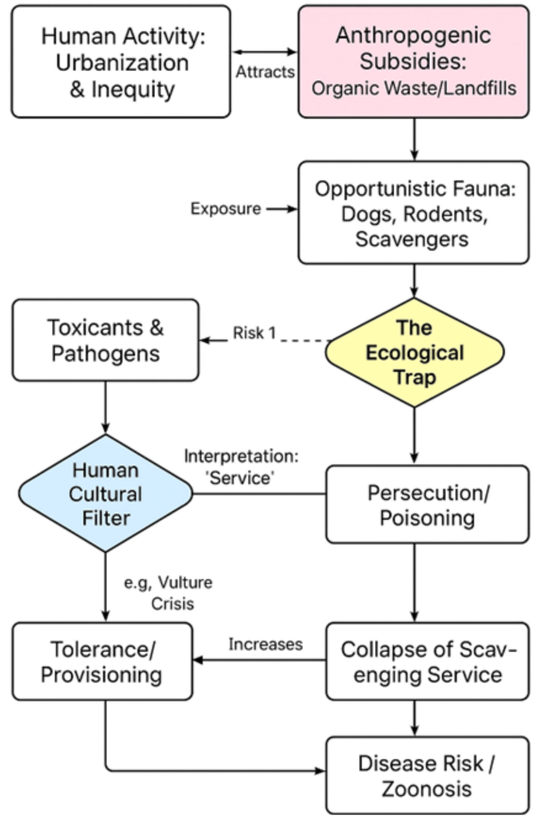
(Kumar et al. 2018a, 2019c, Rutz et al. 2020, Rutz 2022). Tropical regions harbor several characteristics that intensify disease emergence risks. ***First***, they support relatively higher biodiversity than temperate biomes, including diverse assemblages of potential reservoir hosts and vectors (McCallum 2015, Nyhus 2016, Torres et al. 2018). The relatively protracted productive months, which enhance resource availability due to increased net primary productivity in tropical regions, have both direct and indirect implications for the biota (Kumar et al. 2014). This includes the massive quantities of organic waste generated by urban areas with high consumption rates (Kumar et al. 2017, 2019c). ***Second***, rapid yet uneven economic development is transforming land use patterns at unprecedented rates, creating a mosaic of variably developed habitat fragments (Donovan and Thompson 2001, Fahrig 2003). This spatial heterogeneity generates novel ecotones where human, domestic animal, and wildlife populations intersect (Hassell et al. 2017a). ***Third***, these regions host dense human populations, many of whom remain dependent on backyard livestock and poultry rearing due to ongoing developmental transitions (Gerber et al. 2008, Chatterjee and Rajkumar 2015). This proximity between humans, domestic animals, and wildlife is further intensified by cultural agglomerations typical of the Global South (Gupta and Kumar 2024). ***Fourth***, socioeconomic inequities in these regions limit access to healthcare, veterinary services, and biosecurity measures, creating differential vulnerabilities to disease emergence (Steinfeld 2004, Cunningham et al. 2017, Cox et al. 2018, Hassell et al. 2019). ***Finally***, integrating these characteristics, rapidly urbanizing regions in tropical latitudes serve as critical convergence zones for both migratory fauna and human populations (Bhagat and Mohanty 2009, Newton 2010, Bauer and Hoye 2014, Xu et al. 2016, Mesoudi 2018, Kumar et al. 2020). Billions of migratory birds from the Global North winter in southern latitudes closer to the equator, creating seasonal pulses of cross-continental connectivity (Newton 1979, 2010). Simultaneously, variable regional development forces large-scale seasonal human migration, as rural populations move to metropolitan centers seeking casual labor opportunities. These urban immigrant settlements are typically informal, with inadequate housing infrastructure access to sanitation facilities (Gupta and Gupta 2017, Hassell et al. 2017b, Dupont and Gowda 2020, Myers 2021). Such settlements are frequently juxtaposed with affluent areas, and the urban poor are involved as laborers processing poorly disposed solid waste (Kumar et al. 2019c). The accumulation of organic waste on roads and other public spaces attracts diverse assemblages of opportunistic commensal species, including rodents, free-ranging dogs, corvids, and other urban-adapted fauna (Kumar et al. 2019c, Kumar and Sharma 2025). These novel ecosystems can potentially facilitate pathogen dispersal by exposing host vectors to environmental toxicants such as heavy metals and industrial chemicals, which may alter immune function and disease susceptibility (Council 2001, Robertson et al. 2013, Collier 2015). Cultural agglomerations in tropical urban settlements often bring distinct practices of interacting with urban wildlife and maintaining traditional livelihoods (Kumar et al. 2019c, Gupta and Kumar 2024). This creates a predictable confluence where both human and nonhuman migrants pursue resources that are usually associated: low-quality but highly predictable waste with recyclables and anthropogenic subsidies (Kumar et al. 2017). In cities like Delhi, Mumbai, Laos, Kenya and Dhaka, the spatial predictability of settlement patterns, combined with the temporal dynamics of both human and avian migration cycles, creates recurring high-risk interfaces (Newton 2010, Xu et al. 2016, Kumar et al. 2020). The convergence of (poorly documented) shifts in commerce and culture in these dynamic urban landscapes inadvertently generates novel selection pressures at human-livestock-wildlife interfaces, collectively increasing the potential for zoonotic spillover events (Lloyd-Smith et al. 2009, Karesh et al. 2012). This convergence represents a critical yet understudied dimension of One Health in tropical urban systems, where economic inequity, ecological opportunity, and cultural practices intersect to shape disease emergence risks (Kumar et al. 2019c).

Unlike research predominantly reflecting Western perspectives, often rooted in meticulously planned urban environments with distinctively designated living spaces allocated for humans, domesticated animals, and wildlife, tropical systems undergoing development present a highly variegated coexistence (Grace et al. 2012, Jones et al. 2013) (Fig. 1 & 2; Box 1). Out there, traditional human-animal relationships predate modern lifestyle, and anthropocentric priorities evolved over centuries (Gupta and Kumar 2024). Anthropocentrism fosters ecological interactions now increasingly disrupted by the homogenization of biota and cultures that are, in part, driven by globalization (Gibb et al. 2024). The rapid reconfiguration of centuries-old patterns of human-wildlife coexistence in regions such as Latin America, Africa, South Asia, and Southeast Asia is depleting traditional ecological knowledge (TEK) and reshaping folk biological practices (Schiere et al. 2001, Houde 2007), which are increasingly misinformed (Gupta and Kumar 2024). While TEK and values are deeply ingrained in cultural identities, reflecting protracted, dynamic histories of coexistence and mutual tolerance, we have a poor comprehension of the modified rates and quality of nonhuman encounters (Miller 2005, Jarić et al. 2022, Gaston et al. 2023). These altered encounter rates have subsequently transformed relationships and perceptions (Gupta and Kumar 2024), as exemplified by the swift disappearance of vultures across the Indian Subcontinent (Frank and Sudarshan 2024) (Fig. 3 & 4). Significant modifications to biological communities, arising from both intentional actions such as habitat fragmentation and poaching (Fahrig 2003, Ogada et al. 2016), as well as unintended consequences like biological invasions (Bhagwat et al. 2012, Mohanty et al. 2016), organic waste allocation (Kumar et al. 2019c), and competitive release among facultative scavengers, have been consistently identified as potential focal points for emerging infectious diseases, directly impacting humans (Frank and Sudarshan 2024, 2024).

Furthermore, agricultural intensification in developing regions poses particular challenges (Schiere et al. 2001, Ritchie and Roser 2019). The livestock and poultry sectors, along with their associated consumption chains, present significant risks of disease emergence and amplification (Gray et al. 2007, Samanta et al. 2018, Kumar 2023). However, this creates a troubling paradox within the One Health framework. As Grace et al. (2012) highlight, urban poor/rural communities integral to producing essential animal protein for wealthier populations often find themselves marginalized, with limited access to healthcare services and resources (Fig. 2). These communities face heightened risk for both infectious disease threats, nutritional deficiencies and human-wildlife conflicts (Scott et al. 2016, Wong et al. 2017). This inequity underscores the necessity for a more inclusive One Health approach that addresses not only the health of animals and ecosystems but also remains sensitive to varying needs associated with the well-being of multiple human stakeholders/populations (Tarazona et al. 2019).

Primarily, this heterogeneity results in the formation of a habitat mosaic exhibiting varied quality (Zhu et al. 2021). Habitat selection occurs at multiple scales (Kumar et al. 2018a), specific for each taxon, encompassing elements from microhabitat characteristics to broad landscape configurations, involving cross-scalar movement decisions to access resources (Guo et al. 2023). But researchers have insufficiently conceptualized the mechanisms through which anthropogenic impacts modify the information relay systems—specifically, environmental cues and signals—utilized by animal populations and communities for navigating novel environments (Robertson et al. 2013, Collier 2015). Within rapidly evolving human-animal interfaces, animals encounter novel information within environments suited for human use. These altered ecosystems subject animals to novel cues and signals, whose maladaptive processing can lead to poor habitat choices called ecological traps or evolutionary traps (where traditional preferences affect survival/reproduction in altered environments), compelling organisms to establish new survival benchmarks (Schlaepfer et al. 2002, Battin 2004, Gilroy and Sutherland 2007). ***Concurrently***, novel interfaces between human and nonhuman hosts create unique selection pressures on microbiota and pathogens. Globalization disrupts traditional equilibria within ecosystems, facilitating pathogen transmission across human-animal barriers involving multiple host vectors, consequently enhancing the risk of zoonotic diseases (Plowright et al. 2017, Karakus et al. 2024, Poulin et al. 2023). Furthermore, humans possess a unique capacity to culturally interpret animal behaviors through non-biological value chains. Such narratives are part of folk biology (Folke et al. 2016). Recent studies have explored how humans and select nonhuman species collaboratively shape urban ecosystems through such interpretations (Gupta and Kumar 2024).

Box 1. Ecological Traps and Cultural Filters:
Rapid urbanization in South Asian cities creates predictable anthropogenic subsidies through ritual offerings, household waste, and deliberate feeding by devotees. These resources attract urban commensals into built environments. The subsidies appear as reliable food sources, triggering ecological trap dynamics where commensals make foraging choices that may prove maladaptive. Urban environments expose such commensals to threats like vehicular traffic, electrocution from power lines, and zoonotic pathogen exchange at high-density aggregations. Risk manifests where ecological opportunity meets urban hazards. At such interfaces, cultural interpretation bifurcates management responses for animals like free-ranging dogs and macaques. Dogs/Temple-associated macaques receive interpretation as sacred animals deserving provisioning and protection. This "service" framing motivates continued feeding despite escalating human-animal conflicts. Simultaneously, macaques raiding homes or dogs attacking residents undergo reinterpretation as pests requiring removal. Municipal authorities respond with capture-and-translocation programs that prove lethal for most relocated animals. The cascade demonstrates how cultural filters generate contradictory policies. Religious devotion drives feeding that maintains artificially elevated populations. Property damage and bites trigger persecution demands. Translocation satisfies public pressure while failing ecologically, as relocated animals suffer/die from territorial aggression, starvation, or stress. Neither feeding nor removal addresses the fundamental driver: urban design that creates attractants without managing consequences. Until cities implement systematic waste management and regulate feeding practices, such conflicts will intensify, illustrating how cultural interpretations divorced from ecological reality perpetuate rather than resolve human-wildlife tensions with mounting public health implications including increased rabies exposure and herpes B transmission risks.



The One Health framework recognizes the interconnectedness of human, animal, and environmental health (Cunningham et al. 2017, Tarazona et al. 2019). However, its implementation in tropical regions requires careful consideration of local contexts that differ fundamentally from relatively better-studied Western systems (Grace et al. 2012, Marzluff 2017). In this overview, I examine four critical themes that intersect to shape zoonotic disease risks and health outcomes: ***(1)*** animal movement: cross-scale interactions in resident and migratory fauna; ***(2)*** human mobility in a globalized world and its role in pathogen dispersal; ***(3)*** human well-being and resource access between global and local standards; and ***(4)*** nonhuman well-being against changing resource dispersion in the *Anthropocene*. I argue that these themes cannot be understood in isolation. Rather, they interact through what recent scholarship terms "co-cultures," referring to interspecies cultural transmission where horizontal trait transmission between species becomes as significant as vertical transmission within species (Sueur and Huffman 2024). By integrating these themes and examining their intersections, I aim to provide insights for actionable frameworks tailored for developing One Health strategies in tropical contexts while acknowledging their global relevance.

I. Animal movement: cross-scale interactions in resident and migratory fauna

Migration is a pervasive phenomenon that transcends species and ecosystems, associated with a wide array of life forms, including not just birds (Sergio et al. 2014, Abrahms et al. 2019, Fagan 2019, Kauffman et al. 2021). The ecology of migration establishes important links across trophic levels, illustrating how producers, primary consumers such as insects and herbivores, and secondary consumers like predators are interconnected within food webs that extend across continental scales (Bauer and Hoye 2014) (Fig. 1 & 2). Tropical latitudes closer to the equator host billions of migratory birds during the winter months. However, agricultural practices and infrastructure development pose significant challenges to these ecological systems, leading to unmonitored declines in populations and species diversity. This concern is particularly acute in the Afro-Asian regions, which serve as critical wintering habitats for migratory species yet remain understudied (Newton 2010) (Fig. 1).

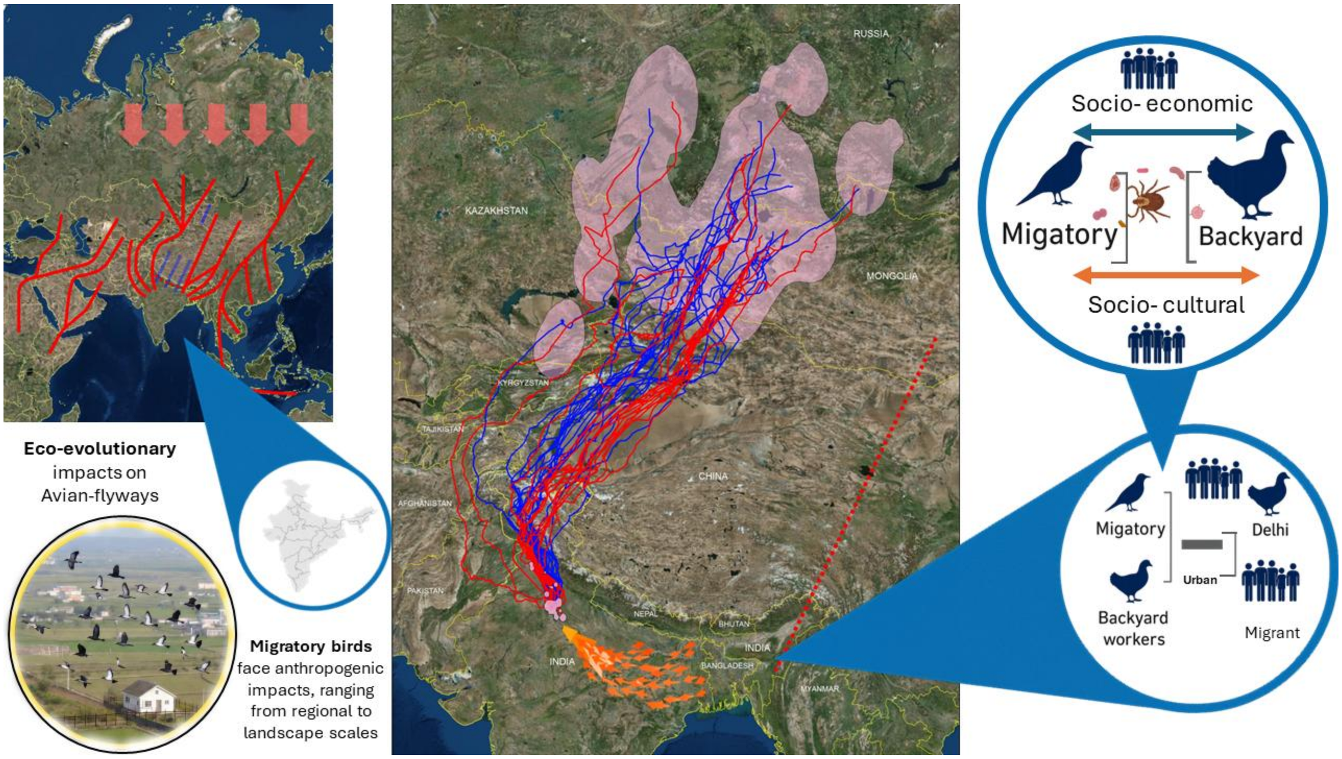


Fig. 1. Cross-scale interactions at the human-wildlife interface: migratory connectivity and disease risk in the Global South: Left panel shows eco-evolutionary impacts on avian flyways, illustrating how migratory birds (red trajectories) from Eurasia converge on the Indian subcontinent during winter months, facing anthropogenic pressures from regional to landscape scales. The inset photograph depicts birds congregating in agricultural landscapes near human settlements, exemplifying direct human-wildlife contact at local scales. Center panel displays GPS-telemetry tracks of migratory black-eared kites *Milvus migrans lineatus* (blue and red lines) crossing Central Asia (Kumar et al. 2020), with orange tracks highlighting urban human migration in the Indian subcontinent. The purple shaded areas represent breeding (larger) and wintering regions (smaller) where billions of migratory birds concentrate seasonally. Right panels illustrate the social-ecological and socio-cultural interfaces connecting migratory and resident avifauna with backyard poultry systems in rural and urban contexts. The upper diagram shows pathogen exchange pathways (indicated by tick symbol) between migratory birds and backyard poultry mediated by socio-economic practices and cultural traditions. The lower diagram focuses on urban contexts like Delhi, where migratory birds, backyard workers maintaining poultry, and human migrants converge in predictable spatial patterns. These multi-scalar interfaces create opportunities for pathogen exchange among resident and migratory taxa, augmented by disease vectors such as ectoparasites that transfer between species at common roosting or foraging sites. Land use change and climate change interact across scales from individual backyards to continental flyways, generating both novel opportunities and unprecedented challenges for migratory fauna while simultaneously creating conditions conducive to cross-species pathogen transmission (Xu et al. 2016). This figure integrates spatial ecology, movement ecology, and epidemiological risk to illustrate how anthropogenic modifications at varying scales structure disease emergence potential in tropical One Health systems.

Human activities both facilitate and restrict animal movement through direct and indirect mechanisms, by resource augmentation, and habitat degradation and fragmentation, respectively (Doherty et al. 2021). Anthropogenic food subsidies in the form of landfills, agricultural waste, and livestock carcasses (Khatri 2013, Jhala et al. 2019, 2021) create novel foraging opportunities that can alter migratory routes and stopover durations (Kumar et al. 2020) (Fig. 3). Urban areas concentrate food resources predictably, drawing both migratory and resident species into closer contact with humans and domestic animals. Conversely, infrastructure development directly restricts movement (Hassell et al. 2017b). Linear barriers such as highways, power transmission lines, and border fencing fragment habitats and increase collision mortality (Drewitt and Langston 2008, Estes et al. 2011, Tella et al. 2020). Agricultural intensification reduces stopover habitat quality, forcing migrants into suboptimal areas where energy replenishment becomes compromised. Indirect effects operate through cascading ecological processes (Moreno-Opo et al. 2010, Arkumarev et al. 2021). The introduction of invasive species fundamentally alters food web dynamics and competitive landscapes (Mungi et al. 2025). Invasive plants and consumers modify habitat structure (Bhagwat et al. 2012), affecting the availability of native food resources (e.g., locusts (Gebregiorgis et al. 2025) on which migratory species depend). Invasive predators (e.g., cat fishes; (Jennings et al. 2016) and competitors can eliminate native prey populations or displace resident species, creating mismatches between evolved migratory timing and resource availability. These cascading effects that could likely extend to disease dynamics have been rarely studied. Novel species assemblages in human-modified landscapes, e.g., via resource compression in the form of landfills, create contact networks that did not exist historically, facilitating pathogen transmission among previously isolated host populations (Xu et al. 2016). Considering that the organic material deposited in landfills often contains residues from livestock or poultry raised with significant antibiotic applications, new ecological dynamics require an immediate investigation into how waste metabolism might amplify the antimicrobial resistome, consequently impacting the microbiome and thus increasing the risk of zoonotic disease transmission (Woolhouse et al. 2015, Hassell et al. 2019, Khan et al. 2020).

Animal movement extends beyond long-distance migration to include local-scale movements that shape disease risk. Pastoral livestock systems exemplify this complexity. Pastoralists move livestock seasonally between villages and grazing locations following traditional routes that optimize forage availability. However, climate change is disrupting the predictability of rainfall patterns and vegetation phenology. Droughts extend beyond historical norms, forcing pastoralists to travel longer distances or hold livestock in degraded areas for extended periods (Mekuyie et al. 2018, Jones et al. 2020, Aduko et al. 2025). These climate-induced shifts compromise animal nutrition, increasing physiological stress, weakening immune function in both livestock and the humans who depend on them (Cummings et al. 2020). Land use changes, in addition, e.g., habitat fragmentation, create additional challenges for pastoral communities (Aduko et al. 2025). Agricultural expansion and the designation of protected areas progressively reduce traditionally available grazing lands. Pastoralists increasingly navigate landscapes where their traditional routes intersect with wildlife reserves, agricultural fields, and urban peripheries (Jhala et al. 2019, 2021, Mungi et al. 2025). These novel interfaces expose livestock to wildlife/pathogens and create conflict situations where livestock losses to predation become common. Progressive degradation of pastoral systems generates a vicious cycle (Ghosh-Harihar et al. 2019, Karanth et al. 2019). Reduced herd sizes and compromised animal health lead to decreased protein availability for human consumption. Nutritional deficiencies impair human immune function, increasing susceptibility to infectious diseases (Karakus et al. 2024). Simultaneously, pressures from surrounding settled agricultural communities restrict mobility further, intensifying resource competition and social tensions (Mekuyie et al. 2018, Jones et al. 2020, Aduko et al. 2025).

In many tropical regions, compromised pastoral systems coexist with active bushmeat consumption and trade networks (Buij et al. 2016). Wet markets serve as critical nodes where wildlife, domestic animals, and humans converge in close proximity. The bushmeat trade ranks as one of the world's largest illegal trades, exceeded only by arms, human trafficking and narcotics (Cawthorn and Hoffman 2015, Short et al. 2021, Nuwer 2025). These markets create ideal conditions for pathogen spillover, which has been one of the plausible explanations for zoonosis. Wild-caught animals experience capture and transport stress, which can activate latent infections and increase viral shedding (Aguirre et al. 2020, Lin et al. 2021, Vez-Garzón et al. 2023, Van Kerkhove 2025, Sushma 2021). Market conditions with poor sanitation, live animal slaughter, and mixing of multiple species facilitate cross-species transmission. The spatial concentration of these activities in urban centers connects rural wildlife populations to dense human populations through commercial networks (Lin et al. 2021).

Conservation interventions introduce further complexities. Rewilding initiatives aim to restore degraded ecosystems by reintroducing extirpated species or allowing natural recolonization (Kane et al. 2015, Kmetova–Biro et al. 2021). While ecologically valuable, these efforts can create new zoonotic risks. Reintroduced wildlife populations may carry pathogens to which local domestic animals or humans lack immunity. Habitat restoration increases wildlife densities in areas adjacent to human settlements, intensifying contact rates. Occasionally, protected area expansion sometimes displaces pastoral communities, pushing them into marginal lands with higher disease prevalence or forcing increased reliance on bushmeat (Ghosh-Harihar et al. 2019, Ingeman et al. 2022, Neupane et al. 2025, Ranjan et al. 2025).

The intersection of migratory patterns, pastoral movements, and wildlife trade creates multiscalar vulnerability. These dynamics often lead to ecological and evolutionary traps that facilitate disease emergence (Cawthorn and Hoffman 2015, Aguirre et al. 2020, Esmail et al. 2020, Glidden et al. 2021b, Lin et al. 2021). Migratory birds attracted to landfills encounter degraded food quality, exposure to toxicants, and high pathogen loads from concentrated fecal contamination. Thus, migratory birds can transport pathogens across continents, introducing novel strains to local ecosystems. When these migrants congregate in urban areas or agricultural landscapes where pastoral communities operate, transmission pathways multiply (Plaza et al. 2019, Murray and Hernandez 2021, Richard et al. 2021, Kobuszewska and Wysok 2024).

Domestic ducks and chickens in backyard systems provide mixing vessels where avian influenza viruses from wild birds can reassort with endemic strains (Verma et al. 2023, Kobuszewska and Wysok 2024) (Fig.1). Pastoral livestock moving through fragmented landscapes serve as mobile hosts, potentially carrying pathogens between isolated wildlife populations and human settlements (Hassell et al. 2017b, Jones et al. 2020).

Understanding these relationships requires integrating movement ecology with epidemiological modeling. Traditional approaches undervalue importance of links in animal populations and their movement ecology in One Health, ignoring patterns in contact networks and pathogen dispersal. However, movement creates dynamic landscapes of risk that shift across seasons and years (Dougherty et al. 2018). Migratory connectivity means that management decisions in breeding grounds, stopover sites, and wintering areas all influence population health and disease dynamics. Similarly, pastoral mobility strategies developed over centuries represent adaptive responses to environmental variability. Restricting this mobility without providing alternatives compromises both livelihood sustainability and disease resilience (Doherty et al. 2021, Somveille et al. 2021, Korpach et al. 2022, Rutz 2022, Aduko et al. 2025).

II. Human mobility in a globalized world and its role in pathogen dispersal

Human mobility operates at multiple scales, from daily commutes to intercontinental travel, each with distinct implications for disease transmission (Xu et al. 2016, Dougherty et al. 2018, Chimento and Farine 2024). The COVID-19 pandemic starkly demonstrated how rapidly pathogens can traverse the globe through air travel networks. Human movement data during the lockdown showed that mobility restrictions served as effective non-pharmaceutical interventions during initial outbreak phases (Rutz et al. 2020). However, the utility of such interventions diminished once community transmission became established, highlighting the critical importance of early detection and rapid response. The relationship between human movement and zoonotic disease risk extends beyond pandemic respiratory viruses. Globalization creates structural conditions that amplify infectious disease threats through interconnected mechanisms (Labonté et al. 2011). Urban centers generate enormous demand for resources, creating powerful economic pull factors that reshape entire regional socio-economies and cultures. This urban pull affects social-ecological dynamics at multiple spatial scales simultaneously (Bradley and Altizer 2007, Krystosik et al. 2020). Peri-urban areas experience rapid land use conversion as agricultural lands transform into residential and commercial developments. Rural areas intensify production to meet urban consumption demands, often adopting industrial agricultural practices divorced from traditional regional norms. Forest edge communities face increased pressure to extract resources, whether timber, bushmeat, or non-timber forest products, to participate in cash economies linked to distant urban markets (Karesh et al. 2012, Sachs 2012, Hassell et al. 2019).

Traditional practices evolved through centuries of trial and error, embedding ecological knowledge about sustainable resource use within cultural frameworks. While tradition does not automatically equate to sustainability or safety, wholesale replacement of traditional systems with industrial models carries significant risks (Schiere et al. 2001, FAO 2019a). Modern resource extraction and allocation systems function as never-satiating source-sink dynamics (Folke et al. 2016). Urban centers consume resources at rates that rural landscapes cannot sustainably supply, yet economic pressures continuously intensify extraction. This imbalance drives landscape transformations that bring humans into novel contact with wildlife that could be pathogen reservoirs. Forest clearing for agriculture creates edge habitats where bats, rodents, and other potential reservoir hosts encounter domestic animals and humans (Bateman and Fleming 2012, Hunold and Mazuchowski 2020, Tella et al. 2020). Intensified livestock production concentrates animals at densities that facilitate pathogen amplification and mutation (Bennett et al. 2018, Klaharn et al. 2022).

The Global South, particularly the Indian subcontinent, exemplifies the scale of upcoming urbanization and its potential health implications. Current projections indicate approximately 500 million people will move from villages to cities by 2050: by land use transformation, or by emigration to urban areas (Anonymous 2016, UNO 2018). This represents the largest contribution to upcoming urbanization. The health consequences of this demographic shift extend beyond direct host-pathogen dynamics. Mass migration strains urban infrastructure, particularly in sanitation, housing, and healthcare delivery. Informal settlements emerge faster than municipal services can expand, creating conditions conducive to disease transmission (Kumar et al. 2019c, Kumar 2023). Simultaneously, rural areas experience labor shortages and demographic shifts that disrupt traditional land management practices and social safety nets (Sietchiping et al. 2014).

Human movement driven by economic necessity differs fundamentally from voluntary migration or tourism. Forced displacement due to climate change, conflict, or economic collapse creates vulnerable populations with limited bargaining power and restricted access to healthcare (Ahmed et al. 2021). Seasonal laborers moving between rural and urban areas often work in occupations with high zoonotic exposure risk, including waste processing, animal slaughter, and construction activities that disturb wildlife habitats (Kumar et al. 2019c, Klaharn et al. 2022, Kumar 2023, Migration data portal 2024). These workers could serve as potential bridges, carrying pathogens between spatially separated ecological systems. Their precarious economic position often means seeking medical care only when severely ill, allowing diseases to spread undetected through social networks (Silk et al. 2017a).

Globalization also shapes cultural perceptions of disease risk in ways that can undermine public health responses. Media coverage during disease outbreaks frequently targets specific communities or cultural practices without adequate scientific justification. Following COVID-19 emergence, irresponsible reporting subjected Chinese food cultures and practices in Northeast India to unwarranted scrutiny (Zhao et al. 2021, E P et al. 2022). Such coverage painted all traditional practices as inherently dangerous, ignoring the reality that most zoonotic spillovers result from recent disruptions to traditional human-wildlife relationships rather than from practices themselves. This blame narrative has several harmful consequences. It stigmatizes communities, driving traditional practices underground where they become harder to monitor and regulate. It obscures the actual drivers of disease emergence, which often involve industrial-scale operations rather than small-scale traditional harvesting. It reinforces cultural hierarchies where Western practices are assumed safe while non-Western traditions are viewed with suspicion (Pivetti et al. 2022, Kunst et al. 2024).

The intersection of mobility and perception creates particular challenges for One Health implementation (Tarazona et al. 2019, Kunst et al. 2024). Communities subjected to stigma become less likely to cooperate with surveillance efforts or report unusual disease events. Fear of economic repercussions or social ostracism motivates concealment rather than transparency (Zhao et al. 2021, E P et al. 2022). This is especially problematic in marginalized communities whose livelihoods depend on activities now labeled as high-risk, whether bushmeat hunting for sustenance, backyard poultry keeping, or traditional medicine collection. Effective disease surveillance requires trust and voluntary participation. When public health messaging assigns collective blame to cultural groups rather than addressing structural vulnerabilities, it undermines the social foundations necessary for early outbreak detection (Gebregiorgis et al. 2025, Yoo et al. 2021).

Long-distance trade networks amplify local spillover events into regional or global threats. The bushmeat trade illustrates this clearly. Animals captured in remote forest areas move through complex supply chains involving multiple handlers, transport nodes, and market intermediaries before reaching consumers. Each step creates opportunities for pathogen exposure and amplification (Hassell et al. 2019, Lin et al. 2021). Markets concentrate diverse species in close proximity under stressful conditions ideal for viral shedding and cross-species transmission. From these nodes, pathogens can reach international destinations through connected commercial networks or infected travelers (Silk et al. 2017b). Climate change adds another layer of complexity to human mobility patterns. Environmental degradation and increased frequency of extreme weather events displace populations at unprecedented scales. Climate refugees often move to ecologically marginal areas or overcrowded urban peripheries where disease risk is elevated (Ahmed et al. 2021). Drought and flooding disrupt agricultural systems, forcing farmers to seek alternative livelihoods that may involve increased wildlife contact. Rising temperatures expand the geographic range of disease vectors like mosquitoes, bringing vector-borne diseases to previously unaffected populations with no acquired immunity (Parums 2024).

Growingly urban-rural interconnectedness means spillover events in remote areas can quickly reach dense population centers. Improving rural livelihoods reduces economic pressures that drive unsustainable resource extraction and migration to overcrowded urban areas. Strengthening primary healthcare in rural and peri-urban settings enables earlier case detection and treatment, reducing the probability that infected individuals will travel while contagious (Altizer et al. 2018). Culturally appropriate health education that respects traditional knowledge while providing information about changing disease risks can encourage voluntary behavior modification without stigmatization (E P et al. 2022). Infrastructure investments in sanitation, housing, and food systems in rapidly urbanizing areas can mitigate the health consequences of ongoing demographic transitions (Sachs 2012, Abu Hatab et al. 2019, Mindell and Watkins 2024). Ultimately, the goal is not to halt human movement, which is both impossible and undesirable, but to ensure that movement occurs under conditions that minimize disease transmission while respecting human dignity and livelihood needs (Mindell and Watkins 2024).

III. Human well-being and resource access between global and local standards

The twentieth century witnessed remarkable agricultural advances that supported exponential human population growth (Bennett et al. 2018, FAO 2019b). However, these gains came with a troubling paradox. While global food production now exceeds what is needed to feed the entire human population, vast equity imbalances persist in access to vital resources (FAO 2019b, 2019a, 2023). This disparity in developing economies is not merely about food availability but reflects deeper structural inequities in economic power, healthcare access, and decision-making capacity that fundamentally shape health outcomes. For instance, in India, economics profoundly influence how health and well-being are conceived and pursued. Approximately 90% of Indians earn less than ₹25,000 per month (WID 2025). While India's economy grows, it has not translated into widespread prosperity. Medical emergencies represent catastrophic financial shocks for most households. This economic precarity fundamentally alters healthcare-seeking behavior in ways that have direct implications for disease surveillance and control: costs of consultation, diagnostic tests, medications, and lost wages from missing work. Minor ailments are typically managed at home using over-the-counter drugs or traditional remedies. Only when symptoms become severe or prolonged do people seek professional care. This delay has epidemiological consequences. Infectious diseases spread undetected through communities during the period when people remain symptomatic but avoid formal healthcare. By the time cases reach medical facilities, opportunities for early intervention and contact tracing have passed (Pampel et al. 2010, Woolhouse et al. 2015, Li et al. 2020, WID 2025).

The situation becomes more acute when considering livestock and poultry health. India's livestock population exceeds 535 million animals according to the 2019 census. This vast population is served by only approximately 67,784 registered veterinary practitioners. The infrastructure includes around 12,234 veterinary hospitals, dispensaries, and aid centers (FAO 2019a, GoI 2019, 2022, Livestock Census of India 2019) (Fig. 2). Most of these facilities lack basic amenities, modern diagnostic tools, and essential medicines. In contrast to human health infrastructure, which despite serious gaps at least exists as a defined structural element in public administration, veterinary public health remains virtually non-existent as an organized system. Rural areas, where most livestock reside, face particularly severe veterinary service deficits. This enormous gap between need and capacity creates predictable consequences. Livestock owners face the same economic calculations as humans seeking medical care. When animals show signs of illness, owners must decide whether veterinary consultation costs can be justified against the animal's economic value. For smallholder farmers whose entire wealth may be tied up in a few animals, this creates impossible choices. Losing an animal to disease can push families into debt or food insecurity. Yet the cost of treatment may exceed what they can afford. This dilemma gets resolved through informal channels like quacks and unqualified practitioners that fill the veterinary service void in rural India (Pampel et al. 2010, Li et al. 2020, Khare et al. 2022, WID 2025). These individuals offer cheaper services than registered veterinarians and are more readily accessible. However, they often lack proper training in diagnosis, dosing, or drug selection. Over-the-counter drug dealers provide another informal pathway. Farmers purchase medications based on symptoms described verbally, without proper examination or diagnosis. Incorrect drug selection and inappropriate dosing are common, contributing to antimicrobial resistance and treatment failures. These informal practices persist because formal alternatives remain economically or geographically inaccessible (Pampel et al. 2010, Khare et al. 2022, Bharati et al. 2025).

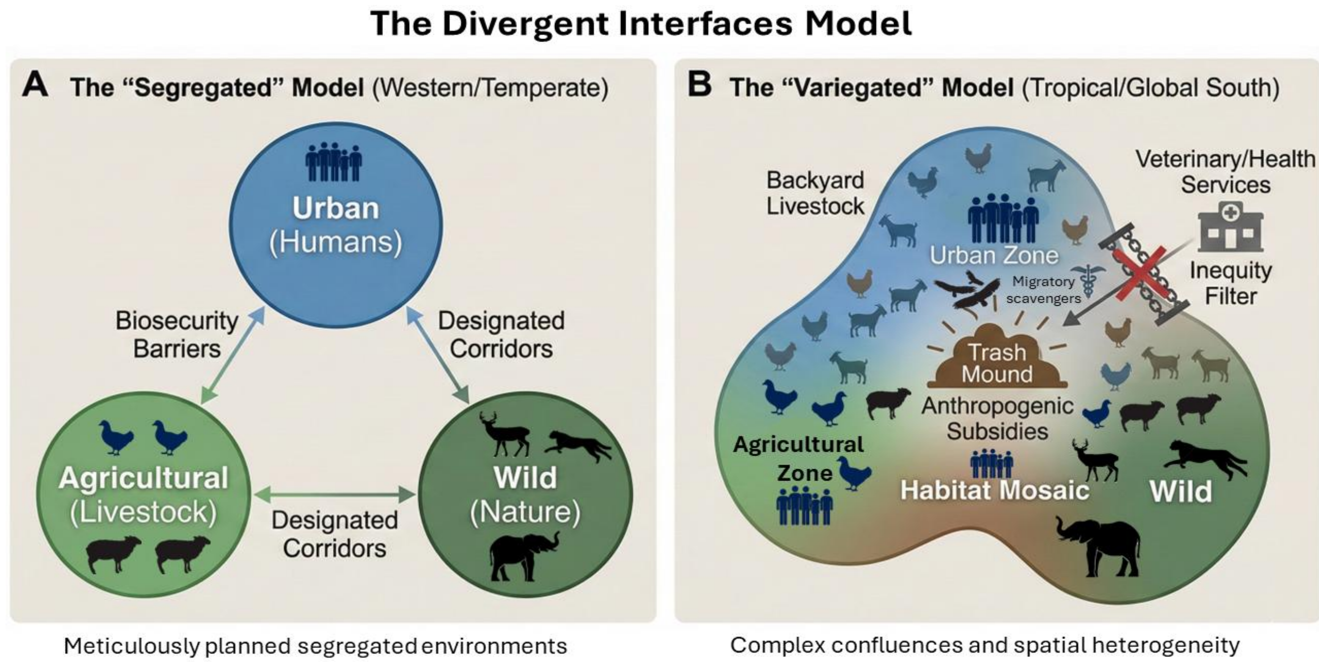


Fig. 2. Divergent spatial models of human-livestock-wildlife interfaces: segregated versus variegated landscapes: *Panel A* depicts the "Segregated Model" characteristic of Western and temperate regions, where meticulously planned land use creates distinct spatial compartments for urban (human), agricultural (livestock), and wild (nature) zones. Biosecurity barriers and designated corridors maintain separation between these domains, minimizing unplanned human-livestock-wildlife contact. This segregated approach assumes sufficient space, resources, and institutional capacity to enforce spatial boundaries. *Panel B* illustrates the "Variegated Model "predominant in tropical and Global South regions, where complex confluences and spatial heterogeneity characterize human-livestock-wildlife relationships. Urban zones contain backyard livestock integrated within human settlements, creating continuous interfaces rather than discrete boundaries. Trash mounds and anthropogenic subsidies attract migratory scavengers, opportunistic commensals, and wildlife into residential areas. Agricultural zones intermingle with habitat mosaics supporting both domestic and wild fauna. Wild areas remain accessible to human communities for resource extraction, traditional practices, and livelihood activities. The inequity filter symbolizes differential access to veterinary and health services, where economic constraints limit healthcare-seeking behavior for both humans and animals, creating vulnerabilities unaddressed by formal systems. The contrast between these models highlights why One Health approaches developed for segregated Western contexts require substantial adaptation for tropical regions.

The vulture collapse in the Indian subcontinent starkly illustrates how gaps in veterinary infrastructure cascade into public health disasters (Fig. 3). Diclofenac sodium, a non-steroidal anti-inflammatory drug, was widely used in livestock treatment during the 1990s. Vultures feeding on carcasses of treated animals suffered acute kidney failure and population crashes. Three *Gyps* vulture species declined by over 97% within a decade, a collapse more rapid than the dodo's extinction. The Indian government banned veterinary diclofenac use in 2006. However, carcass surveys in the 2010s continued detecting significantly high diclofenac, indicating ongoing illegal use despite the ban (Green et al. 2004, Bowden 2009, Acharya et al. 2010, Khatri 2013, Al Fazari and McGrady 2016, Cuthbert et al. 2016, Frank and Sudarshan 2024).

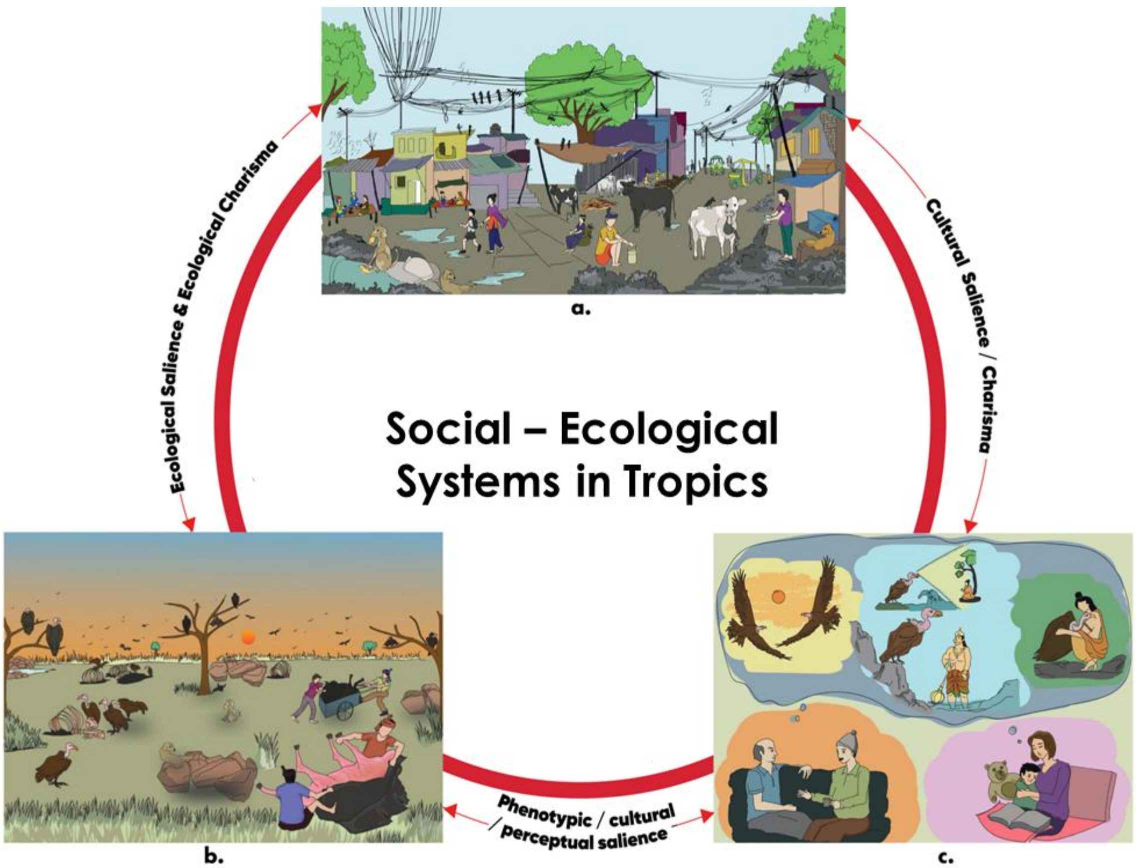


Fig. 3. Cyclical ecosystem-based framework to represent one of the many community-governed social-ecological-systems (Ostrom 2009) during the last century in South Asia. The framework links the ***a).*** nature based solutions for waste management by opportunistic scavengers, including vultures, in shared living spaces; ***b).*** Social-cultural and socio-economic aspects associated with carcass disposal by vultures and involvement of specic stakeholders from certain caste (*Chamar*) and religion (*Muslims*) involved in leatherwork; and ***c).*** Balancing of stigma for vultures through socio-cultural legends, where mythological references (in *Ramayana*) for vultures' volant capabilities and keen sense of sight are topics of reverence, forming the bases for mutual tolerance in the region. This conceptual framework builds on the nonhuman charisma and salience discussed by Lorimer (Lorimer 2007) and illustrates why the ecology of people-nature interaction in

temperate systems differ from tropical human-use landscapes (Soga and Gaston 2020). [Artwork by *Anukriti Karn*]

Why did usage continue after the ban? The answer lies in the veterinary infrastructure gap. Registered veterinarians who might comply with regulatory restrictions simply do not reach most livestock owners. Informal practitioners and drug dealers continue using diclofenac because it is cheap, effective for treating cattle pain and inflammation, and readily available through gray market channels; even human vials have been incorporated. Without veterinary supervision, farmers and informal practitioners prioritize immediate livestock welfare. The absence of accessible, affordable alternatives that work as effectively as diclofenac perpetuates its use. The ecological and public health consequences of vulture loss extended far beyond the birds themselves. Recent research estimated that vulture scavenging services prevented approximately 100,000 human deaths annually before the collapse (Frank and Sudarshan 2024). Vultures consumed livestock carcasses rapidly and thoroughly, preventing decomposition and pathogen proliferation. Their loss created competitive release for dogs, rats, and other opportunistic scavengers. These alternative scavengers are less efficient at carcass disposal and serve as reservoirs for rabies, leptospirosis, and other zoonotic diseases (Bowden 2009, Gangoso et al. 2013, Botha et al. 2017, Hill et al. 2018, Heever et al. 2021).

This case from the Indian subcontinent that has similarities with other developing tropical regions demonstrates how conceptions of health and well-being differ. Preventive measures and long-term considerations become luxuries that economic reality does not permit. Livestock health receives attention only when productivity or survival is threatened. Wildlife health, except where it directly impacts livelihoods through crop damage or livestock predation, remains entirely outside the sphere of concern. Biosecurity measures illustrate these disparities starkly (Cunningham et al. 2017, Samanta et al. 2018, Campbell et al. 2024). International standards for preventing pathogen introduction through livestock and wildlife trade involve sophisticated monitoring, quarantine facilities, diagnostic testing, and enforcement mechanisms. These systems require substantial financial investment and technical capacity. Wealthy nations implement robust biosecurity protocols at borders and throughout domestic supply chains. Developing tropical regions often lack the resources to establish comparable systems. Porous borders, limited inspection capacity, and corruption allow unregulated animal trade to flourish (Aguirre et al. 2020). Smallholder farmers cannot afford biosecurity investments like separated housing for new animals, testing before introduction to herds, or protective equipment during handling (Campbell et al. 2024). Marginalized communities face compounded vulnerabilities. The urban poor, which also includes refugees and displaced populations experience even more precarious conditions, often lacking legal status that would enable access to what limited services exist. Communities living in wildlife conflict-affected areas face economic losses from crop raiding and livestock predation while simultaneously experiencing heightened zoonotic disease risk from increased wildlife contact.

These populations bear disproportionate coexistence burdens in the form of diseases and conflicts (2013, Hassell et al. 2019, Karanth et al. 2019, Heever et al. 2021).

Integrating social-ecological perspectives into health interventions requires acknowledging that vulnerable populations need more than information or recommendations (Folke et al. 2016). They need structural support that makes healthy choices economically feasible. Subsidized veterinary services could reduce reliance on informal practitioners and inappropriate drug use. Mobile veterinary clinics bringing services to remote areas could improve access. Livestock insurance schemes could reduce the economic devastation of animal losses, making preventive care investments more rational (Karanth et al. 2019). Waste management improvements in informal settlements would reduce commensal populations and associated disease risk. These interventions require sustained financial commitment and political will to address inequities that produce differential health outcomes (Kumar et al. 2019c, Kumar 2023, Verma et al. 2023). Until economic realities that constrain healthcare-seeking behavior change, disease surveillance and control efforts will remain hampered by the gap between what global standards recommend and what local conditions permit.

IV. Nonhuman well-being against changing resource dispersion in the *Anthropocene*

Human activities reshape landscapes through urbanization, agriculture, and resource extraction, fundamentally altering resource availability patterns that nonhuman species have evolved to exploit (Kumar et al. 2018b). These changes create novel ecological dynamics with profound implications for wildlife health, behavior, and population persistence (Kumar et al. 2019a). The Anthropocene presents a paradox for nonhuman well-being. While habitat destruction eliminates species at alarming rates, simultaneous resource subsidies allow certain adaptable species to thrive in human-modified environments (Ouled-Cheikh et al. 2021, Chester et al. 2023). Understanding this complexity requires distinguishing between actual nonhuman needs and human conceptions of animal well-being, which often diverge in ways that generate unintended consequences. The vulture case discussed earlier exemplifies how dependence on anthropogenic subsidies creates vulnerability (Green et al. 2004, Basu and Scholten 2012). Vulture populations expanded when livestock carcass availability increased with agricultural intensification (Fig. 3). This subsidy-driven growth made populations dependent on predictable carcass supplies. When diclofenac contamination suddenly rendered carcasses lethal, populations crashed catastrophically. Beyond immediate mortality, we poorly comprehend how this collapse affected biodiversity in relatively pristine ecosystems distant from intensive agriculture. Vultures transport nutrients across landscapes when they forage widely then roost or nest in specific locations. Their loss altered nutrient cycling patterns across the subcontinent. Cascading effects on scavenger guilds, predator-prey dynamics, and plant communities in protected areas remain largely undocumented (Fig. 4) (Donázar et al. 2009, Margalida et al. 2010, Margalida and Colomer 2012, Botha et al. 2017).

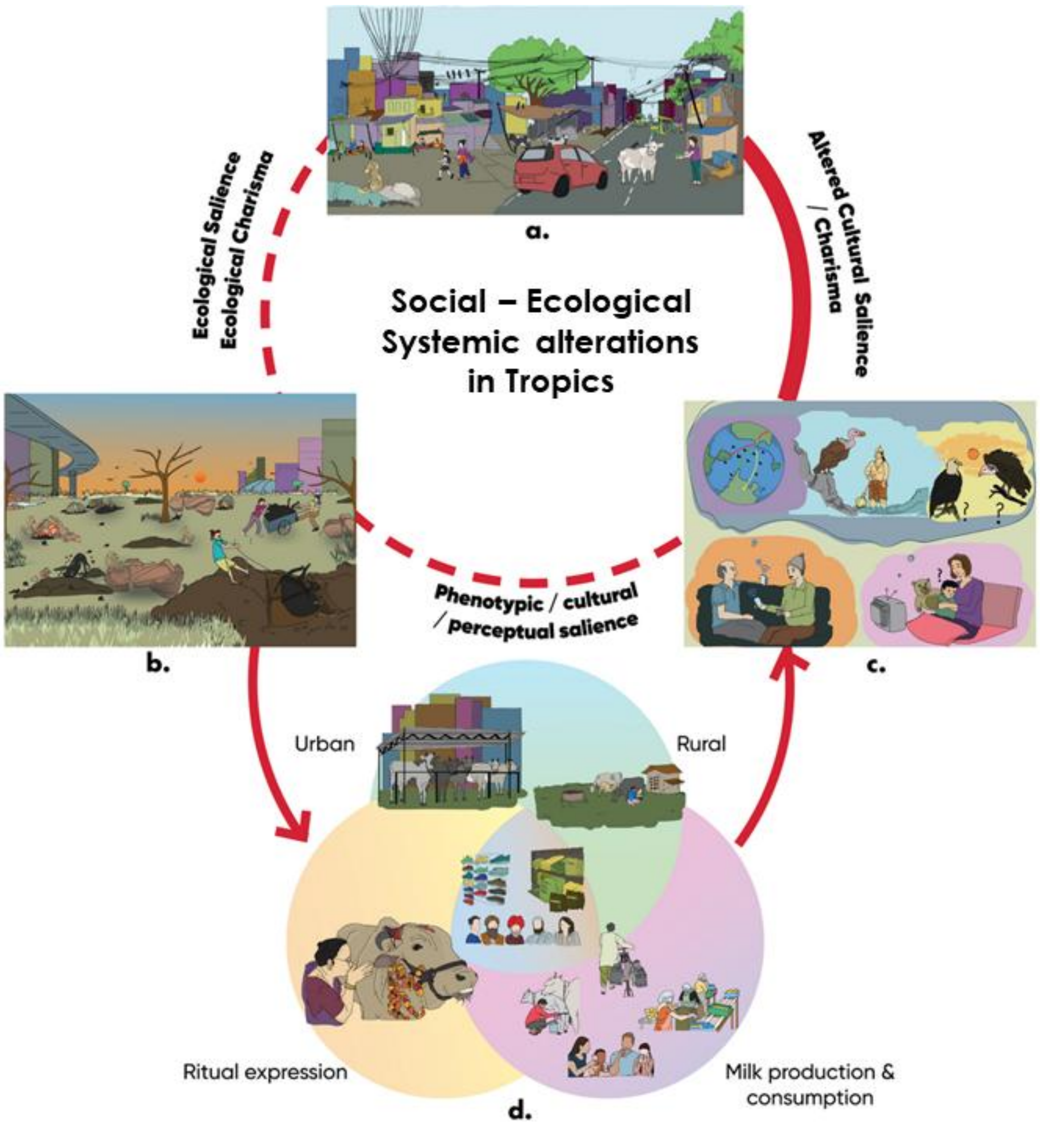


Fig. 4. Cyclical ecosystem-based framework concerning human-vulture interface has attained altered state in the wake of South-Asian extinction of vultures through: ***a).*** Gentrification driving loss of nature-based solutions that decreases people's motivation for sharing living spaces with animals in a tropical urban landscape; ***b).*** Spatio-temporal associations in urbanization and vulture loss has been impacting the sociocultural and economic aspects that now mediate competitive release of other commensals competitors that capitalize on carcasses left or buried within limited spaces; and ***c).*** the loss of direct encounters after decline in vulture populations that previously shared urban-rural areas with humans. Access to television and internet impacts biocultural heritage, often spreading mediatized misinformation (e.g., their local-extinction has been due to "technology-assisted" migration to Japan and USA) (Gupta and Kumar 2024). The broken red lines represent how vulture loss has affected relations that regulate non-human charisma and salience involving vultures (Lorimer 2007). Overall, the impacts on social-ecological relationships led to changes in livestock maintenance for animal protein and leather, depicted in the section ***d).*** that represents how urban practices for livestock keeping across the world are getting homogenized in space and time. [Artwork by *Anukriti Karn*]

Agricultural intensification creates collateral damage extending far beyond intended targets. Indiscriminate antibiotic use in livestock production drives antimicrobial resistance in environmental bacteria. These resistant strains then colonize wildlife populations through contact with livestock, contaminated water sources, or consumption of agricultural waste (Woolhouse et al. 2015). Wildlife become reservoirs of resistant pathogens that can subsequently infect humans. Chemical pesticides applied to crops accumulate in food webs. Predatory birds consuming pesticide-laden prey experience reproductive failures, immune suppression, and direct mortality (Baker et al. 2014, Plaza et al. 2019). Neonicotinoid insecticides devastate pollinator populations, with cascading effects on plant reproduction and the animals depending on those plants. Herbicides eliminate plant diversity in agricultural landscapes, removing food resources for insects, birds, and mammals. The cumulative effect transforms vast areas into ecological deserts that support only the most generalist, human-adapted species (Thompson et al. 2020, Schmitt and Burghardt 2021).

Anthropogenic food subsidies now constitute a massive global phenomenon (Oro et al. 2013). Backyard bird feeding alone represents a multi-billion-dollar industry. In the United States, consumers spend approximately $4 billion annually on birdseed and feeders (Jones 2011, Rodewald et al. 2011). The United Kingdom market exceeds £200 million yearly. Australia, despite its smaller population, contributes around $400 million to backyard wildlife feeding. Global estimates suggest the backyard animal feeding industry, including food for birds, mammals, and other urban wildlife, exceeds $10 billion annually (Newsome and Rodger 2008, Elbein 2022). This figure continues growing as urbanization increases and people seek nature connections within cities. These economic investments reflect genuine affection for wildlife and desires to support conservation. However, the ecological consequences of mass-scale feeding often contradict conservation goals.

Feeding fundamentally alters animal behavior, population dynamics, and community structure (Oro et al. 2013, Kumar et al. 2019a, West and Jones 2022). Species provided with predictable, abundant food resources can achieve densities far exceeding natural carrying capacities. Elevated densities increase intraspecific competition despite food abundance, as animals compete for roosting sites, territories, and mates (Rodewald et al. 2011, Kumar et al. 2019a). Modified reproductive success follows altered resource availability. Some species experience protracted breeding months (Kumar et al. 2014), more frequently, or produce larger clutches/litter when food-limited constraints disappear. Others experience reproductive failures when artificial diets lack essential nutrients. Disease transmission intensifies at artificially elevated densities. Proximity facilitates pathogen spread through direct contact, fecal contamination of shared feeding sites, and aerosol transmission. Altered social behaviors compound these risks. Animals’ sociality and gregarious aggregates around feeding stations could create contact networks ideal for epidemic spread (Wong and Candolin 2015, Silk et al. 2017b).

Urban wildlife feeding illustrates the disconnect between human intentions and animal welfare outcomes (Newsome and Rodger 2008). Many people feed animals believing they provide essential support, particularly during harsh weather or breeding seasons. This perception reflects genuine compassion but often misunderstands actual animal needs. Most urban-adapted species are ecological generalists that thrive without supplemental feeding (Gupta and Kumar 2024). Providing food creates what we might term "partial care," where humans supply nutrition without addressing other welfare requirements like veterinary care, predator protection, or conflict mediation (Newsome and Rodger 2008). This incomplete support generates problems at multiple scales. Furthermore, reforesting degraded lands attracts wildlife back to areas now bordered by human settlements, intensifying contact. Reconnecting habitat fragments through corridors facilitates wildlife movement but also enables pathogen dispersal between previously isolated populations. These risks do not argue against restoration but highlight the need for integrated planning that anticipates health consequences and implements appropriate monitoring and mitigation measures (du Toit and Pettorelli 2019, Hayward et al. 2019).

Macaques in Indian cities exemplify these dynamics. Religious devotion motivates feeding at temples and other sites. Macaques habituate to human presence and associate humans with food provisioning. Fed populations grow beyond natural densities. As groups expand, they increasingly enter human spaces seeking food, causing property damage and occasionally injuring people. Public tolerance erodes as conflicts intensify. Municipalities respond with capture and relocation programs (Priston and McLennan 2013, Govindrajan 2015, Deol 2023). However, translocation often proves lethal. Relocated animals lack familiarity with new territories, face aggression from resident groups, and struggle to find food without human provisioning. Translocation effectively leads to death in poorly managed shelters. The cycle perpetuates because feeding continues despite documented negative consequences (Ross et al. 1993, Radhakrishna et al. 2012, Ganguly et al. 2018, Kumar and Sharma 2025).

The free-ranging dog crisis in India and similar regions represents perhaps the starkest example of how poor ecological understanding creates intractable management dilemmas. India hosts the world's largest street dog population, estimated at 80 million animals. These dogs occupy a liminal space, neither fully wild nor domesticated (Sudarshan et al. 2007). Many receive partial care through community feeding but lack veterinary care, sterilization, or consistent human supervision. This creates conditions where dog populations grow rapidly, leading to increased human-dog conflicts, rabies transmission, and attacks on people, particularly children (Doshi 2018). Management approaches remain mired in contradiction due to absent ecological data on basic questions. *Where can humans and dogs coexist successfully? What densities are sustainable in different urban contexts? What site-specific interventions would reduce conflicts while maintaining animal welfare?* Without this foundational information, policy oscillates between extremes (Cunha Silva et al. 2025).

Since August 2025, the Indian Supreme Court issued multiple contradictory mandates within three months regarding street dog management (Kumar and Coulson 2025). Initial orders demanded mass relocation to shelters, which sparked immediate opposition from animal welfare organizations noting that shelter capacity falls astronomically short of need and that existing shelters operate in deplorable conditions. Subsequent orders backtracked, then reimposed relocation requirements, creating confusion and paralysis in implementation. These judicial flip-flops reflect deeper confusion about what constitutes dog welfare and whose interests should receive priority (Kumar and Sharma 2025). Animal welfare advocates argue that dogs have rights to exist in public spaces and that sterilization programs can eventually stabilize populations. Residents in areas with high dog densities argue for their right to safety and access to public spaces. Both positions reflect diversity in multispecies coexistence perceptions and priorities, yet policy lurches between them without addressing underlying questions (Tiwari et al. 2019). *What are actual dog needs beyond food?* Dogs require not just nutrition but also veterinary care, social stability within packs, and safe spaces away from traffic and human aggression. Human feeding often meets none of these needs beyond the most basic caloric requirements (Bhalla et al. 2021). The gap between human perceptions and animal needs manifests in numerous contexts. People feeding urban birds feel they support conservation, yet evidence suggests feeding alters migration patterns, increases disease transmission, and favors aggressive species that dominate feeders at the expense of shyer species (Dunn et al. 2006, Gupta and Kumar 2024). Feeding wild ungulates in protected areas to “help” them during droughts creates artificial selection for boldness and reduces natural wariness of predators. Provisioning carnivores like foxes or jackals habituates them to humans, leading to conflicts when animals enter homes or threaten pets and children (Vuorisalo et al. 2014, Gil-Fernández et al. 2020).

Addressing these issues requires shifting from emotionally motivated actions to evidence-based interventions grounded in species ecology (Jones 2011, Ouled-Cheikh et al. 2021). This means conducting baseline studies to understand population structures, behavioral ecology, and ecosystem roles of urban-adapted species before implementing management. It means (i) acknowledging that feeding, while emotionally satisfying to humans, often fails to serve animal welfare and may actively harm populations; (ii) we need to design urban spaces that accommodate wildlife needs without creating dependency or conflict; and (iii) developing monitoring systems that detect when habituation crosses thresholds into problematic human-wildlife relationships, allowing early intervention before crises develop (Fuller et al. 2008, Orros and Fellowes 2014, Kumar et al. 2019b, Dasgupta et al. 2021, Griffin et al. 2022, Sotillo et al. 2022). Most fundamentally, it requires recognizing that nonhuman well-being in the *Anthropocene* cannot be secured through human benevolence alone. Animals adapted to exploit anthropogenic resources become dependent on their continued availability (Galushin 1971, Kumar et al. 2019a). When human circumstances change, whether through economic downturns reducing feeding, policy shifts restricting access, or environmental contamination rendering resources lethal, dependent populations face catastrophic declines. True conservation in human-dominated landscapes requires maintaining habitat quality and natural food sources rather than substituting artificial provisioning. It requires managing human behavior and expectations rather than attempting to engineer animal populations to fit human preferences (Kumar and Coulson 2025). Until we bridge the gap between human conceptions of animal welfare and actual ecological requirements for population persistence and health, our well-intentioned interventions will continue generating unintended crises across human-wildlife interfaces (2013, Kumar et al. 2019c, Rittem et al. 2024).

Conclusion: Co-cultures and the moving targets of One Health

The four themes examined in this overview converge on a fundamental reality that One Health is a conjugated system of multiple moving targets. Animal movements across spatial scales, human mobility in globalized networks, disparities in resource access, and nonhuman adaptations to anthropogenic subsidies operate simultaneously and interactively. Each component shifts independently while influencing the others, creating dynamic complexity that defies simple interventions. Understanding this multiplicity requires moving beyond traditional epidemiological frameworks to embrace novel conceptual tools that acknowledge the inherently coupled nature of human, animal, and environmental health.

Novel ecosystems, as concurrent conceptual arguments, provide a useful lens for synthesizing these themes (Robertson et al. 2013, Collier 2015). Tropical regions increasingly consist of assemblages that have no historical analogs. Species combinations, resource distributions, and ecological processes reflect anthropogenic influences operating at multiple scales. These systems cannot be managed by restoring some presumed pristine baseline because no such baseline exists for current conditions. Instead, we must understand how these novel configurations function and what properties emerge from unprecedented species interactions. This requires acknowledging that the *Anthropocene* has fundamentally altered the context within which One Health operates. Nature-based solutions from tropical regions remain underappreciated in scientific and policy discourse (Seddon et al. 2021, Seddon 2022). Long-standing folk practices embody ecological knowledge developed through centuries of trial and error. The role of opportunistic scavengers in waste processing and disease regulation exemplifies this (Gupta and Kumar 2024). Communities that traditionally coexisted with vultures, corvids, and other scavengers understood their ecosystem services implicitly, even if not articulated in scientific terminology. When modern development disrupts these systems, as diclofenac contamination disrupted vulture populations, the loss extends beyond biodiversity to include critical ecosystem functions. Yet these folk benchmarks of nature-based solutions rarely inform formal conservation or public health planning.

The concept of co-cultures offers a framework for integrating human and nonhuman dynamics in ways that traditional One Health approaches often miss (Sueur and Huffman 2024). Co-cultures recognize that interspecies cultural transmission operates through horizontal pathways between species, not just vertical transmission within species. Animals learn from observing humans, and humans modify behaviors based on animal responses. These reciprocal adaptations create coupled evolutionary and cultural trajectories. In urban South Asia, dogs, macaques, corvids, and humans have developed behavioral repertoires through mutual observation and response. These co-cultural dynamics shape disease risk as profoundly as biological factors like pathogen virulence or host immunity.

Political-ecological forces structure the interfaces where co-cultures develop. Economic policies that drive rural-to-urban migration create the settlement patterns where human and nonhuman immigrants converge. Agricultural subsidies influence crop choices that alter wildlife habitat quality. Municipal waste management decisions determine resource availability for urban-adapted species. Infrastructure investments shape movement corridors for both humans and animals. These political-economic structures operate at scales from local to global, creating ecotones of varying sizes where novel interactions emerge. Understanding One Health in tropical regions requires analyzing how these political-ecological dynamics generate the material conditions within which biological and cultural processes unfold.

The epidemiological dimensions of One Health remain central but insufficient alone. Disease emergence, transmission dynamics, and spillover events certainly matter. However, perception and cultural interpretation shape how societies respond to these biological realities. Media coverage can generate moral panic around specific cultural practices while ignoring structural drivers of disease emergence. Mediatized opinions spread through social media platforms increasingly influence policy decisions, sometimes overwhelming scientific evidence (Gupta and Kumar 2024). As urbanization concentrates populations in cities, this mediatization of risk perception becomes critical. Urban residents disconnected from direct wildlife contact form opinions about human-wildlife relationships based on sensationalized media narratives rather than lived experience or ecological understanding (Miller 2005, Soga and Gaston 2016).

The new normal of co-cultures demands recognizing that managing disease risk requires managing perceptions and cultural practices alongside biological interventions. Stigmatizing traditional food cultures prevents honest reporting of unusual disease events. Romanticizing wildlife feeding creates dependency relationships that ultimately harm both humans and animals. Criminalizing pastoral mobility without providing alternatives destroys sustainable livelihood systems adapted to environmental variability. Each of these perception-driven responses undermines the trust and cooperation necessary for effective surveillance and intervention.

Moving forward requires embracing the complexity rather than seeking simplification. We need (i) ecological baselines for urban-adapted species to inform evidence-based management (ii) veterinary infrastructure that matches human healthcare capacity to prevent livestock diseases from becoming public health crises. (iii) biosecurity approaches tailored to resource-constrained contexts rather than imported wholesale from wealthy nations. (iv) cultural humility that respects traditional ecological knowledge while providing information about changing risks in novel ecosystems, and most fundamentally, (v) to acknowledge that One Health in tropical regions involves multispecies hazards, vulnerabilities, and exposures that shift continuously as humans and nonhuman animals respond to rapid environmental changes. In the foreseeable future, these dynamic objectives will effectively render the work analogous to an unending pursuit of chasing the horizon, during which new realities will be uncovered as progress is achieved. Our strategies must become as dynamic and adaptive as the systems we seek to influence, embracing the co-cultural reality that humans and nonhuman species now share evolutionary trajectories in ways unprecedented in our species' history.

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Ethical Statement

The ethical approval for dog study was via permit number 2023/ER/Canine Conundrums/01, from Thinkpaws, with validity: 29.04.2023 to 31.12.2027 and the M.Sc. dissertation committee of Chaudhary Charan Singh University, Meerut, Uttar Pradesh. Since this counting was non-invasive and free-ranging dogs are not under the Wildlife Protection Act, no specific permission from the Department of Forest and Wildlife, Government of NCT of Delhi was required.

Declaration of AI use

This article's sections were revised for grammatical mistakes and were provided rewording suggestions. The software tool 'Grammarly' (App version 1.2.155.1657, embedded in the Google Doc.) was used between 07.11.2025 and 29.11.2025.

Competing interests: I declare no competing interests.

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