

POLICY PERSPECTIVE

Fostering landscape immunity to protect human health: A science-based rationale for shifting conservation policy paradigms

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Abstract

Anthropogenic land use change is a major driver of zoonotic pathogen spillover from wildlife to humans. According to the land use-induced spillover model, land use change alters environmental conditions that in turn alter the dynamics between zoonotic pathogens and their wildlife hosts. Thus, in response to the global spread of the SARS-CoV-2 virus (the agent of COVID-19 disease), there have been renewed calls for landscape conservation as a disease preventive measure, including by the G7 Ministers responsible for Climate and the Environment. Landscape immunity, as a new construct, points to four paradigm shifts the world must favor to effectively mitigate pandemic risks. We provide a landscape immunity primer for policy makers and make the case for “world views” that place *Homo sapiens* within ecological systems, regard human health as an ecological service, prioritize investments in prevention, and apply ecological restoration to human health goals. Crisis is a conversation starter for reimagining and recommitting ourselves to what is most vital and generative. We urge world leaders to make the move to a nature-positive world.

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1 | INTRODUCTION

Unhealthy landscapes lead to unhealthy people. Human-induced land use changes, ranging from deforestation to dam building, are drivers of infectious disease outbreaks at local (epidemic) to global (pandemic) scales. The degradation of ecological systems can further increase the risk of infectious disease emergence by creating the conditions that increase infection, shedding, and cross-species transmission of zoonotic pathogens—microorganisms that originate in animals and are transmittable to people (Faust et al., 2018; Gibb et al., 2020; Halliday et al., 2020; Patz et al., 2004). For example, agricultural expansion and intensification is intimately associated with the emergence of Hendra virus in Australia (Plowright et al., 2011), while dam building has promoted schistosomiasis outbreaks in Senegal by preventing the movement of river prawns that feed on the snails that host the disease-causing parasite (Sokolow et al., 2019). The advent of COVID-19 (caused by the SARS-CoV-2 virus) has demonstrated that these issues are socially and economically important, as well as scientifically complex. Clearly, it is a time for national leaders across the globe to unify—to come together with the vision and commitment to prevent future pandemics. On May 21, 2021, the G7 Ministers responsible for Climate and the Environment recognized that “some of the key drivers of global biodiversity loss and climate change are the same as those that increase the risk of zoonoses, which can lead to pandemics” and that “a healthy natural environment is critical to human health, wellbeing and prosperity globally and underpins sustainable development” (UK, 2021; G7 Communique’). Acknowledging the generalized links between land use change and zoonotic disease emergence, the ministers echoed recent proposals for ecosystem protection as a disease preventive measure (e.g., Andrade et al., 2020; Lovejoy, 2020; Schoonover et al., 2021) and reinforced “the importance of science and evidence in future government policies and decision-making” (UK, 2021).

While the G7 Communique’ rightly calls for more extensive pathogen surveillance and data sharing (UK, 2021), it does not strategically convey the paradigm shifts in policy making that are needed to guide the science-based, practical actions that must be taken globally to prevent and mitigate large-scale outbreaks of zoonotic disease. The framing of these paradigms is not only conceptually necessary, but of great urgency. World leaders are in the process of, among

other relevant actions, developing plans to implement the expanded Aichi Biodiversity Targets under the Convention on Biological Diversity, setting priority agendas for the UN Decade on Ecosystem Restoration, and advancing the Global Health Security Agenda. Unless such efforts stem from a collective vision that is sufficiently compelling to rise above and beyond the traditional species-, discipline-, and sector-specific framing of conservation policy, they will fail to motivate and guide the necessary on-the-ground changes in conservation practice.

All things grow and transform by making incremental yet revolutionary changes. If we are to prevent the next pandemic, that is our task for conservation policy: to initiate the paradigm shifts necessary to nourish global-scale changes in the way conservation is viewed, prioritized, and practiced. With the goal of supporting government leadership in science-based decision making for pandemic prevention, we provide a primer on land use-induced spillover (LUIS) for conservation policy makers and propose four paradigm shifts for conservation policy that focus on safeguarding landscape immunity—healthy landscapes. Our paper advances, and is a timely application of, the body of work initially established under the auspices of conservation medicine (Aguirre et al., 2002) and is now an aspect of the interdisciplinary One Health approach (e.g., Buttke et al., 2015).

2 | LANDSCAPE-INDUCED SPILLOVER: A PRIMER FOR CONSERVATION POLICY MAKERS

In light of the data shortfalls for policy making, the G7 Ministers agreed to convene an International Zoonoses Community of Experts to facilitate scientific and technological collaboration (UK, 2021). This landscape immunity primer is intended to inform this work, as well as related multilateral governance processes identified in the following section. Pathogens and parasites are vital components of biodiversity that drive ecosystem processes and services through their influences on host species population dynamics (Hudson et al., 2006) and may warrant greater conservation attention as native biota (Gómez & Nicholas, 2013). However, anthropogenic ecosystem disruption can inadvertently turn “good guys” into “bad guys” by altering the relational contexts—physical and ecological—in

which organisms exist (Simberloff & Rejmánek, 2011). Recent increases in the frequency, scale, and severity of zoonotic disease outbreaks evidence such phenomena; anthropogenic land use change is a major driver of zoonotic pathogen spillover (transmission) from wildlife to humans (Gottendenker et al., 2014; Hassell et al., 2017; White & Razgour, 2020). Considering “land use change” broadly as anthropogenically induced ecosystem change, we provide examples of zoonotic pathogen transmission from wildlife to humans (“spillover events”) associated with land use change in a Supplementary Table (Table S1). Policy makers can use this table as a resource for identifying case studies of particular relevance to their constituencies. For example, the Ebola virus of West and Central Africa and Nipah virus of Bangladesh are among the World Health Organization’s (WHO) priorities for research and development due, in part, to their pandemic potential (<https://www.who.int/activities/prioritizing-diseases-for-research-and-development-in-emergency-contexts>, accessed 27 November 2021). Both diseases are influenced by land use changes; deforestation causes resource-stressed host species (bats) to inhabit agricultural and urbanizing landscapes where there is increased contact between bats, domestic animals, and people (see Table S1 for details and references).

In general terms, three potentially inter-related linkages between land use and wildlife disease dynamics are clear: (1) ecological patterns across the landscape determine the distribution and abundance of biota, including pathogens and their hosts; (2) environmental stress affects wildlife susceptibility to pathogen *infection*, as well as the likelihood of wildlife *shedding* pathogens in a manner that increases exposure of other animals (including humans); and (3) human-altered landscapes bring wildlife into closer proximity to domestic animals and humans, thus increasing the likelihood that shed pathogens will *spill over* into populations of other species (ultimately, humans) where they may *spread* further.

In the context of zoonotic disease prevention, the available science has enabled us to establish first principles for landscape conservation that include maintaining intact ecosystems while minimizing habitat penetration, fragmentation, and wildlife–human interaction in already disrupted environments (Locke et al., 2019; Sokolow et al., 2019; Johnson et al., 2020). However, until recently, little attention has been given to untangling the mechanisms by which land use change increases pandemic potential. Plowright et al. (2021) conceptualized an empirically informed model for this phenomenon, which they refer to as “land use-induced spillover” (LUIS) and functionally describe as the “infect-shed-spill-spread cascade” (Figures 1 and 2 therein; Figure 1 herein). Their premise, succinctly stated, is that land use changes

Examples of policy frameworks for landscape immunity versus dynamics of proximity (see also Reaser et al. 2022; Reaser et al., 2021a; Reaser & Tabor, 2021)

Landscape immunity

- Land use planning and zoning
- Protected and conserved area management
- Ecological connectivity and corridor management
- Environmental impact assessment

Dynamics of proximity

- Wildlife trade and consumption
- Human–wildlife conflict
- Livestock and poultry management
- Human travel and migration

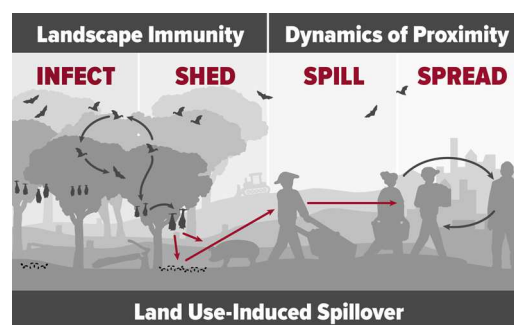


FIGURE 1 Land use-induced spillover: the landscape immunity and dynamics of proximity components. In wildlife, the infection and shedding of zoonotic pathogens is governed by landscape immunity—the ecological conditions that, in combination, maintain and strengthen the immune function of wild species within a particular ecosystem and prevent elevated rates of pathogen shedding into the environment. The dynamics of proximity holistically refers to the pathways, type, degree, and frequency of contact that facilitate pathogen transmission. Dynamics of proximity govern spillover risk (dynamics of animal–human proximity) and spread (dynamics of human proximity)

alter environmental conditions that in turn alter the dynamics between zoonotic pathogens and their wildlife hosts.

The LUIS paradigm is underpinned by two components: “landscape immunity” and the “dynamics of proximity.” Human activities that destroy and degrade ecological systems can trigger the infect-shed-spill-spread cascade. Wildlife stressed by the environmental conditions associated with land use change can decline in immune function, thus becoming more susceptible to zoonotic pathogen infection. Stress can also increase

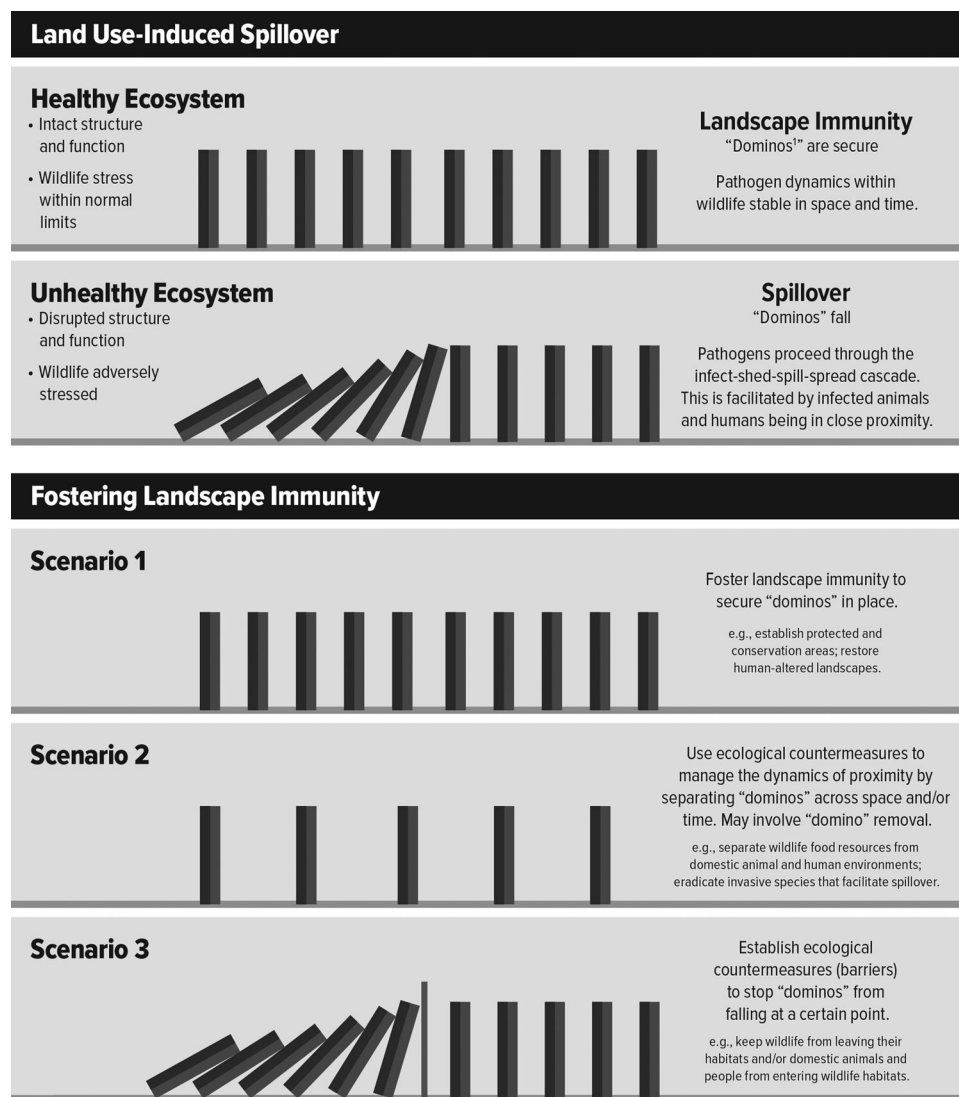


FIGURE 2 Land use-induced spillover: the dominos management metaphor. ¹Domino tiles represent components of the zoonotic pathogen infection, shed, spillover, and spread chain of events triggered by land use-induced environmental stressors. We term this ecological process, "land use-induced spillover." The goal of the "game" is to keep any of the dominos from falling by protecting and restoring landscape immunity, an aspect of ecological resilience. If we can prevent the first "domino" in the infect-shed-spill-spread causal chain of events from falling by protecting and restoring landscape immunity, the other "dominos" remain standing (Healthy Ecosystem panel). However, if landscape immunity is compromised via the disruption of ecosystem structure and function, wildlife infectious disease dynamics can be affected (e.g., through stress) and the chain of events that lead to spillover is triggered (Unhealthy Ecosystem panel). Ecological countermeasures are highly targeted land use interventions designed to minimize the risk of zoonotic pathogen spillover by arresting one or more of the environmental stressors that trigger land use-induced spillover. Although the focus of our paper is on landscape immunity and we make the case that securing landscape immunity is the ideal approach to pandemic prevention, we include ecological countermeasures relevant to the dynamics of proximity in this figure for completeness. In order to be effective, ecological countermeasures need to consider the entire infect-shed-spread-chain of events, placing focus on the components most feasible and timely in each context (i.e., interventions should be spatiotemporally "fit to context"). In some cases, the dynamics of proximity may need to be actively managed until landscape immunity recovers. Scenarios 1–3 are presented independently for clarity. At any location, more than one scenario may be appropriate, enacted simultaneously or sequentially

the likelihood that wildlife will release (shed) pathogens in ways and locations that lead to the infection of other animals of the same or different species, including humans (spillover). Environmental stressors can also change the behavior, abundance, composition, and struc-

ture of wildlife populations in ways that lead to high pathogen prevalence and shedding. Landscape immunity is defined as the ecological conditions that, in combination, maintain and strengthen the immune function of wild species within a particular ecosystem and prevent

elevated pathogen prevalence and pathogen shedding into the environment.

All organisms are physiologically influenced by chemical, physical, and biological conditions and have innate, generally taxa-specific, physiological parameters by which they thrive or are limited (Seiler et al., 2020). A detailed knowledge of what and how land use-induced environmental stressors can initiate the infect-shed-spill-spread chain of events is needed to identify the most strategic approaches to arresting the specific trigger(s) in particular contexts. Metaphorically, this is akin to garnering a thorough understanding of the factors that influence the first dominos to fall and subsequently to cause other dominos to fall. Plowright et al. (2021) propose that a high degree of landscape immunity enables wildlife to resist pathogen infection, lower prevalence, minimize shedding, or reduce their spread *in situ*, thus preventing the chain of events necessary for spillover to humans. From this perspective, landscape immunity thus governs initiation of the infect-shed-spill-spread cascade. In Figure 2, we use falling dominos to depict landscape immunity as an operationalized conservation principle and practice. Fundamentally, the landscape immunity construct considers the biological factors operating at the individual level from a systemic perspective—proposing that “health” is conveyed as a net effect of ecosystem function, and the operation of ecological resilience concepts is best achieved through biodiversity conservation (Chambers et al., 2019).

When land use change increases interaction between infected animals and people, it is more likely that zoonotic pathogens will spill over into human populations. The rate and scale of pathogen spread in human populations is largely driven by patterns of human contact (social behavior) and pathogen biology. The dynamics of proximity holistically refers to the pathways, type, degree, and frequency of contact that result in pathogen transmission. For spillover to occur, the contact must be between animals (or their pathogens) and people (dynamics of animal–human proximity). For spread to occur, the pathogen must be transmissible among people, and person-to-person contact is required (dynamics of human proximity). The dynamics of proximity govern the emergent spill-spread stages (Reaser et al., 2021a; Plowright et al., 2021; Figure 1).

The policy frameworks necessary to address landscape immunity and the dynamics of proximity are substantially different (Box 1). While the need to establish policies and practices to address the dynamics of proximity as an aspect of pandemic prevention is well recognized (e.g., Gibb et al., 2020), far less attention has been given to securing landscape immunity as a public health priority. Landscape immunity, as a new construct, provides the “aha moment” that has been needed to validate general observations, while also pointing to the new paradigms the world

must favor if we hope to effectively mitigate pandemic risks. Further, because landscape immunity factors govern the conditions that initiate the infect-shed-spill-spread cascade, we surmise that a government’s most strategic investment in pandemic prevention is protecting and restoring landscape immunity. For these reasons, the following section explicitly focuses on the paradigm shifts necessary to secure healthy landscapes to the benefit of human health.

3 | PARADIGMS FOR ROOTING LANDSCAPE IMMUNITY IN CONSERVATION POLICY FOR PANDEMIC PREVENTION

We propose four paradigms for policy makers, particularly national leadership, to adopt so as to secure and restore landscape immunity over the long term. Each paradigm places policy emphasis on the initiating components of LUIS—managing the ecological conditions that influence the risk of pathogen infection and shedding in wildlife. These “world views” can provide the overarching belief and value structures needed to actualize the full suite of nature-based solutions to COVID-19 advocated by leading conservation organizations and initiatives (e.g., Patz et al., 2004; Global Goal for Nature Group, 2020; IUCN WCPA, 2021; Schoonover et al., 2021), while preventing future pandemics.

Paradigm 1: Humans influence and are influenced by ecological systems. Government leaders have vital roles to play in helping their constituents recognize that they exist as part of rather than separate from natural systems; this cosmology is fundamental to motivating the world populace to live by values and actions that secure landscape immunity. Humans have always had an impact on the environment, and the environment an impact on *Homo sapiens*. However, there is an ever-increasing psychological and functional rift in the human–nature relationship. The illusion that humans exist apart from ecological system dynamics and the repercussions of ecological deterioration is the overriding essence of our current geological age, the Anthropocene. It is the driving force behind large-scale wildlife mortality events (e.g., Fey et al., 2015) and what some scholars are considering Earth’s sixth mass extinction (Ceballos et al., 2015; Payne et al., 2016). If this nature-dissociative mindset continues to be normalized, the increasing frequency, severity, and scale of anthropogenic land use change will undoubtedly hinder the ability of ecological systems to recover structure and function (Field et al., 2020). This stark possibility has led 12 global conservation and business organizations to call for the adoption of an integrated Nature-Positive Global Goal for Nature (Locke et al., 2021).

The One Health and Planetary Health interdisciplinary approaches provide frameworks for institutionalizing this paradigm of inter-relatedness. Government agencies and other policy-influencing bodies have been slow to demonstrate a strong inclination to break down silo walls and put a human–nature paradigm into practice. However, in light of COVID-19, there has been renewed progress with conceptual bridge-building and catalyzing professional collaborations (Amuai & Winkler, 2020; Waugh et al., 2020). The IUCN World Commission on Protected Areas (WCPA) has taken a leadership role in this regard. Recently, it published a Special Issue of *PARKS* that conveys technical guidance for conservation policy making as a pandemic prevention measure (IUCN WCPA, 2021; see also Hockings et al., 2020), including by identifying priority actions for addressing LUIS in protected and conserved areas (Reaser et al., 2021a). An IUCN WCPA Technical Note on a One Health approach to pandemic prevention has also been released to deliver succinct guidance to policy makers (Reaser, 2021), most notably those engaged in UN Convention of Biological Diversity negotiations (<https://www.cbd.int/sp/>, accessed 27 November 2021). It is our hope that these new guidance documents also prompt government leaders to circle back to the Sustainable Development Goals with the explicit intent of framing Goal 3 (Health) from a One Health perspective and adopting an indicator to measure progress in achieving co-investments in human, animal, and environmental health (<https://sdgs.un.org/goals>, accessed 27 November 2021).

Paradigm 2: Protecting human health is an ecological service. Environmental destruction and degradation negatively affect human quality of life. Thus, the protection of human health should be considered a paramount ecological service provided by nature (Patz et al., 2004; UN Millennium Project, 2005; PCAST, 2011). The landscape immunity construct regards conservationists as health care workers—practitioners safeguarding the health of the environment, wildlife, domestic animals, and people. Highly influential institutions, such as the WHO, acknowledge that “human health ultimately depends upon ecosystem products and services (such as availability of fresh water, food and fuel sources) which are requisite for good human health and productive livelihoods” (<https://www.who.int/globalchange/ecosystems>; accessed 27 November 2021). However, there is still considerable work to be done for governments, donor agencies, conservation organizations, and other policy-influencers to formally recognize the protection of human health as an ecosystem service (e.g., Keesing et al., 2010). Doing so requires that environmental impact assessments consider human health implications. This could help reduce the zoonoses risk of land use projects and increase the data available to link land use change to wildlife disease dynamics, thereby help-

ing to inform predictive models and identify risk mitigation options. For example, although the World Bank has a One Health Operational Framework (World Bank, 2018), it does not recognize the protection of human health as an ecosystem service within the Environment and Social Standards Framework (World Bank, 2016) that guides borrower's projects. If it did, the human health implications of Bank-supported projects that impact ecosystem services, such as dam construction, would need to be considered with regard to landscape immunity constructs.

The Global Health Security Agenda (<https://ghsagenda.org/>, accessed 27 November 2021) exists to achieve the vision of a world safe and secure from global health threats posed by infectious diseases. Although it did not arise with a conservation-explicit mission, it provides an ideal forum—in concept—for policy makers to adopt, and then take concerted measures to foster, an ecologically grounded human health paradigm. Bartlow et al. (2021) make the case for the application of biodiversity conservation to global health security, but point out that there has yet to be a formal mechanism established for integrating the environmental sector in the Global Health Security Agenda. If public health leaders, consistent with the G7 Communique' (UK, 2021), framed the protection of human health as an ecological service and recognized landscape immunity as a national security interest, the conservation sector would necessarily gain a prominent place at the negotiating table. It would also follow that the environmental sector would be recognized as a vital partner in the tripartite collaborations of the WHO, World Organization for Animal Health (OIE), and Food and Agriculture Organization of the United Nations (FAO). Large landscape conservation (i.e., securing landscape immunity) is a substantial gap in their guide to addressing zoonotic diseases (WHO, 2019).

Paradigm 3: An ounce of prevention is worth a pound of cure. Although these words have rung true since spoken by Benjamin Franklin, policy makers routinely fail to make the rational investments in prevention, cornering themselves in crises management scenarios (Segal, 2019). Dobson et al. (2020) provide a coarse-scale assessment of the costs of monitoring and preventing zoonotic spillover driven by tropical forest loss and degradation coupled with wildlife trade, drawing attention to the fact that the increasing demands of the COVID-19 response are likely to far exceed what would have been wise investments in long called for preventive measures. Preventing the introduction and spread of invasive alien species (of which zoonotic pathogens are a component) is well recognized as the most cost-efficient approach to biosecurity, and is also likely to be the most ethical approach to minimizing the hardships on animal and human health. Policy makers are thus wise to be strong advocates of measures to intercept zoonotic

pathogens, as well as the organisms that host and vector them, at points of entry and along conveyance pathways before the pathogens can establish in novel ecosystems (Wittenberg & Cock, 2001; Leung et al., 2002).

With regard to LUIS, prevention measures also include safeguarding landscape immunity to keep the first “dominos” in the infect-shed-spill-spread cascade from falling (Figure 2). Achieving landscape immunity, as an aspect of ecological resilience, is an aspirational yet requisite goal to actualizing conservation and sustainable development values in response to the tough societal reminders delivered by recent outbreaks of zoonotic disease. A comprehensive approach to biosecurity would take an ecological perspective, considering landscape-based conservation within biosecurity frameworks (e.g., Meyerson et al., 2009). Conservation policy practitioners need to seek out opportunities to create and support interministerial bodies, laws, and policies that take a comprehensive approach to biosecurity—one that is not limited to points of jurisdictional entry, but also addresses national security risks that emerge within landscape matrices. Within the “prevention first paradigm,” land use planning policy is thus a biosecurity measure. In human-dominated landscapes, policy makers can help prevent LUIS by taking a “biophilic cities” perspective—calling on biologists, social scientists, and land use planners to design human-dominated landscapes so as to limit human exposure to wildlife-originating pathogens. Human intrusion into wildlife habitats, wild animal–domestic animal contact, and wildlife attraction into human environments need to be considered (Reaser & Tabor, 2021).

Paradigm 4: Ecological restoration can heal a world of wounds. In highly altered ecosystems, restoration ecology principles and practices will need to be brought to bear to secure landscape immunity. Aronson et al. (2016) review the needs and opportunities for restoration ecology to serve public health goals. Reaser et al. (2021b) establish standards for the development of ecological countermeasures consistent for restoration ecology principles, as well as case studies for employing ecological countermeasures to reduce zoonotic disease risk reduction following deforestation and biological invasion. They suggest, for example, evaluating and further developing tree planting projects with zoonoses prevention services in mind. In order to meet biodiversity conservation, carbon sequestration, and other sustainable development goals, large-scale tree planting initiatives are being undertaken throughout the world (Bastin et al., 2019; Domke et al., 2020), although not without controversy (Veldman et al., 2019). These projects have the potential to influence landscape immunity by shifting the population dynamics of zoonotic pathogens, changing wildlife susceptibility to pathogens, and influencing pathogen shedding by altering conditions

that impact wildlife immune systems. Ideally, large-scale tree planting projects would be strategically harnessed as ecological countermeasures to facilitate landscape immunity by reducing the environmental stressors that trigger spillover. Ecological resilience is our best defense against future outbreaks of zoonotic disease.

The UN Decade on Ecological Restoration (<https://www.decadeonrestoration.org/>, accessed 27 November 2021) aims to prevent, halt, and reverse the degradation of ecosystems on every continent and in every ocean. It provides an ideal forum for government leaders and those who influence national-scale policy making to institutionalize this paradigm in multilateral frameworks and programs of cooperation. We encourage policy makers to provide the impetus and support for ecological countermeasures to become a priority feature of the Decades’ Initiatives Hub, thereby demonstrating ecological restoration’s key role in securing landscape immunity.

4 | CONCLUSION

Crisis is a conversation starter for reimagining and recommitting ourselves to what is most vital and generative. Such times call for visionary and courageous acts, a willingness to step into new paradigms at the expense of the systems that have held limiting norms in place. In the case of COVID-19, this means expanding the conservation policy mindset to include maintenance of human health as a vital ecological service, and for public health policy to acknowledge its ecological roots. It means mobilizing world leaders to become even more committed to protecting and restoring landscapes in order to ensure the biological resilience of their inhabitants and processes. It means facilitating public understanding of landscape immunity as a prevailing societal construct for sustaining human well-being. It means that we begin to invest politically, economically, and morally in that which generates life, a nature-positive world.

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CONFLICTS OF INTEREST

The authors do not have conflicts of interest to declare.

AUTHOR'S CONTRIBUTIONS

JKR, RKP, and GMT developed the conceptual framing of the paper with input from all coauthors. JKR led manuscript and figure drafting with substantial input from RKP. BH and MRA prepared the table with substantial input from JKR, RKP, DB, and PH. All authors participated in concept development and contributed their expertise to manuscript drafts. JKR led response to reviewer comments with input from co-authors.

DATA ACCESSIBILITY STATEMENT

There are no data associated with this manuscript.

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