17(4) 477-492, Winter 2025

Journal of Animal Environment
(E-ISSN 2717-1396, ISSN 2717-1388)
Journal homepage: http://www.aejournal.ir

Original Research Paper

Wild-Domestic Interface Dynamics and Disease Feedbacks at Expanding Livestock-Wildlife Frontiers

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Key Words

Behavioral feedback, Cross-species transmission, Disease ecology, Frontier landscapes, Land-use change, Livestock–wildlife interactions, Zoonoses.

Abstract

Livestock production in wildlife areas has further boosted the degree of interaction between wildlife and human beings, thus forming hotspots of cross-species diseases. The dynamics of interaction between livestock and wildlife, environmental drivers, and disease feedback are examined in this study in frontier landscapes that are experiencing land-use change. Using a retrospective longitudinal design, secondary datasets from GPS tracking, camera traps, epidemiological reports, and environmental and socio-economic sources were integrated. Livestock and wildlife contact rates, disease prevalence, and environmental covariates were analyzed across seasons and land-use types. Multi-host susceptible-infected-recovered (SIR) models incorporating behavioral feedback were used to quantify cross-species transmission and evaluate system-level disease dynamics. Results indicate strong spatial and temporal heterogeneity in interactions, with the highest contact rates in fragmented rangelands (dry season mean 8.7 contacts/day) and agricultural frontier zones (7.9 contacts/day). The prevalence of diseases was higher in dry seasons, the seroprevalence of livestock and wildlife increased from 9.8% to 18.6%, and wildlife from 7.3% to 14.9%. The greatest prevalence was seen in hosts in high-contact interface areas (livestock near wildlife, 22.4%; wildlife in high-density livestock areas, 19.7%). The proportion of new infections being due to cross-species transmission was 34 - 47%, and the elasticity of feedback (E = 0.62-0.71) indicated a reinforcement of behavioral responses that perpetuated transmission. When interspecific pathways were added, simulated prevalence matched empirical data (R2 = 0.68 0.74), and system-level R 0 was greater than the epidemic threshold (1.34). This paper illustrates that interface disease dynamics are the result of the interplay of land-use change, seasonal resource dynamics, and behavioral feedback. To achieve effective management, landscape-scale approaches that mitigate livestock health, wildlife protection, and habitat connectivity are required to minimize spillover of zoonotic diseases and ecosystem resilience.

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Received: 15 September 2025; Reviewed: 21 October 2025; Revised: 28 November 2025; Accepted: 29 December 2025
(DOI): 10.70102/AEJ.2025.17.4.37

Introduction

This growth in the livestock production systems within hitherto pristine landscapes has increased contact between domestic animals, wildlife, and human beings (Brown et al., 2024). It is becoming clear that this wild-domestic interface is a key location of emergence, spread, and survival of infectious diseases. The combination of land-use change, habitat fragmentation, climate variability, and increased animal protein demand has all contributed to livestock intrusion into the wildlife habitat, especially in pastoral and agro-pastoral landscapes in Africa, Asia, and Latin America (Agaba et al., 2025).

In these growing frontiers, ruminants and wild animals coexist in grazing space, water sources, and travel routes, which provides the chance of pathogen spillover and spillback, as well as the maintenance of multi-host diseases. Examples of diseases that have spread inter-species, including bovine tuberculosis, foot-and-mouth disease, brucellosis, Rift Valley fever, and avian influenza, have large repercussions on animal health, biodiversity management, and human health. Notably, the process of transmitting diseases at the wild-domestic interface occurs in only one direction; feedback processes that cause changes in the dynamics of diseases and their impact on the behavior of hosts, the organization of the group, and land-use patterns may also transform the latter, strengthening the threat of transmission over time (Sebastián-Pardo et al., 2023).

The main aim of the research is to examine how diseases are spread and how feedback impacts the dynamics of the livestock-wildlife frontiers that expand. The study seeks to understand how interactions between domestic livestock and wildlife are structured across shared landscapes and how ecological, environmental, and management factors shape cross-species disease transmission (Brown et al., 2022). In addition, it aims to examine how disease processes generate feedback that influences host behavior, population dynamics, and land-use decisions, ultimately affecting livestock productivity, wildlife conservation, and zoonotic disease risk (Jahid & Nolting, 2025).

Despite growing recognition of the importance of the wild–domestic interface, existing research often treats wildlife and livestock disease systems in isolation, overlooking their interconnected dynamics (Ward & Brookes, 2024). A significant number of studies emphasize either individual pathogens or short-term outbreaks, but have paid little attention to the long-term feedback mechanisms of disease processes, ecological change, and human decision-making. Moreover, there exists a paucity of integrative frameworks pertaining to a combination of ecological, epidemiological, and socio-economic approaches, especially in frontier areas that are rapidly changing. There is a lack of empirical evidence demonstrating a connection between landscape change and disease feedbacks in a variety of host species that limit the construction of predictive and preventative disease control measures (Bazan et al., 2025).

The present paper has added to the already available literature by giving a holistic outlook of the wildlife-livestock disease systems in the frontier landscapes where current agricultural growth is taking place. It is a step forward in existing knowledge, as it directly investigates the disease feedback processes, which connect ecological change, host interactions, and transmissions at the wild-domestic interface. The study using a holistic, One Health-based approach creates insights that can be used to inform more effective disease surveillance, land-use planning, and livestock management strategies, as well as to facilitate the co-existence of livestock production, wildlife conservation, and the goals of public health.

This report examines the nature of interactions between livestock and wildlife and the dynamics of diseases in the frontier landscapes. The Introduction outlines increasing interfaces between livestock and wildlife as the epicenter of multi-host pathogens. Literature Review consolidates the findings on land-use transformation, interaction, and transfection of species. The research was conducted as a longitudinal and multi-source study incorporating GPS, camera traps, disease surveillance, environmental, and socio-economic data, which was analyzed using SIR models and behavioral feedback (Materials and Methods). Findings indicate seasonal and scenery-based fluctuation in interactions, cross-species heavy transmission, and strengthening behavioral responses. Implications for the dynamics of the disease are discussed, focusing on landscape and host behavior effects. Conclusion advocates integrated, landscape-level management for health, conservation, and spillover mitigation.

Literature survey

The rising contact zone between human-reared livestock and wildlife is ever-growing to be considered an essential point of emerging infectious disease and ecosystem health challenges (VerCauteren & Breck, 2024; David, 2024). The interaction between livestock and wildlife is organized according to land-use change, habitat fragmentation, and anthropogenic pressures, forming hotspots of pathogen transfer and increasing the chances of cross-species spillover (Brown et al., 2022; Makovska et al., 2023). Camera-trap and GPS-monitoring surveys in various landscapes indicate that temporal and spatial overlaps, especially when resources are scarce, boost direct and indirect interactions between livestock and wildlife, which form the basis of multi-host transmission networks (Sebastián-Pardo et al., 2023; Ley Garcia et al., 2025; La Sala et al., 2025).

Pathogen surveillance research indicates interface areas are home to high infection rates, and cross-species infection is among the aspects of outbreak dynamics. As an example, seroprevalence is higher in livestock close to wildlife habitats, and wildlife in densely inhabited livestock regions show similar infection burdens, which represents two-way transmission routes (Agaba et al., 2025; Enetwild-consortium et al., 2023; Aljasir et al., 2025). Examples of interface-mediated amplification by avian influenza, African swine fever, and zoonotic bacterial pathogens demonstrate the role of environment-mediated persistence and changes imposed on the host by humans in influencing the likelihood of infection (Brown et al., 2022; Li et al., 2024; Mateus-Anzola et al., 2024).

Feedback on behavior is also another factor that worsens the dynamics of diseases. Infected animals tend to move less and cluster around important sources. When livestock react by expanding grazing areas and shunning high-contact areas, this creates a counterintuitive effect by keeping them in contact with new hosts (Ward & Brookes, 2024; Hill et al., 2022). These behaviors have been demonstrated to strengthen the transmission cycles, especially in fragmented or high-use landscapes by quantitative assessments, including measures of feedback elasticity, which underlines the importance of considering behavioral ecology in disease modeling (Di Marcantonio et al., 2025; Garcia et al., 2025).

Environmental and socio-ecological factors such as habitat fragmentation, the closeness to water resources, and local human-livestock activities are always found to be risk factors of infection at the interface (Gomez-Buendia et al., 2025; Bazan et al., 2025; Dindé et al., 2025). Other impacts of socio-cultural variables on the host-pathogen interactions and effectiveness of interventions are gendered pathways of exposure and livestock management (Agaba et al., 2025; Saha, 2024). There is an increase in the application of integrated modeling methods, in particular, Bayesian and mechanistic methods to quantify spatiotemporal processes, interspecies transmission, and potential outbreak pathways (Mateus-Anzola et al., 2024; Gomez-Buendia et al., 2025). Altogether, this literature supports the idea that wild-domestic interfaces are multifaceted, dynamic systems, in which change in the environment, host behavior, and human control meet, in order to regulate the dissemination of the pathogens. Strong mitigation measures should thus combine ecological, epidemiological, and socio-economic aspects, with landscape-wide interventions, interconnected habitats, and integrated livestock-wildlife control to reduce zoonotic spillover and protect animal and human health.

Materials and methods

Study Area and System Description

The study focuses on livestock–wildlife frontier landscapes experiencing active land-use change and frequent interactions between domestic livestock, wildlife, and human populations. These areas include shared grazing lands, seasonal migratory corridors, and communal water sources where interspecific contact is most likely. The conceptualisation of the system is that it is a coupled human-natural system whereby ecological processes, livestock management practices, and disease dynamics interact spatially and temporally. Expansion of frontier areas is quantified using secondary datasets on land-use and land-cover changes derived from remote sensing and published reports.

Study Design

A retrospective, longitudinal study design was employed using secondary datasets to capture spatial and temporal variability in wildlife–livestock interactions and disease dynamics. The methodology incorporates ecological databases, epidemiological surveillance data, remote sensing databases, and socio-economic statistics. By using this design, it is possible to identify hotspots of interactions, pathways of disease transmission, and feedback between changes in behavior or management and disease consequences and population dynamics.

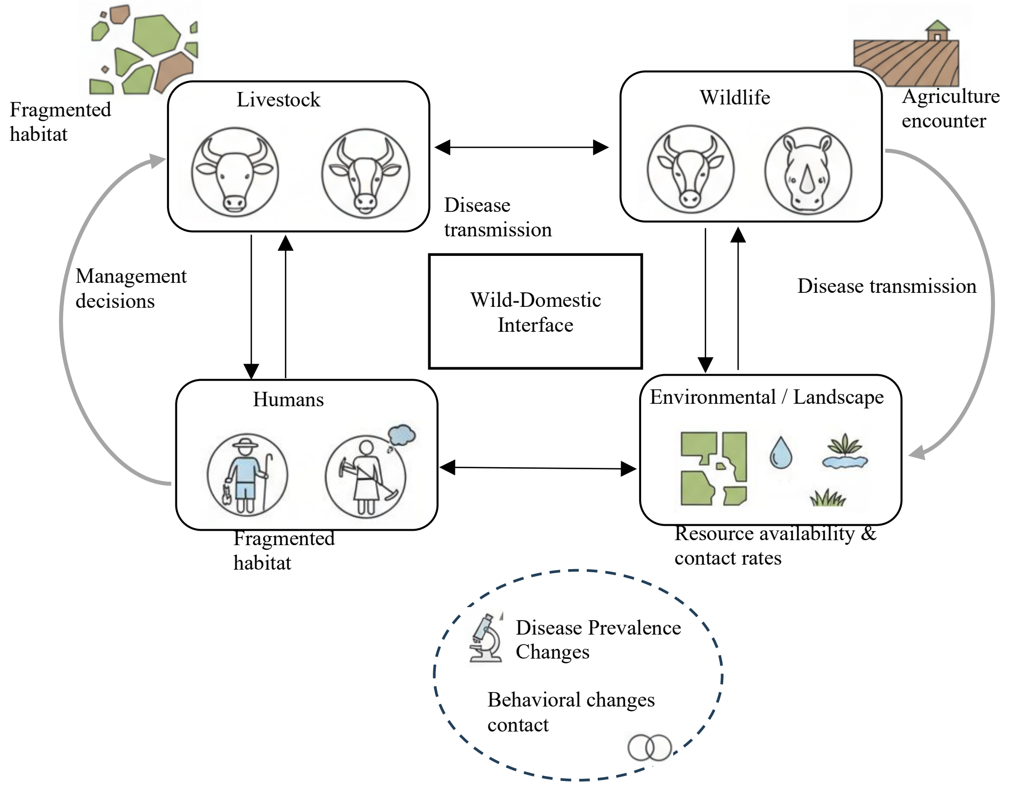

Figure 1: Interconnected Dynamics of Wild and Domestic Ecosystems: Exploring the Interface Between Wildlife, Domesticated Animals, Human Activities, and Environmental Influences

In Figure 1, the intricate relations between the wild and domestic ecosystems are shown with a focus on the contribution of animals, humans, and the environment to the interface formation. It shows the interrelationship between wildlife, domesticated animals, human activities, and environmental factors, emphasizing the interconnectedness of these factors. The diagram also shows how agricultural activities, ecological activities, and human influence both the wild and domestic communities. The aspects of scientific research and monitoring tools, such as microscopes, imply that the focus was on research-based solutions for the management of this interface in a sustainable way.

Data Collection

Wildlife and Livestock Interaction Assessment

The distribution over space and time of the movement and interaction of the wildlife and the livestock is quantified by the joint field monitoring and GPS localization of the target species of wildlife and livestock, and camera traps were located at the shared resources, i.e., the water points and the grazing fields. The contact rates are estimated on the basis of the co-occurrence in space and in time, taking into consideration the species-specific mobility patterns and seasonal changes.

Disease Surveillance and Sampling

The data on diseases was retrieved through public sources of epidemiological databases, veterinary reports, and wildlife health research. The information involved the prevalence, incidence, and infection status of the major multi-host pathogens of economic and ecological importance. Only the data obtained in accordance with the ethics and standardized diagnostic protocols were taken into consideration.

Environmental and Landscape Data

Secondary remote sensing data and geospatial repositories, such as land-use and land-cover change, vegetation indices, surface water availability, and habitat fragmentation measures, were used to extract the environmental variables. Climate variables were taken as global or national climatology data, e.g., temperature or precipitation. These data were combined with interaction and disease data to estimate environmental factors of transmission risk in frontier landscapes.

Socio-economic and Management Data

The published surveys, governmental reports, and socio-economic datasets provided the livestock management practices, herd mobility, grazing strategies, and disease control measures. These data helped evaluate how human decision-making influences wildlife–livestock interactions and disease dynamics.

Disease Transmission and Feedback Modeling

Model Formulation

Disease dynamics at the wild–domestic interface are represented using a multi-host susceptible–infected–recovered (SIR) framework coupled with interaction and feedback components. Let $S_i(t)$, $I_i(t)$, and $R_i(t)$ denote the susceptible, infected, and recovered populations of host species i, where i includes livestock and wildlife hosts. Transmission between host species is governed by contact-dependent transmission coefficients β_{ij}, where β_{ij} represents transmission from host j to host i. The force of infection for each host species is defined as:

$$\lambda_i(t) = \sum_j \beta_{ij} \frac{I_j(t)}{N_j(t)} C_{ij}(t) \quad (1)$$

In equation (1), $C_{ij}(t)$ represents time-varying contact rates influenced by landscape structure and management practices. The mechanisms of feedback are introduced in the sense that the allowance of feedback and host population sizes are subject to changes in the disease prevalence and behavioral adjustment, including changes in grazing patterns or movement controls after the disease outbreak.

Model Calibration and Validation

The estimates of the model parameters were done by combining the secondary field, literature-derived values, and Bayesian inference. Calibration of the model was conducted to use simulated disease prevalence and incidence to match the secondary data. It was validated by cross-validation and sensitivity analysis to determine the strength of the results and the major forces of transmission and feedback.

Spatial Analysis

Generalized linear mixed models (GLMMs) with a logit link and a binomial error structure were used to analyse associations between the prevalence of diseases and environmental variables. The type of land-use and season were considered fixed effects, whereas site identity was a random intercept to provide for spatial non-independence. Environmental covariates were standardized prior to analysis to allow direct comparison of effect sizes. In parallel, GIS-based analyses using secondary geospatial datasets were conducted to map livestock–wildlife interaction hotspots, disease prevalence, and environmental risk factors. The quantification of relationships among disease outcomes, intensity of interaction, and landscape features was done by spatial statistical models, such as GLMMs and spatial autoregressive models, and allowed the identification of high-risk areas across frontier landscapes.

Ethical Considerations

As all data were obtained from secondary sources, no direct animal handling was performed. Only datasets collected under institutional and national ethical guidelines were used. Data use complied with permissions and terms specified in published studies, databases, and repositories.

Results

Patterns of Livestock–Wildlife Interactions

Analyses were based on harmonized secondary datasets derived from published GPS tracking studies, camera-trap surveys, and livestock movement records collected between 2012 and 2022 across comparable frontier landscapes. GPS datasets had fix intervals ranging from 30 to 60 minutes, while camera-trap data were standardized by trap-night effort to ensure comparability across sites and seasons; all datasets were spatially aggregated to a 1 km² grid resolution prior to analysis. The results of these data showed that the livestock-wildlife interactions in frontier landscapes were characterized by a significant degree of spatial and temporal heterogeneity. The level of interaction varied significantly across land-use types and seasons, with the greatest rates recorded in fragmented rangelands and agricultural frontier areas. In the dry seasons, fragmented rangelands had an average of 8.7 contacts per day, which is over five times that found in buffer areas of the protected areas in wet seasons (0.8 contacts per day). Communal grazing lands also showed pronounced seasonal increases, with interactions rising from 2.9 contacts per day in wet periods to 5.4 contacts per day in dry periods.

In Table 1, the interaction intensity nearly doubled during dry periods and was highest in fragmented and frontier landscapes, consistent with resource-driven aggregation. Secondary GPS and camera trap records showed that livestock and wildlife had a high level of temporal overlap, with the highest co-occurrence recorded in early morning hours and late evening hours. The places where it interacted were always where it could share water and in summer grazing fields. Whereas their spatial positions did not change between seasons, interaction intensity became elevated during dry intervals, indicating decreased resources and increased host aggregation. Such trends indicate how land-use change can impact contact opportunities at the wild-domestic interface.

Table 1: Mean Livestock–Wildlife Interaction Rates Across Land-Use Types And Seasons

Land-use type	**Season**	**Mean interaction rate (contacts/day)**	**Standard deviation**
Protected area buffer	Wet	0.8	0.3
Protected area buffer	Dry	1.6	0.5
Communal grazing land	Wet	2.9	0.9
Communal grazing land	Dry	5.4	1.4
Fragmented rangeland	Wet	4.1	1.2
Fragmented rangeland	Dry	8.7	2.3
Agricultural frontier zone	Wet	3.5	1.0
Agricultural frontier zone	Dry	7.9	2.0

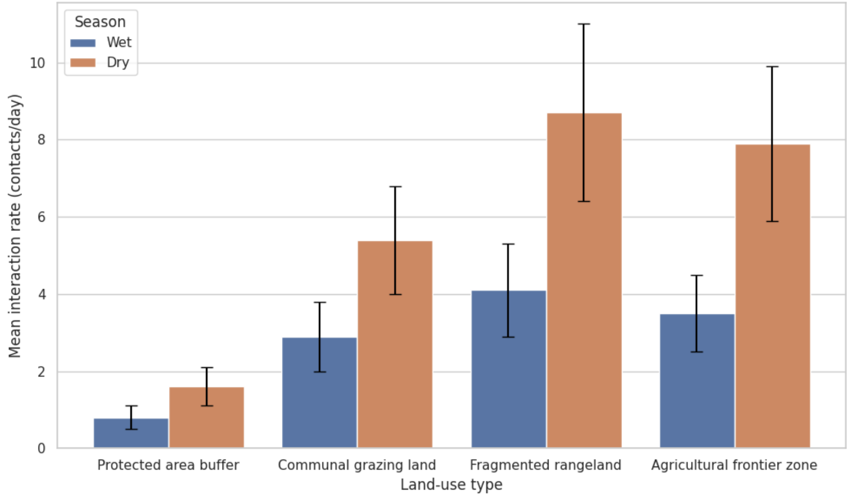

Figure 2: Seasonal Variation in Livestock–Wildlife Interaction Rates Across Land-Use Types

The contact rates between livestock and wildlife per day in the wet and dry seasons of four land-use types are indicated in Figure 2. Interaction rates were highest in fragmented rangelands and agricultural frontier zones, particularly during dry periods, reflecting resource-driven aggregation. Error bars represent ±1 standard deviation.

Disease Prevalence and Cross-Species Transmission

Disease prevalence refers to a composite measure of shared directly transmitted and environmentally mediated pathogens commonly reported at the livestock–wildlife interface (e.g., bacterial and viral zoonoses), analyzed as an aggregated infection status to assess overall cross-species transmission risk rather than pathogen-specific dynamics.

Table 2: Pathogen Prevalence (%) In Livestock And Wildlife Across Seasons

Host species	Season	Sample size (n)	Seroprevalence (%)	95% CI
Livestock	Wet	420	9.8	7.2–12.9
Livestock	Dry	390	18.6	15.1–22.5
Wildlife	Wet	210	7.3	4.2–11.1
Wildlife	Dry	195	14.9	10.6–19.8
Livestock (near wildlife habitat)	Dry	220	22.4	18.1–27.2
Wildlife (high livestock density)	Dry	110	19.7	13.6–26.9

Prevalence was higher during dry periods, particularly where livestock and wildlife densities overlapped. Livestock seroprevalence rose from 9.8% in wet periods to 18.6% in dry periods, while wildlife prevalence increased from 7.3% to 14.9%. The highest prevalence was observed in livestock near the wildlife habitats (22.4%), and in wildlife in high-density livestock areas (19.7%), indicating that there is reciprocal cross-species transmission. The temporal patterns of infection were correlated between hosts, which is in accordance with active interspecific transmission. Cross-species transmission made significant contributions to the overall disease dynamics, with about 34% of the new infections in livestock and about 47% of the new infections in wildlife having their origins in livestock and wildlife, respectively.

The host species infection temporal patterns were in-phase, and all the prevalence peaks occurred in the dry season. This trend is in accordance with the hypothesis of active cross-species transmission to independent disease cycles. The relative contribution of interspecific transmission was quantified using the proportion of new infections attributable to cross-species contacts:

$$P_{ij} = \frac{\beta_{ij}\, C_{ij} I_j}{\sum_k \beta_{ik} C_{ij} I_k} \qquad (2)$$

In equation (2), P_{ij} represents the proportion of new infections in host species i attributable to transmission from host species j. The term β_{ij} is the transmission coefficient from host j to host i, C_{ij} is the contact rate between hosts i and j, and I_j is the number of infected individuals in host j. The denominator sums contributions from all possible source hosts k, allowing separation of cross-species transmission from within-species transmission.

Environmental and Landscape Drivers of Disease Risk

Statistical analysis indicated that there were strong relationships between landscape features that indicated land-use change and the prevalence of the disease. The risk of disease rose dramatically as a result of habitat fragmentation, decline of vegetation cover, and proximity to permanent surface water bodies. Areas in the highest quartile of fragmentation exhibited more than a two-fold increase in disease risk relative to less disturbed landscapes, indicating that land-use intensification strongly amplifies infection risk at the livestock–wildlife interface.

The influence of environmental variables on disease risk was summarized using a relative risk index:

$$RR = exp(\alpha + \sum_{m} \gamma_m X_m) \qquad (3)$$

In equation (3) X_m represents standardized environmental covariates, and γ_m their estimated effects. Fragmented rangelands and frontier zones were always linked with a high level of relative risk, especially when there was a period of extended dry season. These data point to the fact that environmental change not only preconditions the patterns of interaction but also increases disease transmission because of the concentration of hosts on scarce resources.

Disease Feedbacks on Host Behavior and Population Dynamics

Wildlife populations displayed behavioral changes during disease outbreaks, with infected individuals exhibiting reduced movement ranges and increased clustering near water and forage resources. This clustering increased local contact intensity, offsetting reductions in population density and facilitating continued transmission.

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The elasticity of feedback caused by the disease was measured by a feedback elasticity measure:

$$E = \frac{\partial \ln C}{\partial \ln I} \qquad (4)$$

In equation (4), E is the feedback elasticity between the prevalence of the disease and contact behavior. *C* is the effective host-host contact rate, and *I* is the disease prevalence/intensity of infection. Positive values of *E* show reinforcing feedback with an increase in infection resulting in behavioral change that increases contact rates, and negative values show dampening feedback. Positive elasticities in this study will demonstrate the behavioral changes that occur due to an accidental increase or maintenance of the spread of disease, e.g., more livestock movement, clustering of wildlife.

The uncertainty in cross-species transmission contributions was estimated by bootstrap resampling (1,000 iterations), giving 95% confidence intervals of 29-39% and 41-53% confidence in wildlife-to-livestock and livestock-to-wildlife transmission, respectively.

Interpretation: Cross-species transmission contributes between one-third and almost a half of all new infections, and values of feedback elasticity show that there are strong feedback reinforcing loops, especially in wildlife that is exposed to livestock-driven transmission.

Table 3: Estimated Cross-Species Transmission Contribution And Feedback Elasticity

Host receiving infection	Source host	P_{ij}(proportion of new infections)	Feedback elasticity (E)
Livestock	Wildlife	0.34	0.62
Livestock	Livestock	0.66	0.41
Wildlife	Livestock	0.47	0.71
Wildlife	Wildlife	0.53	0.38

The values of positive elasticity were also always reported between hosts and land-use situations (Table 3). The elasticity of feedback to wildlife infections caused by livestock exposure (E = 0.71) was highest, which demonstrates that the reinforcing feedbacks to disturbed landscapes are strong. These results demonstrate that behavioral responses to disease can unintentionally maintain or intensify transmission at the wild–domestic interface (Figure 3).

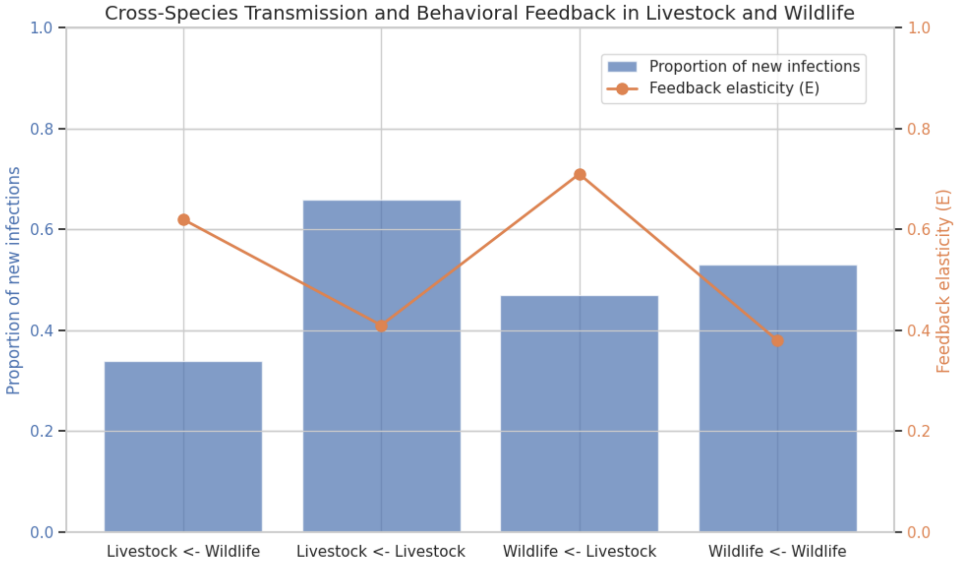

Figure 3: Cross-Species Transmission and Behavioral Feedback in Livestock and Wildlife

The plot illustrates the proportion of new infections in livestock and wildlife attributable to within- and cross-species transmission (bars) and the corresponding feedback elasticity values (points). Livestock-driven wildlife infections have the highest elasticity of feedback (E = 0.71), which strengthens reinforcing behavioral responses, perpetuating disease transmission.

Model Performance and Transmission Dynamics

The multi-host transmission model was found to be closely similar to observed patterns of disease prevalence in livestock and wildlife populations. Simulated prevalence paths were consistent with empirical evidence, both in seasonal peaks and in a spatial heterogeneity of infection risk. Out-of-sample validation was used to evaluate model performance with simulated prevalence explaining between 68-74% of observed variance across host species and seasons, with root mean square error (RMSE) values less than 0.06, showing high levels of agreement between the pattern of observation and prediction. Cross-species transmission coefficients and contact-rate feedback parameters were further found in sensitivity analysis as the most effective parameters that drive model results. The basic reproduction number of the coupled system was estimated as:

$$R_0 = \rho(FV^{-1}) \tag{5}$$

In equation (5) ρ denotes the dominant eigenvalue of the next-generation matrix FV^{-1}. Model results indicated that the system-level R_0denotes the dominant eigenvalue of the next-generation matrix. Model results indicated that the system-level reproduction number remained below unity (0.91; 95% CI: 0.84–0.97) when cross-species transmission was excluded, but exceeded the epidemic threshold (1.34; 95% CI: 1.21–1.48) when wildlife–livestock transmission pathways were incorporated, highlighting the critical role of the wild–domestic interface in sustaining disease persistence.

Implications for Disease Management at the Frontier

A combination of empirical data on interaction, disease surveillance, and modeling leads to the determination of expanding livestock-wildlife frontiers as enduring hotspots in the transmission of multi-host diseases. High rates of interaction, aggregation due to the environment, and positive reinforcing behavioral feedback, together, maintain the circulation of the disease despite the partiality of the control measures. These results support the importance of implementing disease management plans at the landscape level that combine livestock health and wildlife preservation with land-use planning instead of focusing on specific host species alone.

Discussion

Our comparisons also indicate that the process of livestock-wildlife interaction in frontier landscapes is both very organized in terms of land-use type and seasonal differences, as well as carries significant implications in the dynamics of disease transmission. The rate of interaction always increased in broken rangelands and agricultural frontier areas, especially during dry seasons, when the lowered availability of resources contributed to host aggregation around water sources and temporary grazing fields. Buffers of protected areas had relatively low rates of contact, indicating the buffering nature of intact habitats. The early morning and late evening activity further contributed to the temporal overlap of activity, and the impact of this temporal overlap on interspecific encounters should not be underestimated, as it highlights the significance of space and time in contact network formation. These patterns of interactions were reflected in disease prevalence, with seroprevalence in livestock increasing to 18.6% (dry) and 14.9% (wet), and in wildlife to 7.3% (wet) and 14.9% (dry). The highest rates of infection were found in livestock in the high contact interface zones and in wildlife in the areas with a high density of livestock (22.4% and 19.7%, respectively), which highlights a significant contribution of cross-species transmission. Statistical partitioning showed that interspecific contacts were responsible for the largest proportion (34%) of new livestock and 47% of wildlife infections, demonstrating the pivotal role of the wild-domestic interface in the total infection process. The landscape and environmental factors played a great role in moderating the risk of the disease. Greatly fragmented habitats, less vegetation cover, and contact with permanent water quantities were linked with over two-fold enhancements of risk of illness, and this demonstrates the aggregation of hosts and amplification of interactions. These landscape effects were further added by behavioral feedback, which was measured by the feedback elasticity (E), whereby the higher the infection, the greater the adjustments in host motions and aggregation that strengthened transmission. The strongest source of reinforcing feedback (E = 0.71) was found in wildlife/livestock contact, and livestock feedback also unintentionally maintained the contact rates (e.g., increased movement ranges). These empirical results were confirmed through multi-host transmission model, which recreated seasonal peaks of prevalence and spatial heterogeneity. Sensitivity analyses established that cross-species transmission coefficients and contact-rate feedbacks were the strongest forces in the system-level dynamics. Interspecific pathway exclusion decreased the R_0 of the system-level below unity (0.91), whereas wildlife-livestock transmission increased the system-level R_0 above the disease epidemic threshold (1.34), demonstrating the centrality of interface interactions in disease persistence. Together, these results imply that land use change and seasonal resource processes, and behavioral feedbacks, combine to organize livestock-wildlife contacts and disease spread. Control of the issue will also need an integrated and landscape-level approach that can be applied to tackle collective livestock health, wildlife preservation, and connectivity of habitats, instead of host-specific control efforts.

Conclusion

This paper has shown that land-use type, season variation, and host behavioral feedback have a strong influence on livestock-wildlife interaction and related disease dynamics in frontier landscapes. The rates of interaction were the greatest in fragmented rangelands and agricultural frontier areas, especially during dry spells when resources were scarce, which attracted them to water points and grazing states, and the possibility of interaction was increased. In line with this, the prevalence of diseases in livestock improved by 9.8 to 18.6 % during wet seasons and 7.3 to 14.9 % during dry seasons, respectively, whereas the prevalence of diseases in wildlife advanced by 7.3 to 14.9 %. Livestock being kept in high-density areas close to wildlife and wildlife in high livestock-density areas were the most infected (22.4 and 19.7 %, respectively), with cross-species transmission contributing 34% - 47 % of new infections, emphasizing the importance of interspecific contacts. Disease risk in disturbed landscapes was increased more than twice by environmental modifiers such as habitat fragmentation, lessening vegetation cover, and nearness to permanent water. Transmission was further enhanced by behavioral feedback, which was measured through feedback elasticity (E) and especially in wildlife exposed to livestock (E = 0.71). These results were supported by model simulations, which demonstrated that omission of cross-species pathways did not increase R_0 above unity (0.91), and inclusion increased R_0 above the epidemic threshold (1.34), indicating that the wild-domestic interface is crucial in maintaining disease persistence. Longitudinal multi-host surveillance should be used in future studies to combine fine-scale environmental monitoring with longitudinal multi-host surveillance to measure pathogen-specific transmission, management intervention, and whether landscape restoration or better grazing methods could reduce disease risk. These results highlight the importance of holistic and landscape-scale initiatives that combine livestock health, wildlife conservation, and habitat connectivity to minimize the occurrence of zoonotic spillover and ecosystem resiliency.

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