One Health Outlook

COMMENTARY

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Zoonosis: social and environmental connections in the Mexico-United States border region

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Abstract

The emerging risks facing humanity have highlighted the need to address and prevent challenges through multilateral preventive strategies. The Mexico-United States (US) border is a region with great biological biodiversity and both countries shared a similar history and intense socioeconomic, and cultural interrelationships. Also, it has an extraordinary ecological contrast, resulting in an enormous biological diversity in a broad Nearctic-Neotropical transition zone. This dynamic region has important disparities due to the lack of bilateral strategies to face emerging issues (e.g., infectious diseases) in an integrated and holistic approach. In this context, we describe the various socio-ecosystemic contexts of the shared border and present different diseases transmitted, and different zoonoses that affect ecosystemic public health that must be addressed under collaborative schemes that can develop preventive policies under the One Health approach with emphasis on the Mexican zone. We describe the social determinants of health issues for the border, but we add ecological contexts infrequently studied in classical epidemiological approaches. Strategies towards One Health require international and multidisciplinary approaches that strengthen diagnostic capabilities, recognizing social, and environmental challenges. Recognizing these aspects will allow the establishment of joint monitoring, prevention, and mitigation strategies with benefits for both countries.

Keywords Disease transmission, One Health approach, Migration, Marginalization, Environment degradation

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The Mexico-United States (US) border region extends 3,168 km from the Gulf of Mexico to the Pacific Ocean and is defined as a strip of land within 100 km on either side of the Mexico-United States border. There are approximately 14 million people concentrated primarily in 14 binational sister cities, 7.3 million residing in the United States and 6.8 million in Mexico [1]. Additionally, it is one of the busiest international land borders in the world with constant legal and illegal migration, including migrants with a wide variety of nationalities, mainly from Central America, South America, and the Caribbean islands [2, 3]. The Mexico-United States border historically has maintained a relationship of human mobility as well as political and economic processes [4]. The unilateral border control policies of the United States are the most conspicuous expression of the asymmetry of border relations [5]. Which have their counterpart in the ideology of opportunity that still is prevalent on the Mexican side. Not surprisingly, given the marked inequality between Mexico and the United States, the geopolitical border is a region of many ecological, socioeconomic, and cultural contrasts, and similarities [6]. Based on this, emerging issues in justice, equity, conservation, sustainability, and health must be addressed comprehensively in One Health approaches to generate social welfare.

Driven by the biological complexity of neglected (e.g. tuberculosis), emerging and re-emerging infectious diseases (e.g. vector borne diseases), and endemic diseases (e.g. hepatitis A, HIV) occurring along the border, we emphasize in this manuscript this transdisciplinary conflict showing how social, and ecological challenges are related between each other in the transmission and maintenance of infectious diseases in the Mexican border region. We propose bilateral and transdisciplinary strategies that can be implemented by contrasting the two borders through assessment, mitigation, and prevention actions under a One Health initiative. Because we emphasize the Mexican border aspects, the examples exposed in this manuscript are particularly related to the Mexican reality.

Scenarios of risk and exposure to infectious diseases

The Mexico-United States border is a dynamic region that receives many migrants from all parts of the world. Migration from southern Mexico and other Latin American countries is continuous and increasing, both for the search for employment and housing in the Mexican border cities (Baja California, Sonora, Chihuahua, Coahuila, and Tamaulipas), as well as attempts to cross into the United States [7].

In 1994, the most important trade agreement between Mexico and the United States (The North American Free Trade Agreement - NAFTA) was signed, substantially increasing binational trade transactions (US$406 billion in 2010), however it did consider the labor flow between both countries [8]. With a wage differential of almost ten times between the two countries, undocumented labor migration became massive. Population movements can accelerate the spread of pathogens in the human population due to population displacements because of constant interactions between countries [8].

These dynamics have led to an environment in which populations remain socially vulnerable, leading to scenarios of risk and exposure to various infectious diseases, including zoonosis. Border region migration patterns may contribute to the risk of infectious diseases favored by marginalization [8] through the insertion of populations into scenarios of political dispute that bring about confrontations with multiple socioeconomic inequalities between access and the right to health care services [9].

For example, within Baja California is situated one of the busiest border crossings of the world (Tijuana-San Ysidro), where millions of people and vehicles cross the border each year [10]. This is of major concern because a high rate of flow of people leads to (1) a higher human density population that increase the spread of diseases through contact; (2) the introduction of new pathogens in places where neither people nor animals may have been in previous contact due to the various reasons caused by human migration. These include irregular immigration of human populations whose health processes are significantly impacted and violated by the conditions of marginality, which may be related to a higher prevalence of diseases (e.g., gastrointestinal ailments due to lack of water sanitation, or treatments for chronic degenerative diseases which need to be monitored, and are neglected for fear of deportation); and (3) a higher consumption of products that create a greater amount of waste which saturate municipal landfills causing a profusion of commensal animal species such as *Rattus rattus*, *R. norvegicus* and *Mus musculus*, as well as ectoparasites and mosquitoes, important reservoirs and vectors of zoonotic pathogens [11, 12].

Marginalization for health care access

Directly or indirectly, the inhabitants of the border areas are affected in their daily lives by the challenges that arise from being part of an international border and are impacted by the relations and political choices of both countries. All these socio-economic disparities have an impact on the health systems with contrasting gaps in the quality of health between both countries as well. With the restrictions on crossing into the United States which began to increase in the 1990s, asymmetries were revealed between both countries, changing behavior among their inhabitants, and resulting in a cultural process occurring through ethnic and racial relations of subordination and processes of exploitation, exclusion, and expulsion [13]. The lack of education on disease transmission, clinical symptoms, and prevention, coupled with marginalization for health care access, and massive migration, have reduced the capacity for prevention, and control of multi-causal diseases [14].

30% of all tuberculosis cases reported in both the United States and Mexico occur at the border region between these two countries, a disease caused by *Mycobacterium* species [15]. The incidence of tuberculosis in the United States has declined over the past decade. Despite its decline, the border states (California and Texas) are among the four states with the highest incidence of tuberculosis in the United States [16]. The northern border states of Mexico, Baja California, Sonora, and Tamaulipas have the highest rates of tuberculosis in the country [15]. The path of movement of the *Mycobacterium* species tends to reflect the migratory routes from the central and southern states of Mexico, as well as from Central America to the United States [15]. The migration process, poverty, prolonged infectiousness, increased drug resistance and poor access to health services are likely to favor disease transmission. At the same time, the cultural frameworks and particular health processes of migrants that may or may not contain knowledge about the transmission of infectious diseases from the place to which they arrived [15, 16].

Poor sanitation, changes in customs and lack of education

The structural and political conditions of international illegal migration generate overcrowding and poor sanitary conditions, which in turn, may bring about a confrontation between the habits and customs of migrants exposed to new health contexts leading to the spread of infectious diseases [17].

During their transit, migrants run a high risk of contracting, developing, and transmitting diseases. The constant fear of being caught keeps migrants away from public health services, delaying the diagnosis and treatment of diseases. In the case of HIV (Human Immunodeficiency Virus), the change in the migrant's environment may favor the presence of people who are homeless, isolated, alone, and financially unstable, resulting in significant cultural contrasts. These factors can result in behavioral changes, limited access to medical care, new sexual partners, and drug use [18], this is evidenced by an increase in the number of HIV diagnoses at the Mexico-United States border. According to a study conducted in 45 counties in Arizona, New Mexico, and Texas, 47% of people diagnosed with HIV in this border region are Hispanic [19]. In these bordering states, Hispanics are more likely to be uninsured, which increases the likelihood of delaying or not receiving medical care due to cost [19].

The migratory process, especially when it is considered "Illegal" is a displacement that may be related to socioeconomic, political, health or environmental conflicts [20]. The constant arrival of new populations with various epidemiological backgrounds, when sufficiently consistent and massive, may alter of the epidemiological profile of the host country. This in turn leads to new infectious disease burdens in unexpected environments [21].

Environmental degradation

From its ecological conception the northern border of Mexico, stands out for its presence of six ecoregions, containing desert scrublands, temperate forests, semi-desert grasslands, plains, subtropical scrublands, freshwater, and marine wetlands, ensuring a huge and varied diversity of species [22]. Due to its vast extension, the Mexico-US border is not only composed of diverse ecosystems, but also varies in the type of human activities that impact the environment and, therefore, generate an imminent hazard for the burden of future zoonoses [23]. In the six states that compose the border on the Mexican side (East to West: Baja California, Sonora, Chihuahua, Coahuila, Nuevo Leon, and Tamaulipas), there are also variations in public policies and in efforts and interests by the civilian population regarding human health, animal health, and environmental health issues [11, 24]. The effects of environmental degradation on disease emergence have huge information gaps. Therefore, there is an urgent need for increased research in this field.

Environmental pollution

One of the most important global challenges in public health, especially in less favored regions, is infectious diseases transmitted by contaminated air, water, or food [25]. These require a multidisciplinary and multi-causal approach to understand the patterns and processes that favor the establishment and transmission of these infectious agents. It is common for there to be enormous differences in prevention, control, and monitoring programs between sister regions with different social and economic conditions [26].

Air pollution linked to the high number of vehicles crossing into the US and the pollutants from Industry as *Maquiladoras* represents an imminent risk to human health by decreasing the animal and/or human host response against respiratory pathogens [24, 27]. Other phenomena of high importance in the region are related to mining activity because of their negative effects on environmental, animal, and human health. A clear example of both phenomena in Sonora was the case of the ecological disaster in the Bacanuchi and Sonora Rivers in 2014 caused by a toxic waste spill from the Buenavista del Cobre copper mine [28]. Although poorly addressed, it has been evidenced that certain residues from mining activities can exert a decrease in the immune response of different organisms, including animal species that can potentially be hosts [29]. Therefore, a deficiency in the immune response may make certain species even more susceptible to infection by new pathogens with zoonotic potential [30].

Several important neglected zoonotic infections of poverty occur due to water pollution. Their transmission depends on host-vector-pathogen interactions and landscape characteristics that facilitate or limit this interaction [31]. Water pollution is a major concern due to the urban and agriculture use of the Colorado River and the Rio Bravo basins, in which the presence of fecal coliforms and potential risk of infection for *Cryptosporidium* have been reported [32, 33]. Additionally, a cluster of suspected cases of Guillain-Barré syndrome related to a previous *Campylobacter jejuni* outbreak was identified in San Luis Río Colorado, Sonora, Mexico and Yuma County, Arizona, USA. Twenty-six patients, 18 from Sonora, eight from Arizona (all with travel history to the San Luis Río Colorado area) were identified with Guillain-Barré syndrome. The 61% of the 18 patients evaluated were seropositive for IgM antibodies to *C. jejuni*. Exposure data and an environmental assessment suggested that the cases were due to a large outbreak of *C. jejuni* infection due to untreated drinking water in San Luis Río Colorado. This was the first outbreak reported in continental North America since 1976 [34].

Environmental disturbed and Biodiversity loss

The Mexico-US border is a region where complex social and ecological processes interact and where human activities have produced diverse environmental impacts and a high degree of landscape heterogeneity [35]. Land-use change, mainly for agricultural and livestock purposes, followed by increasing urban transformation where lives most of the human population, represent the most important threats to the environment [36, 37]. Thus, animal communities can be affected by modifying their composition either by decreasing their richness or by increasing the abundance of invasive species often reported as important reservoirs of zoonotic pathogens [38]. The result of these changes relay on the risk of zoonotic diseases due to increased contact between humans and animal reservoirs, thus potentially facilitating pathogen transmission [39].

In the region of Janos, Chihuahua, evaluating the influence of habitat type on the abundance and distribution of hantavirus reservoirs, seropositive were found in mesquite and grasslands without prairie dogs (*Cynomys ludovicianus*; 32% overall seroprevalence). Mesquite thickets harbored significantly higher abundance of reservoir hosts (*Peromyscus leucopus* and *P. maniculatus*). Because black-tailed prairie dogs prevent the expansion of mesquite thickets into grassland habitats, their colonies may indirectly prevent hantavirus host dispersal and expansion in this landscape [40]. In recent decades, it has been hypothesized that the loss of diversity driven by the intensification of land use and fragmentation of conserved areas could increase the likelihood of zoonotic pathogen transmission [41].

In 2010, the first known outbreak of Shiga toxin-producing *Escherichia coli* (STEC) was reported in the desert leafy green vegetable production region of the western Mexico-US border. It was implicated in a multi-state outbreak of *E. coli* O145:H28 infections. According to local vegetable growers, lose or stray domestic dogs and free-roaming coyotes are a major problem due to intrusions into their crop fields. In fecal samples from stray dogs (358) and coyotes (103) from land near the production fields, atypical enteropathogenic *E. coli* (aEPEC) strains comprising 14 different serotypes were isolated. *Salmonella* spp. was cultured from samples from dogs and coyotes, comprising 29 serovars. Although it cannot be suggested that stray dogs and coyotes are sources of STEC, they are potential reservoirs of pathogenic *E. coli* and *Salmonella* spp [42].

Intraspecific host encounters

Considering that most zoonotic diseases can also infect multiple host species, it is essential to recognize the risk factors associated with the dynamics of disease transmission, specifically the risks and sources of transmission between humans, their domestic animals, and wild animals [43].

Based on more than 15 years of research in the Mexico-United States border area by researchers from the Laboratory of Disease Ecology and One Health of the Faculty of Veterinary Medicine and Zootechnics, National Autonomous University of Mexico. It is worth mentioning the presence of zoonotic infectious agents in domestic, wild hosts, specially synanthropic animals, and ectoparasites that highlight the need for more research and disease control programs. For example, In Chihuahua, the presence of *Borrelia burgdorferi sensu stricto* and *Rickettsia massiliae*, responsible for Lyme disease and rickettsial fever, has been detected in ticks associated with free-ranging dogs and wild mammals [44], and in this same state and in neighboring Sonora, a high genetic diversity of *Bartonella* bacteria has been observed in rodents, carnivores and their fleas [45–47]. In Baja California, López-Pérez et al. [48] stated that dogs can serve as sentinels and play an important role in spreading ticks and pathogens. In addition, at the border region shared by Yuma in Arizona, and Ensenada and Mexicali in Baja California, the presence of multiple zoonotic agents of Spotted Fever Group Rickettsia was detected in wild animals and ectoparasites [49].

Also, migration is important in the dynamics of vector borne infectious diseases. Migrants are transported in unsanitary crowded conditions, which promote direct contact benefiting vectors such as lice or fleas. In addition, the transit of migrants through areas far from the main towns forces them to seek resting places and paths to walk on, which considerably increases exposure to ticks and chiggers found in the vegetation. These vectors can also be found on wild and feral animals, which can come into contact with migrant groups. These contacts, direct or indirect, facilitate the movement of pathogens from one country to another [50].

Approximation of the interaction between domestic animals and wildlife – case of domestic dogs

Marginalized areas of the Mexican border are characterized by poor access to sanitary and health systems, reduced awareness of domestic animal management and deficient epidemiological control programs. Canine populations in urban environments with high dog density have a higher rate of contact and therefore a higher risk of transmission of different diseases [51]. However, in the case of zoonotic diseases, the probability of interspecific transmission is higher at the rural interface, where there is more contact between humans, and domestic and wild animals [52]. These emphasize aspects related to care and management of domestic animals, highlighting the free movement habits of dogs [53].

A survey that we conducted with owners of dogs in three border regions (Janos, Mexicali, and Los Fresnos) shows deficient care by owners than has been attributed to a lower initial value invested in the animals. The deficiency in the type of food provided (mostly leftovers) and dependence on other food sources may be causing a need for movement of the dog in search of food. One could expect an entry of dogs to protected or agricultural areas in search of food, favored by their freedom of movement. Also, most animals in the three regions present low vaccination, and internal and external deworming. These conditions are commonly associated with unprivileged socioeconomic circumstances of the owners, such as those generated in rural and marginalized areas [54].

Cross-border dynamics of mosquito-borne disease transmission

Mosquito-borne diseases present considerable public health challenges in the U.S.-Mexico border region, exacerbated by human migration, bird migration, and the transportation of mosquito larvae in water containers. Arboviruses such as dengue, Zika, and chikungunya are principally transmitted by *Aedes aegypti* and *Aedes albopictus* mosquitoes, whose proliferation is facilitated by human activities. The importation of used tires from the U.S. to Mexico provides ideal breeding grounds for these vectors, contributing significantly to disease transmission dynamics [55]. The large-scale importation of used tires is a major contributor to the spread of *Aedes albopictus*, a highly efficient vector of arboviruses not native to the region. The accumulation of water in these tires creates ideal breeding sites for mosquitoes, leading to outbreaks of dengue, Zika, and chikungunya in both Mexico and the U.S [56].

Infected individuals crossing the border, legally or illegally, introduce pathogens into ecosystems where susceptible mosquito populations thrive, further linking the epidemiology of outbreaks in Mexico and U.S. border states [57, 58]. Additionally, mosquito larvae transported in stagnant water containers, such as those in vehicles, pose a less-recognized but significant risk for spreading pathogens across the border. Once larvae establish themselves in new locations, arbovirus transmission can occur, provided conditions are favorable [59]. Although substantial progress has been made in understanding vector-borne disease transmission, gaps remain, particularly concerning the role of human migration in cross-border disease dynamics. Further research is needed to understand how imported mosquitoes establish themselves in local ecosystems and interact with native populations to develop effective vector control strategies.

Migratory birds serve as natural reservoirs for various pathogens, including the West Nile virus, which is transmitted by mosquitoes. Birds crossing the U.S.-Mexico border can transport these pathogens over long distances, introducing infectious diseases into new areas. Several studies have shown that migratory routes overlapping the border may be linked to increased vector-borne disease incidences, especially in regions where mosquitoes are abundant [60].

Agricultural trade and transportation of live animals

The movement of livestock, particularly cattle, between the two nations is frequent, with numerous animals crossing the border for breeding, rearing, and slaughter purposes [61]. This is particularly relevant given the high demand for agricultural products on both sides of the border, where the meat and poultry sectors play a crucial role in trade [62]. When safety protocols are not strictly followed meat and poultry products can serve as vehicles for the spread of diseases such as avian influenza, salmonellosis, and other bacterial or viral infections [63]. Factors such as inadequate sanitation, poor handling, and improper storage or transportation conditions can exacerbate the risk of disease transmission [64].

While the regulated trade of live animals is largely controlled and monitored, the illegal trade of exotic and domestic animals across the U.S.-Mexico border presents a significant biosecurity concern [65]. The transportation of live animals, especially under inadequate sanitary conditions, increases the potential for the spread of infectious diseases. This is particularly true when considering animals that are not part of the usual agricultural supply chain, such as wildlife and exotic species, which may harbor unknown pathogens with zoonotic potential. The introduction of these animals, either legally or illegally, into new environments may disrupt local ecosystems and expose both humans and animals to novel infectious agents [66]. These pathogens can spread rapidly in both wildlife populations and domestic animals, and they may also pose direct risks to human health. The lack of adequate sanitary measures during illegal transportation exacerbates the situation, providing ideal conditions for pathogens to thrive and spread. The risks posed by illegal wildlife trade across the U.S.-Mexico border must therefore be taken seriously and addressed through coordinated surveillance.

Impact of the U.S.-Mexico border wall on wildlife and pathogen dispersal

The construction of the U.S.-Mexico border wall has had profound effects on the movement of both humans and wildlife. While the wall is designed to limit illegal human immigration, it also presents a formidable barrier to the natural migration of wild animals. This disruption of migration patterns can have significant ecological consequences, particularly for species that rely on cross-border movement for breeding, feeding, or other ecological needs [67].

The interruption of wildlife migration may also have consequences for the spread of zoonotic diseases. Wildlife migration is a crucial process for species conservation. However, this migration poses the risk of bidirectional transmission of endemic infections between countries, making constant monitoring indispensable. Migratory species, such as birds and large mammals, can act as reservoirs or carriers of pathogens, which they may introduce into new environments as they traverse different regions. Although the potential for wild animals to disperse pathogens across the U.S.-Mexico border is still underexplored, it is an increasingly concerning issue that warrants further investigation. The border wall may inadvertently concentrate animal populations on one side of the border, increasing the density of species such as deer, coyotes, and rodents, which are known carriers of zoonotic pathogens [67]. This could lead to localized outbreaks of diseases that may otherwise have been mitigated by natural migration patterns.

Additionally, the fragmentation of habitats due to the border wall may force wildlife into closer proximity to human settlements and agricultural areas, further increasing the risk of human-wildlife interactions and the potential transmission of zoonotic diseases [68] The need for more comprehensive studies on the long-term impacts of the border wall on zoonotic disease emergence is evident, as current evaluations have largely focused on the immediate effects on wildlife behavior and biodiversity loss.

Conclusions

In conclusion, the border region between Mexico and the United States presents a complex landscape of interconnected socio-ecological challenges that have a direct impact on public health. The dynamic interactions among human populations, migration patterns, environmental degradation, and biodiversity loss create fertile ground for the emergence and transmission of infectious diseases and zoonoses. This manuscript highlights the urgent need for collaborative and holistic approaches, particularly within the One Health initiative to address the multifaceted issues affecting the border region. By recognizing the interplay between social determinants of health, environmental factors, and disease dynamics, we can develop comprehensive preventive strategies that benefit both countries.

Since several human-induced phenomena can be directly or indirectly related to the risk of zoonotic diseases at the border region between Mexico and the United States, and due to the small number of studies demonstrating this association, we encourage researchers to consider a landscape scale that includes human activities as an integral part of the overall system, as well as their effects on the dynamics of pathogens and their reservoirs, encompassing not only animals but also abiotic reservoirs such as soil or water. In this scenario, several socioeconomic and ecological variables or methods can help assess the degree of disturbance (or conservation) in the region, ranging from the use of individual indicators such as the degree of land-use change and fecal pollution in water [69, 70], to more integrative methods such as anthropization, human footprint, or ecological vulnerability/integrity indices [71, 72].

The U.S.-Mexico border region presents a unique ecological and socio-political environment that fosters the transmission of vector-borne diseases. Human migration, bird migration, and the movement of mosquito larvae through human activities such as tire importation all play a role in introducing and sustaining mosquito-borne pathogens. However, several knowledge gaps limit our ability to fully understand the transmission dynamics across this border. Addressing these gaps is essential for developing targeted interventions and control measures. Future research should focus on improving our understanding of how human mobility, environmental changes, and trade activities influence the spread of vector-borne diseases across borders. By closing these gaps, public health efforts can more effectively manage and prevent outbreaks in this vulnerable region.

By leveraging the One Health approach, this manuscript underscores the importance of collecting and integrating data across human, animal, and environmental health sectors. Through collaboration among diverse institutions—universities, diagnostic laboratories, NGOs, and public health agencies—data sharing becomes the backbone of a successful zoonotic disease prevention strategy. Using successful models, this initiative can address public health challenges along the U.S.-Mexico border. Furthermore, through sustainable financing and international support, this strategy can be effectively implemented, offering a robust response to emerging zoonotic diseases.

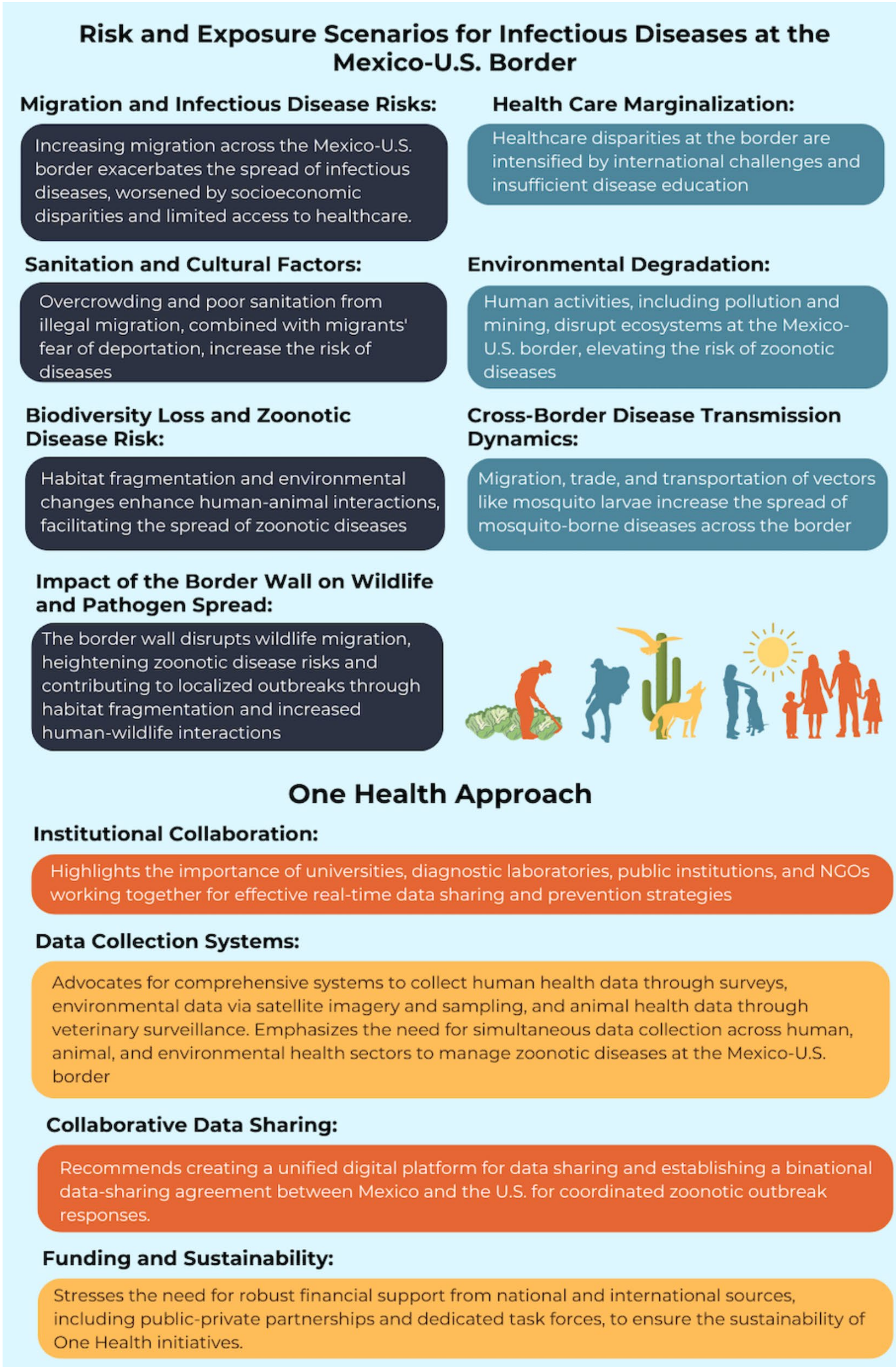

Fig. 1 The Mexico-U.S. border region faces a complex interplay of factors contributing to infectious disease risk, including high human migration, environmental degradation, and changes in wildlife dynamics due to the border wall. These factors interact to create scenarios of increased risk and exposure to various infectious diseases, highlighting the need for a comprehensive One Health approach to disease prevention and control in this region

This is enhanced by a commitment to the generation of research related to health and wildlife conservation, promoting science from a transdisciplinary, holistic integral and binational perspective. In this region, the effects of environmental degradation on disease emergence have enormous information gaps, so there is an urgent need for increased research in this field. We would like to encourage researchers to consider a landscape scale that includes human activities as a part of the whole system as well its effects on the dynamics of pathogens and its reservoirs. Only until all the components involved in the problem are understood is it feasible to think about intervention. It is therefore necessary to first compile an integrated picture from the perspective of different areas of knowledge to then generate integrated initiatives in the control of zoonotic infectious diseases.

One Health approach

This manuscript posits that social and ecological factors contribute to the emergence of infectious diseases of public health importance along the northern border of Mexico. Through the lens of a One Health strategy, this paper evaluates infectious agents with diverse transmission routes and emphasizes the critical need to collect integrated data from human, animal, and environmental health sectors. By focusing on the interplay between these domains, we present a framework that brings together a range of institutions—including universities, diagnostic laboratories, public institutions, and NGOs—working in collaboration to collect, analyze, and share data in real time, ensuring the development of robust prevention and control strategies for zoonotic diseases (Table 1).

Integrated data collection and institutional collaboration

One Health aims to break down the traditional silos of data collection that often separate human health, animal health, and environmental surveillance. In the context of zoonotic disease prevention, it is imperative to design a comprehensive data collection system that gathers data across these sectors concurrently. For human health data, public health institutions and universities can conduct surveys and diagnostic screenings within migrant and local populations to monitor infectious disease prevalence, nutritional status, vaccination coverage, and other critical health indicators [73]. This information can be combined with socioeconomic data obtained through focus group interviews with key community stakeholders, particularly women and household heads, who are essential in shaping community health practices [74].

In parallel, environmental health data collection must focus on monitoring water quality, air pollution, and the presence of vector-borne disease habitats such as standing water, agricultural waste, or deforested areas. NGOs, in collaboration with universities, could utilize drones and satellite imagery to map potential hot spots for vector proliferation, identifying areas where human-environment interactions may increase disease risks [75]. Regular environmental sampling for pathogen detection (e.g., waterborne pathogens or soil-borne contaminants) can also be conducted by environmental agencies and research institutions [76].

Animal health data can be gathered through veterinary clinics, diagnostic laboratories, and local field surveillance teams monitoring both domestic and wild animal populations. It is crucial to track the health status, vaccination coverage, and movement patterns of livestock,

Table 1 Summary of the One Health Strategy for Zoonotic Disease Prevention and Control at the Mexico-U.S. Border

Aspect	Description	Examples/Models
Integrated Data Collection	Coordinated effort to collect data on human, animal, and environmental health through surveys, diagnostic analysis, and environmental monitoring.	- Human health monitoring: migrants and locals: physical condition, vaccines, infectious agents. - Domestic and wildlife health monitoring: physical condition, vaccines (domestic animals), infectious agents. - Environmental data collection: water and air quality.
Animal Monitoring	Supervision of domestic and wildlife health using GPS, camera traps, blood and tissue analysis.	Example: Analysis of species such as birds, rodents, and medium-sized carnivores.
Vector Monitoring	Systematic surveillance of mosquito and ectoparasite populations is conducted to assess species distribution, abundance, and the presence of potential infectious disease	An integrated monitoring program employing traps and field surveys to collect data on vector density and species composition, facilitating targeted vector control efforts
Participating Institutions	Collaboration between universities, diagnostic laboratories, NGOs, and public institutions.	Example: USAID's *PREDICT* project.
Collaboration Network and Data Sharing	Creation of a digital platform for real-time data sharing among human, animal, and environmental health institutions.	Model: *Animal Disease Information System (ADIS)* of the European Union.
Community Support and Participation	Integration of local actors and development associations to ensure active participation and ownership of the knowledge generated.	Example: Training of local monitoring groups and officials.
Funding and Sustainability	Funding through international grants, government funds, and public-private partnerships.	Example: USAID-funded *STOP Spillover* initiative.

domestic pets, and wildlife species such as birds, rodents, and carnivores [77]. The use of camera traps, GPS collars, and biological sampling (e.g., blood and tissue testing) will allow institutions to map out potential interactions between animals and humans, which could serve as transmission pathways for zoonotic pathogens [78].

A One Health model for integrated data collection can be seen in the PREDICT project, funded by USAID, which operated in more than 30 countries, including Mexico, to monitor emerging zoonotic viruses. The project gathered data from multiple sources—humans, animals, and environmental samples—using a collaborative network of international organizations, universities, and local government agencies to prevent viral spillover from animals to humans.

Building a collaborative network for data sharing

Given the diversity of data sources and the necessity of real-time collaboration, the creation of a unified digital platform where data can be shared across institutions is paramount. Universities and diagnostic laboratories will serve as key hubs for data collection and analysis, sharing their findings with local and federal public health authorities [79]. NGOs and environmental agencies, which are often at the frontline of data collection, will contribute their on-the-ground observations to the central data hub. This system could be modeled after the European Union's Animal Disease Information System (ADIS), which allows real-time exchange of disease-related data across member states, ensuring rapid communication and coordinated responses to emerging threats [76].

In the U.S.-Mexico border region, a binational data-sharing agreement between Mexican and U.S. public health and environmental agencies would be a critical step towards the implementation of a One Health strategy. By harmonizing data protocols and ensuring transparency, this initiative would enable institutions from both countries to act quickly in response to cross-border zoonotic disease outbreaks [73]. Such collaborative networks will not only help prevent and control disease but also build trust and foster long-term partnerships between governments, academia, and civil society organizations.

Financing and sustaining a one health initiative

A sustainable One Health program requires robust financial support. In addition to national government funding, international donors such as the World Health Organization (WHO), the Food and Agriculture Organization (FAO), and the World Bank can offer significant grants to support infrastructure development, personnel training, and long-term surveillance programs [75]. Another model to consider is public-private partnerships, where local businesses collaborate with government institutions to fund monitoring programs, particularly in sectors like agriculture and tourism that benefit directly from healthy human, animal, and environmental systems [76].

The establishment of a dedicated One Health Task Force, funded through multilateral grants and supported by national government allocations, will be essential to ensure the continuity of this initiative. Similar programs, such as the STOP Spillover initiative funded by the United States Agency for International Development (USAID), provide a blueprint for financing and launching integrated zoonotic disease surveillance and response programs. STOP Spillover, for instance, focuses on building local capacities for zoonotic disease prevention and includes financial support for local governments, ensuring the development of a sustainable surveillance system [78].

Case example of a one health approach: the rift valley fever model

A pertinent example of the successful implementation of a One Health approach is the control of Rift Valley Fever (RVF) in Kenya, which demonstrates the importance of cross-sector collaboration and data sharing. The Kenyan Ministry of Health worked with veterinary services, environmental agencies, and international partners to monitor RVF outbreaks by integrating human health data with livestock monitoring and environmental surveillance, such as rainfall and mosquito population data. This early warning system allowed for timely interventions, including vaccination campaigns and the restriction of livestock movement, which successfully reduced the incidence of human and animal infections [73]. This model could serve as a template for addressing zoonotic diseases in the U.S.-Mexico border region, where similar ecological and socioeconomic variables contribute to disease risk [74].

Abbreviations

US	United States
NAFTA	The North American Free Trade Agreement
R.	Rattus
HIV	Human Immunodeficiency Virus
IgM	Immunoglobulin M
C.	Campylobacter
P.	Peromyscus
STEC	Shiga toxin-producing Escherichia coli
E.	Escherichia
aEPEC	atypical enteropathogenic Escherichia coli
sp.	species
spp.	species (plural)
e.g.	for example

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Author contributions

AC: Conceptualization, Writing – original draft, review and editing,. HM: Writing – review & editing. AH: Writing – review & editing, MP-Z: Writing – review & editing, AML-P: Writing – review & editing. AF: Writing – review

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