One Health Tropical Wetlands: A Transdisciplinary Framework for Assessing the Risks of Emerging Zoonotic Diseases in the Brazilian Pantanal

Abstract:

The Pantanal wetland ecosystem of Brazil is experiencing unprecedented local challenges from anthropogenic pressures, as well as from global climate change. These pressures escalate the zoonotic risks from wildlife populations, whose own susceptibility to disease is enhanced by stressors including habitat loss and fragmentation with the resulting decrement in food availability, immunity and resilience in the face of compounding disease risks. This continuous degradation and fragmentation of the ecosystem increases interactions between animals and humans (including indigenous peoples and local communities) (IPLC) further increasing disease risks for the human populations. Weak health systems across the Pantanal are reflected in limited pathogen surveillance, and poor sanitation and disease control measures, serving to further amplify the region's epidemic and pandemic potential. Using a transdisciplinary One Health (OH) approach to understand the ecological, social and biological drivers of infectious diseases, our research network developed a framework to conceptualise the current tools, evidence and processes for effective research and knowledge production in the Pantanal Wetland ecosystem. Drawing on the expertise of researchers and non-academic key-stakeholders can inform the work of global OH research networks and strengthen the evidence base for OH policy and practice in the Pantanal and other tropical wetland systems.

Introduction

The COVID-19 pandemic has highlighted the importance of an integrated One Health (OH) perspective to evaluate how anthropogenic activities may serve to drive the emergence of novel zoonotic pathogens and provide the conditions for zoonotic outbreaks to achieve epidemic scales (Patz et al. 2004; Amuasi et al. 2020; Bonilla-Aldana et al. 2020). Frameworks for assessing complex epidemic risks are key to fulfilling international commitments to strengthen the OH Agenda (Aguirre et al. 2019; Ebi et al. 2020; de Thoisy et al. 2021). Also critical is the necessity to expand the focus beyond traditionally held centres of epidemic risk, to consider rapidly changing ecosystems where zoonotic risks are escalating rapidly. An approach that fully integrates the human-animal-environment nexus is needed to understand the scope of the challenge and to identify ways to effectively mitigate risks. Transdisciplinary approaches recognise that key expertise can be drawn from indigenous people and local communities (IPLC), and other non-academic stakeholders, to further solution-orientated knowledge production for pressing societal challenges.

The Pantanal wetland system in South America is a dynamic ecosystem, associated with an increasing risk of novel pathogen emergence of epidemic (and ultimately of pandemic) potential (Winck et al. 2022). The region is considered an evolving locale for emerging zoonotic pathogens in a range of wildlife species, given that land use and climatic changes are altering fragile ecosystems in this region (Tomas et al. 2019). The same pressures are driving increasing interactions between humans, livestock and wildlife (de Souza et al. 2014; de Souza et al. 2018). These interactions provide greater opportunities for zoonotic disease outbreaks and transmission from wildlife to humans, and in the absence of a robust local healthcare system there are insufficient measures for prevention, detection and response to emerging disease outbreaks.

In the context of sustained global attention on the need for OH action within the global health security agenda, the current work seeks to develop a conceptual framework for an integrated transdisciplinary evaluation of emerging zoonotic risks in this critical ecosystem. Such an approach is necessarily collaborative, involving scientists across disciplines, local participation from stakeholders and diverse publics including indigenous organizations, government agencies and legislators, public health professionals, non-government charitable and private organizations, and international stakeholders. Approaching the Pantanal ecosystem in a way that integrates wildlife and livestock health, climate change and land use scenarios, pathogen epidemiology and surveillance, health systems and policy, ethnography and local knowledge, provides the foundations for a more holistic evaluation model. A conceptual framework for achieving this goal is presented here, which begins to address the neglect of potentially high-risk ecosystems by incorporating health security concerns and the research agendas needed to support burgeoning efforts in applying the principles of OH. Efforts such as this are critical within wider health security and OH agendas, which have been criticised for their failure to localise evidence development and translation within specific ecosystems (IDS 2018). The process of framework development and evidence synthesis is crucial to inform future work in diverse global ecosystems utilising transdisciplinary OH approaches.

Background

As the largest continuous wetland system in the world, this 230,000 km^2 alluvial plain is a site of exceptional biodiversity (e.g. Harris et al. 2005). The Pantanal spans three countries: Brazil, Paraguay and Bolivia (Fig. 1). The region comprises of a series of interconnecting natural and human dominated landscapes, including tropical forests, aquatic ecosystems, savannahs, agricultural farmlands, fisheries and cattle pastures. It is home to endangered species such as the jaguar (*Panthera onca*), giant otter (*Pteronura brasiliensis*), marsh deer (*Blastocerus dichotomus*), and pampas deer (*Ozotoceros bezoarticus*). It is also home to numerous other wildlife species such as capybaras (*Hydrochoerus hydrochaeris*), tapirs (*Tapirus terrestris*), giant armadillos (*Priodontes maximus*), bats, caimans and a wide range of bird species (Damasceno-Junior, 2022; Tomas et al. 2019). The landscape is shared with a range of domestic livestock populations, including cattle (*Bos* spp.), domestic pigs (*Sus domesticus*) and buffalo (*Bubalus bubalis*). The area delivers ecotourism, whilst supporting local and regional food systems, and supporting the livelihoods of resident populations, including IPLCs (Wantzen et al. 2023).

The Pantanal region is considered a high-risk zone for zoonotic pathogen spillover; *Brucella,* avian influenza virus*, Leptospira*, *Lyssavirus*, *Leishmania* spp, *Trypanosoma cruzi* and diverse arboviridae have all been detected across wildlife populations in the Pantanal (e.g Jorge et al. 2010; Porfirio et al. 2018; Bourscheid et al. 2020; Dalazen et al. 2020; de Silva Neves et al. 2022; de Macedo et al. 2022; Santos et al. 2022). Remote populations across the region are highly diverse and include 5 different indigenous groups (Kadiwéu, Kinikinau, Terena, Bororo, Guató) as well as traditional fishery communities, farmers and cattle ranchers, and an increasing number of transient visitors, including both migrant workers and international tourists. Local communities face poverty and inadequate public health services due to limited provision, with incomes often falling below one-third of the Brazilian minimum wage (Chiaravalloti 2019). These challenges are exacerbated by environmental pressures and human activities, which further increase the risks for vulnerable populations. The ongoing expansion of agricultural land for cattle pastures in areas bordering the plain, along with anthropogenic and climate change-related events, is intensifying pressures on local human-animal-environmental networks (Schulz et al. 2019; Tomas et al. 2019), thereby heightening the risk of emerging infectious diseases (EIDs) (Lima-Camara 2016; Ferreira et al. 2023).

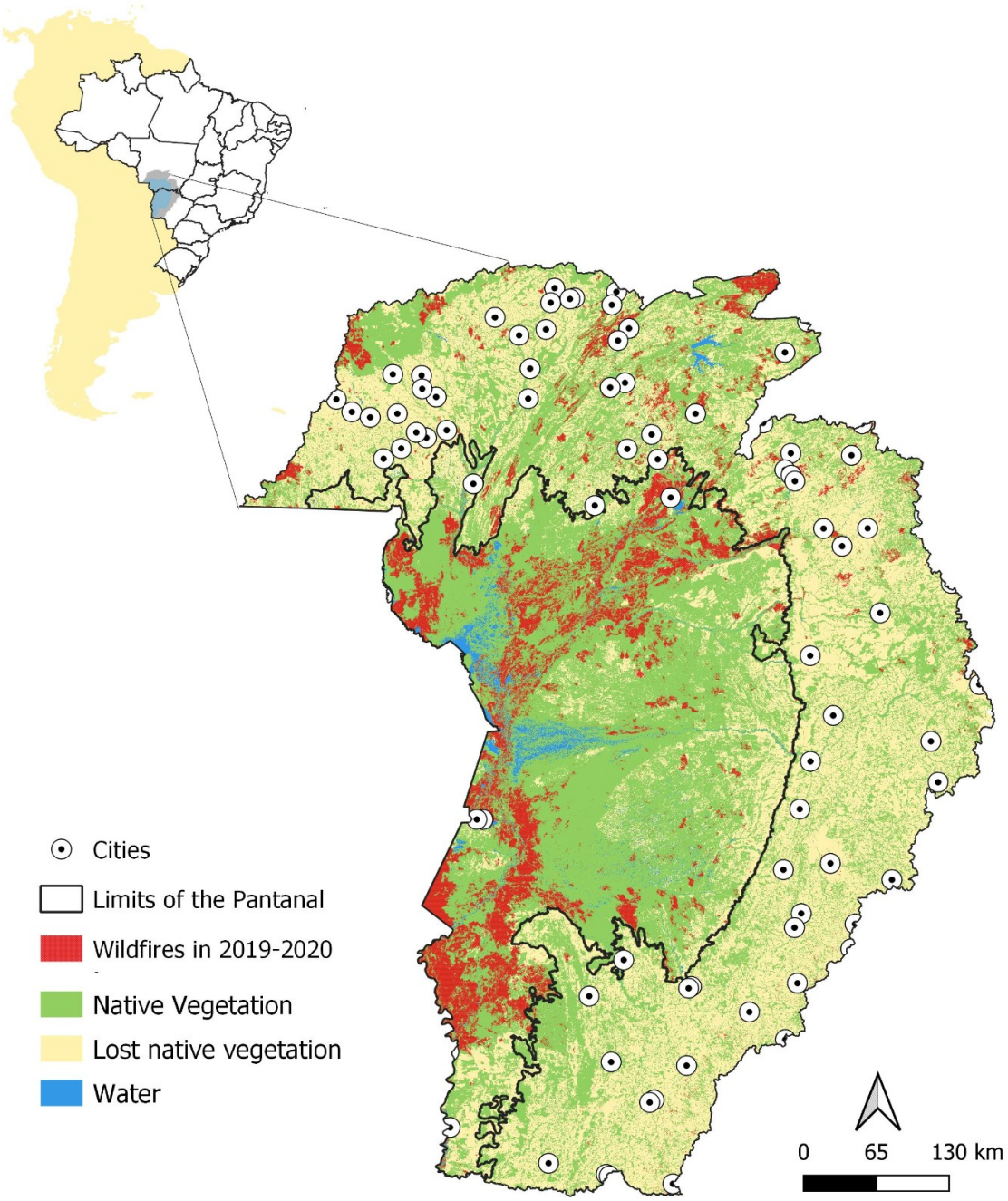
Cities
Limits of the Pantanal
Wildfires in 2019-2020
Native Vegetation
Lost native vegetation
Water
0
65
130 km

Fig. 1: Location of the Upper Paraguay River Basin in South America and Pantanal wetland in the Brazilian states of Mato Grosso and Mato Grosso do Sul. Colour background indicates native vegetation and regions that have suffered from recent wildfires. Source: MapBiomas Project - Collection 8.0 of the Annual Series of Land Cover and Land Use Maps of Brazil, accessed on August 30, 2023. On the link: https://brasil.mapbiomas.org/; and Instituto Brasileiro de Geografia e Estatística - Base Cartográfica Contínua do Brasil. Acessado em: 30 de agosto de 2023. Em: https://www.ibge.gov.br/

These anthropogenic changes are placing unprecedented pressures on both animal populations and the environment in the region (Alho and Silva, 2012; Tomas, et al. 2021, Wantzen et al. 2023). This is of particular concern in the "Arc of Deforestation'' in the Upper Paraguay River Watershed, which is experiencing profound land-use change, fragmentation of the landscape (Siqueira et al. 2018), and intensification of human activities (de Oliveira Roque et al. 2021). Land-use and climate change are altering wildfire and flood regimes in the region (Kumar et al., 2022; Barbosa et al. 2022). Because the Pantanal drains the Upper Paraguay River Basin System, flood dynamics underpin the integrity of the whole wetland system. Climate studies indicate that the region has 13% fewer days of rainfall in the wet season than 42 years ago, and over the last 10 years has seen a reduction of 16% in total water volume during the dry season (Lázaro et al. 2020). Moreover, the co-occurrence of compound hot and dry spells in the region is becoming more frequent and severe since the turn of the 21st century (Libonati et al., 2022a). Deforestation and the construction of hydroelectric plants have further altered normal hydrological patterns (Fantin-Cruz et al. 2015; Medinas de Campos et al. 2020). Other hydrological stressors arise from the presence of expanding agribusiness around the Pantanal, such as dredging river-beds to connect transit routes to the Atlantic in order to facilitate the global export of soybean crops; this threatens the ecological integrity of the entire wetland system (Coelho-Junior et al. 2022). Wildfires in the Pantanal have become a significant problem in recent years, with almost a third (30%) of the total terrain experiencing wildfire activity in 2020 – the largest since records began (Tomas et al. 2021; Libonati et al., 2020; de Barros et al., 2022).

Habitat destruction in the Pantanal is placing wildlife communities under increasing stress, which in turn makes them more susceptible to infection (Winck et al. 2022). For example, delays to the annual flood pulse compromise the normal patterns of reproduction in many aquatic species, resulting in dwindling food sources for wildlife that normally feed upon them (Alho and Sabino 2012). Alterations in food availability forces wildlife to migrate across new territories, increasing their exposure to domestic animals, to new wildlife populations and to human communities (de Souza et al. 2018), with greater opportunities for pathogen transmission across all of these species. Habitat fragmentation results in increased density of wild animals in the remaining space, creating greater competition for access to dwindling resources and often resulting in the use of inadequate habitats as they lack better options. Changing water systems also strongly influence the transmission dynamics of vector borne pathogens, in particular those transmitted by mosquitoes (Ferreira et al. 2023). Sampling of Pantanal mosquitoes is increasingly showing the presence of novel viruses, raising concerns that epidemic risks are intensifying in a wide range of animal taxa (Maia et al. 2019).

Public health is in a precarious state throughout the inhabited regions of the Pantanal in light of the poor provision of health and sanitation services. The several resident indigenous and other traditional communities are particularly vulnerable to disease threats, given relatively limited access to basic health services such as immunization programmes, antimicrobial therapies and antenatal care. Medical boats provided by government authorities deliver sporadic primary care services to some communities, however tertiary level care is accessible only in larger cities of the region, which makes access logistics quite complex and limited, as it involves high costs in terms of time, travelling and accommodations in the cities, both for patients and their relatives. There is limited literature concerning the health status of IPLCs, but there is concern that these groups' vulnerabilities to disease are being amplified by changing environmental conditions. Ranch workers also suffer from the inaccessibility of health services (Fontoura-Junior & Guimaraes 2020). Several studies have identified the risk of emergence of key infectious diseases within these populations including: leptospirosis, brucellosis, toxoplasmosis, Hepatitis A & B, leprosy, yellow fever, paracoccidioidomycosis, chagas disease, leishmaniasis and highly pathogenic avian influenza (Pauvolid-Corrêa et al. 2014; Tourinho et al. 2015; Porfirio et al. 2018; Bourscheid et al. 2020; Dalazen et al. 2020; Kluyber et al. 2021; Maia et al. 2021; De Macedo et al. 2022). Additional health security pressures arise from the expansion of tourism into the region with international populations visiting the area for its famed biodiversity (Ferreira et al. 2023).

The COVID-19 pandemic has further complicated the epidemic risk burden. In the context of ongoing wildfires, the dual burden of respiratory illnesses related to smoke inhalation and viral infection overwhelmed hospitals (Arini 2021). Hospitalizations of children in respiratory distress increased by 30% relative to other territories in 2020, and the region became one of the epicentres of the pandemic, suffering some of Brazil's highest mortality rates (Oliveira et al. 2020). The Pantanal's residents are vulnerable to epidemics from multiple directions: environmental degradation is a source of internal risks for novel pathogenic emergence, whilst weak health services render local communities more vulnerable to external epidemic threats.

Furthermore, cross-border public health risks emerge due to criminality associated with the illicit drug trade extending across Pantanal's western borders with Bolivia and Paraguay (Neves and Ludwig 2021). Public health approaches are required that take account of these varied axes of vulnerability to effect equitable health delivery to all resident populations in the wetland territory.

The Requirement for a Pantanal One Health framework

As health security and OH agendas have gained prominence within outbreak-response architectures, the frameworks that have emerged to guide decisions increasingly implicate important aspects of socio-ecological systems. However, we argue that most remain too general, and do not suitably consider regional specificities capable of supporting decision-makers and practitioners at local scales. For example, they do not consider particularities of key environments such as tropical wetlands, which play a vital role in global biodiversity, and climate and health security (Davidson et al. 2019). Localising conceptualizations of risk production necessitates greater collaboration across research disciplines and involved communities. A common framework, shaped by the diverse expertise of local stakeholders and technical experts, provides a shared understanding of the problem and builds a platform for joint working using OH principles. The complexity of the Pantanal necessitated that our team (of researchers, practitioners and community leaders) develop an evidence-informed framework which would lay the foundation for a long-term programme of work in the region.

Methods

Framework development

The process of framework building involved approximately 30 individuals in roundtable meetings, field visits and collaborative evidence synthesis. Our transdisciplinary approach reflects the process described by Jahn, Bergman and Keil (2012), which provides a model for connecting complex societal challenges with gaps in existing bodies of knowledge through a single integrative process. First, in 2019, we created a organizing team composed by 2 researchers from Brazil (Universidade Federal de Mato Grosso do Sul and Universidade Dom Bosco) and two from UK (University of Nottingham and King's College) which invited researchers who published papers about zoonotic diseases, social aspects, and ecology. In total, we invited 30 researchers. We received positive feedback from 12 people which we aligned their agendas for a 2 days' workshop in person in Campo Grande, Mato Grosso do Sul, at Universidade Federal de Mato Grosso do Sul. The first day of the workshop was to ensure a common language of terms and core principles. During the next two days, the participants set up the methodological phases: Phase (i) visioning and general approach development through a participatory meeting (whole team); Phase (ii) discussion with two local stakeholders to address gaps in the visions; Phase (iii) formulation of key questions and knowledge gaps by the expert groups; Phase (iv) consolidation of the potential issues to be explored in potential papers. After the event, the team started a co-writing process of the manuscript using the tools of google-docs. The Brazilian organizing team was responsible to finish the paper, including information about Brazilian laws and particularities about the Pantanal.

Consequently, our framework was formulated with input from academic and non-academic experts from within Brazil, the EU and the UK, from fields spanning public health, ecology, social science, veterinary medicine, human medicine, geography, anthropology, ethnobiology, advocacy groups and politicians (see the full list in the acknowledgements). The purpose of this framework was to develop a synergistic understanding of the OH landscape in the Pantanal by characterising the human-animal-environment interface. This involves consolidating methodology and utilising expertise from diverse fields to identify pathways for assimilating new evidence for developing policy and strengthening local capacity.

The approach also included an evaluation of the challenges faced by selected wildlife (including species targeted by illegal hunting, trade, and consumption) and livestock populations, that may result in their reduced health and resilience. This would then increase their risk of contracting infectious agents and could then result in adverse impacts on biodiversity and on particular species of conservation concern (e.g., endangered species). The potential consequences of multi-host pathogen spill-over on the health of human and animal populations (who are particularly vulnerable as a result of land use and environmental changes) are assessed.

In combination with the data on animal health, integrative models linking land use change scenarios with social, ecological, and economic considerations are incorporated, to better understand their impacts on the health of animals, humans and the environment. This holistic assessment framework can then be used to predict the risks for the emergence of zoonotic pathogens –particularly those with epidemic potential – in the Pantanal wetland. This can ultimately be used to develop a crucially needed early warning system identifying outbreaks of these pathogens within animal and/or human populations and developing appropriate responses to curtail the spread of the infectious agent. Such a system is particularly timely, given the increasing frequency and likelihood of catastrophic disturbance events resulting from changes in climate and in land use in the region.

Certain individual factors, such as gender, age or role in the community, serve as determinants of unequal zoonotic risk exposure, which generate inequitable health and social outcomes, are incorporated in the conceptual framework, with particular attention to vulnerable and marginalised communities in the region. For example, consideration is given to evaluating the sociocultural factors mediating gender roles, that determine differential human-animal-environment interfaces within local communities. The framework also integrates the role of public health services in the management of zoonotic disease in vulnerable populations. In the future, this novel framework can be used to aid risk mitigation strategies by identifying appropriate intervention pathways, and opportunities for scaling up wider policy interventions. Focus is placed on community engagement through co-production with relevant communities to acquire indicator data using citizen science approaches. A structured approach, such as that outlined in our framework, will shape future research and practice in the Pantanal, to support the identification of indicators and signals to feed into early warning datasets. This is essential for developing community-informed, gender-responsive, One Heath programmes to promote sustainable land use practices, protection of biodiversity, safer human-animal interaction and behaviours supporting improved health outcomes in resident communities in the Pantanal.

Results

The Framework

Our framework integrates data from a range of sources – including both primary research and open-source data – to achieve two basic functions; 1) The assessment of current pathogen spillover risk; and 2) Forecasting future pathogen spillover events. Figure 2 is illustrative of the approach. The development process accepted the limitations in current evidence availability in key knowledge pools such as comprehensive pathogen mapping, animal-human interface networks and human epidemiology in the region. However, the framework also charts a common pathway for diverse interdisciplinary researchers to contribute new and evolving datasets and thus enhance synthetic evidence development for the community of practitioners.

First, key data is generated from a range of sources, including: 1) animal health data (including serological and molecular studies for zoonotic infectious agent assessment); 2) Socio- ecological studies; 3) Ethnographic and human behaviour studies; 4) Human health & early warning systems; and 5) Policy analysis and development. Information from these 5 areas is integrated by generating biological, risk and social-behaviour risk indices, which are standardised into a simulation of current spillover-risk within the context of the health and policy landscape. This can also be used to look at the risks associated with the potential for global transmission. This future risk potential will also be influenced by changes in biological, spatial and social-behavioural risks, so these need to be incorporated into forecast modelling. The applied methods cut across domains of concern including human, animal and ecosystem health, and public policy.

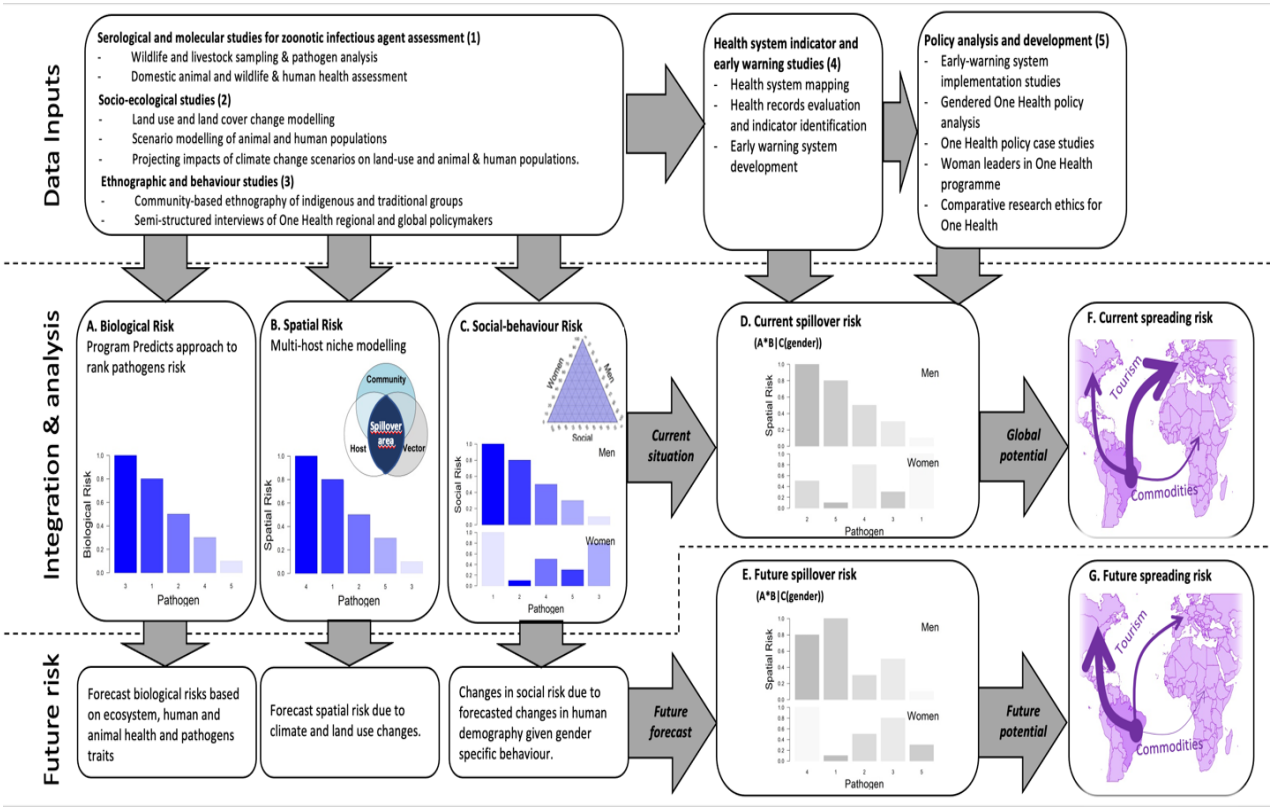

Fig. 2: Spillover risk (zoonoses) framework for the Pantanal Wetland System

Our approach considers multi-host (Box A in Fig. 2), spatial risk (Box B in Fig. 2), and social-behaviour risk (Box C in Fig. 2), highlighting gender-specific differences in activities and routines observed within traditional communities. Therefore, **biological risk** (BIOR) will follow the example set out by USAID's Predict Programme, which estimated and ranked virus spillover risk based mostly on pathogen biology factors. Data to estimate BIOR will be acquired through serological and molecular samples.

Furthermore, **spatial risk** (SPAR) will be estimated through a standard niche tool (i.e. MaxEntropy)[5] for each pathogen in each community, considering all vectors and hosts implicated in that local cycle. Niche modelling will be performed based on species distribution records collected during the field work, and from public repositories as well (gbif – https://www.gbif.org/). The SPAR will be considered the area of overlap between all implied vectors, nonhuman, and human hosts (Box B in Fig. 2).

Social-behaviour risk (SOCR) will be based on interviews or ethnographic studies that will help us to measure the exposure factors specific to pathogen hosts and vectors. As performed in the Predict Programme, we will use a series of factors (questions) measured through interviews and social network analysis to qualitatively assess zoonotic spillover risk. The overall virus spillover risk for each community will consider biological, spatial, and social-behaviour risk, being the result of BIOR, SPAR and SOCR (Box D Fig. 2). Once the overall **spillover risk** by community has been ascertained, community tourism information, and local commodities exportation information can be used to forecast likely routes of worldwide disease spreading following a local spillover event (Box E Fig. 2).

The forecasting of future scenarios of pathogenic spillover is based on updated pathogen biology information, models of land use and climate change for the current century, as well as through expected- and induced-switches in local human behaviour. For example, existing land cover land use change (LCLUC) modelling (e.g. De Oliveira Roque et al. 2021) projects changes in the Pantanal by 2050 under different scenarios, including agricultural expansion, and predicts significant land use change under a business as usual (BAU) scenario. Future climate scenarios could be used

to extend land use mapping to project future flood and wildfire extents, with implications for human-animal interactions. Such forecasts can help us to identify how public health systems, local, regional, federal and global stakeholders can play in modulating local spillover risk and subsequent transmission.

Discussion

Framework utility

Perspectives across diverse methodologies, perspectives and technical disciplines have shaped the development of the transdisciplinary Pantanal-OH framework. The process of development has involved exercises in stakeholder and dataset mapping, which has already provided important synthetic functions to support current research and future evidence generation the region.

Given the complexity of the Pantanal ecosystem, partly related to the highly dynamic socio-ecological conditions due to seasonality and hydrological pulses (Ivory et al. 2019), and its diverse human and animal communities, the imperative to work in an integrated fashion provides both challenges and opportunities. Centring pathogen spillover risk at the heart of intersecting problems, such as wildlife health, climate change and ecological degradation strengthens the understanding that OH priorities are ultimately a product of diverse global pressures compromising every dimension of health in its broadest sense. They are also connected processes, with impacts in one region potentially impacting distant communities and areas due to, for example, the exportation of meat and crops, and international tourism (Wittman et al. 2017). Therefore, these critical global problems demand multi-scale solutions that cannot be produced when divorced from local evidence and knowledge communities.

Our framework development process is the first stage of a longer-program of community-engaged research with scholars from a range of Brazilian institutions and partners in the UK. Building global transdisciplinary OH networks is a priority, driven by agendas led by World Health Organisation (WHO), the World Organisation for Animal Health (WOAH) and the Food and Agriculture Organisation (FAO). Further political support has been driven by intergovernmental groups such as the G7 which has recently expressed its prioritisation of OH as part of wider health security undertakings (G7 2021).

Data Sourcing and Collection: Opportunities and Challenges

During the development of the framework, a number of challenges arose that require further development within a transdisciplinary OH approach. The first major challenge is the sourcing of key species data and consequent modelling. Primary data on species distribution and population dynamics are critical for informing our framework. Currently, few monitoring systems of species populations exist for the Pantanal. There are some limited surveillance initiatives underway, focused on Jaguars (e.g. Projeto Onçafari, Projeto Conexão Jaguar, Panthera), blue macaw (projeto Arara Azul), fish (Upper Paraguay Artisanal Fish Monitoring), otter (Projeto Ariranhas), deer (projeto Embrapa), giant-armadilho (ICAS) and tapirs (Iniciativa Nacional de Conservação da Anta Brasileira INCAB-IPÊ). These programmes are limited in scale however due to financial and access constraints.

Expanding the biodiversity monitoring systems in the Pantanal is an urgent priority. In relation to animal health, a promising system, the SISS-Geo is currently under implementation in the Pantanal (https://sissgeo.lncc.br), developed by the Brazilian Agency FIOCRUZ Biodiversity and Wild Health Institutional Platform, with support from the National Laboratory of Scientific Computing. It is free, available on smartphones and on the web, for monitoring the health of wild animals in natural, rural and urban environments. It supports the investigation of the occurrence of disease-causing agents, such as infectious agents, which can affect people and animals. As a citizen-science instrument, it makes it possible to act on reports made by ordinary citizens, health professionals, the environment, researchers and wildlife specialists. Another relevant system is the "Animal Rescue" Mobile Application in the Serra do Amolar, implemented in 2022 which facilitates the geo-located reporting of sick animals. Further development of tools which permit reporting of animal disease across the large spatial territories of the Pantanal will be key to prove the validity of citizen science tools in remote geographies. New possibilities have been opened since 2020 with the rollout of mapping infrastructure based on energy demands and using artificial intelligence and high-resolution mapping techniques.

Datasets on land-use and landscape changes such as wildfire dynamics have received significant investment in the last decade and can now deliver near real-time monitoring. Examples include tools such as LASA/UFRJ and INPE which provide satellite surveillance of wildfire events. Also, the MAPBIOMAS initiative now provides historical information regarding land-use and cover changes. Despite these advances, there are still few weather monitoring stations in the Pantanal, which would deliver important safeguards against worsening wildfire seasons. Furthermore, the role of the Pantanal in the wider climate agenda is under-recognised (Junk et al. 2013; Kolka et al. 2016) and producing evidence from monitoring systems would usefully contribute to global models of climate change.

In terms of human health, The Unified Health System (Sistema Único de Saúde (SUS)) has enabled substantial progress towards Universal Health Coverage (UHC) in Brazil. However, structural weakness, economic and political crises and austerity policies that have capped public expenditure growth are threatening its sustainability and outcomes in the last 4 years. The datasets from SUS are available for research purposes. However, it provides datasets aggregated by municipality which poses a challenge for the development of high-resolution spatial models due to the size of the Pantanal's constituent territories. It is also important to highlight that the State of Mato Grosso do Sul launched a OH State Initiative which opens a window implementing integrated systems. However, given the particularities of the Pantanal Wetland System, it remains essential to strengthen the collaboration between territorial authorities of the provinces of Mato Grosso do Sul, Mato Grosso and the relevant authorities in neighbouring Paraguay and Bolivia.

Finally, critical gaps in current evidence centres on social, cultural and demographic knowledge. There is a lack of up-to-date data on the distribution of communities across the vast expanse of the Pantanal region. Reliance on assessments carried out by local NGOs on river-based provide some data on specific communities, however systematic work on the diverse communities of the Pantanal Wetlands remains lacking.

Conclusion

The Pantanal is a critical region for global health security given its unique biodiversity, commodities exportation and international tourism, as well as growing vulnerability to anthropogenic pressures and weak public health systems. Nevertheless, the region remains understudied in global health and scientific research communities. Our research network has sought to synthesise diverse research approaches through the development of a OH framework, demonstrating the vital transdisciplinary linkages across research domains and methods. This exercise has highlighted the challenges and opportunities for transdisciplinary working in the Pantanal Region, whilst highlighting the absence of crucial data in key areas. This effort marks the early stage of a long-term collaboration to develop the evidence base for OH in the Pantanal, which can inform wider work on health security risks in tropical wetland systems globally. This work demands international collaboration and essential financial commitments from donors to ensure that neglected high-risk ecosystems remain at the forefront of OH practice and policy.

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