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Relationships between the risk of emerging zoonotic diseases and architecture of interactions between people, domestic animals and wildlife in the Pantanal

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Índice

General Abstract

There is a growing acknowledgment of the public health risks linked to human interactions with both wild and domestic animals. Approximately 70% of Emerging Zoonotic Diseases (EZDs) and many recent pandemics can be traced to human-animal interactions. Factors such as social dynamics and gender roles significantly influence these interactions, affecting the epidemiology of infectious diseases. The perception of EZD risks varies across social groups, with socially vulnerable populations experiencing heightened risks due to barriers – such as accessibility to health services and education. The role of landscapes in zoonotic disease dynamics is also emphasized. Anthropogenic land use changes disrupted biodiversity and altered human-animal interaction patterns. Prior studies suggested that this context could lead to increased pathogen transmission and heightened interaction frequencies. However, responses in interaction networks are viewed as context-dependent, influenced by socio-economic factors and cultural practices. These factors are believed to shape agricultural structures and subsequently affect species abundance and public health risks. This dissertation comprises two interconnected chapters that investigate socio-economic, gender, and environmental factors in the interactions between people and animals in the Pantanal. An appendix presents a risk assessment framework for emerging zoonotic diseases in the Pantanal wetland, developed collaboratively with researchers.

The first chapter examines risk perception and gender dynamics in the Pantanal. It posits that while men have more interactions with animals, they possess lower risk perception; in contrast, women have heightened risk perception tied to caretaking roles. The study anticipated a negative correlation between risk perception and interaction frequency, expecting Riverine Communities to show more interactions due to higher biodiversity. The results revealed that men interacted more with animals than women resulting in a richer network then, and Riverine Communities exhibited greater richer than those in Settlements. Nevertheless, perceived risk levels did not vary significantly between genders or social groups. Fieldwork indicated distinct gender roles, highlighting greater gender equality in Riverine Communities compared to Settlements.

The second chapter investigates how gradients of native vegetation impact human-animal interaction networks in agrarian Settlements. The hypothesis suggested a positive correlation between interactions and the amount of native vegetation (NV). Network analysis revealed that only a small portion of interactions could be explained by the NV gradient, and the network displayed degree assortativity, indicating that nodes with similar interaction levels tend to connect. There was no significant relationship between shared interactions, NV, and property distances. While the evidence did not strongly support the hypothesis, factors like functional connectivity through patches of NV were suggested. The study emphasises the need to understand human-animal interactions in the Pantanal to inform effective public health and conservation policies. It advocates for a participatory conservation model involving local communities in policymaking, promoting the co-production of health and conservation strategies to enhance acceptance and effectiveness. The significance of network metrics in epidemiology and conservation is noted, along with a call for collaboration with global zoonosis databases for better disease outbreak tracking. It recommends integrating biodiversity conservation into One Health programmes, focusing on gender, changing human behaviours, and raising awareness of biodiversity benefits to mitigate zoonotic disease risks while supporting conservation efforts.

Key Words: One Health; Conservation; Socio-metacommunity; Zoonosis

Resumo Geral

Há um reconhecimento crescente dos riscos à saúde pública relacionados às interações humanas com animais selvagens e domésticos. Aproximadamente 70% das Doenças Zoonóticas Emergentes (DZE) e muitas pandemias recentes podem ser atribuídas ao aumento das interações entre humanos e animais. Fatores como dinâmicas sociais e papéis de gênero influenciam significativamente essas interações, afetando a epidemiologia das doenças infecciosas. A percepção dos riscos associados às DZE varia entre diferentes grupos sociais, sendo as populações socialmente vulneráveis as que enfrentam riscos aumentados devido a barreiras, como o acesso a serviços de saúde e educação. O papel das paisagens na dinâmica das doenças zoonóticas também é enfatizado. Mudanças no uso da terra causadas por atividades antropogênicas prejudicaram a biodiversidade e alteraram os padrões de interação entre humanos e animais. Estudos anteriores sugeriram que esse contexto poderia levar a um aumento na transmissão de patógenos e a uma maior frequência de interações. No entanto, as respostas nas redes de interação são vistas como dependentes do contexto, influenciadas por fatores socioeconômicos e práticas culturais. Acredita-se que esses fatores moldem as estruturas agrícolas e, subsequentemente, afetem a abundância das espécies e os riscos à saúde pública. Esta dissertação é composta por dois capítulos interconectados que investigam fatores socioeconômicos, de gênero e ambientais nas interações entre pessoas e animais no Pantanal. Um apêndice apresenta uma estrutura de avaliação de risco para doenças zoonóticas emergentes na área úmida do Pantanal, desenvolvida de forma colaborativa com pesquisadores.

O primeiro capítulo examina a percepção de risco e as dinâmicas de gênero no Pantanal. Postula que, embora os homens tenham mais interações com animais (uma rede com maior riqueza de animais), eles possuem uma percepção de risco mais baixa; em contraste, as mulheres têm uma percepção de risco elevada vinculada a papéis de cuidadores. O estudo também antecipou uma correlação negativa entre percepção de risco e número de interação, esperando que comunidades ribeirinhas mostrassem mais interações devido à maior biodiversidade. Os resultados revelaram que os homens realmente interagiram mais com os animais do que as mulheres apresentando uma rede mais rica em composição, o mesmo aconteceu com as comunidades ribeirinhas em relação aos assentamentos. No entanto, os níveis de risco percebidos não variaram significativamente entre os gêneros ou grupos sociais. Observações feitas em campo ainda indicaram maior simetria no papel dos gêneros entre os moradores das comunidades ribeirinhas. O segundo capítulo investiga como os gradientes de vegetação nativa impactam as redes de interação entre humanos e animais em assentamentos agrários do pantanal. A hipótese sugeriu uma correlação positiva entre interações e a porcentagem de vegetação nativa. A análise da rede revelou que apenas uma pequena parte das interações poderia ser explicada pelo gradiente de vegetação nativa, e a rede apresentou assortatividade de grau, indicando que nós com graus semelhantes tendem a se conectar. Não houve uma relação significativa entre interações compartilhadas, vegetação nativa e distância entre propriedades. Embora as evidências não tenham apoiado fortemente a hipótese, fatores como conectividade funcional através de fragmentos de vegetação nativa foram sugeridos. O estudo enfatiza a necessidade de entender as interações entre humanos e animais no Pantanal para formulação de políticas públicas de saúde e conservação eficazes. Defende um modelo de conservação participativa que envolva as comunidades locais no processo de formulação de políticas, promovendo a coprodução de estratégias de saúde e conservação para melhorar a aceitação e a eficácia. A importância das métricas de rede na epidemiologia e conservação é destacada, juntamente com um apelo à colaboração brasileira com bancos de dados globais de zoonoses para um melhor rastreamento de surtos de doenças. Recomenda-se a integração da conservação da biodiversidade em programas de One Health, com foco em gênero, na mudança de comportamentos humanos e na conscientização sobre os benefícios da biodiversidade para mitigar os riscos de doenças zoonóticas, ao mesmo tempo em que se apoiam os esforços de conservação.

Palavras-chave: One Health; Conservação; Socio-metacomunidade; Zoonoses

Resumo popular

Cada vez mais, as pessoas estão reconhecendo os riscos à saúde pública que surgem das interações entre humanos e animais, tanto selvagens quanto domésticos. Cerca de 70% das doenças zoonóticas emergentes (doenças que passam de animais para humanos) e várias pandemias recentes estão ligadas a esse tipo de contato. Fatores como as dinâmicas sociais e as funções que homens e mulheres assumem nas atividades diárias influenciam muito essas interações, o que afeta como as doenças zoonóticas são transmitidas. A percepção de risco das doenças zoonóticas varia entre os diferentes grupos sociais e entre homens e mulheres. As populações mais vulneráveis enfrentam maiores riscos devido à falta e/ou dificuldade de acesso a serviços, como os de saúde e educação. Além disso, o ambiente em que essas interações acontecem também é importante. As mudanças que os humanos fazem no uso da terra afetam a biodiversidade e alteram os padrões de contato entre pessoas e animais, o que pode aumentar a transmissão de doenças. Isso faz com que o risco de contrair uma doença zoonótica seja diferente em cada caso. Este estudo analisou como fatores sociais, econômicos, de gênero e ambientais influenciam as interações entre pessoas e animais no Pantanal. A pesquisa foi dividida em dois capítulos e possui um apêndice, apresentando uma metodologia para estudar sobre o risco de zoonoses no Pantanal. O primeiro capítulo investigou a percepção de risco e as dinâmicas de gênero no Pantanal. Nele relatamos que os homens relatam mais interações com animais doque as mulheres, mas homens e mulheres apresentaram a mesma percepção de risco de doenças zoonóticas. Também se observou que as comunidades ribeirinhas, que convivem com maior biodiversidade, relatam mais interações com animais do que os assentamentos. No entanto, ribeirinhos e assentados não tiveram diferenças quanto a percepção do risco. O segundo capítulo analisou o impacto da porcentagem de vegetação nativa existente na propriedade dos entrevistados sobre as interações entre eles e os animais em

assentamentos agrários. A hipótese inicial era de que mais vegetação levaria a mais interações, mas a análise mostrou que essa relação não era tão forte quanto esperado, explicando apenas 16% das interações. Outros fatores, como a conectividade entre fragmentos de vegetação, podem ser mais relevantes. Além disso, a rede de interações entre pessoas e animais apresentou assortatividade de grau positiva, indicando que pessoas com número similar de conexões tendem a relatar os mesmos animais. Também foram verificadas, separadamente, a proximidade entre propriedades e a semelhança na quantidade de mata nativa para ver se influenciavam os relatos de animais, mas não encontramos relações significativas.

Além dos dois capítulos, o estudo inclui um apêndice que apresenta uma estrutura para avaliar os riscos de doenças zoonóticas no Pantanal. Essa estrutura foi desenvolvida em colaboração com outros pesquisadores e pode ajudar a criar estratégias de prevenção e controle de doenças na região. Por fim, esse estudo ressalta a importância de entender essas interações para criar políticas públicas de saúde e conservação mais eficazes. Ele defende que as comunidades locais participem do processo de tomada de decisão, o que pode aumentar a aceitação e o sucesso dessas políticas. Além disso, recomenda-se a integração da conservação da biodiversidade em programas de saúde como o One Health, que trata da saúde humana, animal e ambiental de forma conjunta, com foco em mudanças de comportamento e na conscientização sobre os benefícios da biodiversidade.

Popular Abstract

Increasingly, people are recognising the public health risks arising from interactions between humans and animals, both wild and domestic. Approximately 70% of emerging zoonotic diseases (diseases that pass from animals to humans) and several recent pandemics are linked to this type of contact. Factors such as social dynamics and the roles that men and women assume in daily activities significantly influence these interactions, affecting how zoonotic diseases are transmitted. The perception of risk regarding zoonotic diseases varies among different social groups and between men and women. The most vulnerable populations face greater risks due to a lack of and/or difficulty in accessing services such as health and education. Furthermore, the environment in which these interactions occur is also important. Changes that humans make to land use affect biodiversity and alter the patterns of contact between people and animals, which can increase disease transmission. This means that the risk of contracting a zoonotic disease is different in each case. This study analysed how social, economic, gender, and environmental factors influence interactions between people and animals in the Pantanal. The research was divided into two chapters and includes an appendix presenting a methodology for studying the risk of zoonoses in the Pantanal. The first chapter investigated risk perception and gender dynamics in the Pantanal. We reported that men report more interactions than women, but both men and women have the same perception of the risk of zoonotic diseases. It was also observed that Riverine Communities, which coexist with greater biodiversity, report more interactions with animals than Settlements. However, there were no differences in risk perception between Riverine Communities and Settlements.

The second chapter analysed the impact of the percentage of NV on the properties of the interviewees on their interactions with animals in agrarian Settlements. The initial

hypothesis was that more vegetation would lead to more interactions, but the analysis showed that this relationship was not as strong as expected, explaining only 16% of the interactions. Other factors, such as connectivity between fragments of vegetation, may be more relevant. Additionally, the network of interactions between people and animals exhibited positive assortativity, indicating that individuals with a similar number of connections tend to report the same animals. Proximity between properties and similarity in the amount of native forest were also examined separately to see if they influenced animal reports, but no significant relationships were found.

In addition to the two chapters, the study includes an appendix that presents a framework for assessing the risks of zoonotic diseases in the Pantanal. This framework was developed in collaboration with other researchers and may help create strategies for disease prevention and control in the region. Ultimately, this study emphasises the importance of understanding these interactions to create more effective public health and conservation policies. It advocates for local communities to participate in the decision-making process, which can enhance the acceptance and success of these policies. Furthermore, it is recommended that biodiversity conservation be integrated into health programmes such as One Health, which addresses human, animal, and environmental health in a holistic manner, focusing on behaviour change and raising awareness of the benefits of biodiversity.

General Introduction

In 2020, with the onset of the COVID-19 pandemic, there has been a notable recognition of the public health risks associated with interactions between humans and both wild and domestic animals (Di Marco et al. 2020). About 70% of Emerging Zoonotic Diseases (EZDs) and nearly all recent pandemics (e.g., MERS-CoV, Ebola) can be associated with an increase of these interactions (Olival et al. 2017; Stel et al. 2022). However, factors beyond pathogens and host animals play a significant role in shaping human-animal interactions. Aspects related to humans, such as social dynamics and gender roles, contribute to disparities in risks associated with emerging zoonotic diseases and influence the epidemiology of infectious diseases (Hassel et al. 2017). The distribution of zoonotic risks among human populations is not homogeneous; women and men engage with animals and expose themselves to pathogens in varying degrees of intensity and intimacy. Therefore, understanding how different social groups and genders—defined by social constructs—perceive the risks of EZDs that stem from these interactions is a crucial component of successful infectious disease prevention (Friedson-Ridenour et al. 2019, Garnier et al. 2021, Rana et al. 2021, He et al. 2022, Cataldo et al. 2023). Moreover, infectious disease outbreaks often disproportionately impact the health of socially vulnerable groups, including traditional and indigenous populations, who face heightened risks due to social barriers (Richard et al. 2021, Magalhães et al. 2023), such as precarious access to health services, precarious sanitary conditions, poor economic conditions and education, for example.

Additionally, numerous studies have underscored the significant role of landscapes in the complex dynamics of zoonotic diseases (Faust et al. 2018, Plowright et al. 2021, Perfecto et al. 2023). Human-dominated ecosystems, altered by anthropogenic activities such as land use changes, lead to loss of native vegetation NV and significantly influence interaction patterns and ecological networks by disrupting biodiversity dynamics (Plowright et al. 2021). A major public health concern arising from this context is the potential increase in new pathogen interactions and transmission, along with heightened human-animal interactions (Reaser et al. 2021). However, the responses of interaction networks, as well as the patterns of these interactions, can be highly context-dependent, shaped by socio-economic factors and human practices within a landscape (Cazeta & Fahrig. 2021). Furthermore, human actions within landscapes are often driven by cultural and economic trends. As human social systems evolve, the repercussions for ecological networks can create a cascading effect (Renaud et al. 2018). Consequently, human practices, such as the structure of agricultural activities, contribute to the formation of vegetation gradients that influence species abundance and diversity (Perfecto et al. 2023), thereby impacting human-animal interaction networks and the associated public health risks.

The interplay of gender, social, economic, and environmental factors in shaping human-wildlife interactions has not been thoroughly explored. Social determinants such as socioeconomic status and gender play a critical role in health inequalities and significantly affect both the epidemiology of infectious diseases and the perception of EZD risks (Hassel et al. 2017). Furthermore, land use change is a key environmental factor that facilitates the transmission of pathogens from wildlife to humans (Reaser et al. 2021). Thereby, the first chapter of this study aims to assess the relationships between risk perception, interactions with animals, and gender among social groups in the Pantanal, particularly in Settlements and Riverine Communities. It is anticipated that men will exhibit a greater richness of interactions with animals within the network and a lower perception of risk, as they tend to demonstrate lower adherence to preventive behaviours (Bronfman et al. 2021). In contrast, women are expected to have fewer interactions but a heightened perception of risk, driven by their roles in tasks such as cleaning meat, cooking, and caring for sick family members, which enhance their awareness of disease symptoms and associated risks (Bronfman et al. 2021). A negative correlation is also expected between risk perception and the frequency of interactions with animals; as the perception of risk increases, interactions are likely to decrease. Furthermore, Riverine Communities are anticipated to display a greater number of interactions due to their locations, which feature higher biodiversity and greater distances from urban centres.

The second chapter investigates how gradients of NV at the property level impact the interaction network between humans and animals as perceived by local inhabitants in agrarian Settlements and communities in the Pantanal. It is hypothesised that individuals' node degrees (number of interactions with animals) will positively correlate with the amount of NV on their properties. The network is expected to exhibit a positive degree assortativity pattern, indicating that nodes with high interaction degrees are likely to connect with other high-degree nodes, while low-degree nodes connect with similar low-degree nodes, reflecting a shared composition of reported animals. Additionally, the similarity in interaction composition is anticipated to be influenced by the percentage of NV on each property, as well as the distances between areas. The insights gained from this network analysis will shed light on how interactions between humans and animals correspond to the gradient of NV and spatial factors, with important implications for regional public health strategies, conservation efforts, and the mitigation of emerging zoonotic disease risks.

In addition to the two chapter, a framework was developed, integrating expertise from different knowledge areas – such as public health, ecology and social sciences. It aims to assess and forecast pathogen spillover risks by mapping the human-animal-environment interface, while accounting for social factors such as gender and community roles that influence vulnerability. The framework also emphasises the need for enhanced biodiversity monitoring and data collection on species dynamics and human health, facilitating informed decision-making to mitigate disease risks and promote sustainable practices. By fostering community engagement and interdisciplinary collaboration, this initiative seeks to advance One Health approaches and strengthen health security in the Pantanal.

Social and gender disparities in the Pantanal shape human-animal interactions, but not zoonotic risk perception

Abstract

The recent COVID-19 pandemic has highlighted the need to investigate socioecological interactions between human and animals, particularly the social and gender contexts underlying this problem. These factors have been identified as important determinants of the heterogeneity of risk, vulnerability, and risk perceptions to emerging zoonotic diseases (EZDs), especially in ecologically and socially vulnerable populations. In this paper, we report the influence of social and gender factors on EZDs risk perceptions, and interactions with animals in Riverine Communities (RC) and Settlements (ST) in the Pantanal wetland, the largest continuous continental floodable area in the world.

Data were collected and analysed from 90 interviewees, comprising 45 people from RC and 45 ST (50 women and 40 men). Using generalised linear mixed models, we fitted two models: one to predict interactions with animals based on the variables social group (i.e., RC and ST), gender and risk perception score, and a second to predict risk perception based on social groups, gender and interactions with animals. Age was included as a random effect in both models. We found that gender (p=0.019) and social group (0.001) were related to interactions between humans and animals in the Pantanal. The analysis indicated that men had more contact with animals than women resulting in a richer network, and people from RC had more contact with animals than those from the ST. However, there was no difference in perception of risks between men and women, or between RC and ST.

During the field campaign, a notable difference in gender roles was observed between social groups (i.e., RC and ST). While on the ST there was a distinct association between daily activities and gender roles, the RC exhibited a more evident gender equality. Our study provides evidence supporting the open property regime related to gender symmetries—access to common resources is equitable, sustainable, and efficient. '*Synthesis and applications*'- In attempts to prevent EZDs in the Pantanal wetland, particularly in the promotion of gender and social equity, it is important to avoid *a priori* assumptions that all interactions between humans and animals culminate in major threats to human health or biodiversity. Otherwise, we may create significant barriers with health and conservation policies and measures that exclude local people. We strongly suggest that health and conservation planning programmes should be co-produced with the local populations.

Key words: One Health; socioecology; infectious diseases; conservation

Resumo

A recente pandemia da COVID-19 destacou a necessidade de investigar as interações socioecológicas entre humanos e animais, abordando os contextos sociais e de gênero, uma vez que esses fatores foram identificados como determinantes da heterogeneidade do risco, da vulnerabilidade e da percepção de risco para doenças zoonóticas emergentes (DZEs), especialmente em populações ecológica e socialmente vulneráveis. Neste artigo, relatamos os resultados de um estudo que examinou a influência de fatores sociais e de gênero na percepção de risco de EZDs e nas interações com animais em comunidades ribeirinhas e assentamentos no Pantanal, a maior área continental contínua inundável do mundo. Os dados foram coletados e analisados a partir de 90 entrevistas no total, que incluíram 45 pessoas das comunidades ribeirinhas e 45 dos assentamentos (dos 90 entrevistados, 50 eram mulheres e 40 homens). A análise foi realizada por meio de modelos lineares generalizados mistos, e descobrimos que o gênero ($p=0.019$) e o grupo social ($p=0.001$) estavam relacionados às interações entre pessoas e animais no Pantanal. A análise indicou que os homens tiveram mais contato com os animais do que as mulheres resultando em uma rede de interação com maior riqueza de interações, e as pessoas das comunidades ribeirinhas tiveram mais contato com os animais do que as pessoas dos assentamentos. No entanto, não houve diferença no risco percebido, entre homens e mulheres, ou entre comunidades ribeirinhas e assentamentos. Durante o trabalho de campo, foi observada uma diferença notável nos papéis de gênero entre os grupos sociais (comunidades ribeirinhas e assentamentos). Enquanto nos assentamentos houve uma clara associação entre as atividades diárias e as regras de gênero, um nível maior de igualdade de gênero foi observado nas comunidades ribeirinhas. Nossos resultados fornecem mais evidências de que um regime de acesso aberto ou de propriedade aberta está relacionado a simetrias de

gênero. Nas tentativas de evitar EZDs na área úmida do Pantanal e de promover a igualdade social e de gênero, é importante não fazer uma suposição a priori de que qualquer interação entre pessoas e animais é uma grande ameaça à saúde humana ou à biodiversidade, ou podemos acabar com políticas e medidas de saúde e conservação que excluem a população local. Sugerimos enfaticamente que as medidas e o planejamento em saúde e conservação sejam coproduzidos com as populações locais.

Palavras-chave: One Health; socioecologia; doenças infecciosas; conservação

Introduction

Several studies emphasize the growing global importance of risk perception of zoonotic diseases in the context of social and gender roles, as these factors are crucial determinants for successfully preventing infectious diseases (Friedson-Ridenour et al. 2019, Rana et al. 2021, Garnier et al. 2020, He et al. 2022, Cataldo et al. 2023). According to the World Health Organization (WHO. 2020), the term zoonotic disease refers to an infectious disease that passes from a non-human animal to humans, and they constitute a major problem to public health emanating from close relationships between humans and animals.

During the COVID-19 pandemic, the possible infectious disease implications of human-animal interactions gained much greater attention on a global scale, highlighting that the social and gender-based risks and vulnerabilities are not uniform across different populations and regions of the world (Rana *et al*. 2021). For example, according to the Global Gender Gap Report (2024), Pakistan ranked as one of the lowest countries in women´s health and survival, despite its gender and social disparities. But, during Covid-19 about a year later, the values of risk perceptions and coping mechanisms were higher in women than men. The pandemic also highlighted the necessity for inclusive and suitable approaches to integrate social and gender-related perspectives into public health measures, since they can significantly contribute to more effective mitigation strategies and the promotion of more equitable global health (Bono *et al.* 2021, Crespí-Lloréns *et al.* 2021). Moreover, it is crucial to recognize that infectious disease outbreaks often disproportionately affect the health of socially vulnerable groups, who are at a higher risk of disease contraction because of social barriers that usually keep them isolated (Richard *et al*. 2021, Magalhães *et al*. 2023).

Vulnerability originates from the overlap of several individual particularities and interlinked social aspects that typically border on poor access to healthcare, education, and food security, which can result in these population groups being more susceptible to diseases (Oliveira *et al.* 2021). Populations of Traditional and indigenous populations or small groups of ranchers are – usually - difficult to access as a result of poor road and transport infrastructure. They are largely predisposed to higher risks of exposure to zoonotic pathogens and are often exhibit high susceptibility to the devastating consequences of an epidemic or pandemic.

Understanding the impact of different social groups, including gender, on the amplification of health inequalities and in the epidemiology of infectious diseases is of paramount importance (Hassel *et al.* 2017, Coyle *et al.* 2020). Indeed, it is crucial to investigate gender-based disparities in the perception and management of risks associated with infectious diseases, particularly juxtaposed against socioeconomic scenarios (Rana *et al*. 2021). In this context, gender is considered a product of socially constructed roles that encompass behaviours, characteristics and attributes culturally designated as appropriate for men or women (Friedson-Ridenour *et al.* 2019, Cataldo *et al*. 2023).

In some regions and cultures across the world, human daily activities are socially determined and intrinsically linked to gender roles. This in turn, plays a crucial impact on how they forge interactions with their local biodiversity (Garnier *et al*. 2020). For example, men tend to have more contact with animals through activities such as hunting, while women perform tasks, such as cleaning meat for cooking, and caring for sick family members (Coyle *et al*. 2020). This different gender-based implied roles cause men and women to interact with animals in varied ways and intensities. Importantly, they result in heterogeneous distributions of vulnerabilities to emerging zoonotic diseases (EZD) (Garnier *et al*. 2020, Cataldo *et al.* 2023*)*. Moreover, comprehension of gender-based roles, and socially determined distinctions among populations are of utmost importance for public policy creation with a special focus on EZDs (Galiè *et al.* 2024), as well as in environmental education and biodiversity conservation.

Environmental pressures in areas of high biodiversity have a critical role to play in the complex landscape of EZDs (Hassel *et al*. 2017, Namusisi *et al*. 2021, Magalhães *et al*. 2023). A notable example is the Pantanal, which is the most preserved and largest continuous continental wetland in the world, and yet about 90% of the landscape consists of cattle ranches that produce over 3.8 million cattle per year (Chiaravalloti *et al*. 2023). In addition, local communities are in constant contact with the biological richness of the environment for incomes. This wetland faces challenges such as floods and fires, which constitute critical drivers of ecological processes in the Pantanal landscape (Chiaravalloti *et al*. 2023). All of these intensify human-animal interactions (Hassel *et al*. 2017), and consequently increase the risks of EZDs. Overall, the precariousness of the health system and limited access to basic sanitary conditions in remote and sparsely inhabited regions place local communities at significant vulnerability to EZDs (Garnier *et al*. 2020, Clímaco *et al*. 2021).

Since the Pantanal is a place of rich biodiversity, there are constant interactions between local human populations with animals in pursuit of their daily socioeconomic activities, which may influence EZD risk distribution (Rana *et al*. 2021, Cataldo *et al*. 2023). Moreover, this could have strong linkages with gender (Garnier *et al*. 2020), propelling high consequences to risk perception of EZDs. However, not much is known about this subject in wetlands around the world. Although gender and social centred analytical frameworks have been suggested to tackle this challenge, there is an overarching insufficiency in evidence-driven analyses to clearly establish the role of gender and social factors in public health interventions against EZDs in vulnerable groups (Friedson-

Ridenour *et al*. 2019, Garnier *et al.* 2020).

The aim of this study was to assess the relationship between risk perceptions, human-animal interactions and gender within Pantanal social groups - comprising Riverine Communities (RC) and Settlements (ST). First, we hypothesized that men would have higher animal interactions and lower risk perceptions than women. This is based on the critical rationale that, in comparison to women, men have lower rates of adherence to preventive behaviours (Bronfman *et al*. 2021). Second, we hypothesized that women would have fewer interactions with animals but exhibit higher risk perceptions - since women perform domestic tasks, such as cleaning meat, cooking, and caring for sick family members. Generally, women tend to have a greater perception of the risks to which they are exposed, including higher knowledge about disease symptoms, and are therefore more aware of the risk they are running (Bronfman *et al*. 2021). Thus, it is expected that there will be a negative relationship between risk perceptions and the number of animal interactions for this gender. This implies that increase in perception would lead to decrease in humananimal interactions. Third, it is expected that RC would exhibit higher human-animal interactions than ST as they are in a more conserved location farther from the city, and access to higher biodiversity.

Methods

Study site

The study was conducted in the Pantanal. It is an extensive wetland region covering around 179,300 km² (Junk *et al*. 2006), stretching across the territories of three countries: Brazil, Bolivia and Paraguay (Junk *et al*. 2006, Wantzen *et al*. 2023). The Mato Grosso do Sul part of the Pantanal stretches from the north of the state, from the city of Coxim, to the extreme south-west, in the city of Porto Murtinho, passing through Aquidauana, Miranda, Ladário and Corumbá. About 5.7% of the Pantanal's total wetland area is designated as Stricted Protected Area, covering zones protected at federal, state, and municipal levels, while another 7.4% corresponds to Indigenous Territories (Wantzen *et al*., 2023). This vast wetland is home to remarkable biological diversity, comprising over 2,000 plant species, 464 birds, 124 mammals, 177 reptiles, 41 amphibians, and 325 varieties of fish (Junk *et al*. 2006).

The landscape is profoundly influenced by flood pulses, determining the distribution of trees from dry savannah to floodplain forests (Junk *et al*. 2006). During the rainy season (October – March), vast areas are flooded, forming extensive wetlands, while in the dry season (April – September), the water recedes, revealing temporary fields and lagoons (Da Cunha *et al*. 2023). Even centimetres of difference in elevation have remarkable impact on the establishment of woody plants (Wantzen *et al*. 2023). This complex hydrological dynamic is essential for the Pantanal's rich biodiversity, directly influencing vegetation, wildlife, and human activities (Wantzen *et al*. 2023).

Human population of the area includes indigenous groups: Kadiwéu, Kinikinau, Terena, Bororo, Guató and Umotinas, as well as RC, ranchers, national and international tourists attracted by the fishing opportunities, wildlife and the exuberant natural landscape (Wantzen *et al*. 2023). On the western edge of the Pantanal, Sul-Mato-Grossense contains approximately 400 riverine people living in four main RC: Barra do São Lourenço, Paraguai-Mirim, São Francisco and Porto Amolar (Zanatta 2010). They predominantly engage in fishing, bait gathering, and harvesting of natural resources. Most of the population was born and raised on the banks of the Paraguay river, where they still live, and many of them descend from local indigenous communities. Between the cities of Ladário and Corumbá, there are agrarian reform Settlements, which housed around 1,411 families until 2015 (Conceição 2015). Their main economic activities are land-based, involving small-scale plantations, livestock and dairy production (Figure 1).

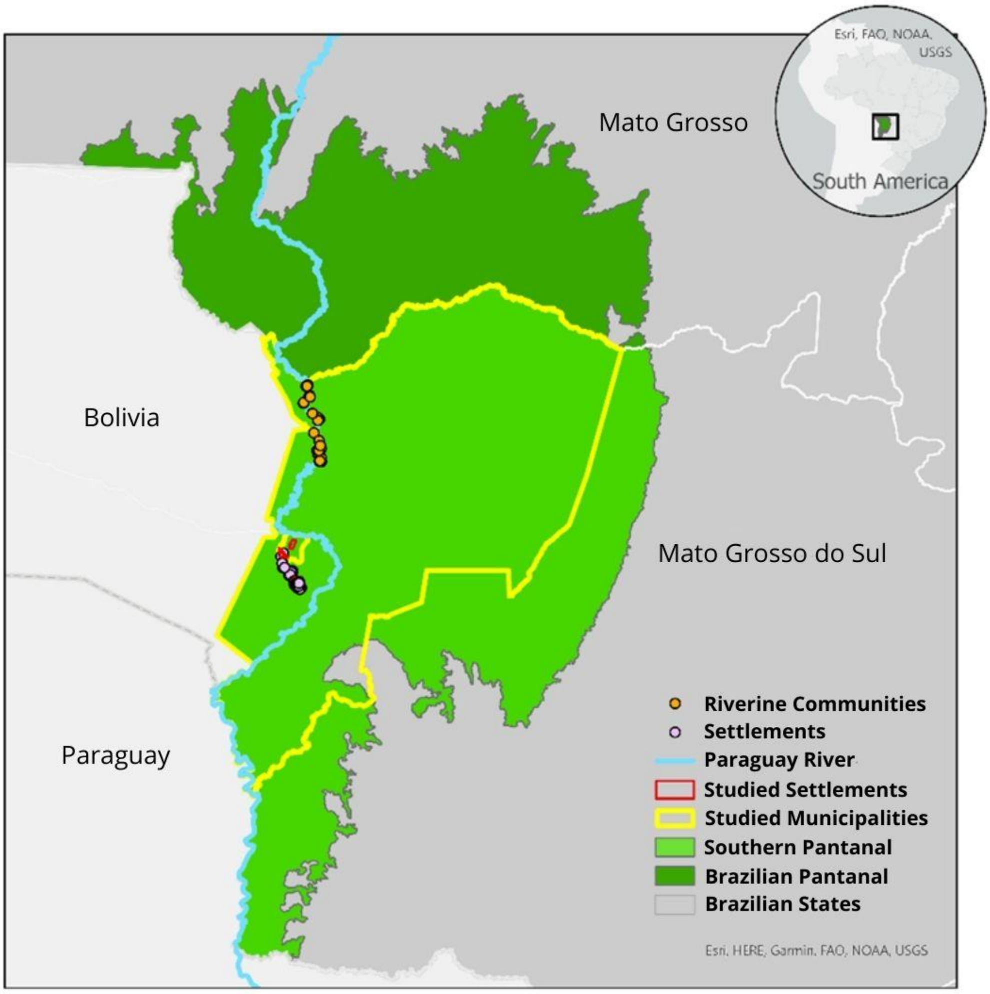

Figure1: Localization of the Pantanal wetland in South America, highlighting the Paraguay River, and the RC and ST.

Data Sampling

Four RC and four ST were chosen for this study. We build a semi-structured questionnaire with open-ended questions inspired by research conducted by Paige *et al* (2015). These contained questions about human contact with animals, perception of disease symptoms, including time allocation, contact with animals during and after fire episodes, as well as demographic information (Appendix 1). Residents of the RC and ST were approached at their homes. After personal introduction, the content of the research was explained and, if the people agreed to be interviewed, the interview coordinates were then taken. Then, the participants were asked to sign an "Informed Consent Form" in accordance with the current legislation of the National Health Council (Resolution 466/2012), which was authorised by the Federal University of Mato Grosso do Sul Ethics Committee (CEP/UFMS) nº 468700121.9.0000.0021. All participants were free to comment on the questions and to refuse answer any question they did not feel comfortable. A total of 90 people participated in the research (45 RC and 45 ST), with similar proportions of men and women in each location. The field survey was conducted twice, specifically in January 2023 for the ST and in July 2023 for the RC. A total of 50 women and 40 men were interviewed in the study. Their age ranged from 18 to 103 years; the distribution of participants between gender and social groups can be seen in Table 1 – a, as well as the average age and number of interactions with animals of each group and gender (Table 1 – b).

Table 1

a)	Questionnaire Participants and Characteristics								
	Men	Women	Riverine	Settlement	R Women	S Women	R Men	S Men	Total
N	40	50	45	45	27	23	18	22	90
%	44.44	55.55	50	50	30	23.55	20	24.44	
Age (mean)	49.27	49.84	43.11	55.97	45.62	54.78	39.55	57.22	49.58
Age (SD)	15.82	15.8	17.27	11.18	19.08	8.87	13.21	13.28	15.72

b)	Interactions with domestic and wild animals								
	Men	Women	Riverine	Settlement	R Women	S Women	R Men	S Men	Total
N	523	561	604	480	338	223	266	257	1084
%	48.24	51.57	55.71	44.28	31.18	20.57	24.53	23.7	
Mean	13.07	11.22	13.42	10.66	12.51	9.69	14.77	11.68	12.04
SD	4.25	4.08	4.26	3.77	4.07	3.61	4.3	3.75	4.23

Table 1- Distribution of questionnaire participants between genders and social groups – Riverine Communities and Settlements. As well as the standard deviation, average age and number of interactions by gender and social group.

Personal photos illustrating Riverine Communities - a) Serra do Amolar seen from a boat on the Paraguay River; b) Residents of the riverine community of Barra do São Lourenço cleaning fish and chatting on the banks of the Paraguay River with the Serra do Amolar formation in the background; c) Houses commonly built by the families of the communities on banks of Paraguay River.

Personal photos illustrating the Settlements - a) Maciço do Urucum, a mountainous formation that can be seen from many properties. It is currently being exploited by mining companies. b) Domestic pig lying in a mud puddle on one of the properties visited. In the background you can see a clean pasture, with denser forest on the horizon. c) Guinea fowl from one of the properties visited. Note that the ground is bare right up to the edge of the fence. After that, a green landscape dominates outside the property.

Data analysis

The survey responses were subjected to standardisation. The questions about EZD risk perceptions were separated and assigned scores of zero (absence of risk perception) and one (presence of risk perception). This way the sum of each question gave each participant score between zero and ten, with the highest score (ten) corresponding to the highest risk perception. The number of interactions each person had with animals was also taken from the interviewees. This information involved comments on all the animals that they had encounter.

Next, bipartite networks of interactions between humans and animals were generated to visually explore the data using the package 'bipartite' in R studio. Here, the total number of interactions of each person and animal corresponds to their node degree within the network. Each human and animal constituted a node, each link between a human node and an animal node denote an interaction. For inclusion within the network, only animals that were identified with high specificity by the interviewees were considered. These include wild pigs, domestic pigs and peccaries, or night monkeys, capuchin monkeys and howler monkeys. Animals associated with vague or uncertain comments, such as unidentified small birds, were excluded from the network.

Generalised linear mixed models (GLMM) were used to assess the relationships between the response and predictor variables (Magalhães *et al*. 2023). The models included age as random effect. The first model evaluated risk perception scores as response variable with predictors gender, number of interactions and social groups. The second model estimated the number of interactions between humans and animals as a response variable, with predictors gender, social groups and risk perception scores.

Results

Within the first model (Table 2 – a) the effect of interactions ($p = 0.45$; $z = -0.76$), social groups ($p = 0.15$; $z = -1.42$) and gender ($p = 0.23$; $z = -1.18$) were statistically non-significant to predict risk perception score. The explanatory power was $r^2 = 0.06$. However, the effects of gender and social groups in interactions with animals were positive and significant, where men and RC clearly demonstrated higher number of interactions than for women and the ST. Within the second model (Table 2 - b) the effects of social group RC ($p = 0.001$; $z = 0.67$) and gender male ($p = 0.019$; $z = 0.48$) were statistically significant and positive. The explanation power of the model was $r^2 = 0.17$. The interaction networks (Figure 2 - b) revealed 10 animals with which men and women (RC and ST in the same network), and RC and ST (men and women in the same network) have more contact. These interactions were scarcely different between gender. Yet, the order of appearance of the animals in the network revealed that women engage more with bats and chickens than men. The networks to each social group revealed that the composition of the network of RC comprises a higher number of wild animals in comparison to the ST network.

Table 2

a)

	Generalized Linear Mixed Model						
	Dependent variable: Perception						
	beta	95% CI	t	p	Std. Beta	95% CI	z
Interactions	-0.03	[-0.11, 0.05]	-0.76	0.448	-0.09	[-0.32, 0.14]	-0.76
Social RC	-0.46	[-1.11, 0.18]	-1.42	0.159	-0.32	[-0.76, 0.13]	-1.42
Gender M	-0.38	[-1.01, 0.25]	-1.19	0.238	-0.26	[-0.69, 0.17]	-1.18

Intercept: beta = 8.53 (95% CI [7.61, 9.44], t(84) = 18.55, p < .001, z = 18.54)

R2 = 0.06; Observation (90); Log Likelihood (-161.96); Akaike Inf. Crit. (335.92); Bayesian Inf. Crit. (350.919)

Note: *p<0.1; **p<0.05; ***p<0.01

b)

	Dependent variable: Interactions						
	beta	95% CI	t	p	Std. Beta	95% CI	z
Social RC	2.82	[1.14, 4.50]	3.34	0.001***	0.67	[0.27, 1.06]	3.33
Gender M	2.02	[0.34, 3.70]	2.39	0.019**	0.48	[0.08, 0.12]	2.39
Perception	-0.22	[-0.81, 0.36]	-0.76	0.448	-0.08	[-0.28, 0.12]	-0.76

Intercept: beta = 8.53 (95% CI [7.61, 9.44], t= 18.55, p < .001, z=4.54)

R2 = 0.17; Observations (90); Log likelihood (-247.44); Akaike Inf. Crit. (506.87); Bayesian Inf. Crit. (521.878)

Note: *p<0.1; **p<0.05; ***p<0.01

Table 2- Generalized linear mixed model results from 90 interviews. The first one (a) analysed the perception of zoonotic risks score as the response variable, with the predictors being interactions, social group, and gender, where no significant influence was found. The second one (b) analysed interactions as the response variable, with social group, gender, and perception as predictors, showing a positive and statistically significant influence of social group (RC) and gender (M).

Figure 2.

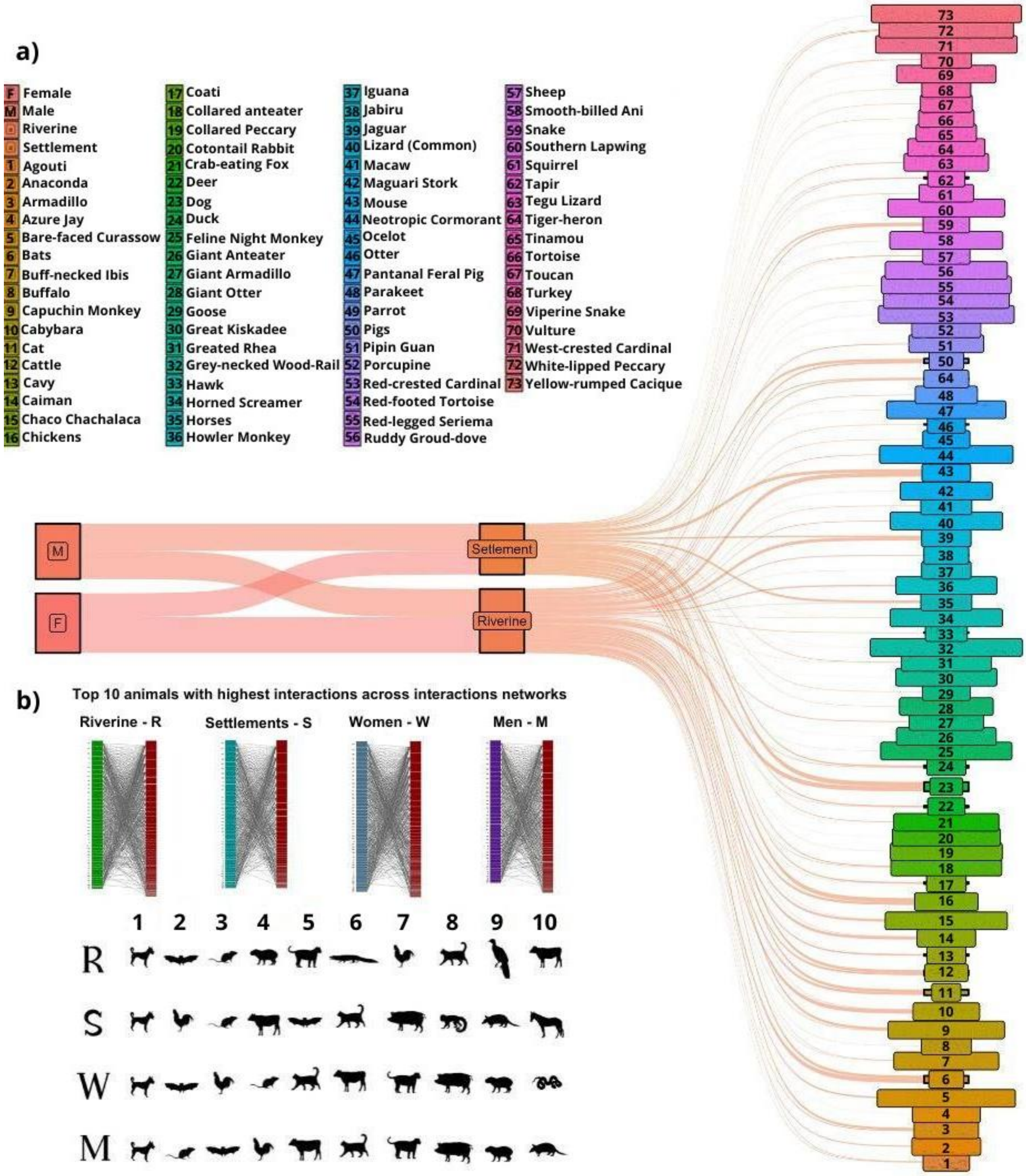

Figure 2: a) Sankey graph (packages: ggplot2 and ggsankey) visualising all 73 animals that males and females had contact with in Settlements and Riverine Communities; b) interaction networks of Riverine Communities, Settlements, women, and men, with a scheme highlighting the 10 most interacted animals in each group: R – dog, bat, mouse, capybara, jaguar, caiman, chickens, cats, chaco chachalaca, cattle; S – dog, chickens,

mouse, cattle, bat, cat, domestic pig, monkey, armadillo, horses; W – dog, bat, chickens, mouse, cat, cattle, jaguar, domestic pig, capybara, snakes; M – dog, mouse, bats, chickens, cattle, cat, jaguar, domestic pig, capybara, armadillo.

Discussion

The current study evaluated gender and social groups of two social groups (RC and ST) living in the Pantanal, with respect to human-animal interactions. The results of this study matched our hypotheses that socioeconomic orchestrated disparities between gender and social groups regarding interactions with animals in the region. These findings corroborate the idea that social roles and gender in shaping the relationships between humans and animals, as already observed in recent research (He *et al*. 2022, Magalhães *et al*. 2023). However, it is worthy of note that the disparities do not extend to risk perception to zoonotic diseases. In essence, while we identified notable differences in how men and women, as well as different social groups, relate to animals, the risk assessment of zoonotic diseases was not substantially influenced by these variables. These findings have significant implications for the design of strategies aimed at reducing the risk of zoonotic diseases in the Pantanal wetland, as they highlight the importance of consider social and gender factors independently when developing risk reduction measures.

We confirmed a higher number of interactions between men and animals. Yet, the disparity between genders was not very evident in terms of the composition of the networks, especially for the more frequently cited species (the first 10 species). On the other hand, a difference in the order in which the animals appeared in the network suggested the influence of the social role of gender on these interactions. For example, in women's networks, chickens appeared in third place, while in men's networks, bats occupied this position, which led to the deduction that women spent more time within their properties on chores related to domestic care. Among the social groups, as expected, the RC stood out in terms of interaction with animals, although the network had some limitations, as there were hardly any comments on invertebrate animals, and, oddly, on fish, which are in constant contact with RC, forming what we called a 'ghost network.' Within this 'ghost network,' there were also animals that were not identified by people, as they found it difficult to approximate identification based on their characteristics. In addition, the network composition of RC also differed from that of ST: among the top 10 animals, six were wild, compared to four in the ST networks. This was expected, given that they are in a well-conserved region with high biodiversity and difficult access, allowing for a greater number of contacts and varied interactions, as seen in the Barra do São Lourenço community.

Furthermore, in the ST during field work observations, there was a clearer association between the activities carried out and gender roles. A pattern that was not repeated in RC. Men and women carried out activities such as fishing and bait-catching in a predominantly collaborative way, which may explain the greater number of interactions with animals among the RC. Besides, they resided in a community where there were no fences between houses, and people collaborated with each other, even if they were not blood relatives, which may have created similar narratives about animal contact. This contrasted with what was observed in the ST, where individual activities prevailed over collective ones. The lack of property boundaries combined with the equality observed between men and women led us to speculate on the association between gender symmetries and the type of socioecological system regime in the RC. For the RC, it could be associated with an open access regime, as described by Chiaravalloti & Dyble (2018), and where environmental management provided by the communities occurred without defined limits (Moritz 2016). Dyble et al. (2015) explored gender equality in the social structure of hunter-gatherer communities and described an analogous situation, attributing gender equality to a scenario where cooperation among unrelated individuals evolved in the absence of wealth accumulation and individual needs above collective ones.

The risk perception of the Pantanal communities in question was not higher in women as expected, and did not vary between genders, even though other studies suggest otherwise (Rana *et al*. 2020, Niño *et al*. 2021, Barber & Kim 2021). In addition, both genders scored highly for risk perception, which stands in contrast to the findings of Bronfman *et al* (2021). However, a significant portion of the studies on risk perception focus on COVID-19 (Bronfman *et al*. 2021, Dryhurst *et al*. 2022, Niño *et al*. 2021). Furthermore, since the beginning of the pandemic there has been a large flow of information about prevention, vaccines, and health in general, which may have influenced the high scores, and homogeneity found regarding risk perception.

Another question to be raised about the results regarding the risk perception of EZDs by Pantanal communities is related to the concordance bias (Baron-Epel *et al*. 2010), which is common among populations made up of more than one ethnic group and consists of the tendency to provide extreme or positive answers. For example, although some interviewees answered in the affirmative that they thought animals could transmit diseases to humans, they also said they did not adopt preventative measures, creating a duality. This discrepancy may illustrate the influence of concordance bias, as individuals might align their beliefs with the group's views while failing to act accordingly.
In the context of public health and conservation, this study investigates the specific interactions between humans and animals in the region, providing insights that can help formulate public policies that are gender-sensitive and socially oriented. Such policies are crucial for effectively preventing infectious and zoonotic diseases at local and regional levels. Moreover, this research generates relevant information for assessing the risks of emerging zoonotic diseases (EZDs) in the Pantanal. For example, given that women in Pantanal communities interact more frequently with birds than men, they may be at a

higher risk of contracting Avian Influenza.

However, we cannot get blind to the idea that these interactions are a major threat to human health or biodiversity. There are many actors interacting in ways that influence whether zoonotic diseases occur. If we continue to view these interactions solely as threats, we risk creating barriers between public health policies and biodiversity conservation. This perspective often reflects a neocolonial approach to environmental conservation, which tends to alienate people from nature.

Kashwan et al. (2021) highlight the urgent need to transition from a neocolonial and racialized global conservation model to one that is inclusive and regenerative. They criticize the marginalization of local populations through imposed conservation measures that violate human rights and ignore traditional knowledge, community livelihoods, and the historical relationships developed over time. These imposed measures often restrict access to natural resources, lack consultation and participation from local communities in decision-making, and apply conservation practices that disregard the cultures and traditional knowledge of these groups.

Such a neocolonial view of conservation poses significant obstacles to achieving environmental and social justice. We must break the paradigm that separates people from nature and work towards a more participatory, respectful and fairness conservation approach. This approach should recognize local populations as active participants in the formulation and implementation of conservation policies. We strongly advocate for health and conservation planning and measures to be co-produced with local communities rather than imposed from the top down. This collaborative approach is crucial for enhancing effectiveness, acceptance, and positive outcomes.

Weak relationship between Land Use Cover and multiple facets of Human-Animal Interaction Networks in Pantanal Wetland Settlements

Abstract

Landscape characteristics, such as gradient of native vegetation (NV), and human practices impact species diversity and ecological networks. Socio-economic factors are also critical in shaping these interaction networks. Here, we evaluate the effects of (NV) gradient on interactions between people and animals in the Pantanal Settlements as perceived by local people. Data was collected and we evaluate facets of the interaction network generate from 41 interviews about contact with animals – such as assortativity degree, relation between node degree (number of interactions), shared interactions and gradient of NV at property level. A General Linear Model (GLM) was conducted, and we found that a small part of the node degrees is explained by the NV gradient ($R^2 = 0.16$; $p = 0.052$). The network was analysed using the package "igraph" on RStudio and display positive degree assortativity ($r=0.28$). Partial Mantel was cast on shared interactions as response variable and percentage of NV as predictor variable while controlling the effects of distances, and we found a non-significant relationship ($r=-0.06$; $p=0.9$). A second Partial Mantel was applied on shared interactions as response variable and distances as predictor variable while controlling the effects of NV, but also does not support our prediction ($r = -0.11$; $p=1$). Our results poorly sustain our hypothesis, however some reasons to that were raised. First, we ignore people´s movement through the gradient of NV. Second, landscape connectivity and patches of NV allowing animals to move through the properties and region. Third, lack of data about zoonoses in Brazil makes it difficult to address zoonotic risks, even though we have information on animal identification.

Forth, confused identification of animals by interviewees, since the network reflect a socio-metacommunity, where human-animal interactions are reported according to people´s perception. We end the paper with some recommendations about One Health programmes and conservations measures supported by spread of knowledge, educating people about the importance in maintain the biodiversity and how it relates to reduce the risk of zoonotic diseases.

Key-words: Metacommunity; Assortativity Degree; Zoonotic Diseases; Conservation.

Resumo

As características da paisagem, como o gradiente de vegetação nativa (NV), e as práticas humanas influenciam a diversidade de espécies. Fatores socioeconômicos também são críticos na formação dessas redes de interação. Neste artigo, relatamos os resultados de um estudo sobre os efeitos do gradiente de NV nas interações entre pessoas e animais nas comunidades e assentamentos do Pantanal. Os dados foram coletados e analisados a partir de 41 entrevistas sobre contato com animais. Um Modelo Linear Generalizado (GLM) foi aplicado, e a análise revelou que uma pequena parte dos graus de nós é explicada pelo gradiente de NV ($R^2 = 0,16$; $p = 0,052$). A rede foi analizada por meio do pacote “igraph” no Rstudio, e exibiu assortatividade de grau positiva ($r = 0,28$). Ao realizar um teste de Mantel Parcial com interações compartilhadas como variável resposta e o percentual de NV como variável preditora, controlando os efeitos das distâncias, encontramos uma relação não significante ($r = -0,06$; $p = 0,9$). Um segundo teste de Mantel Parcial com interações compartilhadas como variável resposta e distâncias como variável preditora, controlando os efeitos da NV, também não foi suportado ($r = -0,11$; $p = 1$). Nossa análise pouco sustenta nossa hipótese; no entanto, levantamos algumas razões para isso. Primeiro, sobre o movimento das pessoas através do gradiente de vegetação nativa. Segundo, a conectividade da paisagem e os fragmentos de NV presentes na paisagem. Terceiro, falta de dados sobre zoonoses no Brasil faz com que seja dificil identificar riscos direcionados a doenças especificas, mesmo com a identificação dos animais. Quarto, uma reflexão sobre as interações percebidas pelas pessoas. Concluímos o artigo com algumas recomendações sobre programas de Saúde Única e medidas de conservação apoiadas pela disseminação de conhecimento, educando as pessoas sobre a importância de manter a biodiversidade e sua relação com a redução do risco de doenças zoonóticas.

Palavras-chave: Metacomunidade; Assortatividade de grau; Doenças Zoonóticas;

Conservação.

Introduction

Anthropogenic activities exert a profound influence on ecological networks and interactions patterns, encompassing mutualism, predation, and competition, thereby altering biodiversity dynamics (Glidden 2021, Plowrigth *et al*. 2021). These changes often heighten human encounters with wildlife, including reservoir of zoonotic diseases like Rodentia, Chiroptera, Passeriformes, Carnivora, Primates, and Psittaciformes, that thrives within human-dominated ecosystems (Gibb *et al*. 2020; Roque *et al*. 2023), particularly evident amidst intermediate levels of land use conversion (Faust *et al*. 2018). Human-dominated ecosystems are variable, for example, with some agricultural modes of production expressing social formations that can promote (or protect us from) the emergence of new zoonoses in the same way they can harm (or protect) species biodiversity (Perfecto *et al*. 2023). Consequently, the socioecological characteristics of the human-dominated system are expected to influence human-animal interaction networks and then the probability of zoonosis emergence (Perfecto *et al*. 2023).

Landscape characteristics can influence human-animal interactions in many ways. The effect of habitat loss (e.g. Native Vegetation) is the most evident with consequences to animal communities and infectious diseases epidemiology (Johnson *et al*. 2021, Jackson *et al*. 2024). Generally, it causes loss of species that depend on Native Vegetation (NV) amount which lead to changes in ecological networks, and consequently in the human contact with biodiversity, threaten both human and other animals – per example, usually generalist mammals that persist in human-modified ecosystems often host high pathogen loads with serious zoonotic disease risks (Moore *et al*. 2023). Moreover, landscape configuration, matrixes and human practices can also account for some patterns (Perfecto *et al*. 2023) and the responses of interactions networks could be very context dependent when we consider human practices in the landscapes and socioeconomic factors. Agrarian structure, practices and spatial arrangement of the human communities can also contribute to a gradient of vegetation on landscape setting up a matrix that can modulate species abundance and diversity (Perfecto *et al.* 2023). Nevertheless, human actions are influenced by ever-evolving cultural and economic trends and have a cascading effect on ecosystems - as human social systems shift, they profoundly impact ecological networks (Renaud *et al.* 2018). However, few studies have addressed aspects of the human-animal interactions network that arise from these landscape composition and configuration.

A quick search on Web of Science platform (assessed on July 25-2024) revealed 869 publications on “human-animal network". When refining the search with the keyword "landscape", the number of publications drops to 21, with none addressing human-animal interaction networks across landscape gradients. Studies on ecological networks typically explore metrics such as degree, which is a basic network metric that reveals the number of connections each node has (Smith & Escudero 2020). In the case of a network between people and animals, node degree reveals the number of interactions between them. However, ecological interaction networks can be analysed in many ways, revealing different characteristics and trends based on the chosen metrics, the field of study—such as ecology, social sciences, or computer science—and the specific data of interest (Proulx *et al*. 2005, Janssen *et al*. 2006, Ings *et al*. 2009). Degree assortativity is a network metric that measures the tendency of nodes to connect to other nodes with similar degree values (Zhang *et al*. 2012). In the case of animal-human interaction network, it could mean, for example, that people similar in number of interactions (degree) tend to interact with a similar set of animals, their associated pathogens, and yet among people themselves. Under this context, this metric can provide insight into the structure and resilience of the network, highlighting patterns of connectivity that may not be apparent through single degree values. In social networks, positive degree assortative networks are frequently seen, especially on dynamic processes like spread of knowledge, “fake news”, pathogens and opinion (Vasques & O’Neale 2020). Moreover, assortative mixing pattern can be driven by the dynamic of animals in landscapes, since animals aggregate and sort in non-random patterns influenced by biotic and abiotic factors (Newman 2002, Escoda *et al*. 2018, Peel *et al.* 2018, Devan-Song *et al.* 2022). Therefore, evaluating biodiversity facets and exploring network approaches is crucial for understanding the structure and composition emerging from socio-ecological dynamics of human-animal interactions in response to land-use changes and their consequences for zoonotic diseases. By integrating degree assortativity to approaches to environment-human-animal interface, researchers can better understand the dynamics of human-animal.

Within this perspective, the Pantanal wetland emerges as a particularly compelling location for investigating the intricate network interactions between humans and animals. The area is the most preserved continuous continental wetland in the world and yet produces 3.8 million cattle a year (Chiaravalloti *et al*. 2023). In the southern Pantanal, the city of Corumbá is home to 96,268 people (IBGE, 2022 - https://cidades.ibge.gov.br/brasil/ms/corumba/panorama - access in 05/08/2024). In addition, its home to several animals well known as zoonotic pathogens host, like capybara, jaguar, giant anteater, collared peccary and giant armadillo (Roque *et al*. 2023). Moreover, pathogens such as *Brucella*, avian influenza virus, *Leptospira*, *Lyssavirus*, *Leishmania* spp, *Trypanosoma* spp and diverse arboviridae have all been detected across wildlife populations in the Pantanal (Porfirio *et al*. 2018, Roque *et al*. submitted). Furthermore, a previous study on drives and projections of vegetation loss suggests that Pantanal might lose 14,005 km2 of NV through 2050 (Guerra *et al*. 2020), what emphasize the urgency of understanding the complex dynamics involved in interaction between human and animals in this unique ecosystem across a gradient of land use changes. With that in mind, this study investigates how a gradient of NV, at property scale, impacts the interaction network between humans and animals, perceived by local people, in agrarian Settlements (ST) in the Pantanal (Fig.1).

Figure 1.

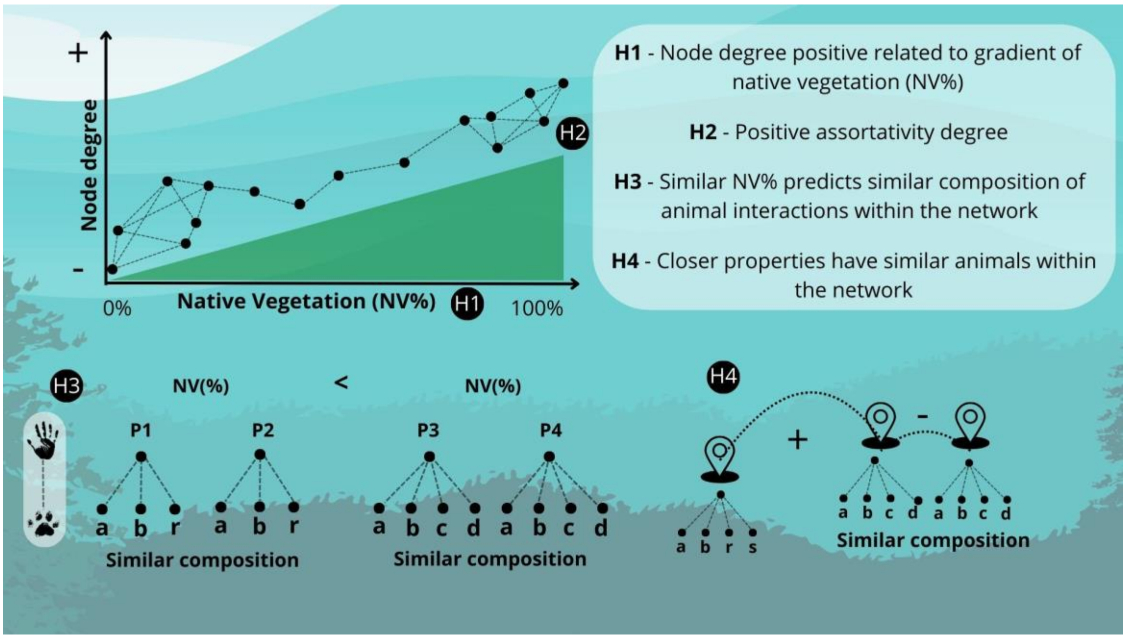

Fig. 1 – Image illustrating our hypotheses: H1- positive relation between node degree and native vegetation (NV) amount; H2 - positive degree assortativity; H3 - similar network composition among similar degrees with similar percentage NV (NV%) (P1-4 = people; a, b, c, d, r and s = different animals); and H4 – Closer properties will share similar animal interactions within the network.

We expect that people´s node degree (number of interactions with animals) will be positively associated with the amount of NV. We also hypothesized that the network would display positive degree assortativity pattern, in other words, nodes that shows higher degrees will be more likely to connect with similar nodes in degree, while nodes with low degrees will connect with similar low degrees, and both cases will share similar composition on reported animals. Moreover, we expected that the similarity on composition of interaction will be explained by the percentage of NV in each property as well as the distances between areas. Finally, we will discuss insights from this network analysis, examining how the interactions between humans and animals relate to the gradient of NV and space. We will explore implications for regional public health approaches, conservation strategies, and the challenges and limitations for mitigation and suture studies of emerging zoonotic disease risks.

Materials and Methods

Study area

The data was collected on Pantanal ST, that until 2015, housed around 1.411 families (Conceição 2015). We select three ST and one community that are located inside the study area of Paisagem Modelo Pantanal Project, along Highway BR-262, near the cities of Corumbá and Ladário MS and at the end of the Pantanal Road Park (Figure 2). Pantanal is in the Upper Paraguay Basin, and displays remarkable biodiversity influenced by the Amazon, Chaco, Cerrado and Atlantic Rainforest (Junk *et al*. 2006, Wantzen *et al*. 2023). This vast wetland has a remarkable biological diversity, comprising more than 2,000 species of plants, 464 types of birds, 124 mammals, 177 reptiles, 41 amphibians and 325 varieties of fish (Junk et al. 2006). Its habitants live in constant contact with the local biodiversity, carrying out subsistence activities ranging from small plantations to low and high intensity of livestock.

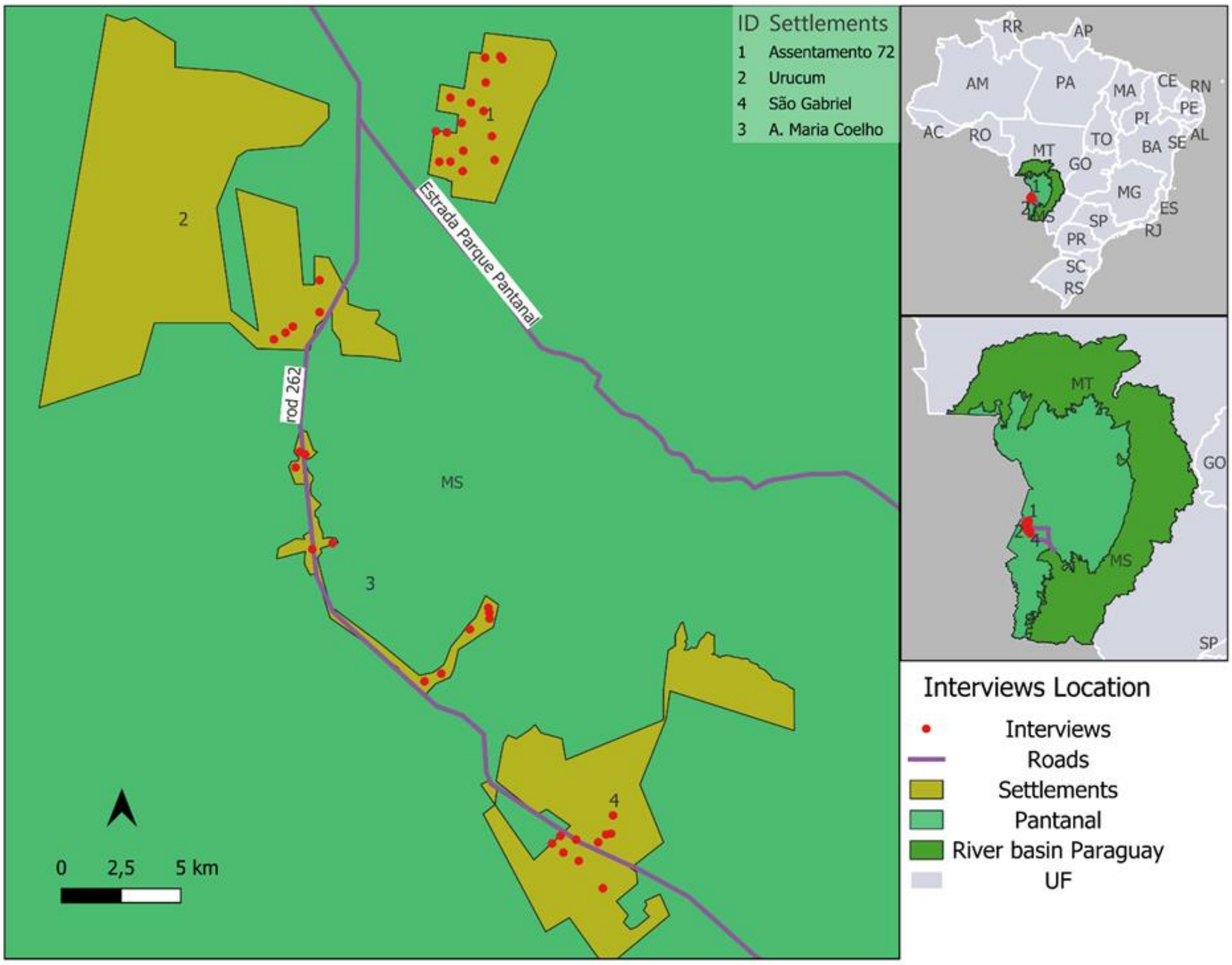

Figure. 2: Location of the Upper Paraguay River Basin in South America and Pantanal wetland in the Brazilian states of Mato Grosso and Mato Grosso do Sul. The Settlements' locations and the interviews (red dots). Instituto Brasileiro de Geografia e Estatística - Base Cartográfica Contínua do Brasil. Acessado em: 30 de agosto de 2023. Em: https://www.ibge.gov.br/

Accessing the interaction network and land use and cover

The interaction network was accessed through interviews employing a semi-structured questionnaire concerning daily contact with animals (Appendix 2), following a methodology akin to Paige *et al*. (2017). Questions was open-ended and included inquiries such as: "Have you ever reared animals?"; "Are there any animals inside your residence?"; "Have you ever slaughtered an animal? If so, which animals?". A total of 45 residents consented to participate in the study and were interviewed. All animals mentioned during the interviews were meticulously documented, leading to the creation of a matrix illustrating the presence or absence of interaction between individuals and animals.

The interviews were conducted at participants homes between January and February 2022. Their locations were geotagged using Avenza navigation app, developed by Avenza Systems. The points data were then integrated into geoprocessing software QGIS along with information from Corumbá Rural Environmental Registry (CAR - https://www.imasul.ms.gov.br/cadastro-ambiental-rural-car-ms/), enabling us to calculate the area of each participant's property in square meters and generate a Euclidean distance matrix between properties. At this point if two people were interviewed in the same location (wife and husband) one of them was excluded from analysis. Further analysis using MapBiomas data on land use and land cover from the year 2022 (MapBiomas Project - Collection 8 of the Annual Series of Land Cover and Land Use Maps of Brazil, accessed on 20/05/2024 via the link: https://storage.googleapis.com/mapbiomas-public/initiatives/brasil/collection_8/lclu/coverage/brasil_coverage_2022.tif) and the package “landscapemetrics” on R Studio, allowed us to assess the proportions of native forest, non-native forest, and bodies of water on each property, providing land use and cover patterns. The land use conversion is expressed here as the percentage of NV on each property, with consists of the sum of NV values. As the data about the land size on CAR document is self-declared, we assume that is the total area they are using for living and land activities. This work was authorised by the Federal University of Mato Grosso do Sul (CEP/UFMS) Ethics Committee (nº 468700121.9.0000.0021).

Statistical Analysis

To analyze and visualize our network, we used the bipartite package in R Studio to plot the interactions between people and animals (Fig.3). To test our first hypothesis, we performed a Generalized Linear Model (GLM) with the degree of each person node—the number of interactions reported (links) by each person (blue nodes)—as the response variable, and the percentage of NV on people's properties as the predictor variable. We assessed the amount of NV using the landscapemetrics package in R Studio, land use and cover data provided by MapBiomas, and the geoprocessing software QGIS to locate the interview points on people's properties and to determine the matrix of Euclidean distances between properties (third hypothesis).

For our second hypothesis, we conducted an assortativity degree analysis using the igraph package in R Studio. This involved performing a correlation of the interactions of each node by taking the original matrix and multiplying it by its transpose, which emphasises the number of links shared between nodes (Zareie et al. 2020). The result is a triangular matrix that indicates how many animals a person reported in common with another person in the network. The degree assortativity coefficient (r) is measured by the Pearson coefficient, which ranges between -1 and 1, with values close to 1 indicating a positive assortativity degree.

Finally, for our third hypothesis, we performed a partial Mantel test using the vegan package in R Studio. We tested the relationship of interactions shared between each node (composition of interactions) as the response variable, with the percentage of NV of each property as the predictor variable, using the Bray-Curtis dissimilarity index calculated with the 'vegdist' function in the 'vegan' package. We controlled for the effects of Euclidean distances between properties, calculated using QGIS software. The partial Mantel test was chosen for analyzing the correlation between two matrices, controlling the effect of a third matrix (Bertuzzi et al. 2018). This statistical test allows the control of variables, handles distance data (similarity, dissimilarity) effectively, and is suitable for spatial data. Thus, it offers flexibility in application, due to its flexibility in handling different types of data (Somers & Jackson 2022).

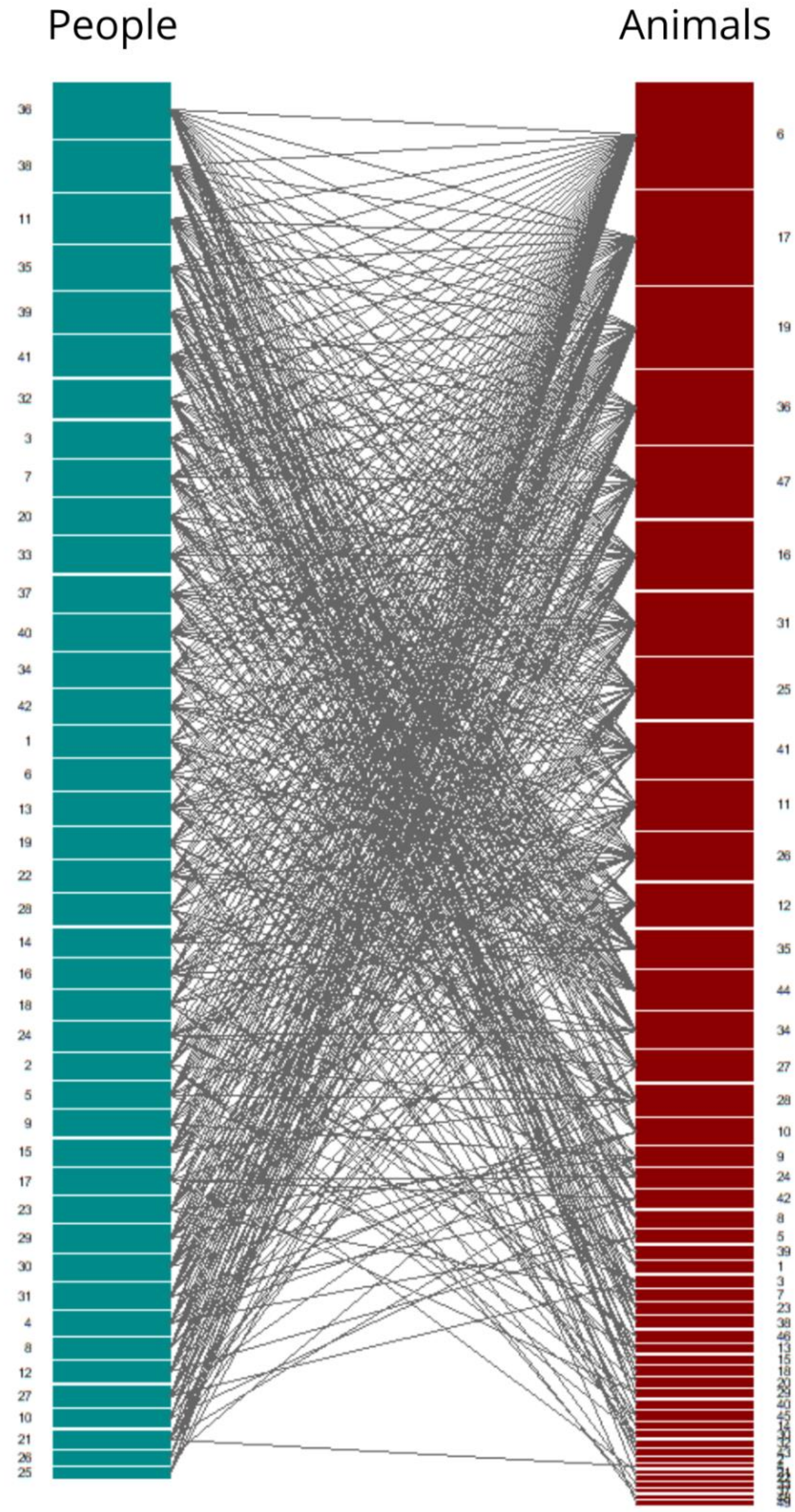
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Figure 3.

Fig.3 - Interaction network between people and animals based on interviews with residents of the Pantanal ST - People are in blue; each number is an interview in descending order in terms of number of interactions. (6-Dog, 17-Chicken, 19-Cat, 36-Mouse, 47-Bats, 16-Cattle, 31-Pig (domestic), 25-Capuchin, 41-Nine-Banded Armadillo, 11-Horse, 26-Jaguar, 12-Snake, 35-White-lipped peccary, 44-Deer, 34-Coati, 27-Parrot, 28-Duck, 10-Collared peccary, 9-Sheep, 24-Crab eating fox, 42-Tegu lizard, 8-Capybara, 5-Sheep, 39-Giant anteater, 1-Chaco chachalaca, 3-Howler monkey, 7-Terrapin, 23-Cayman, 38-Cariama, 46-Buff-necked ibis, 13-Squirrel, 15-Goose, 18-Ocilla, 20-Fish, 29-Anteater, 40-Spider, 45-Greater rhea, 14-Turkey, 30-Feral hog, 32-Vulture,43-Macaw, 2-Donkey, 4-Insects, 21-Tortoise, 22-Brazilian Guinea pig, 33-Frog, 48-Porcupine, 49-Horned screamer).

Results

Our first hypothesis was partially corroborated. We fitted a linear model to predict degree within the network (number of interactions with animals) with percentage of NV, the model's explanatory power is statistically weak ($R^2 = 0.16$). Yet, 16% of the interactions were explained by the percentage of NV. Within this model the effect of NV is statistically non-significant and positive ($p = 0.052$; $z = 1.93$) (Fig.4).

The second hypothesis was supported: the network of interactions between people and animals showed positive degree assortativity mixing ($r = 0.28$). As such, the network has a moderate positive tendency for nodes with higher degrees to connect to nodes of a similar degree and for nodes with lower degrees to connect to others of a similar degree.

Our third hypothesis was not corroborated. When we run a Partial Mantel on shared interactions as response variable and percentage of NV as predictor variable while controlling the effects of distances, we found a positive, but no significant relationship ($r=-0.06$; $p=0.9$). We then performed a Partial Mantel of shared interactions as response variable and distances as predictor variable while controlling the effects of NV, the relation also does not corroborate our hypothesis ($r = -0.11$; $p=1$).

Figure 4.

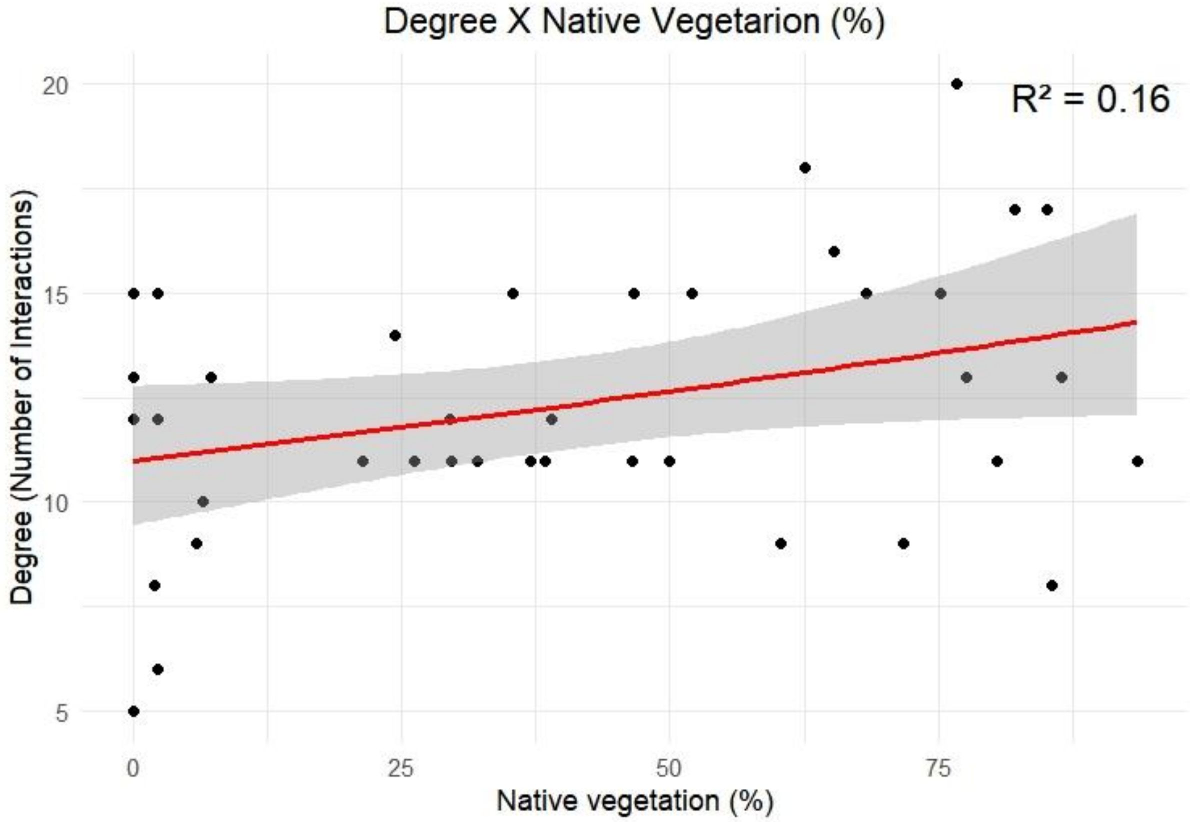

Fig. 4 – Network nodes degrees distribution of each interview point on the NV gradient ($p = 0.052$; $z = 1.93$).

Discussion

Our study evaluates different facets of animal-human network, measured here mainly by the diversity of interactions perceived by humans, in ST in the Pantanal that are experiencing recent land use changes. As expected (first hypothesis), we found that the number of interactions per person decreased with low remaining NV areas, however this relationship was weak. People who lived on properties with low amount of NV, presented network interactions characterized mainly by domestic animals. We also found evidence that people who live in properties retaining large NV areas have a weak tendency to have higher number of interactions (degree) and converge into the same composition of animals. While in the opposite site, people who live in properties with low amount of vegetation tend to report one or two interactions with different wild animals like horned screamer (anhuma), cavy, ocelot, greater rhea, buff-necked ibis, macaw and chaco chachalaca (aracuã), major birds found in open spaces, even though there is a tendency to less interactions (lower degrees). Moreover, we found positive degree assortativity observed within the network (second hypothesis) and the tendency of interaction was not explained by landscape variables as well as spatial distance (third hypothesis). Below we explore potential explanations for these patterns, and some implications of our findings for conservation and public health.

The effects of habitat amount on the structure of interaction networks have been widely studied and reported in the literature (Camargo et al. 2019, Wu et al. 2022, Adams et al. 2023). Deterministic processes, such as the loss of NV, directly interfere with the abundance and distribution of animals (Bogoni et al. 2020). Consequently, interactions within a network will also undergo changes. However, our study revealed that the amount of NV had a weak influence on explaining the number of interactions experienced by people (degree). A possible explanation can be that most landscapes in the ST are characterised by patches of NV embedded in pastureland which may maintain functional connectivity. Therefore, NV gradient maybe is not so prominent yet, impressing a weak response (Roque et al. 2017). Yet, it is important to remember that the network in question was constructed based on self-reported contacts and the individual perceptions of each interview participant. This subjectivity could be a significant factor influencing our results. Furthermore, we did not consider the daily movement patterns of people and animals, which could have a considerable impact on our findings. Many interactions likely occur while people are moving through the region, rather than solely within their properties, where the percentage of NV was measured. This oversight highlights a potential limitation in our study, suggesting that future research should account for the mobility of human individuals to better understand the dynamics of human-animal interactions in this context.

We observed a positive degree assortativity in the network, meaning there is a tendency for the network's nodes to attach to others with similar degrees (Newman 2002). Several underlying processes can generate assortative patterns in our network. First, people living at the extremes of the environmental gradient of vegetation may interact with different subsets of species. This can be partly due to the non-random response of species loss along the gradient of NV (Newman 2002, Escoda et al. 2018; Peel et al. 2018, Devan-Song et al. 2022) and the potential similarity in species sets at the gradient's extremes. However, the assortativity of human-animal networks also depends on the perception of interactions which can mean that individual biases and subjective experiences play a significant role in shaping the observed network. Positive assortativity can also be partially explained by the spatial proximity of residences, social relationships among the people involved, social learning, or even degrees of kinship. For example, in the studied settlement, relatives live on nearby properties (Chiaravalloti. 2019), exchange information, and may create similar narratives regarding animal sightings.

Our results reveal that the environment (amount of NV on properties) and spatial distance between properties have no significant values that explains the similarity in animal composition among people in the ST of the Pantanal. While space might indicate stochastic processes in shaping metacommunities patterns (Leibold et al. 2004, Peres-Neto et al. 2012), we believe that in the case of interactions between animals and people, the spatial signal could be interpreted as an indicator of human interactions and potential non-random land-use changes in the region. Individual perception, influenced by social, political, and cultural factors such as access to information, prior knowledge about local animals, exposure to nature (Rendler et al. 2023), work and social activities, can also have spatial signals. An illustrative example from our study is that reports of bird interactions and the sharing of these interactions are more frequent in areas with a lower percentage of NV. This may be influenced by the significant impact of charismatic species on human perception of biodiversity, the ease with which people identify characteristics of these species, and the easy sighting of these animals in open environments (Rendler et al. 2023). Consequently, our network is a social metacommunity construction through the interplay of social factors, including people's perception of the surrounding biodiversity, their spatial proximity, and the environmental context. This dynamic aligns with the assertion that social networks predominantly exhibit a positive assortativity degree (Vasques & O'Neale 2020) which is also evident when considering spatial proximity (Devan-Song et al. 2022). Our conclusions are that social and environmental elements contribute to the patterns of interaction and sharing within our studied network.

Limitations of our study and opportunity for improvements

Our analysis cannot unveil the full complexity of the system. However, we made key assumptions during the process of unfolding our results. First, we do not account for the movement of individuals through varying vegetation gradients, such as during their daily commute to work. Consequently, a person residing on a property with 20 percent NV might report sightings and interactions in different areas, which could have a higher or lower percentage of NV than that present on their own property – where the NV was measured. This oversight can lead to an underestimation or overestimation of the actual interaction rates and biodiversity dynamics experienced by individuals.

Second, the region may exhibit connectivity, and despite the presence of an environmental gradient, it can sustain a flow of movement, which allows animals to travel the landscape. In our case, the landscapes in the ST of the Pantanal are predominantly pasturelands with patches of NV that is maintained by some residents on their properties, known as Legal Reserve – “Reserva Legal” (RL). These patches can be used as stepping stones by the animals to move through the region, as several properties are close to bigger NV patches, thus the landscape can also be a permeable matrix (Ray et al. 2002, Yabe 2009). This connectivity could account for the relatively muted impact of environmental variables found, as the animals are able to move freely across the habitat. Nevertheless, this apparent resilience might be indicative of an extinction debt (Halley et al. 2016; Ausprey et al. 2023); while animals may currently occupy certain areas, this does not guarantee that these locations can support sustainable populations in the long term.

Third, it is difficult to address zoonotic risk due the lack of data on zoonotic viruses in Brazil when searched on the SpillOver global. The platform has data of Global Virome Project (Carrol et al. 2018), and registers only four viruses for Brazil, a number that certainly does not reflect the reality of a country with continental dimensions. Despite this data gap, the animal orders identified in the interaction networks are globally recognized as reservoirs for 37 different zoonotic viruses (Carrol et al. 2018). This discrepancy underscores the urgent need for comprehensive virological surveillance and research in Brazil to better understand and mitigate zoonotic threats, especially in ecologically sensitive and biodiverse regions like the Pantanal.

Forth, some identifications may be mistaken by the interviewee, since it depends on the knowledge about the animals, and might not know the name of the animal or is unable to approximate the identification accurately, as seeing on Chapter 1. Furthermore, there are likely many animals with a higher number of interactions that go unreported because they often go unnoticed by people. For example, opossums, fish and insects may have significant presence on people's life, and yet remain largely unobserved and unmentioned by the interviewees. And finally, as discussed on chapter 1, there´s a “phantom network” that arise from interactions perceived by people between people and those unidentified, unreported and unnoticed animals

Despite the current limitations, our work provides valuable insights into how network metrics, such as degree assortativity, can enhance epidemiologic and conservation strategies. Degree assortativity can indicate the transfer of information flow in social interactions and, epidemiologically, the contagion and transmission of diseases from a given point (Arlidge et al. 2021). Given its applicability in both areas, assortativity should be more frequently explored to uncover the multiple facets involved in developing effective conservation and health strategies within a socio-metacommunity. We also recommend that researchers contribute to global databases on zoonoses in Brazil, such as the SpillOver platform, to address the gap on data. By pooling information about shared interactions within the network and associating it with pathogens related to animals, we can better trace future disease outbreaks, monitor the epidemiological ecology of various diseases, and integrate ecological, social, and health information of human communities. For this to be successful, it is crucial that local communities be actively involved. Their perceptions on biodiversity must be heard in the development of conservation measures, strategies and public health policies that directly impact them and their environment, as to the management of EID, it is preferable to focus on changing human behaviour, rather than wildlife disease surveillance (Muehlenbein 2016, Reaser et al. 2021). This inclusive approach ensures that the strategies are practical and considerate people and ecosystems they aim to protect.

Therefore, considering that 1) biodiversity can play a crucial role in maintaining the dilution effect, thereby preventing disease spillovers (Perfecto et al. 2023); 2) to mitigate the risk of zoonotic disease emergence, it is essential to avoid thresholds of biodiversity loss across gradients of NV (Roque et al. 2023); 3) socio-economic factors shape human behaviour and the best way to work on preventing infectious diseases is to work on changing human behaviour (Reaser et al. 2021). We recommend that One Health programmes in the region incorporate measures for biodiversity conservation as well as consider the perceived biodiversity by local people. Hence, as it can provide insights on when and how people are interacting with animals, educational efforts can be addressed to promote conservation through increase people’s knowledge about the benefits of regional biodiversity (Reaser et al. 2021) – as maintaining regional biodiversity levels is crucial to prevent the dominance of species that are potential zoonotic hosts - thereby reducing the risk of disease.

Thus, to the development measures that considers the interplay between social and environment on human-dominated ecosystems through education approaches, a special attention must be given to avoid negative information to interactions with animals. Since not all interactions and animals displays an imminent danger to both, biodiversity and human life, as discussed on Chapter 1. Nevertheless, based on our findings, we recommend that people's perceptions of animals be considered in relation to landscape connectivity and matrix permeability, rather than solely focusing on the gradient of NV, in future studies and the development of conservation and health measures.

General Conclusion

In conclusion, this research underscores the intricate interplay between human-animal interactions and public health, particularly in the context of biodiversity conservation in the Pantanal. By shedding light on the gendered dimensions of these interactions—such as the heightened exposure of women to Avian Influenza due to their greater engagement with birds—it lays the groundwork for more nuanced and socially equitable public health policies aimed at mitigating the risks of emerging zoonotic diseases. However, viewing these interactions solely as threats can undermine efforts towards both public health and biodiversity conservation, reinforcing a neocolonial framework that often marginalises local communities and disregards their traditional knowledge and practices. The imperative for a shift towards an inclusive, participatory conservation model is clear, one that recognises local populations as vital stakeholders in the formulation and execution of health and conservation initiatives. To foster effective outcomes, it is crucial that public health strategies, especially One Health programmes, are co-produced with local communities. This collaborative approach not only enhances the acceptance and efficacy of measures but recognises the essential role of biodiversity in preventing zoonotic disease spillover. Educating communities about the benefits of regional biodiversity can facilitate a deeper understanding of the need for conservation, while simultaneously encouraging responsible interactions with wildlife. Ultimately, maintaining biodiversity is not just vital for ecological balance but also serves as a foundational element in safeguarding human health.

Appendix 1

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

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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) (ILPC) 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 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 One Health research networks and strengthen the evidence base for One Health policy and practice in the Pantanal and other tropical wetland systems.

Resumo

O ecossistema do Pantanal no Brasil está enfrentando desafios locais sem precedentes devido às pressões antropogênicas, bem como às mudanças climáticas globais. Essas pressões aumentam os riscos zoonóticos das populações de animais silvestres, cuja própria suscetibilidade a doenças é aumentada por fatores estressantes, incluindo a perda e a fragmentação do habitat, com a consequente diminuição da disponibilidade de alimentos, da imunidade e da resiliência em face dos riscos crescentes de doenças. Essa degradação e fragmentação contínuas do ecossistema aumentam as interações entre animais e seres humanos (incluindo povos indígenas e comunidades locais) (ILPC), aumentando ainda mais os riscos de doenças para as populações humanas. A fragilidade dos sistemas de saúde no Pantanal se reflete na vigilância limitada de patógenos e nas medidas precárias de saneamento e controle de doenças, o que contribui para ampliar ainda mais o potencial epidêmico e pandêmico da região. Usando uma abordagem transdisciplinar de Saúde Única para entender os fatores ecológicos, sociais e biológicos das doenças infecciosas, nossa rede de pesquisa desenvolveu uma estrutura para conceituar as ferramentas, as evidências e os processos atuais para a pesquisa e a produção de conhecimento eficazes no ecossistema do Pantanal. A utilização do conhecimento especializado de pesquisadores e das principais partes interessadas não acadêmicas pode informar o trabalho das redes globais de pesquisa de Saúde Única e fortalecer a base de evidências para a política e a prática de Saúde Única no Pantanal e em outros sistemas de áreas úmidas tropicais.

Introduction

The COVID-19 pandemic has highlighted the importance of an integrated One Health 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 One Health 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 One Health 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 One Health. Efforts such as this are critical within wider health security and One Health 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 One Health 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 (Fig. 2). 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* spp and diverse arboviridae have all been detected across wildlife populations in the Pantanal (e.g. de Brito et al. 2019; Bourscheid et al. 2020; Dalazen et al. 2020; de Silva Neves et al. 2022). Remote populations across in 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 experience poverty and poor public health due to limited local provision, with income reaching as low as less than one third of the Brazilian minimum wage (Chiaravalloti 2019). There is an ongoing drive to expand agricultural land for cattle pastures in the areas bordering the plain, as well as anthropogenic and climate change related events, which are amplifying the pressures on local human-animal-environmental networks (Schulz et al. 2019; Tomas et al. 2019) and increasing emerging infectious diseases risks (EIDs) (Lima-Camara, 2016; Ferreira et al. 2023).

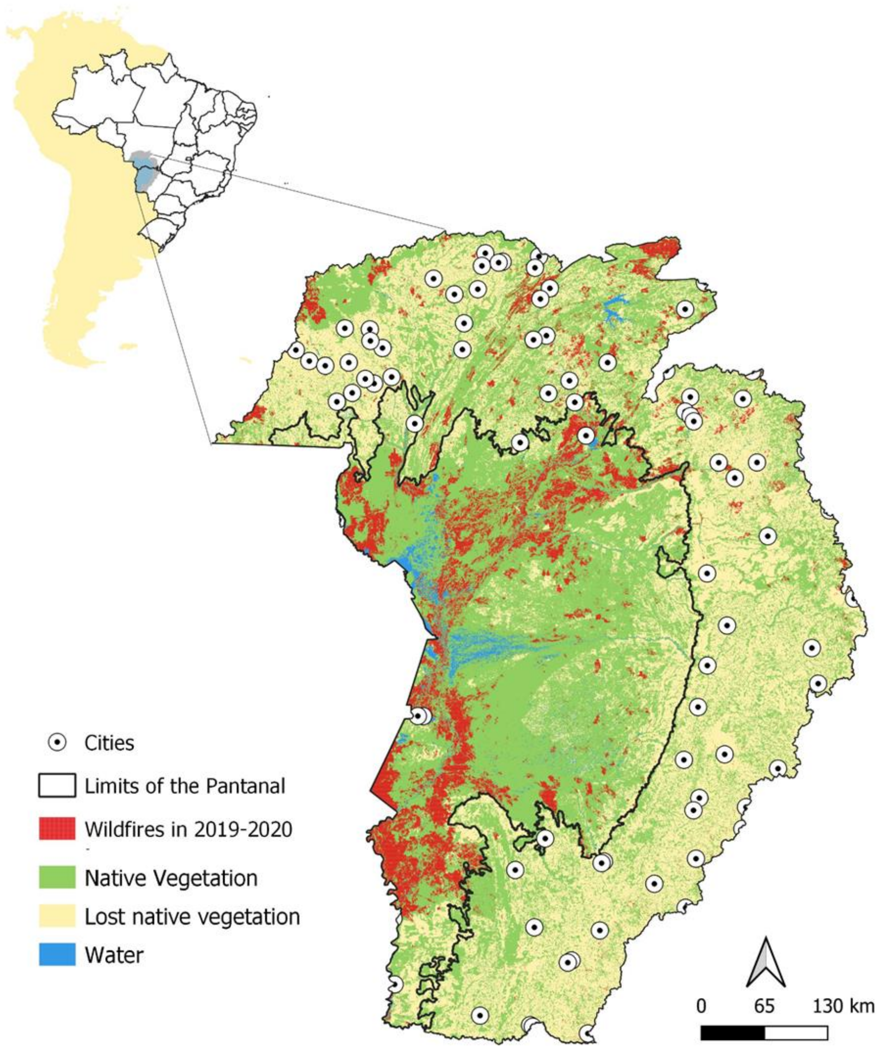

Figure. 1: Location of the Upper Paraguay River Basin in South America and Pantanal wetland in the Brazilian states of Mato Grosso and Mato Grosso do Sul. Colour background indicates NV and regions that have suffered from recent wildfires. Source: MapBiomas Project - Collection 8.0 of the Annual Series 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 riverbeds 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. There is limited literature concerning the health status of IPCLs, 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 emergence of key infectious diseases within these populations including leptospirosis, brucellosis, toxoplasmosis, Hepatitis A & B, foot and mouth disease, leprosy, spotted fever, yellow fever, paracoccidioidomycosis, tuberculosis and highly pathogenic avian influenza. Additional health security pressures arise from the expansion of tourism into the region with international populations visiting the area for its famed biodiversity (Ferrreira 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. 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 One Health 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 One Health 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.

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. 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 One Health 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 development of appropriate responses 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.

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 3 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. 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.

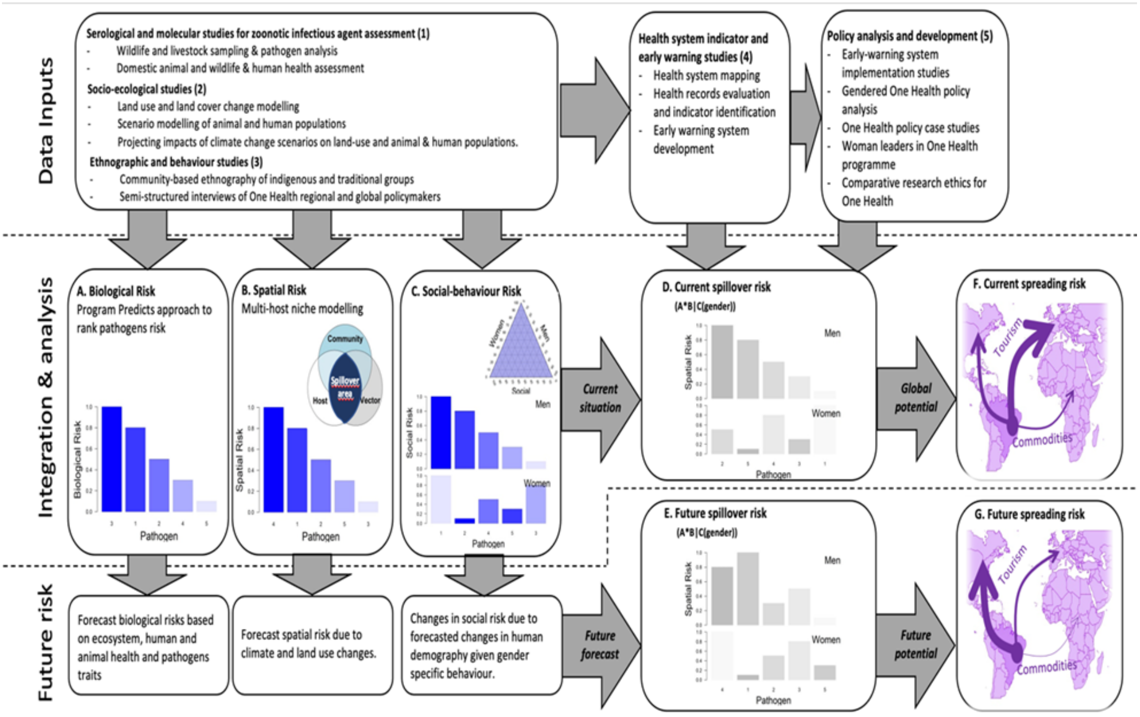

Figure 2: ***Spillover risk (zoonoses) framework for the Pantanal Wetland System.***

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 Figure 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 Figure 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 Figure 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.

Framework utility

Perspectives across diverse methodologies, perspectives and technical disciplines have shaped the development of the transdisciplinary Pantanal-One Health 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 One Health 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 One Health 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 One Health 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 One Health 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 One Health 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 One Health 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 "One Health" 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 One Health practice and policy.

Anexo 1:

Guide of the questions made during the interview.

Date: Location:
Name: Sex:
Latitude: Longitude:
Demographic Section:

1. How old are you?
2. Where do you live?
3. How long have you lived here?
4. How many people live in your home?
5. How many residents are children under 5?
6. How many are male?
7. How many ate female?
8. How many rooms are there in your home?
9. Is the house a permanent structure?
10. Where do you get your water from?
11. Is the water you drink treated?
12. Is your drinking water source used by animals?
13. Is there a place in your house for excrement, such as a sewer or cesspit?
14. How do you store food as home?
15. What is your schooling?
16. How much schooling does your mom have?

Family Income Section

17. In the last year, what activities have you done to earn a living?
18. If there is more than one activity, which one have you spent the most time since last year?
19. Do you receive any aid from the federal government?
    19.1. If yes, which one?
20. How many people are responsible for supporting the household?

Perception of Symptoms and Diseases Section

21. How do you identify signs of illness in your family members?
    21.1. What symptoms alert you?
22. How do you determine the severity of an illness?
    22.1. What are the symptoms that worry you?
    22.2. Do you think a person´s age has a bearing on severity? Why do you think so?
23. What do you think are the causes of the symptoms and illnesses?
24. Do you think animals can give us diseases?
    24.1. If so, how do you prevent it?
    24.2. What do you do with sick animals?
25. What precautions did you take during the pandemic?
26. Do you think the environment influences your family´s health?

Movement Section

27. Have you done any travelling in the last year?
28. Where did you travel to, and why?

Animal Contact Section

29. Have you ever had or do you have a pet in or near your home?
30. Have you ever treated animals?
31. Have you raised animals?
32. Have you ever seen animal faeces in the kitchen or near food before you´ve eaten it?
33. Have you ever eaten food after an animal has touched of partially eaten it?
34. Are there any animals in the house where you live?

35. Have you ever eaten an animal that you knew was sick or unwell?
36. Did you ever find a dead animal and pick it up to eat or share?
37. Have you eaten bush meat?
    37.1. If yes, which animals?
38. Have you ever slaughtered an animal?
39. If you get scratched, bitter or cut while cutting meat or slaughtered animals, what do you do?
40. Do you think the is any risk associated with slaughtering an animal or handling meat when there is an open wound on your hands?
41. Are you concerned about disease outbreaks in live animals on your site?
42. Table – Mark according to actions:

	Pet	Handling	Raised	Feaces/ Near food	Inside the house	Sick	Dead	Scratched or bitten	Slaughtered	Clean for consumption
Bat										
Monkey										
Birds										
Cattle										
Dogs										
Cats										
Rats										
Other animals:										

Fire and Animal Contact Section

43. Have you ever noticed an increase in the number of animals appearing near your home after fires?
    43.1. If so, which animals?
44. Have you raised any animals that survived fires?
45. What did you do when you found injured animals after the fires?
    45.1. Is there a place that takes care of these animals?
46. What kind of animal you found dead after fire?
47. What did you do with the dead animals after the fire?
48. Has the zoonosis control centre made any visits?
49. Time allocation: Can you describe your main activities throughout the day? Where do you spend the most time and at what times?

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