Context:

The expansion of human activities into natural landscapes increases human-wildlife interactions and can generate both positive and negative outcomes including cross species pathogen transmission. However, despite their impact on public health, biodiversity and the global economy, the underlying ecological and socio-economic drivers of human-wildlife contacts, particularly those generating a risk of disease transmission, remains almost unknown. Identifying these drivers is key for our global effort to reduce disease burden in humans and wildlife using a One Health approach. This interdisciplinary PhD follows the promising results of the Master thesis conducted by Jonas Farrugia-Audri at MIVEGEC under the supervision of Dr. Benavides on this topic in 2024 (Farrugia-Audri et al. in prep, master's degree with highest honors). Indeed, Jonas developed complex statistics (e.g. GlmmTMB Zero Inflated models) allowing to account for spatial and temporal autocorrelation in testing spatial associations at municipality level, and high-quality rasters of human activity and disturbance (e.g. deforestation level using the MapBiomas raster database). These results, while encouraging, highlight the complexity of the analyzed dynamics and the need for further investigation and in-depth statistical analyses, requiring a PhD. This PhD would therefore aim to identify and quantify the effect of multiple drivers that can potentially influence the occurrence and frequency of risky contacts (e.g. bites) with non-human primates and bats in the megadiverse and highly disease vulnerable country of Brazil. This PhD will also stand on ongoing and crucial collaborations between IRD's PhD supervisor Dr. Benavides and multiple Brazilian stakeholders including the Brazilian Ministry of Health, who has already provided the data (Benavides et al. 2017, 2020, 2022, 2023) in order to co-construct scientific based strategies to maintain a healthy coexistence with wildlife. The results of this PhD will contribute to strengthen the French-collaborations in One Health, creating new opportunities for future work with researchers from Sorbonne University working in One Health challenges in low and middle income highly diverse countries.

Scientific objectives and justifications:

The overall objective of this PhD is to identify and quantify municipality-level associations between socio-economic, ecological and biodiversity parameters, to the occurrence and frequency of bites reported by humans that were bitten by non-human primates (NHP) and wild bats (known reservoirs of pathogens for HIV, Ebola, Herpes B virus, coronaviruses, arboviruses for NHPs, and coronaviruses, Nipah virus, Hendra virus for bats). To achieve this goal, this project will take advantage of megadata provided by the Ministry of Health (Notifiable Diseases Information System (SINAN) forms, around half a million filled per year) and previous results from Jonas' master to achieve the following specific objectives.:

1. Identify hotspots of bites per municipality and test associated factors and spatially analyze the human-wildlife contact dynamics.
    - Identify the contact dynamics following environmental (deforestation, habitat fragmentation, urbanization) and socio-economic (poverty, access to health facilities, inequality index, urbanization level, distance to closest main hospital, …) gradients in Brazil.
    - Create spatial models to test the associated socio-economic and environmental factors.
2. Develop spatial predictive models generating hotpots of bites without the bias of the associated factors
    - Utilize the results from the spatial models to create maps that are weighted with the tested factors. These maps will help detect high-risk zones and contexts while accounting for environmental and socio-economic drivers.
3. Co-construct scientifically based recommendations with Brazilian public health authorities to reduce bite frequency and disease transmission risk (e.g. rabies) using a one health approach.
    - Present recommendations and tools (e.g. risk maps) to the Brazilian health authorities (e.g. Secretaria de Vigilância em Saúde, Ministério da Saúde, Coordenação-Geral de Zoonoses e Doençasde Transmissão Vetoria, (Fransisco Edilson, Alexander Vargas, Silene Rocha)) who provide the data, following a One Health approach to reinforce monitoring and prevention of zoonotic diseases, while proposing mitigation strategies for managing human-wildlife interactions.
    - Implement prevention measures in France, through informational materials for tourists going to Brazil (e.g. flyers informing about the risks of NHP bites in visa offices), and awareness

campaigns about contacts with bats in mainland France (e.g. prevention in areas with public access caves, abandoned buildings).

Methodology:

This PhD project utilizes federal monitoring data from the SINAN system of the Brazilian Ministry of Health to analyze bites from NHPs and bats between 2008 and 2020 in 5570 Brazilian municipalities (with around 3000 NHP bites per year and 4000 bats bites per year), as well as diseases outbreaks data from the Brazilian Ministry of Health (i.e. rabies data in animals and humans in bites reporting forms). These types of data have previously been used by Dr Benavides across multiple studies (Benavides et al. 2017, 2020, 2022, 2023). The PhD also incorporates ecological drivers (deforestation, primates species richness, biome, etc., taken from the MapBiomas database and IUCN maps) and socio-economic factors (poverty, HDI, access to health facilities, etc., issued from the IBGE, the Brazilian institute of geography and statistics). Linking these data using spatial models would allow the identification of key drivers of these contacts, and their implication for zoonotic transmission.

Suitability to the "global health approach" theme:

This project comes within the scope of a global health approach, leveraging interdisciplinary knowledge to address a major public health and ecological challenge: the transmission of zoonotic diseases at the human–wildlife interface. Brazil, being a country with the highest diversity of NHP and an important hotspot for neglected tropical diseases, represents an essential stake in the global fight against emerging infectious diseases. By integrating epidemiological, ecological, and socio-economic dimensions, this research adopts a holistic perspective that extends beyond the strict framework of human health to encompass the social and environmental dynamics influencing zoonotic emergence risk.

The study of human–NHP and human–bat interactions provides an opportunity to explore the influence of the exposome by examining how environmental factors, combined with socio-economic determinants, shape pathogen transmission risk. Three main hypotheses will be investigated: (1) ecosystems heavily impacted by human activities (deforestation, urbanization, habitat fragmentation) increase the frequency of bites and human–wildlife contacts; (2) socio-economic factors such as poverty, inequalities, tourism, and access to healthcare play a key role in the intensity of these interactions; (3) a high frequency of contacts increases the risk of zoonotic disease transmission. This research follows an approach that highlights the impact of anthropogenic transformations on population health while proposing risk mitigation and prevention strategies in alignment with a One Health framework. Furthermore, this PhD contributes to a global reflection on health challenges related to human–wildlife interactions, integrating an international perspective on the dynamics of disease emergence. Through its interdisciplinary and applied nature, this project aligns with the objectives of the call for proposals by promoting the sharing of knowledge for the benefit of society, proposing action plans to reduce health risks, and contributing to a better consideration of vulnerable populations facing zoonoses in a context of significant environmental and socio-economic changes. The supervisors of this thesis will bring their expertise on the relevant topics: Sébastien Barot (Dr IRD at IEES, Paris, co-supervising 2 PhD students who will defend their thesis in September 2025), specializing in biodiversity and tropical ecosystems, which are key elements for understanding interactions with Brazilian wildlife, and Julio Benavides (Dr IRD at MIVEGEC, Montpellier, supervising 2 PhD students), a specialist in wildlife disease ecology, One Health systems in Latin America including Brazil, with more than 5 years working with Brazilian partners such as the Ministry of Health, primatologists, conservation NGOs, and local health authorities.

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