# Exploring trait-based approach for understanding and approximating pathogen spillover systems

*NORDITA. Unifying the epidemiological and evolutionary dynamics of pathogens. May 29 – June 22. Stockholm. Sweden*

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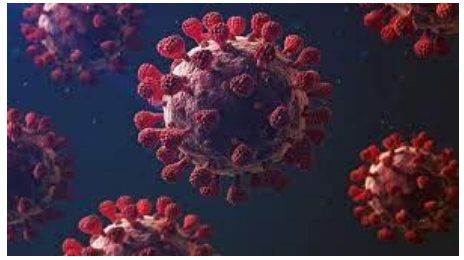
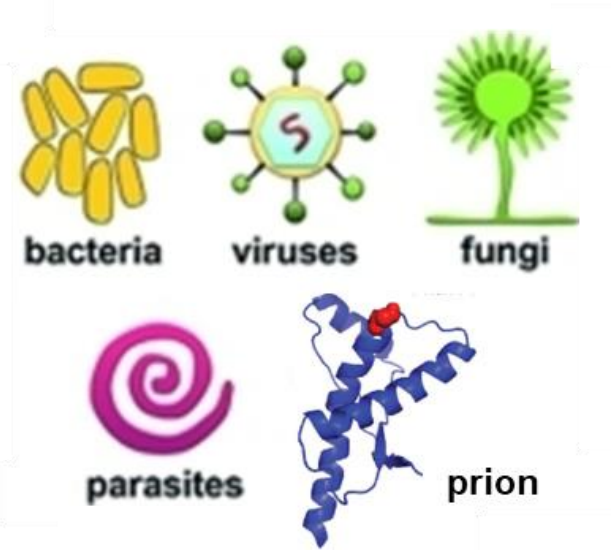
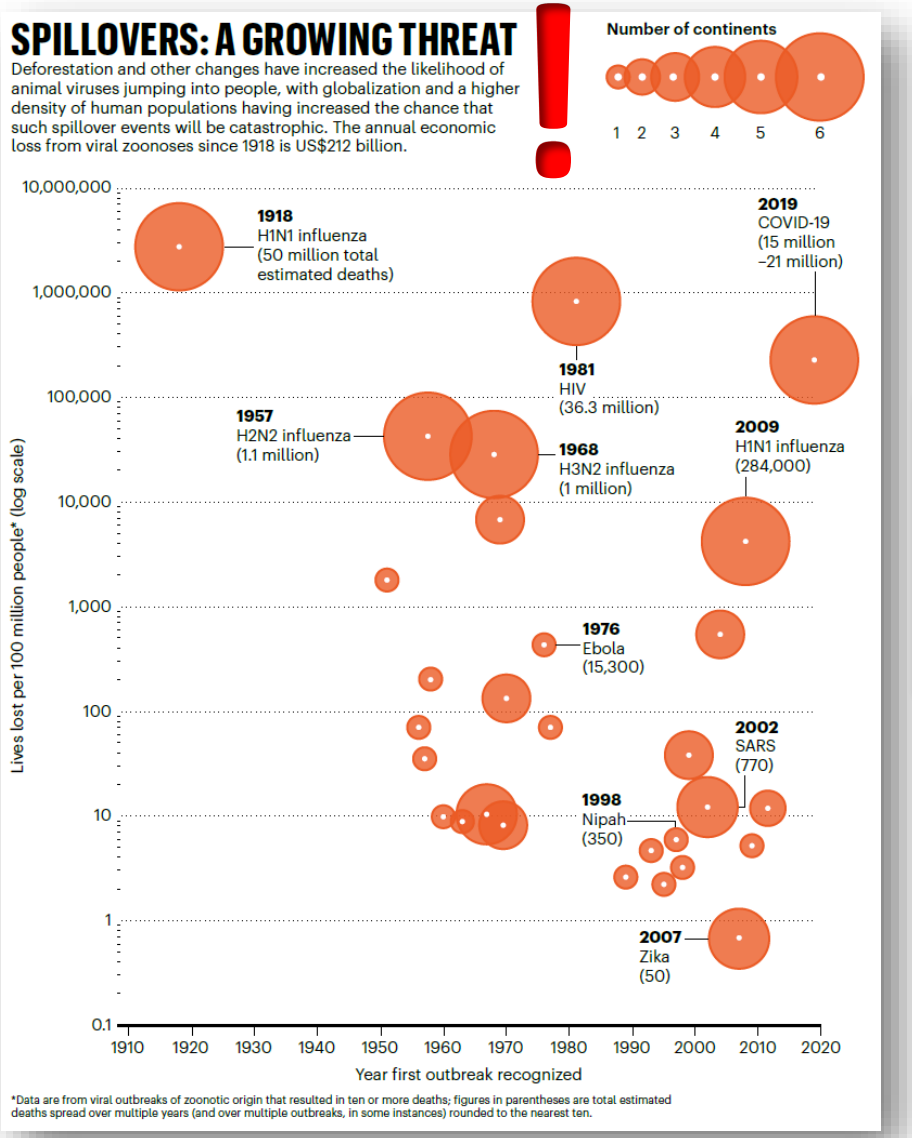
# Zoonoses

- Infectious disease caused by pathogens transmissible from a non-human animal to humans



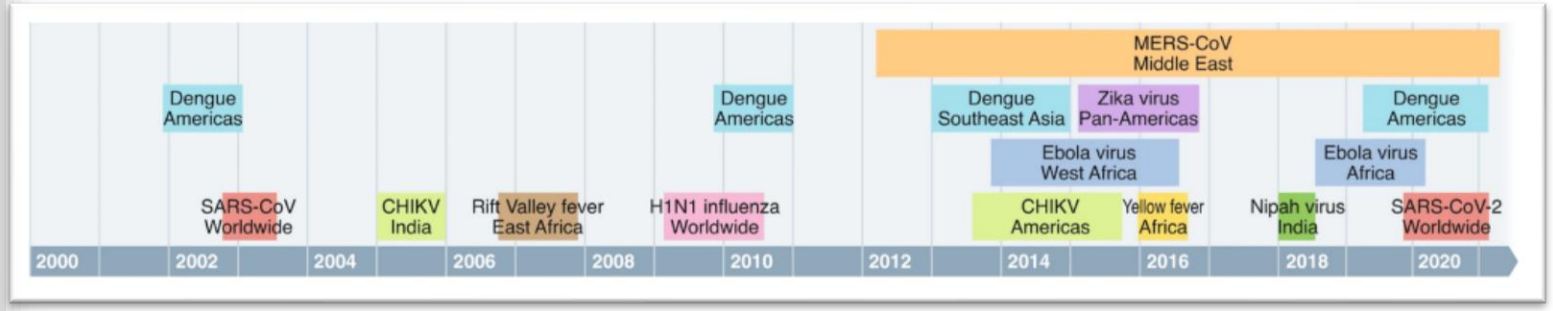



# Disease emergence is strongly associated with ecological disturbance




Source: Vora et al (2022)

The current issue is **increasing frequency** of disease emergence rather than the fact of it in humans




Timeline of twenty-first-century viral outbreaks, from 2000 to the present day.
Source: Meganck et al (2022)

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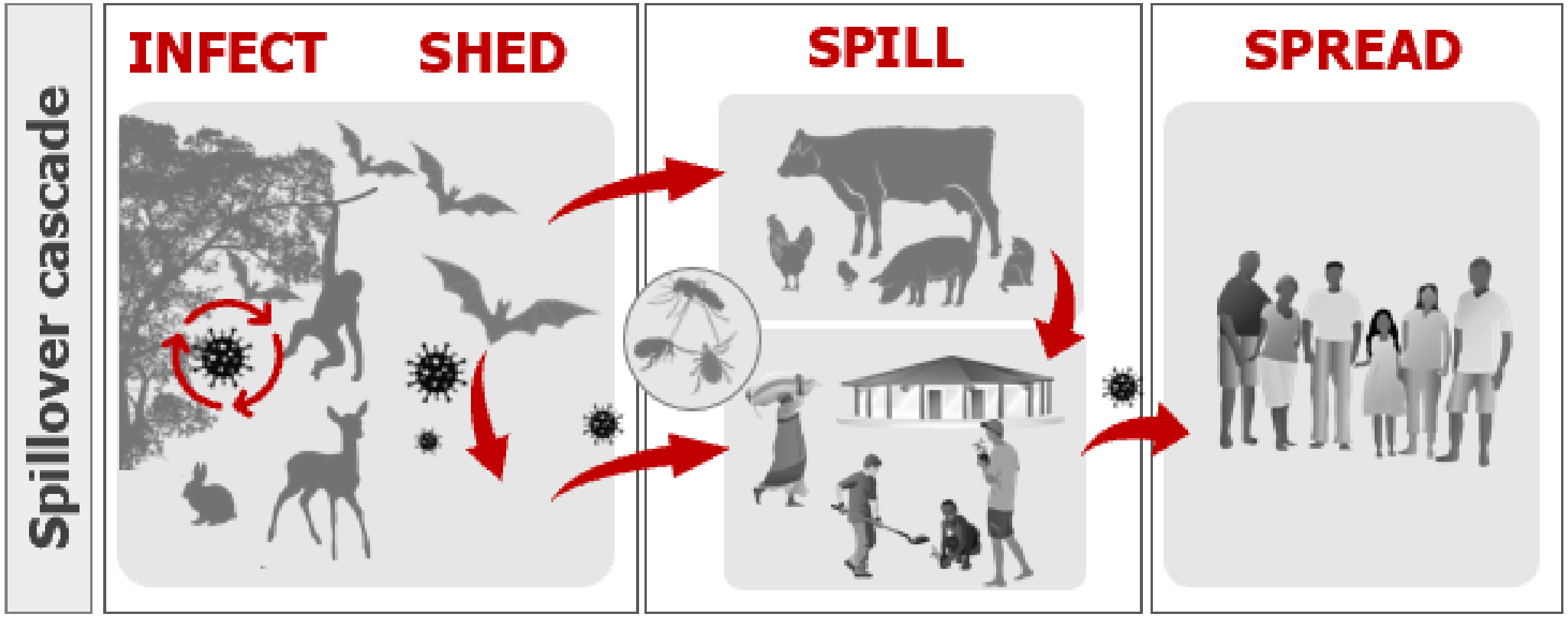
# Spillover is a key step in zoonotic disease emergence




Spillover is defined as direct or indirect cross-species pathogen transmission from
1) source host to recipient host;
2) source host to vertebrate intermediate host to recipient host;
3) source host to invertebrate intermediate host to recipient host; and
4) source host to the environment to the recipient host.

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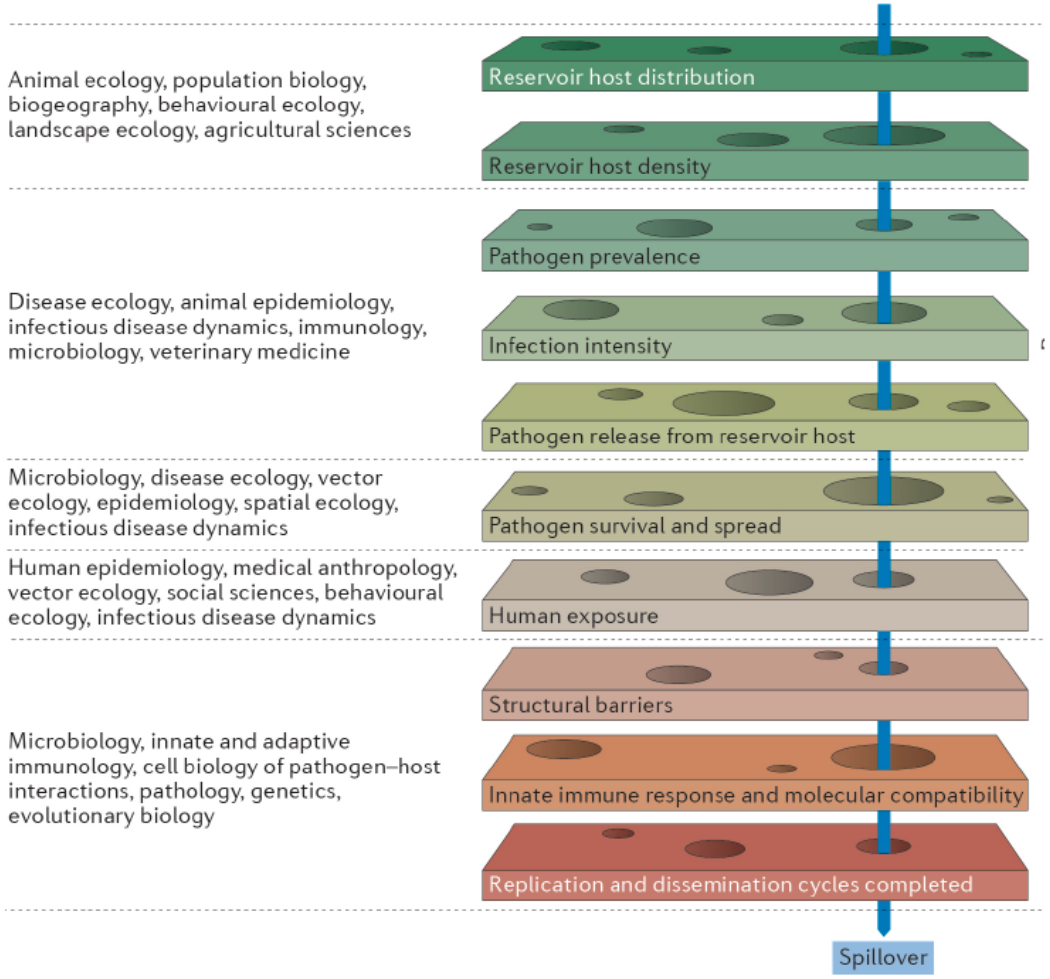
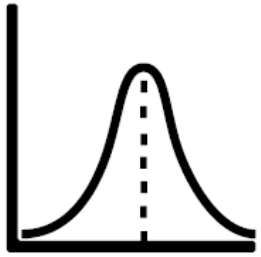
# Zoonotic spillover: barries in space and time

Pathogen pressure -> dose and route of pathogen exposure -> probability of infection




Plowright et al. 2017 Nature Reviews Microbiology

- Wildlife/Reservoir-host ecology.
- Animal and human behaviour.
- Within host processes and viral evolution.
- Zoonotic and human transmission.
- Strategies for spillover/pandemic prevention.



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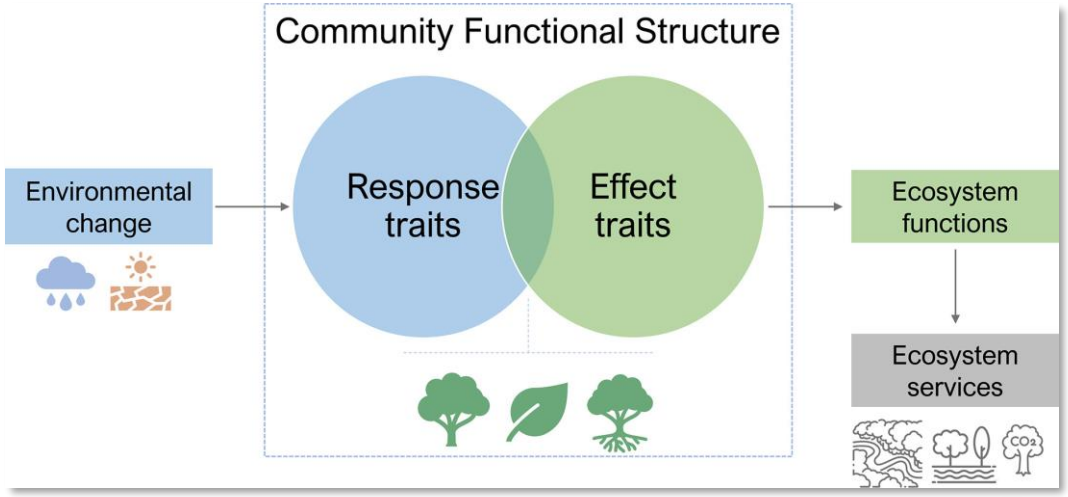
# Trait-based approach

- *Objective:*
  - understand and predict changes in patterns of transmission potential driven by environmental change and intervention
  - support evidence-based management and planning decisions
- *About:*
  - Comes from: functional diversity approach of community ecology and conservation biology developed over the last decades
    - Identifying key functional attributes of organisms (size, shape, nutrient requirements, etc.) that are important for community structure and function
  - Group hosts based on having a set of attributes not as belonging to certain species
  - -> Models with hosts communities represented as trait distributions without regard to species identity

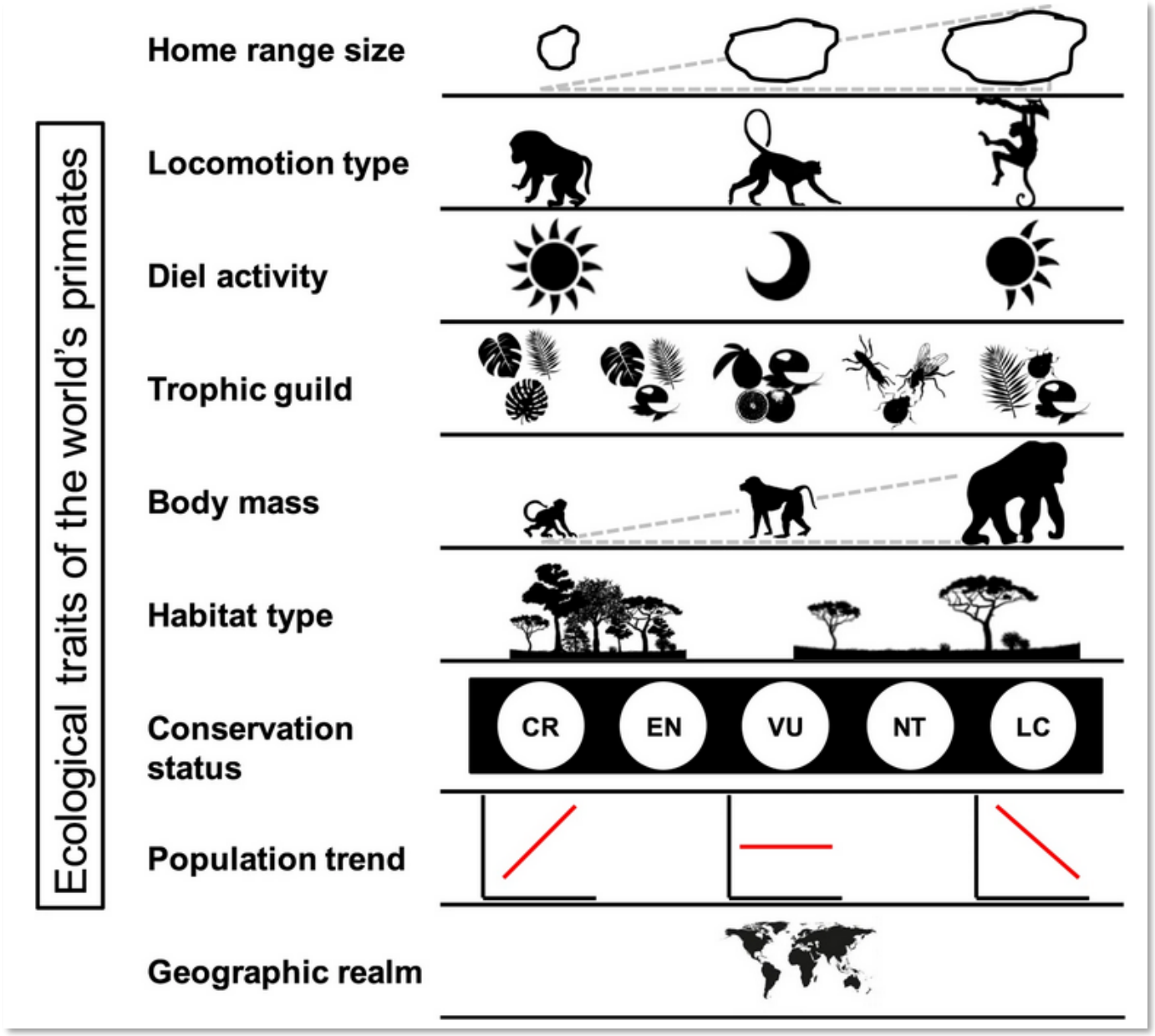
# Functional traits

- Functional traits: any morphological, physiological, behavioral, or phenological characteristic that,
  - *impacts the fitness* of an organism
  - reflects *interactions with the environment* either:
    - mirroring the impact on some ecosystem process **effect traits**
    - and/or by responding to environmental changes **response traits**
    - Response and effect traits can overlap to different degrees, from being closely correlated to being random.




Source: Portela et al (2023) https://doi.org/10.1016/j.scitotenv.2022.160549

# Example of trait topology for primates




Source: Galán-Acedo, C., Arroyo-Rodríguez, V., Andresen, E. *et al.* Ecological traits of the world's primates. *Sci Data* **6**, 55 (2019). https://doi.org/10.1038/s41597-019-0059-9

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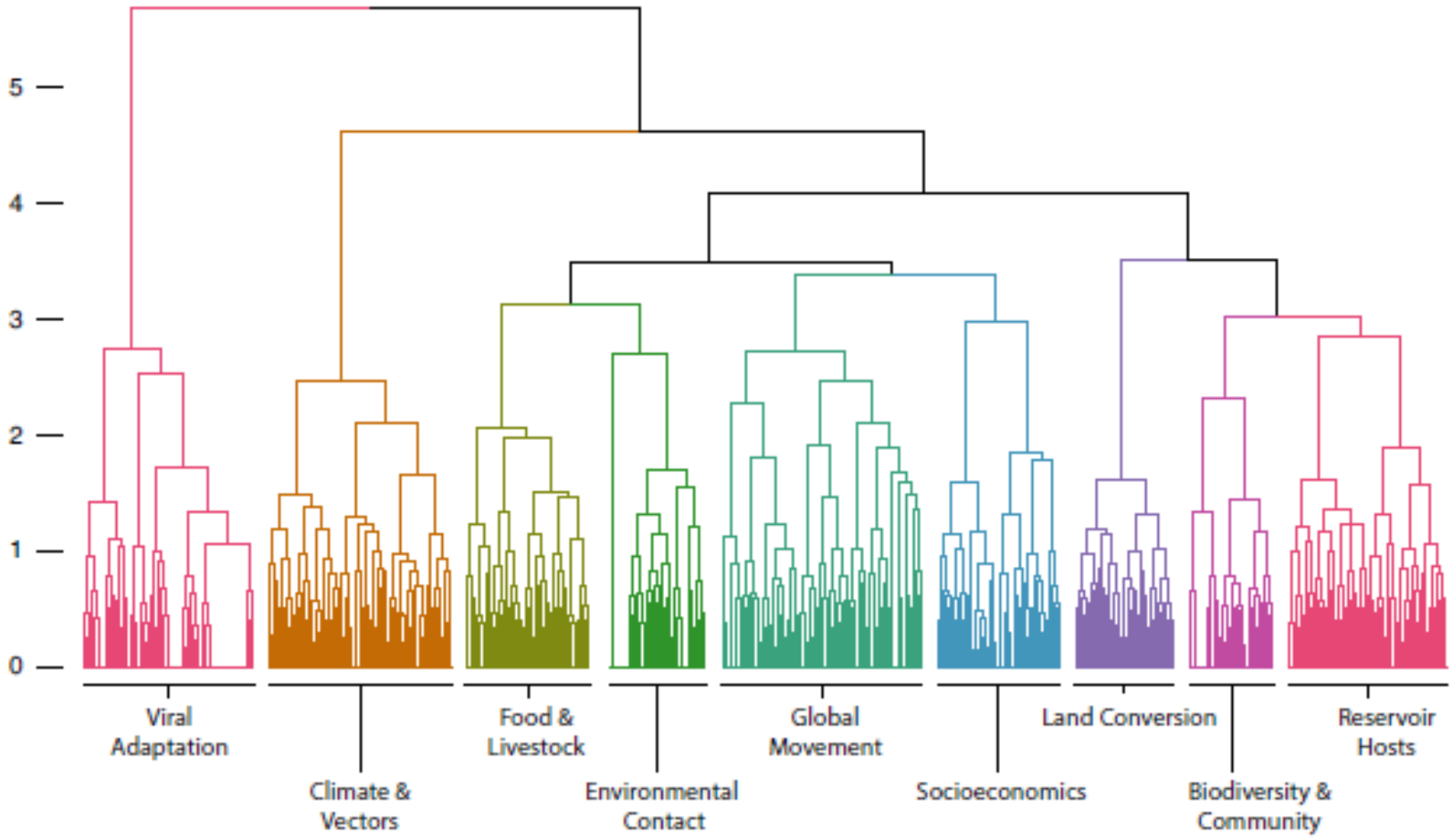
# Opportunities for trait-based approaches

- Advantages for ecosystem model of infectious disease:
  - Ecological questions associated with community assembly and habitat filtering and biodiversity patterns along environmental gradients, and ecological processes
  - Considers within-species variation
  - Approach to scale down parameter space for multi-host pathogen systems
  - Allows merging of trait-based models with network modeling to understand multi-host transmission across space and time and effects of environmental drivers within a process-based model
  - Results have the potential for across-community generality

# Anthropogenic global environmental change relevant for spillover

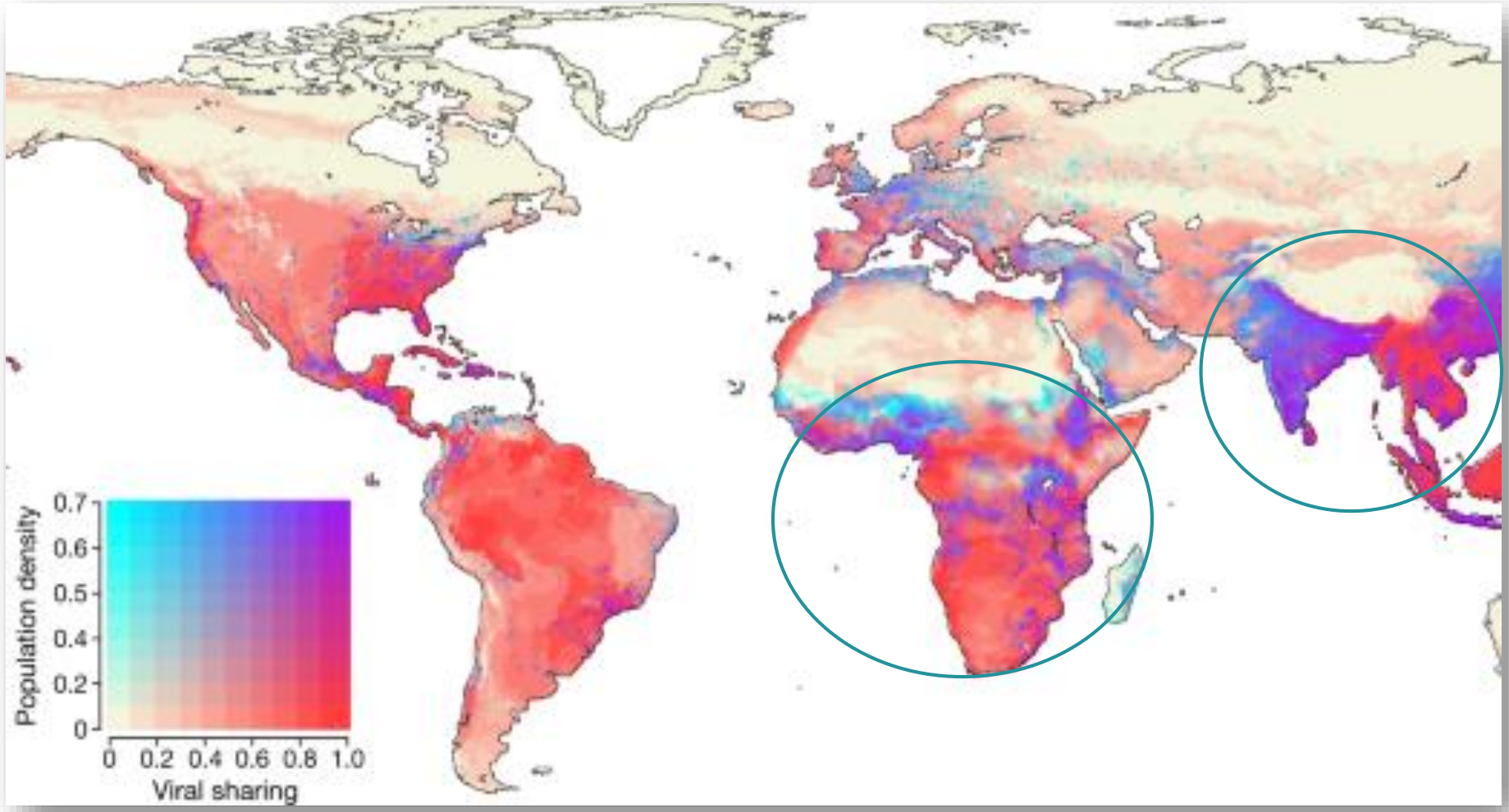



- Climate change
- Land use
- Habitat fragmentation
- Urbanization
- Deforestation
- Pollution
- Biodiversity loss

Zoonoses Public Health. 2021;68:563–577. https://doi.org/10.1111/zph.12846

# Mammals adaptation can change the virome and drive new zoonoses

- In 2070 species will aggregate in new combinations at high elevations, in biodiversity hotspots, and in areas of high human population density in Asia and Africa
- Cross-species transmission of their associated viruses to increase an estimated **4,000 times**




Source: Carlson et al (2022)

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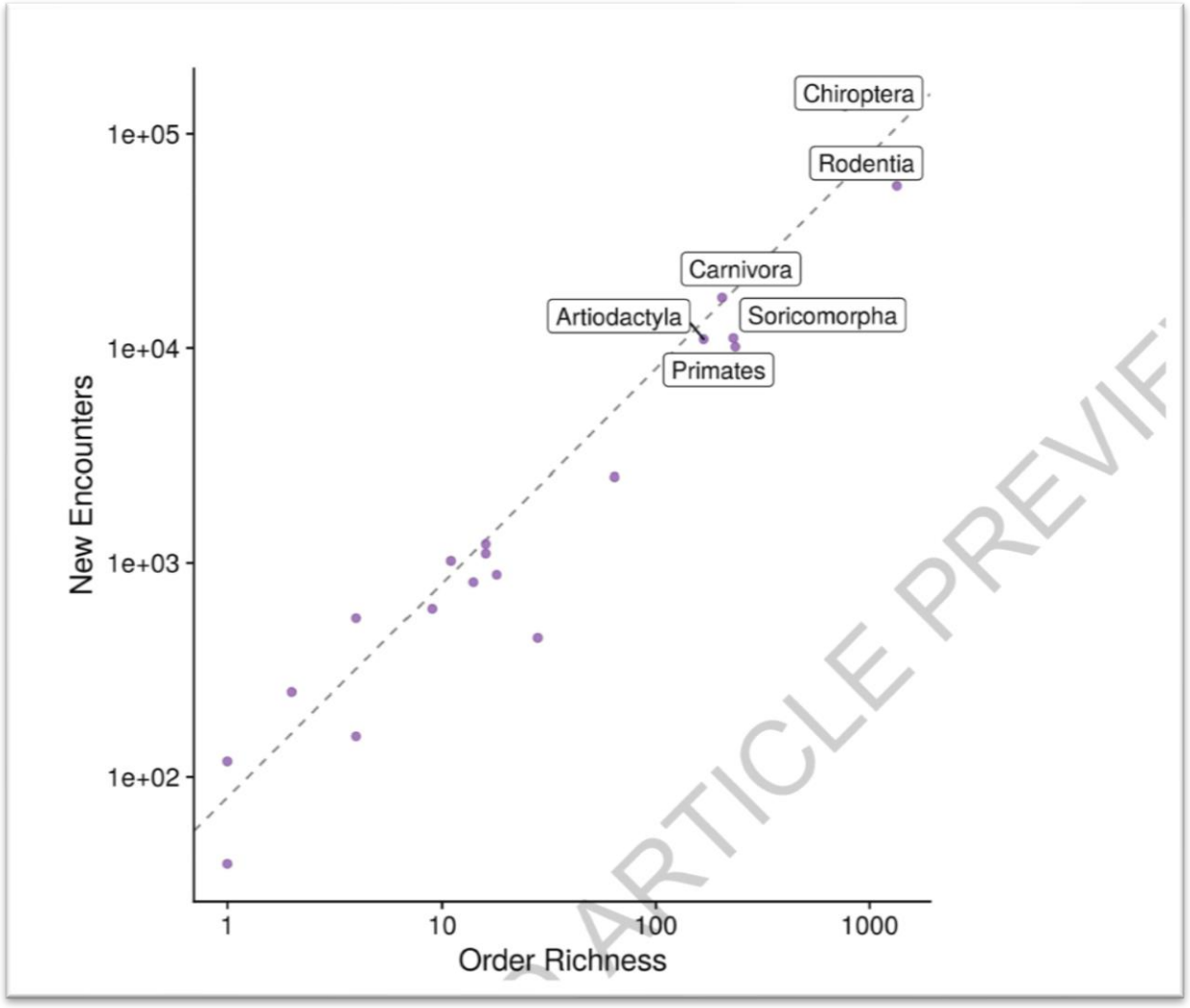
# Climate change increases cross-species viral transmission risk (Carlson et al.)

- Climate change linked to cross-species viral transmission
- Environmental change alter mammal communities in ways that expose hosts to novel viruses, altering the structure of the whole mammal-virus network
- Modelling: species distribution models and viral sharing model
- Cross-species transmission depends on *opportunity* and *compatibility*
- Opportunity:
  - Ecological or geographical overlap among the hosts
  - Encounter:
    - Potential interactions (direct contact) depend on behavioral characteristics
    - Transmission via vector (indirect contact) requires spatial proximity
- Compatibility:
  - Given a contact a virus requires certain host characteristics to be able to enter cells and reproduce
  - -> compatibility w.r.t. host cell receptors and immunity
- Because closely-related species share both ecological and immunological traits through identity by descent, *phylogeny is a strong predictor of pathogen sharing and of susceptibility to invasion* by new viruses

# Animal dispersal capacity as a driver

- **Animal dispersal capacity play a role** in first encounters and novel viral sharing.
- Trophic position and body size determine dispersal capacity
- **Viral sharing hotspot is driven disproportionately by bats.**
- Are some animal groups more common sources of zoonotic viruses than others ?
  - pose a greater zoonotic and pandemic risk?
- Why can some mammals be key hosts for zoonotic viruses?
  - Close proximity: live near human settlements, act as food sources
  - Closely related to humans that viruses face little challenge in host adaptation



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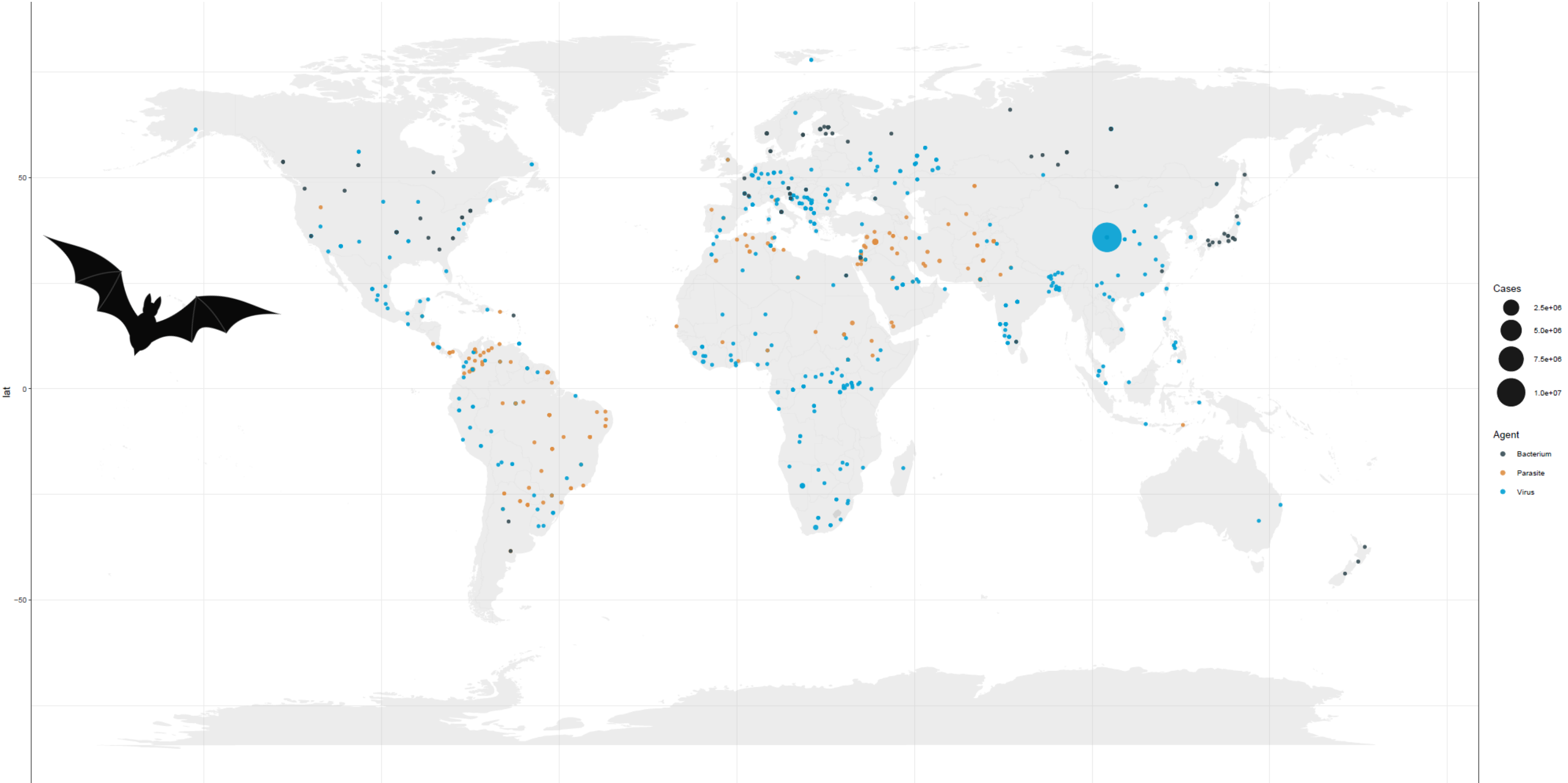
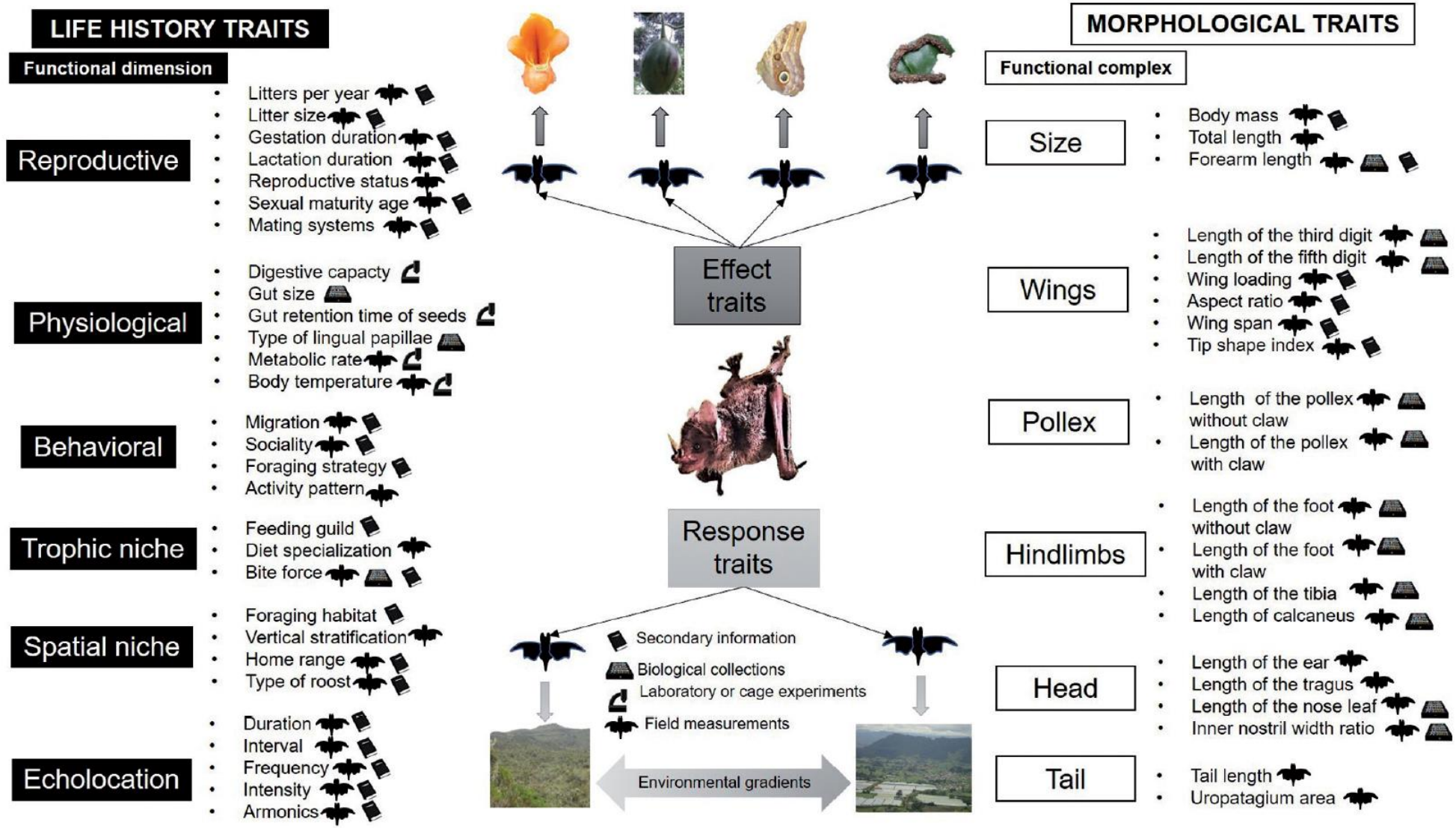
# GIDEON: Infectious diseases with bats stated in reservoir host designation



# Schematic model of biological traits of Neotropical bats




Source: Castillo-Figueroa & Pérez-Torres (2020). http://doi.org/10.11606/1807-0205/2021.61.24. Life history traits in black boxes whereas morphological traits are depicted in white boxes.

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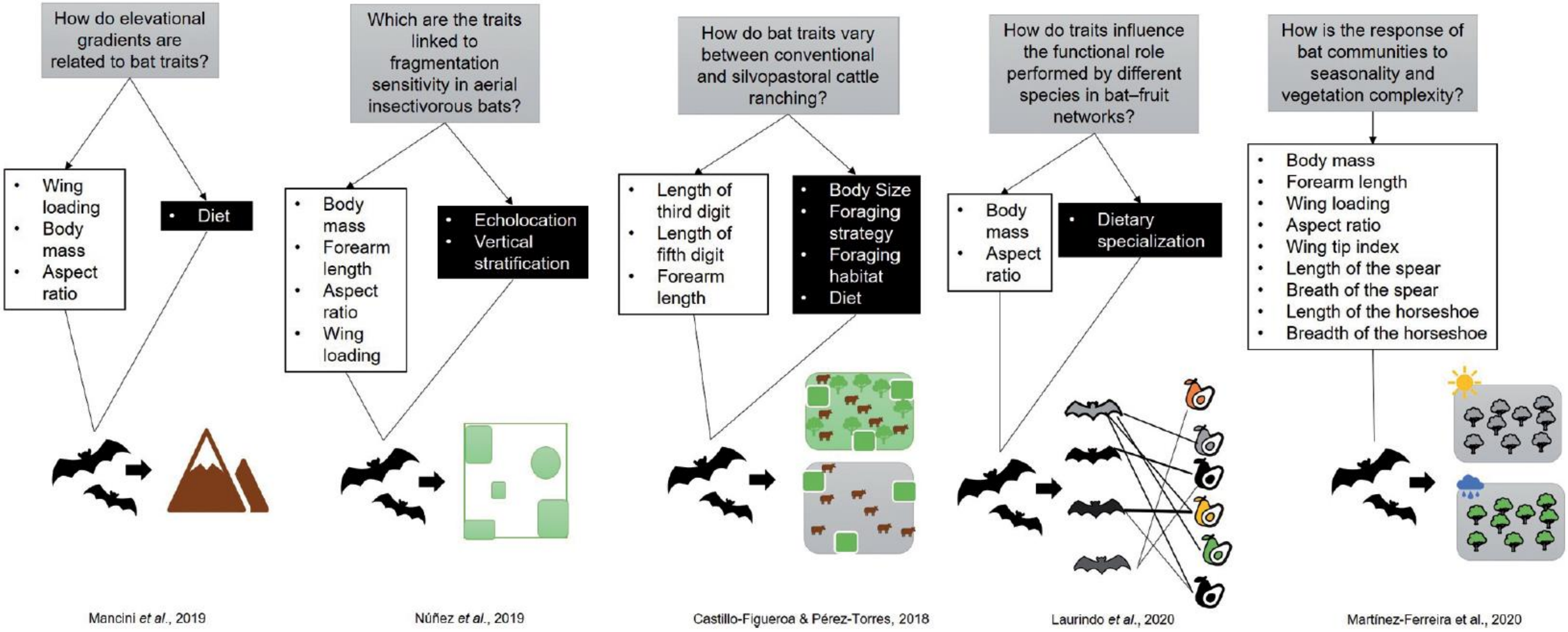
# Study cases using trait-based approach in Neotropical bats

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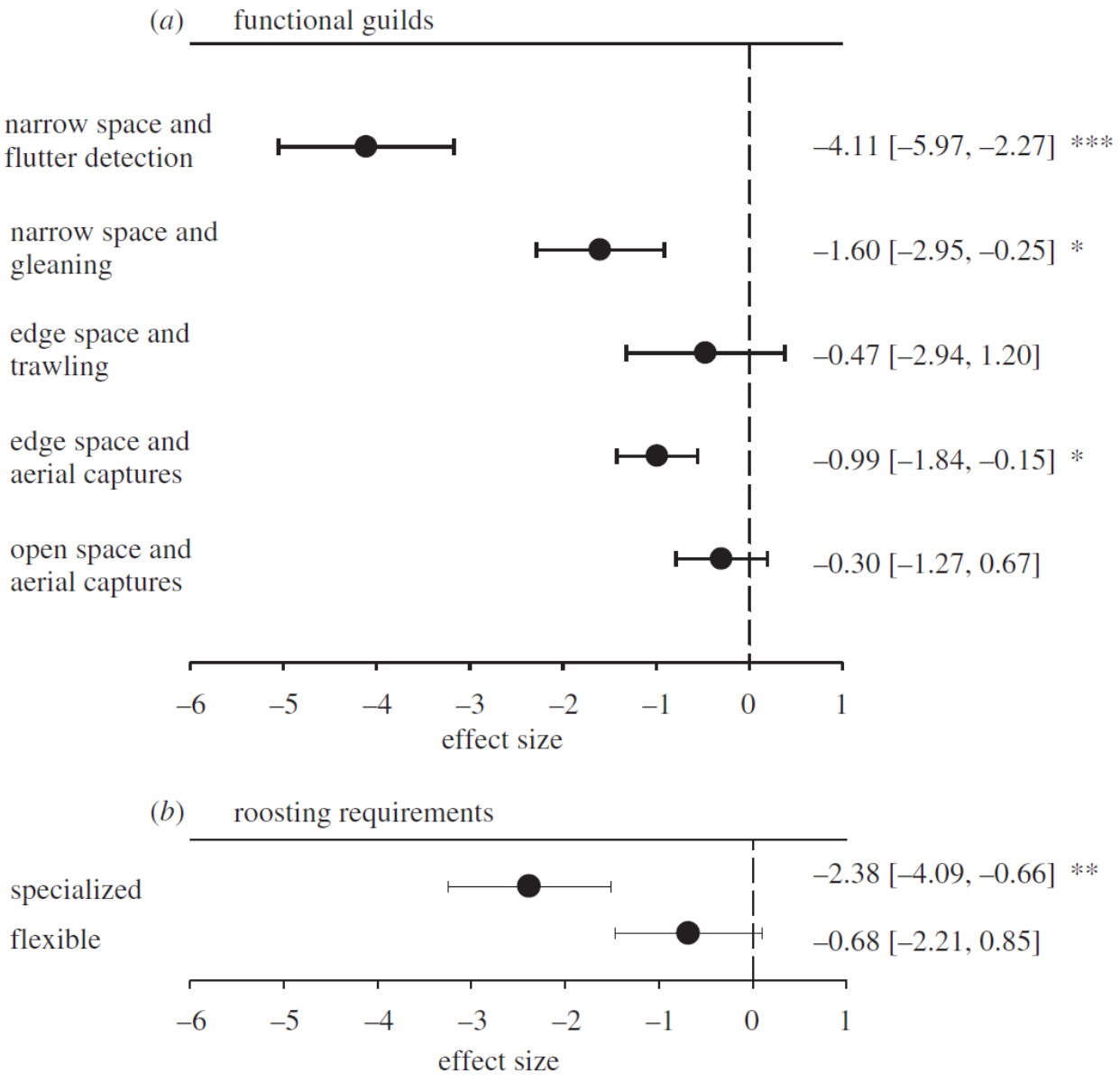
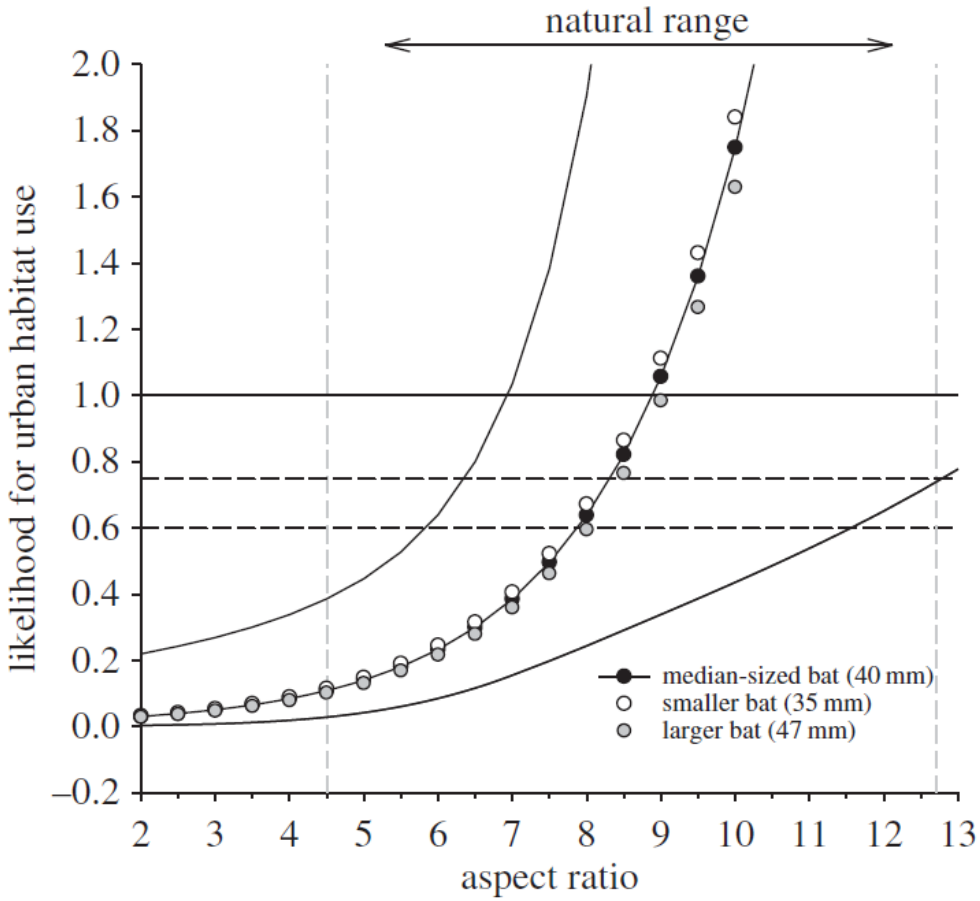
# Trait-dependent tolerance of bats to urbanization




Source: Jung K, Threlfall CG. 2018
http://dx.doi.org/10.1098/rspb.2018.1222.

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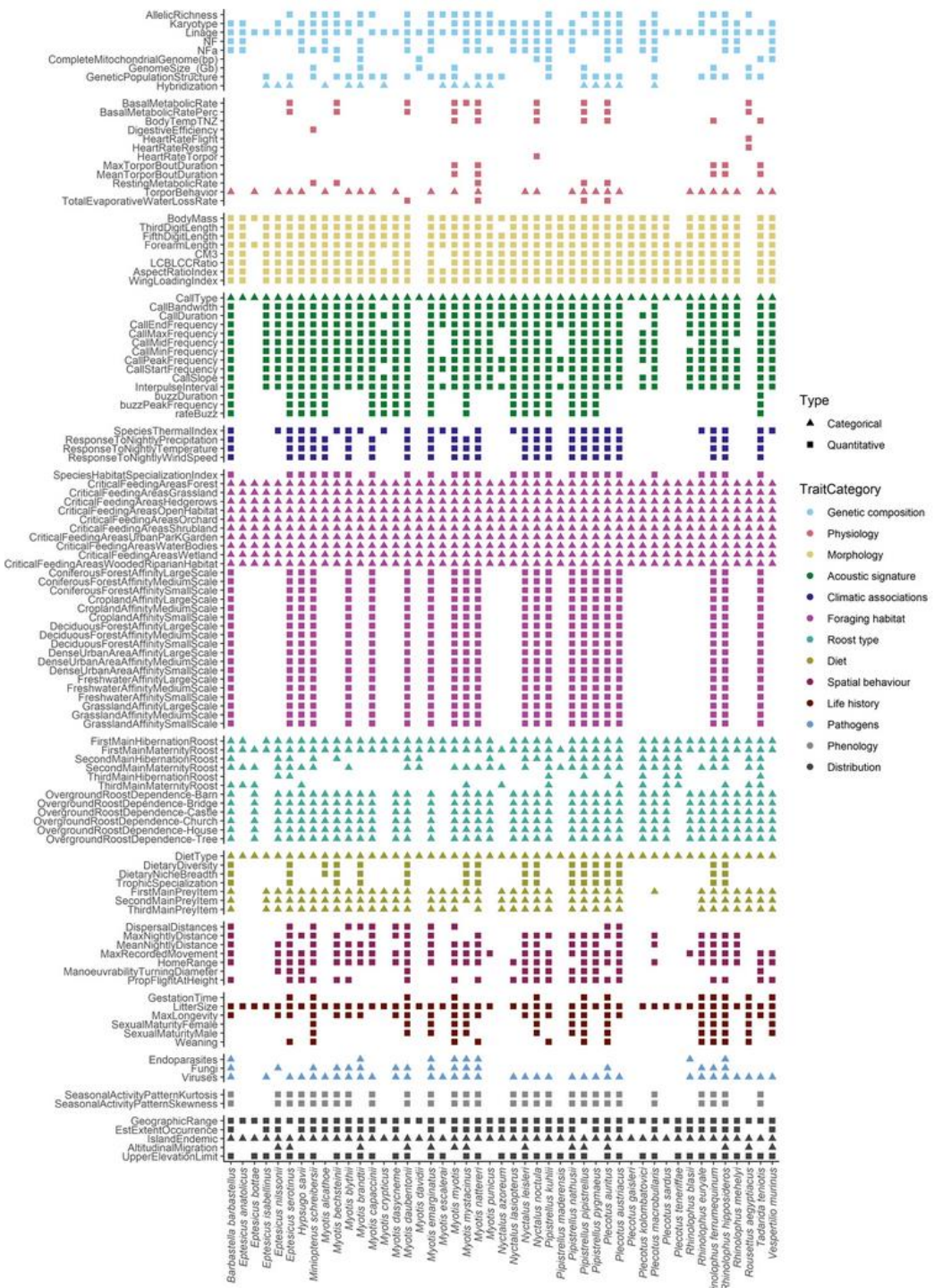
# A species-level trait dataset of bats in Europe and beyond

- EuroBaTrait:
- data on 118 traits: genetic composition, physiology, morphology, acoustic signature, climatic associations, foraging habitat, roost type, diet, spatial behaviour, life history, pathogens, phenology, and distribution.
- obtained from: (i) a systematic literature and dataset search, (ii) unpublished data from European bat experts, and (iii) observations from large-scale monitoring programs.

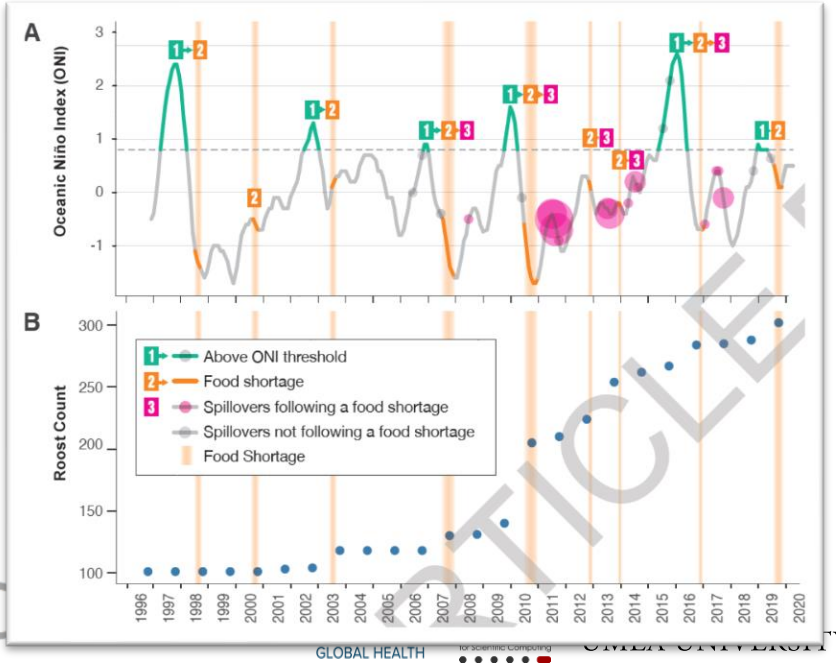



Source: Froidevaux, J.S.P., Toshkova, N., Barbaro, L. *et al.* (2023). https://doi.org/10.1038/s41597-023-02157-4.

# Show-case: Hendra virus spillover in subtropical Australia (Eby et al 2022)

- Hendra: Australian flying foxes
  - transmitted to horses (the intermediate host) causing a highly lethal disease
  - capable of spilling over from horses to humans => a severe or fatal infection.
- interactions between land-use change and climate altered the behavior of wildlife reservoir hosts, increasing their proximity to domestic or human recipient hosts
  - spillover was coming from small populations of bats that had just formed in agricultural areas
- the highest risk of spillover was from bats in agricultural areas after a food shortage when no winter habitat produced food (nectar)
- potential solution to stop spillover is to restore the winter habitat of the bats and preserve what is left

Source: https://www.newsweek.com



# Discussion

- Can traits be a useful tool in rapid assessment and monitoring of changes in infectious disease due to anthropogenic ecological disturbance?
- Can they become indicators?
- Which bat traits are good predictors of sustainable ecological and conservation practices that provide reduction of spillover risk for people and livestock?

# Thank You!


—CSIDlab—

Climate-Sensitive Infectious Diseases lab