Exploring the socio-ecological interactions of tick-borne diseases using agent-based models

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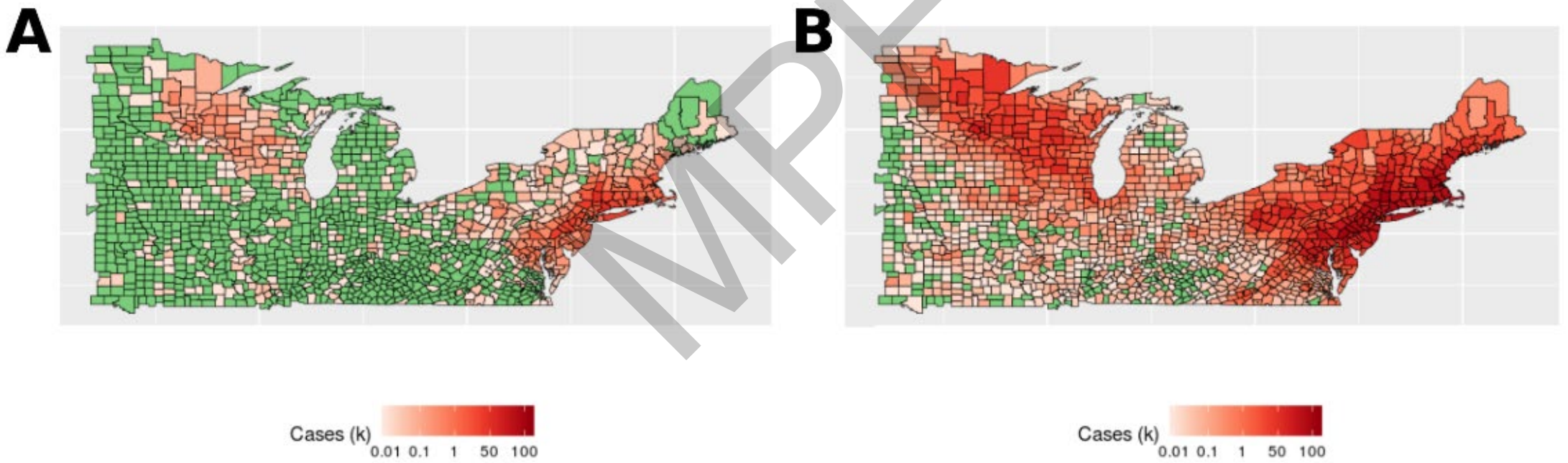
Geographic expansion of Lyme disease cases between 2000 and 2017

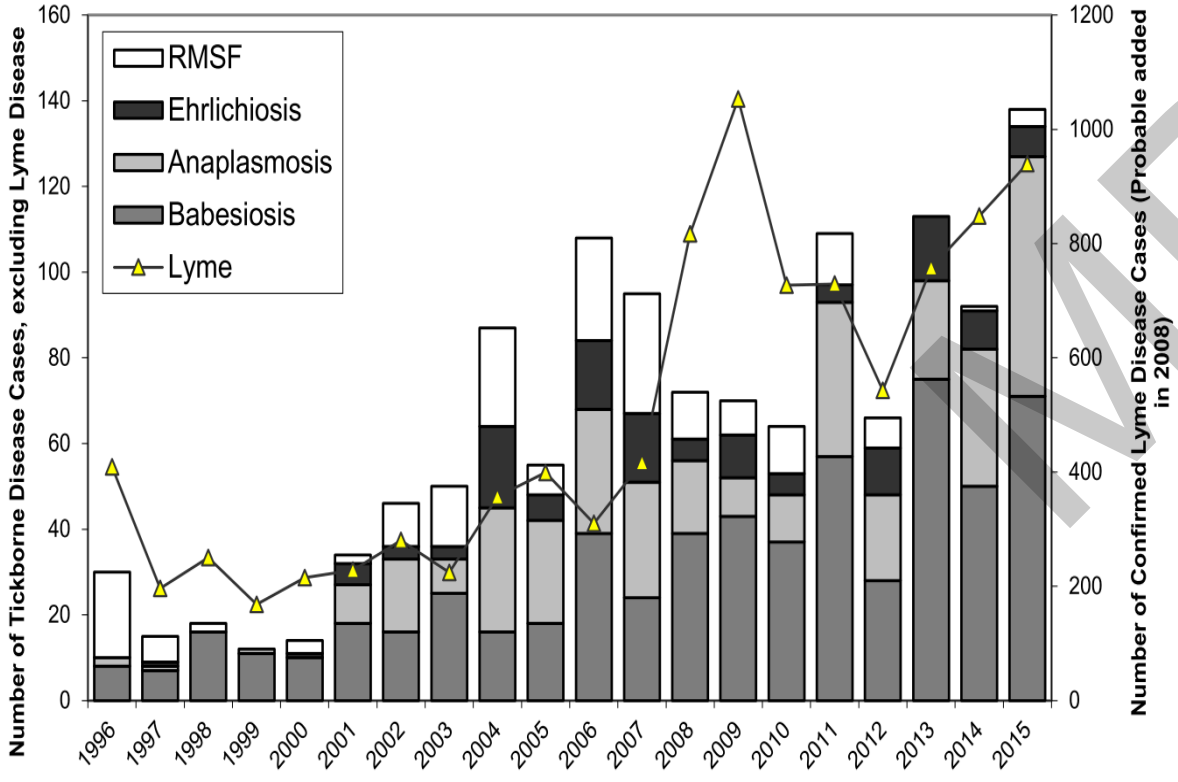
Bisanzio et al. *JAMA Network Open, 2020*



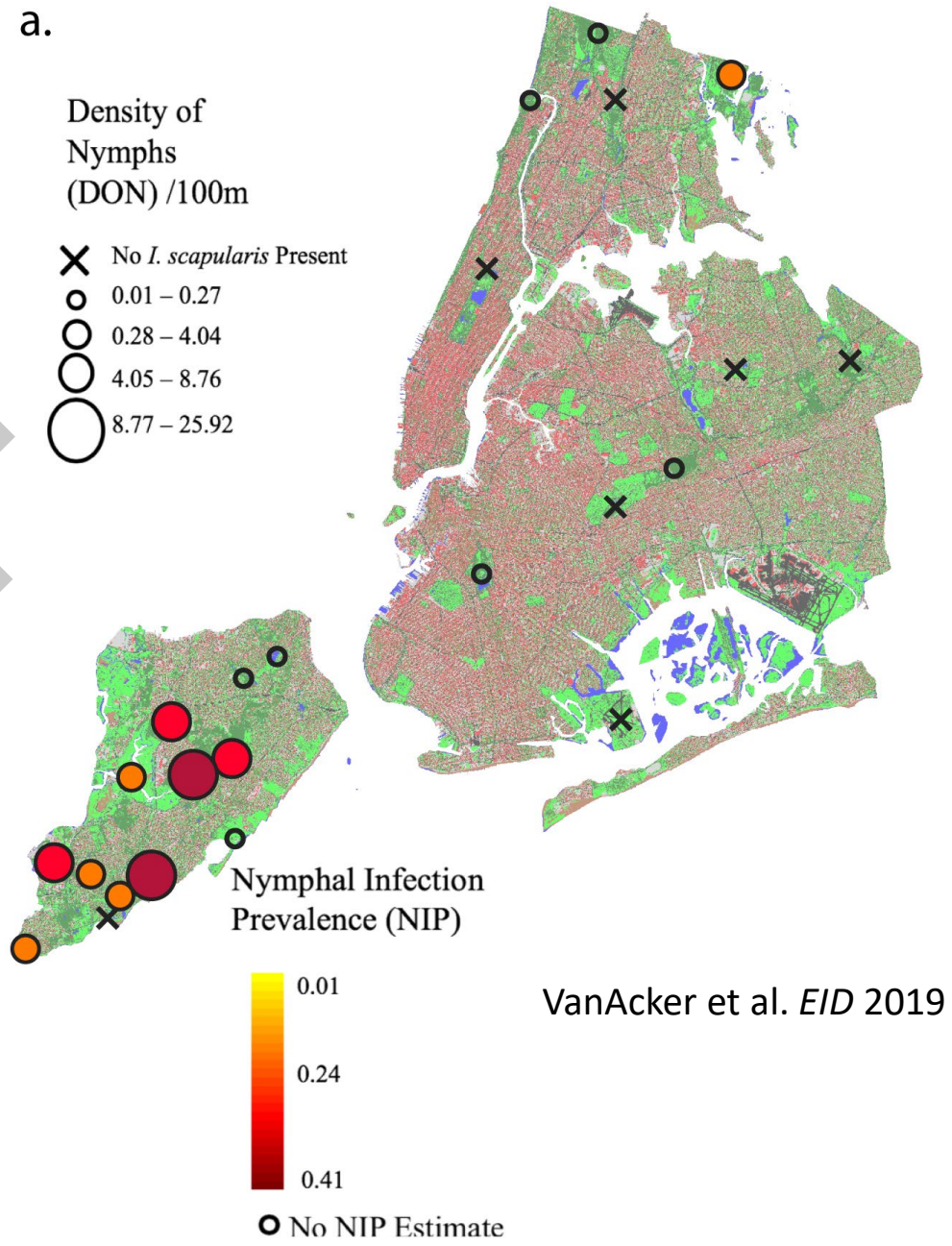
Reported cases in 2000

Reported cases in 2017

And also into urban areas of long-endemic areas…

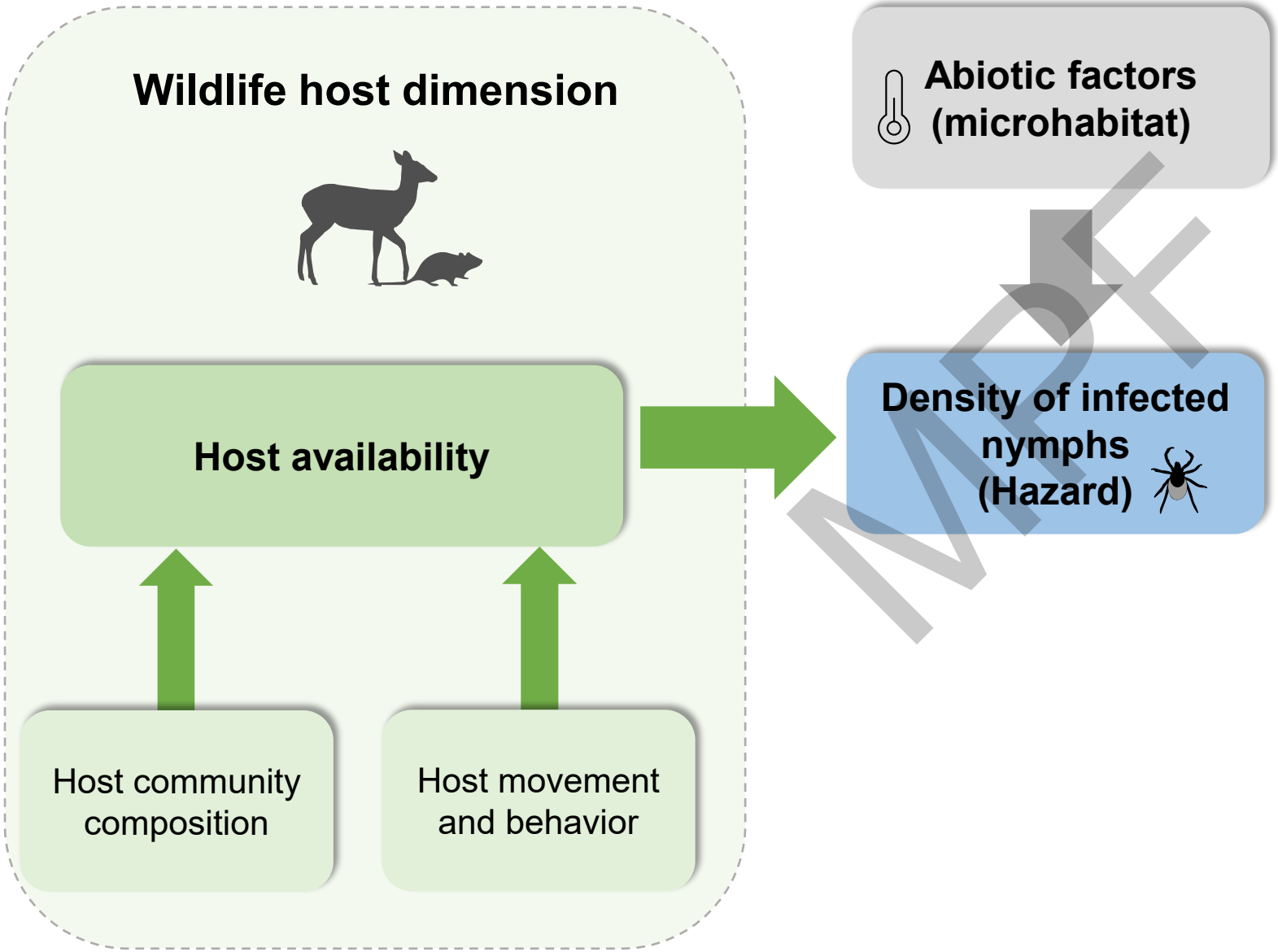


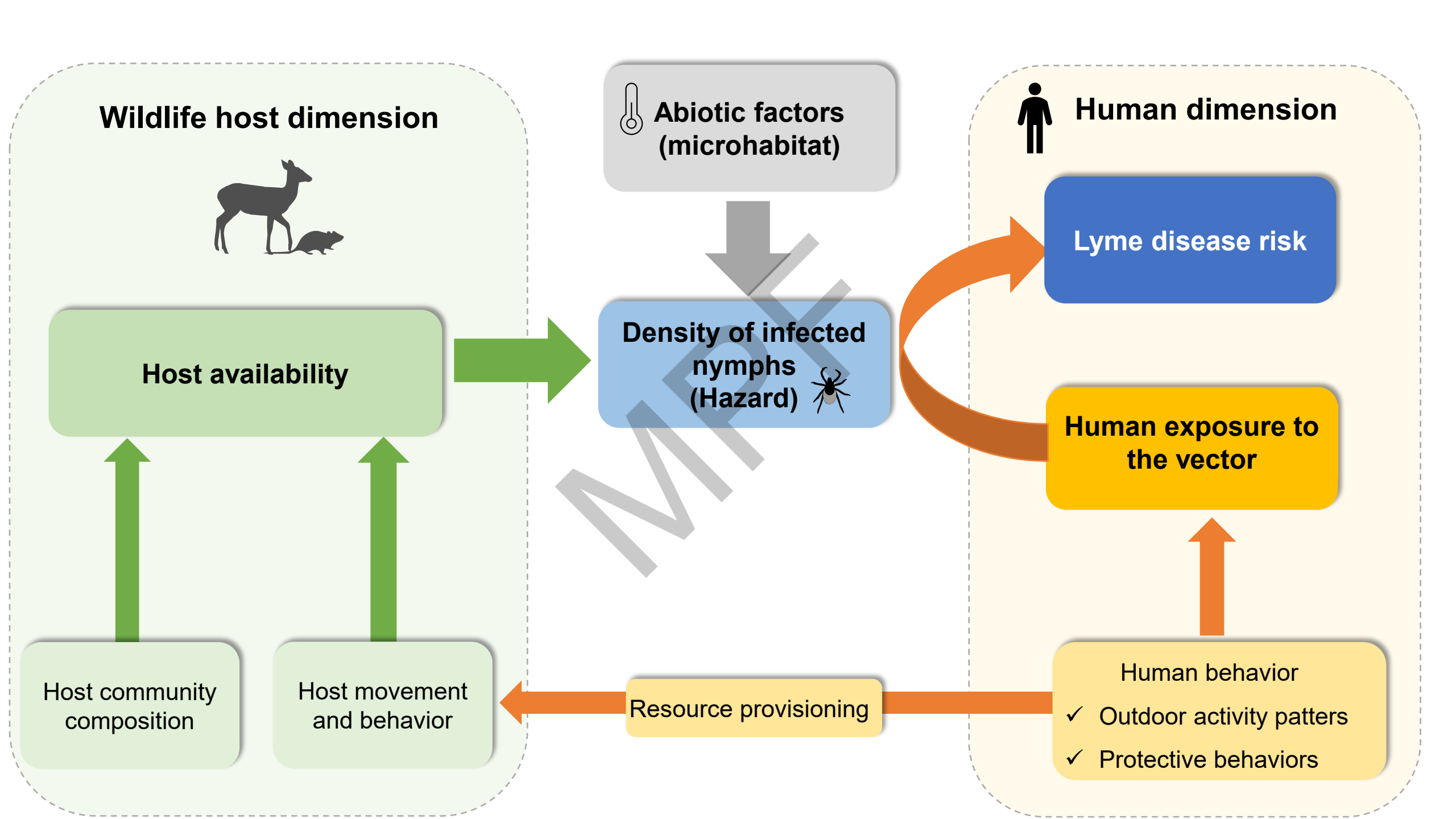
NYC Department of Health



VanAcker et al. *EID* 2019

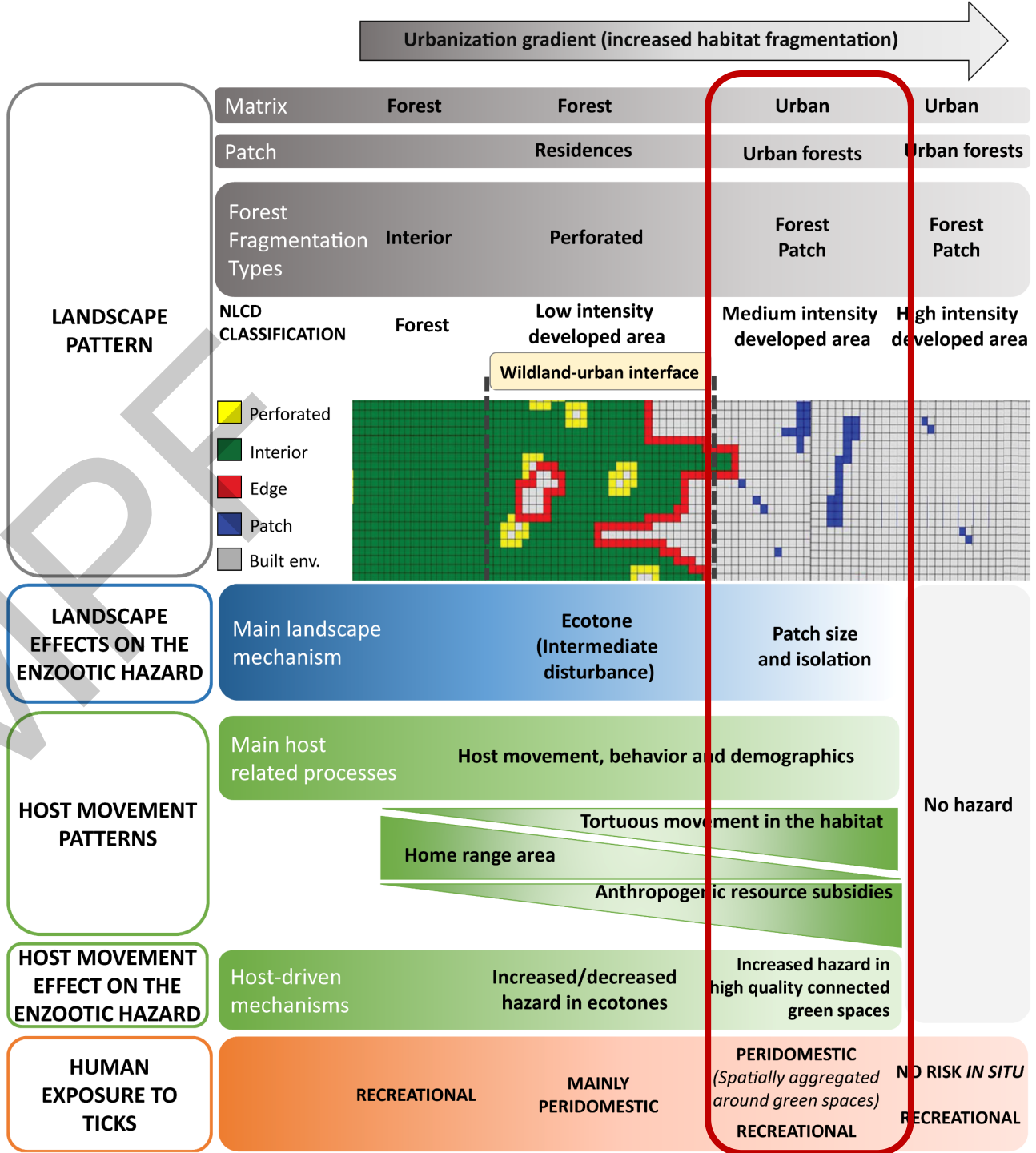
More ticks, more cases?



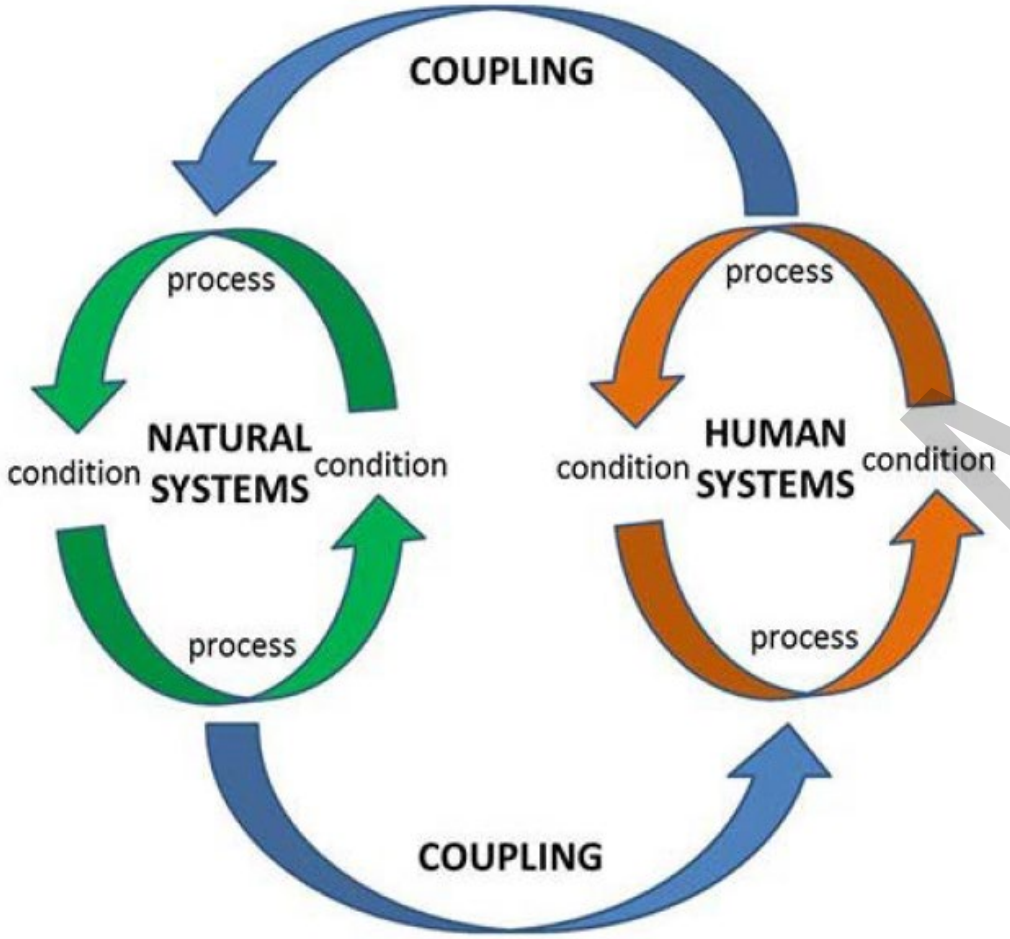

Wildlife host dimension
Abiotic factors (microhabitat)
Human dimension
Lyme disease risk
Host availability
Density of infected nymphs (Hazard)
Human exposure to the vector
Host community composition
Host movement and behavior
Resource provisioning
Human behavior
✓ Outdoor activity patters
✓ Protective behaviors

Landscape configuration

Diuk-Wasser et al JME, 2020



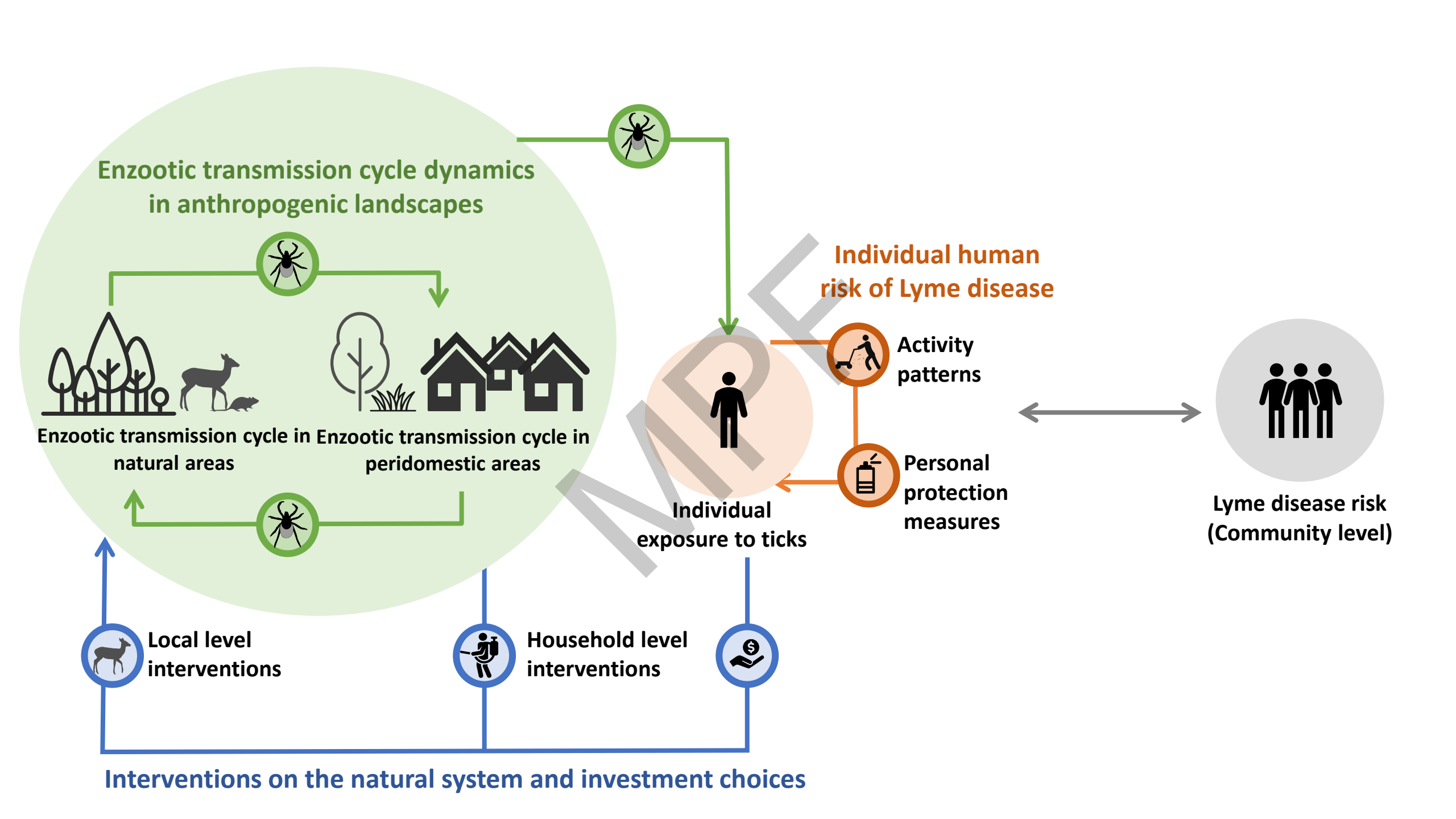
Formalizing the socio-ecological interactions of Lyme disease: "Coupled Natural Human Systems"

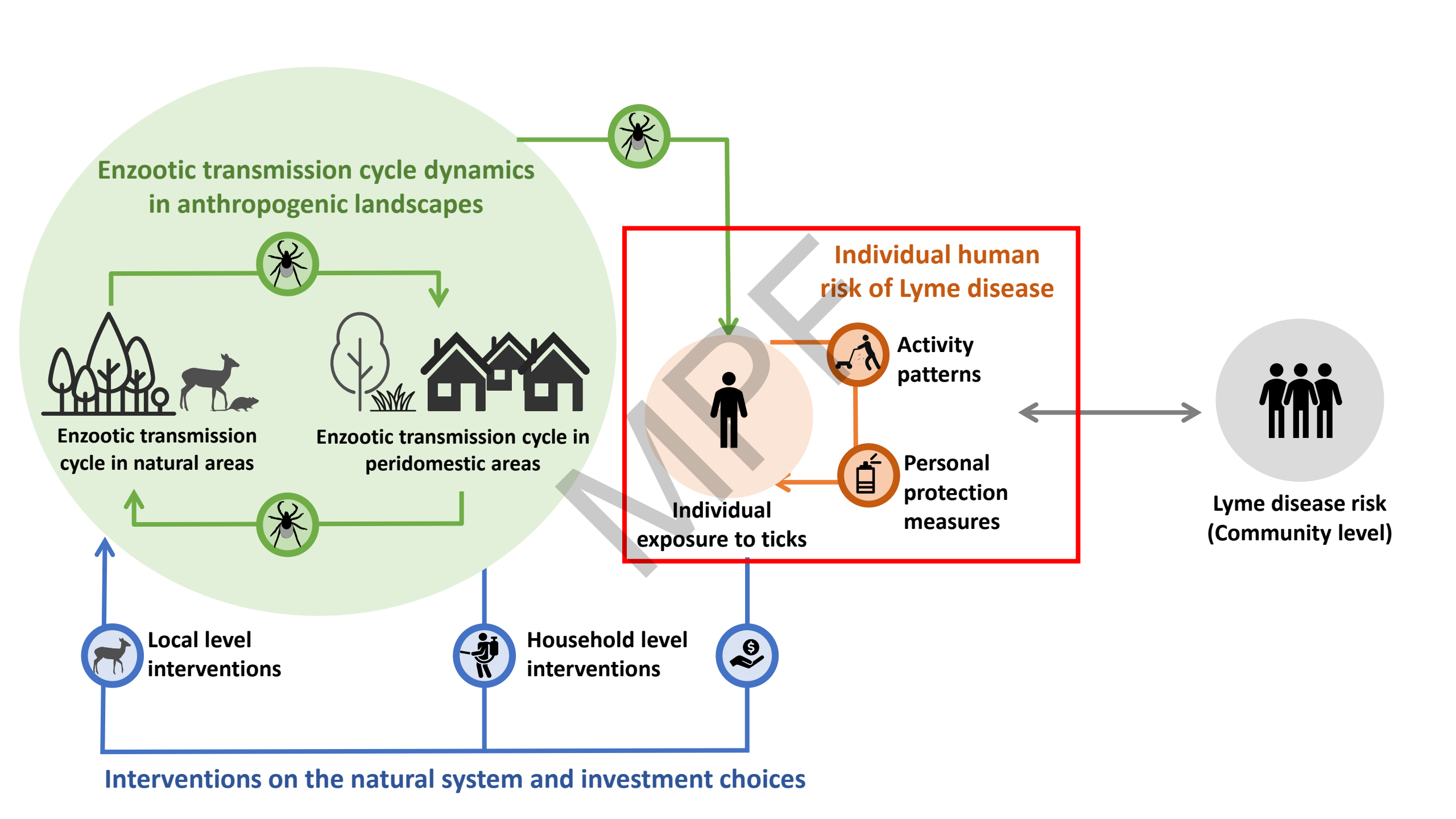


1- Human system dynamics

2- Natural system dynamics

3- Coupling processes


Enzootic transmission cycle dynamics in anthropogenic landscapes
Enzootic transmission cycle in natural areas
Enzootic transmission cycle in peridomestic areas
Individual human risk of Lyme disease
Activity patterns
Personal protection measures
Individual exposure to ticks
Lyme disease risk (Community level)
Local level interventions
Household level interventions
Interventions on the natural system and investment choices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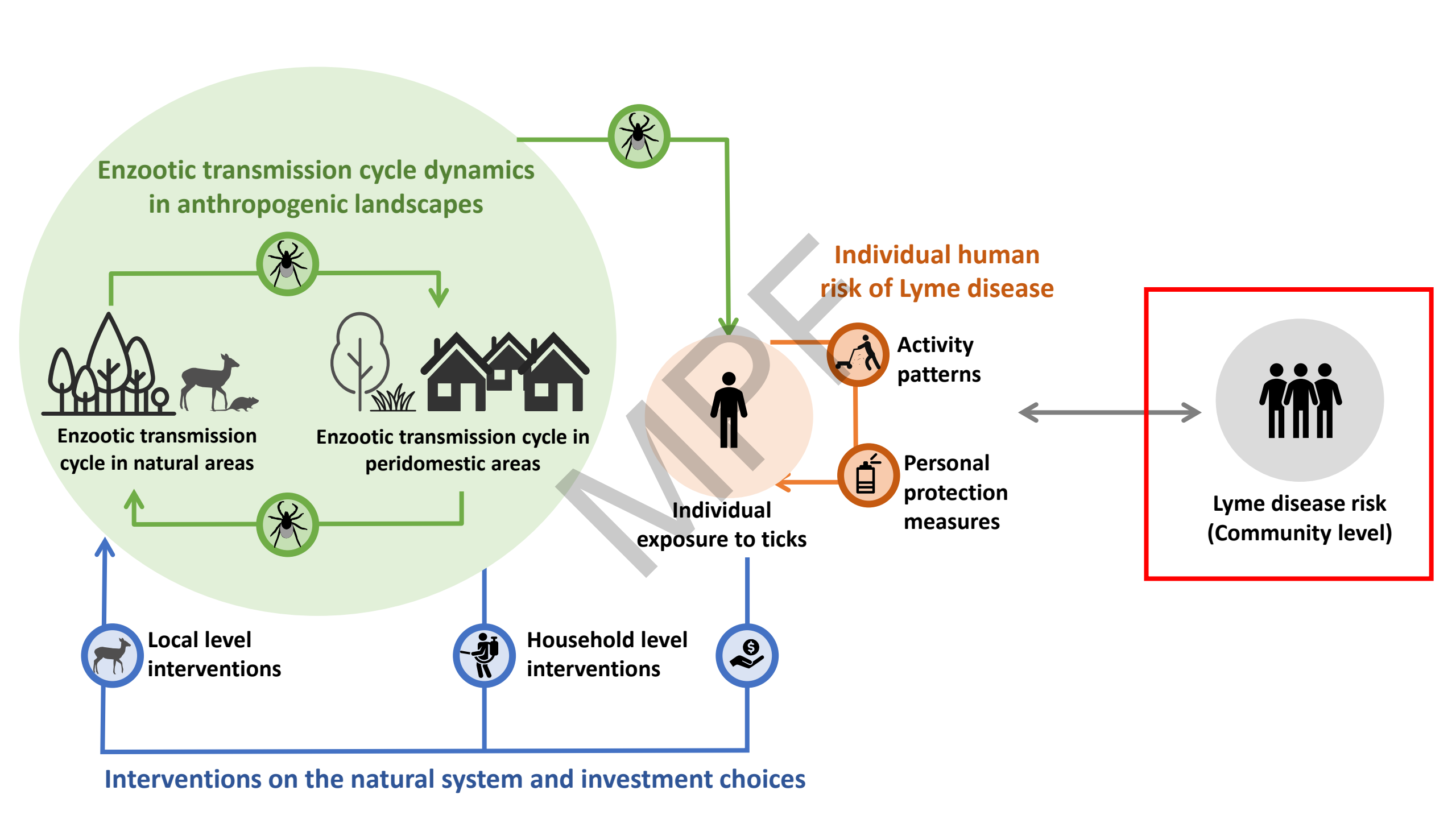
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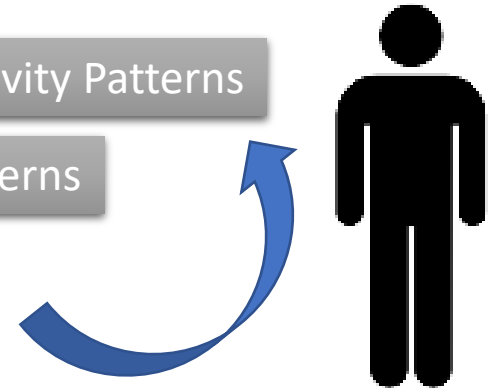
How to estimate human-tick contact rate?

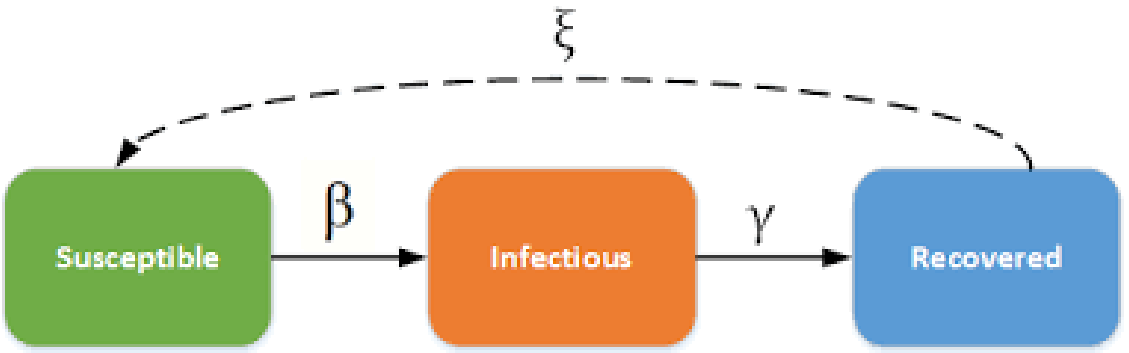
Which **activities** increase the risk of exposure?

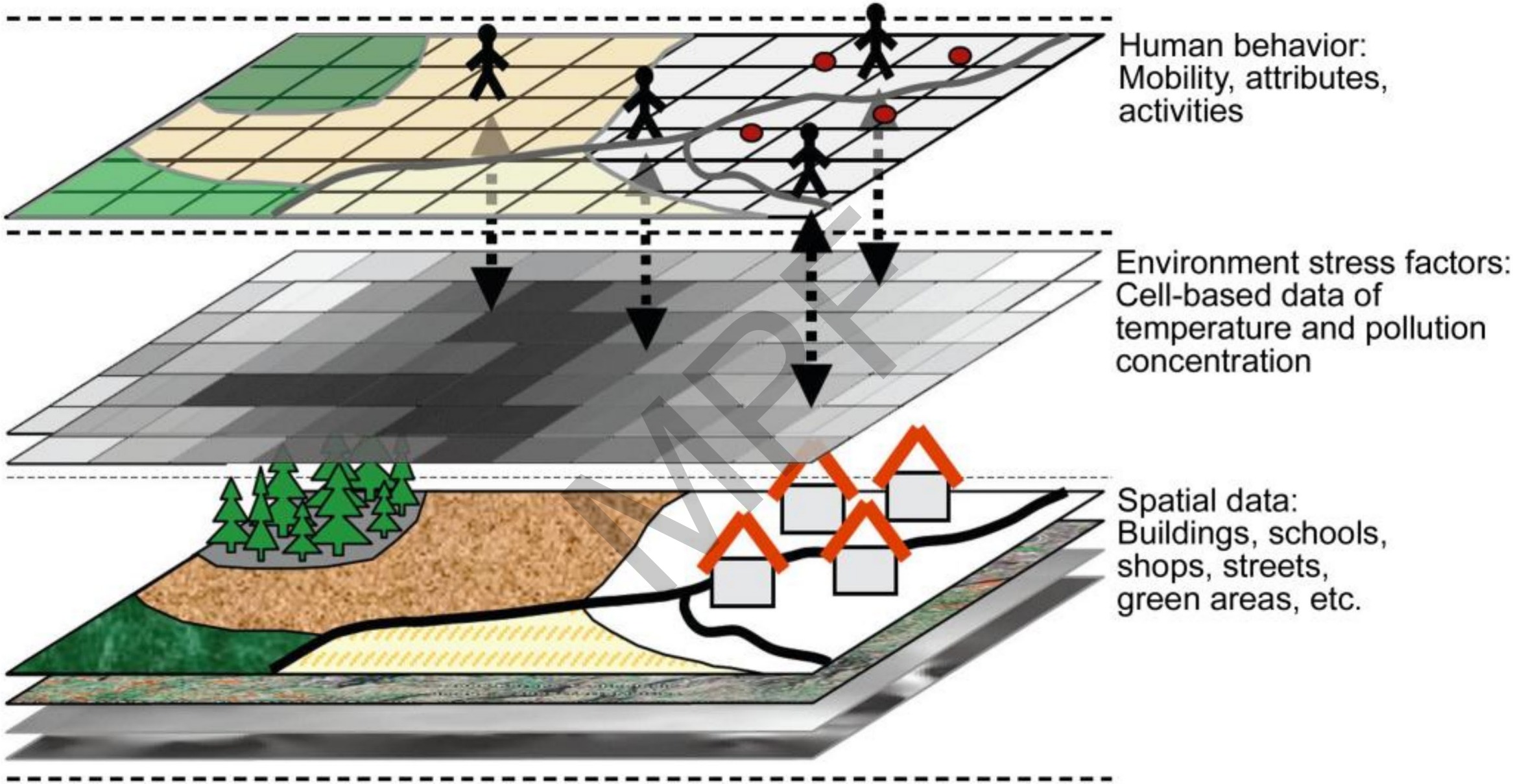
Where do people are exposed to ticks?

How does the ecological context affect risk perception?



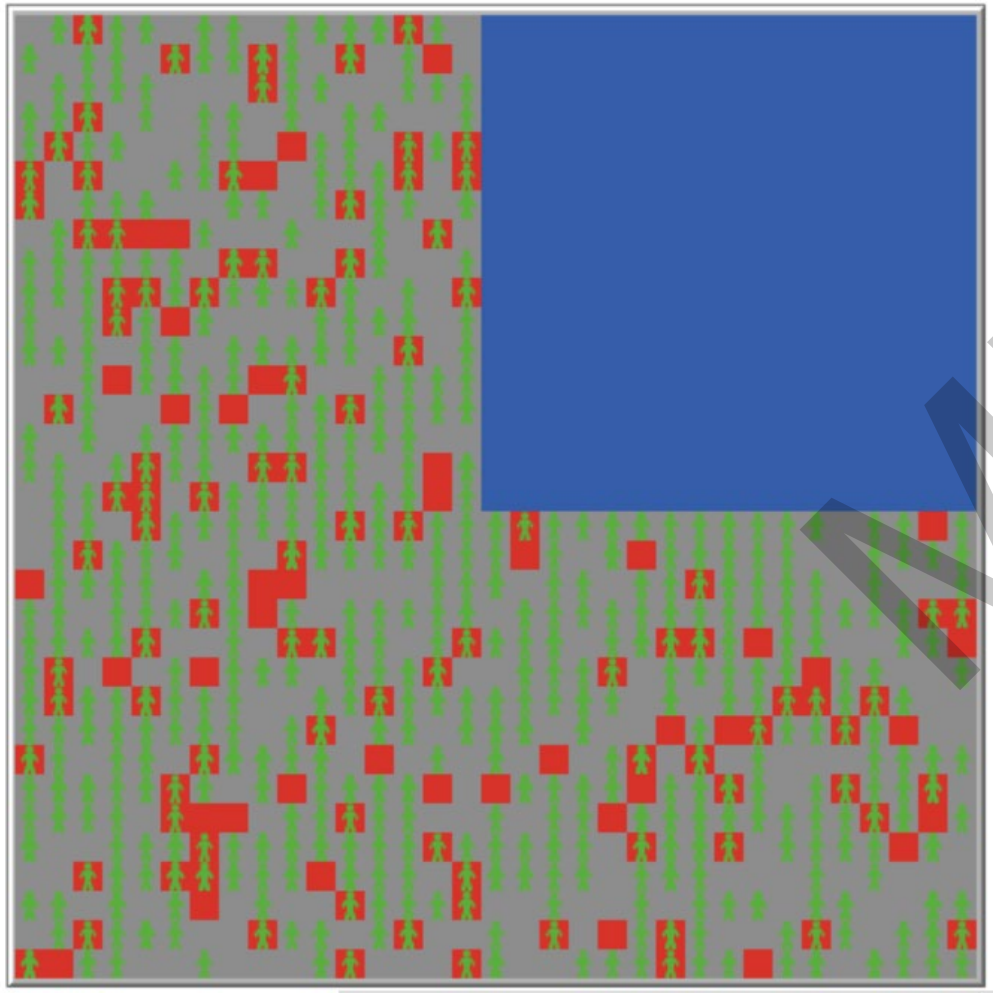
Why ABM? Heterogeneity in human movement and activity patterns and stochasticity will determine emerging properties at the population-level (e.g., human-tick encounter rates).




Human behavior:
Mobility, attributes,
activities
Environment stress factors:
Cell-based data of
temperature and pollution
concentration
Spatial data:
Buildings, schools,
shops, streets,
green areas, etc.

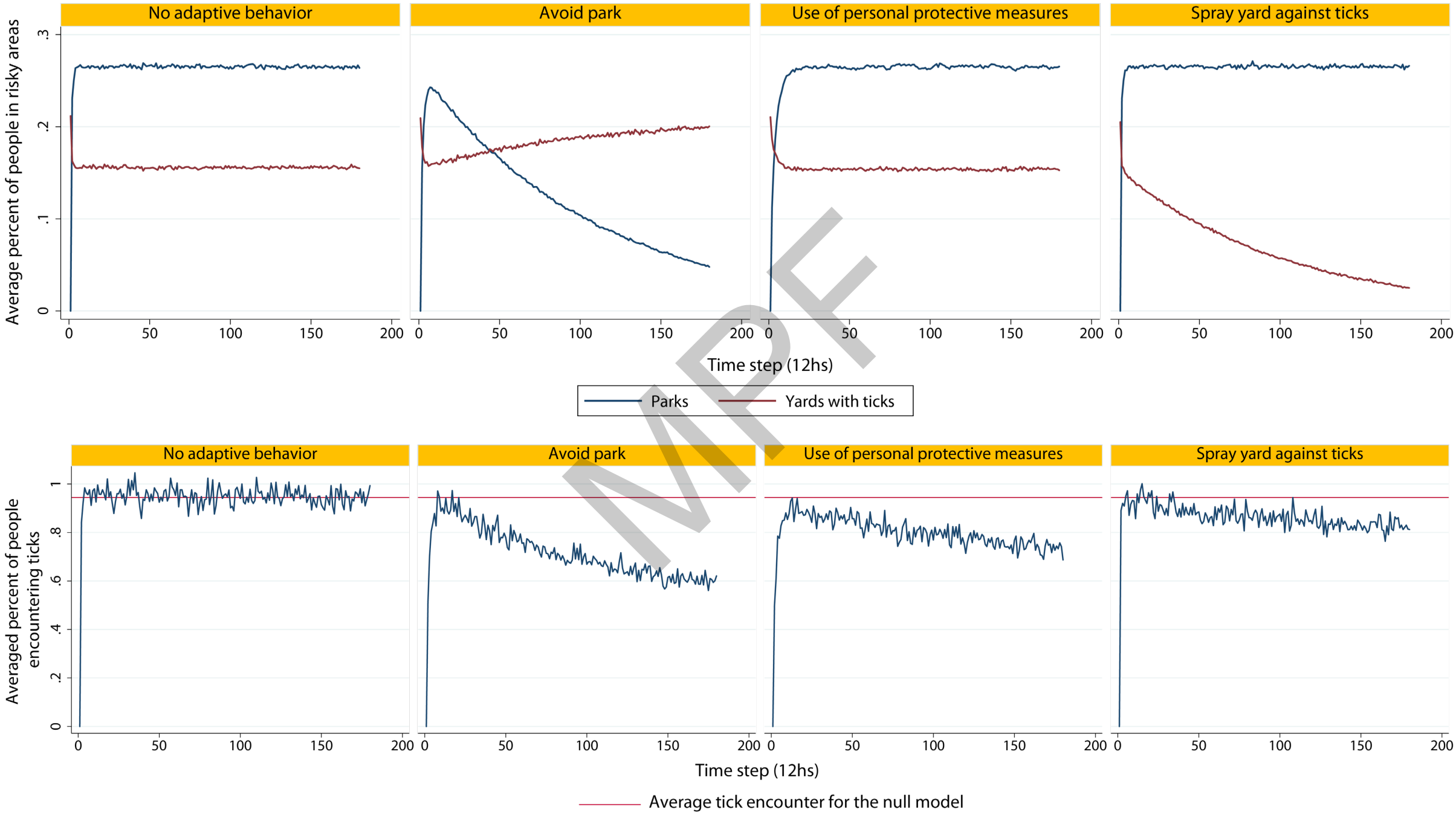
Implementation of a preliminary Agent-based model

T=0

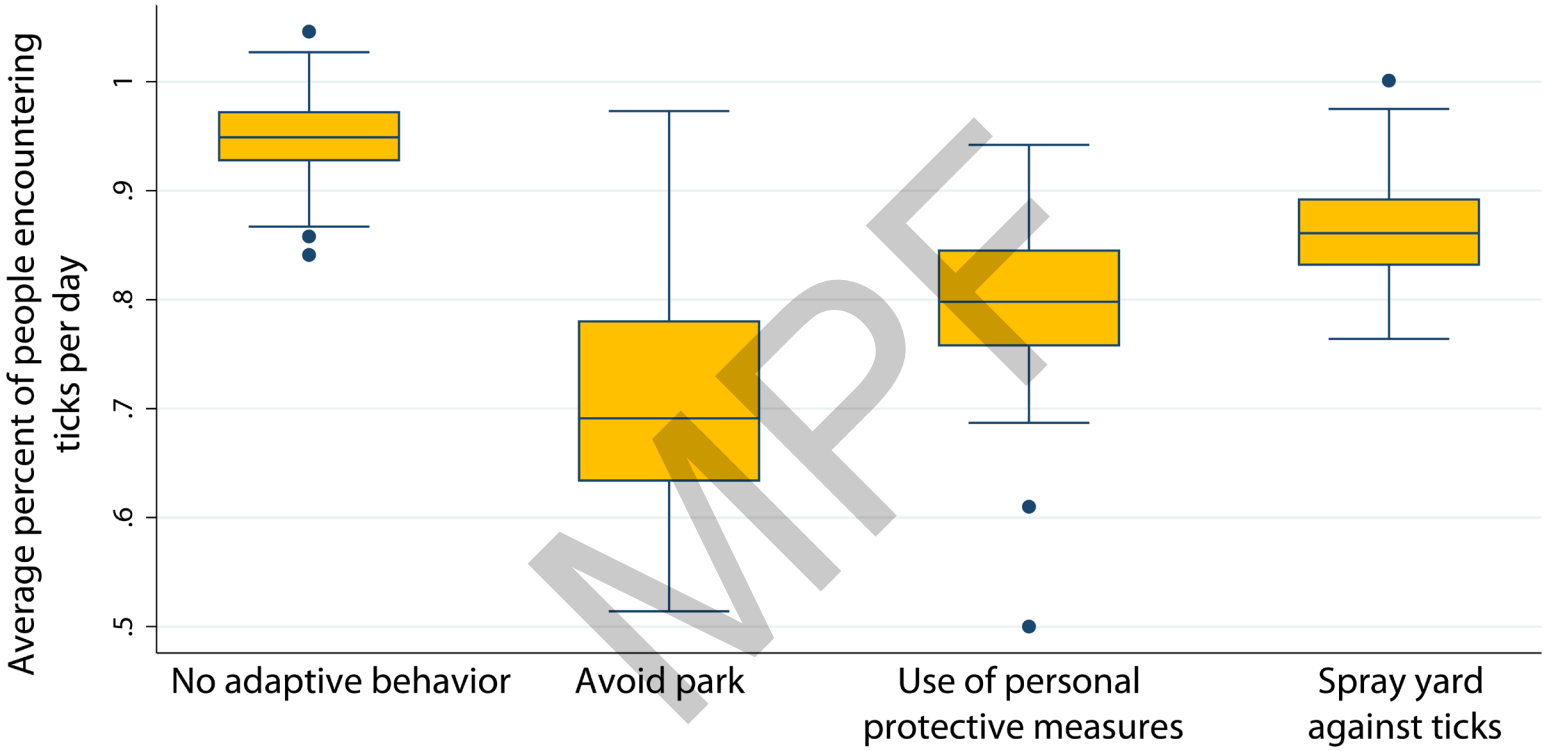


T=90 days

Human movement: random walk
Pb of tick encounter if risky area: 0.03


No adaptive behavior
Avoid park
Use of personal protective measures
Spray yard against ticks
Average percent of people in risky areas
0
.1
.2
.3
0
50
100
150
200
Time step (12hs)
Parks
Yards with ticks
No adaptive behavior
Avoid park
Use of personal protective measures
Spray yard against ticks
Averaged percent of people encountering ticks
0
.2
.4
.6
.8
1
0
50
100
150
200
Time step (12hs)
Average tick encounter for the null model

All adaptive behaviors led to reduction on tick encounters but avoiding the park had the highest impact



But…

What if agents have memory?

What if they react differently to perceive risk in the neighborhood vs. personal experience?

The effect of landscape configuration on human-tick contact rates

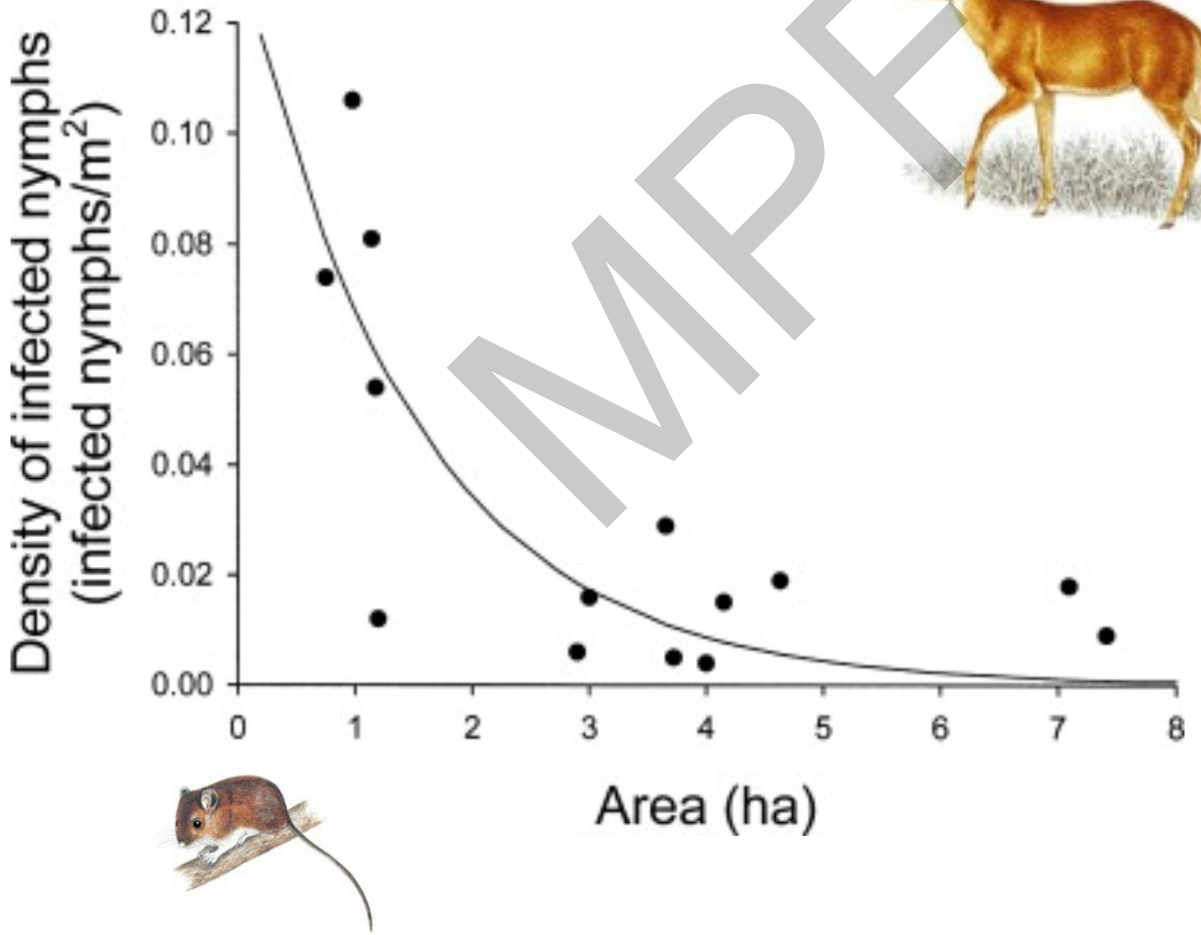
Two processes:

1. Dilution effect of the pathogen by biodiversity
2. Human contact with risky environments

Effect of Forest Fragmentation on Lyme Disease Risk

BRIAN F. ALLAN,* FELICIA KEESING,†§ AND RICHARD S. OSTFELD‡

Conservation Biology, 2003 17(1):267–272

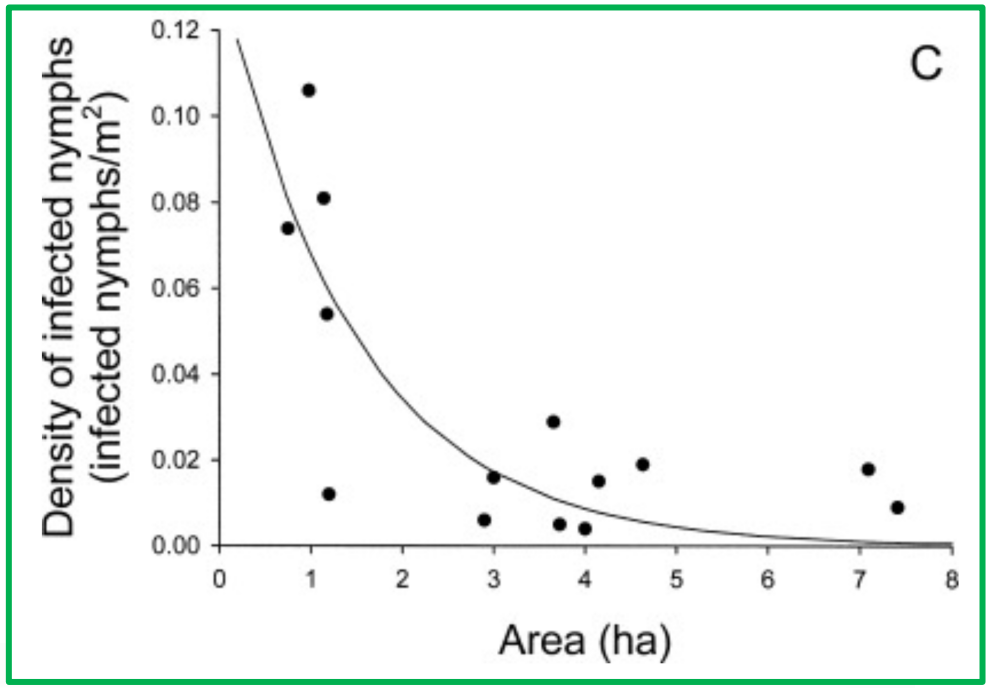


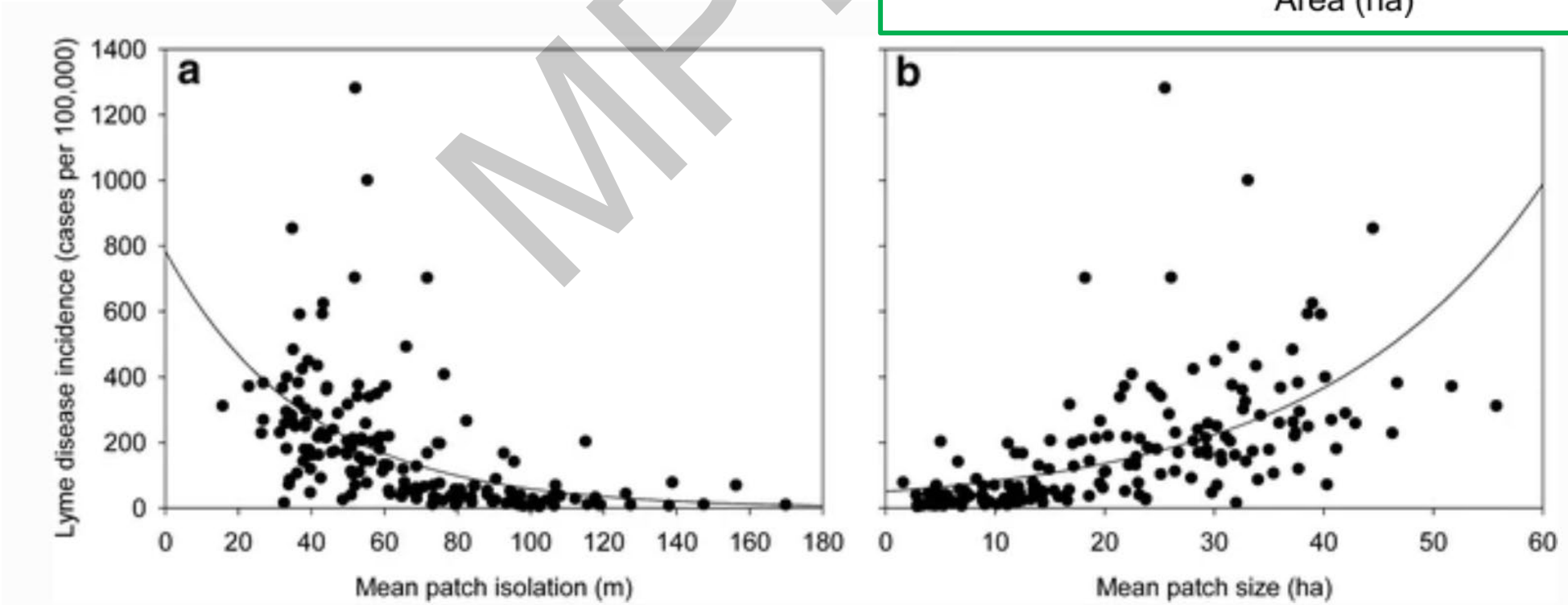
?

John S. Brownstein · David K. Skelly
Theodore R. Holford · Durland Fish

Forest fragmentation predicts local scale heterogeneity of Lyme disease risk

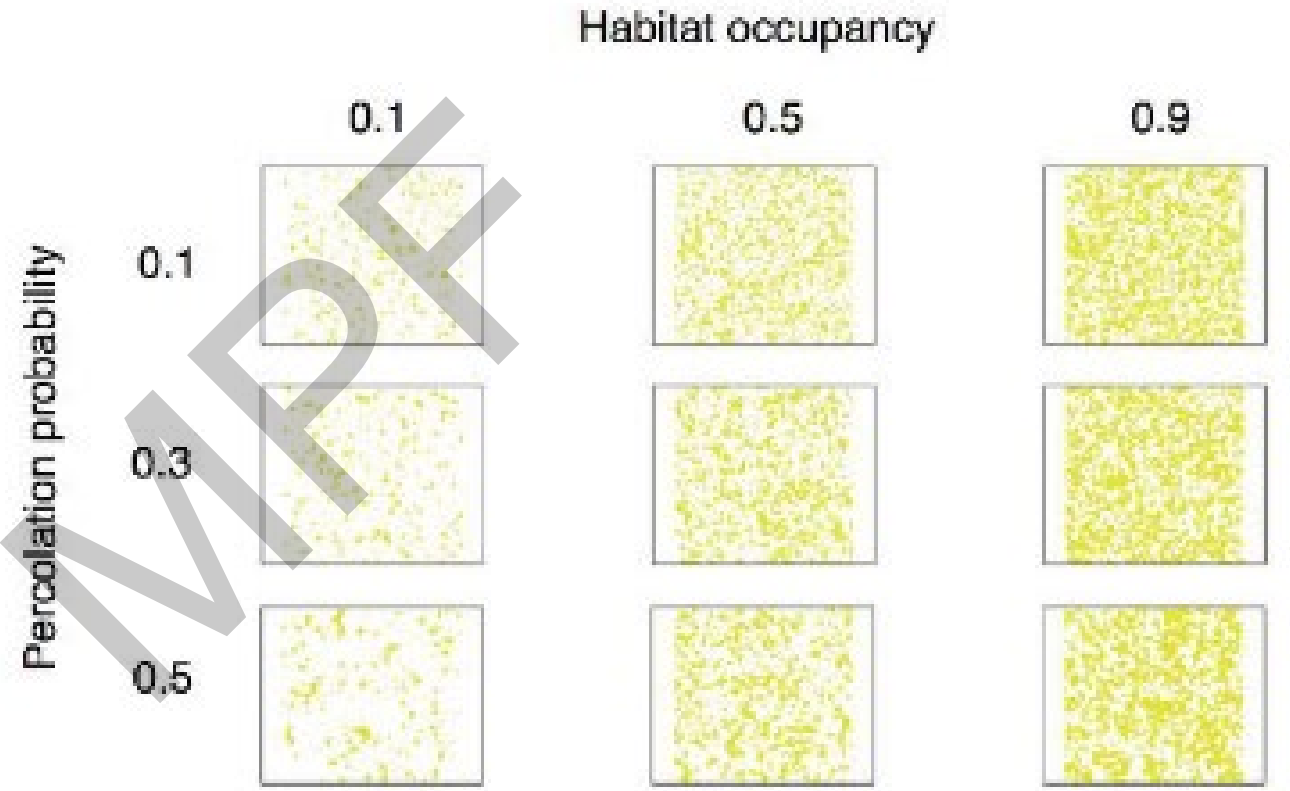
Oecologia, 2005 146:469–475





The effect of landscape configuration on human-tick contact rates

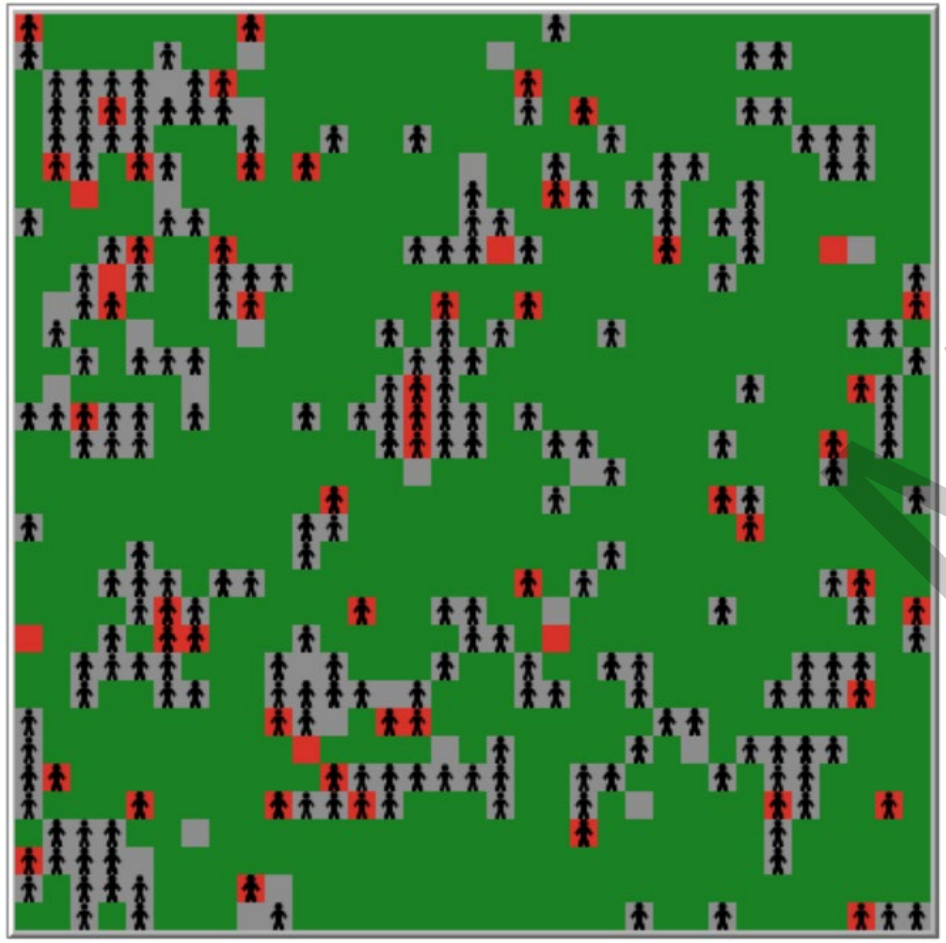
We created simulated landscapes with different levels of percolation and forest cover (habitat occupancy)
Percolation pb is a measure of aggregation: more percolation pb, more aggregated the forest patches will be (less fragmentation in the landscape)

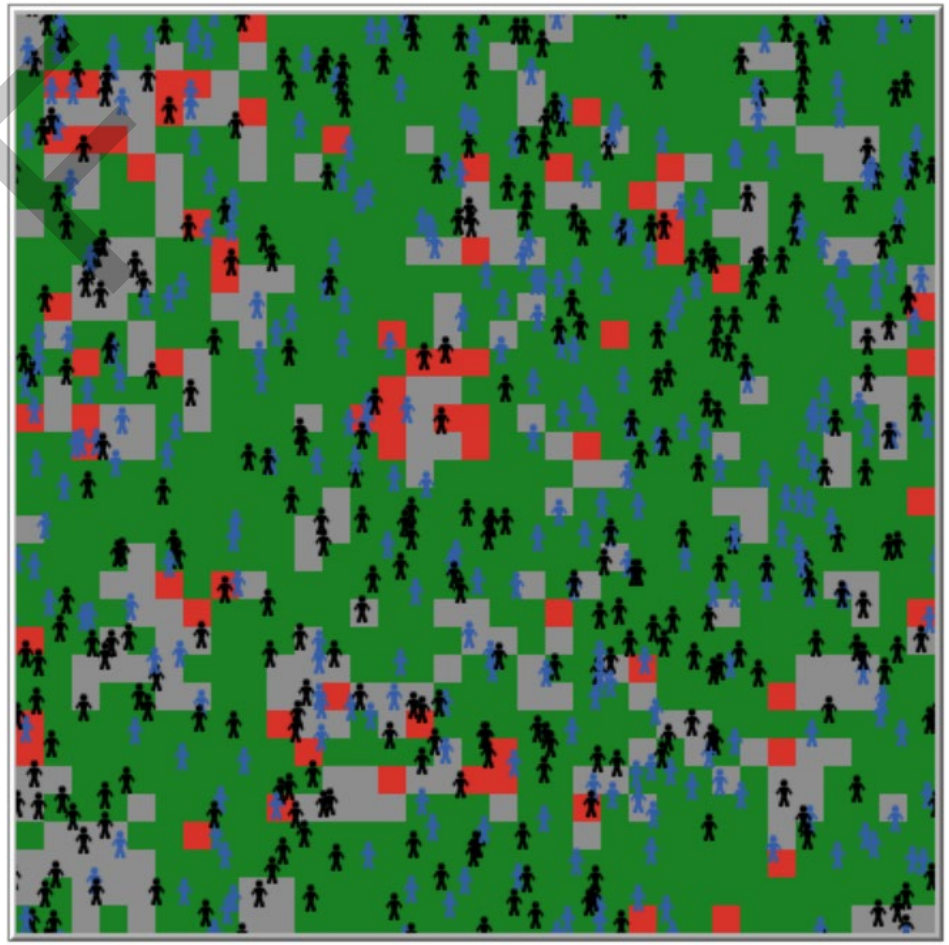


(a)

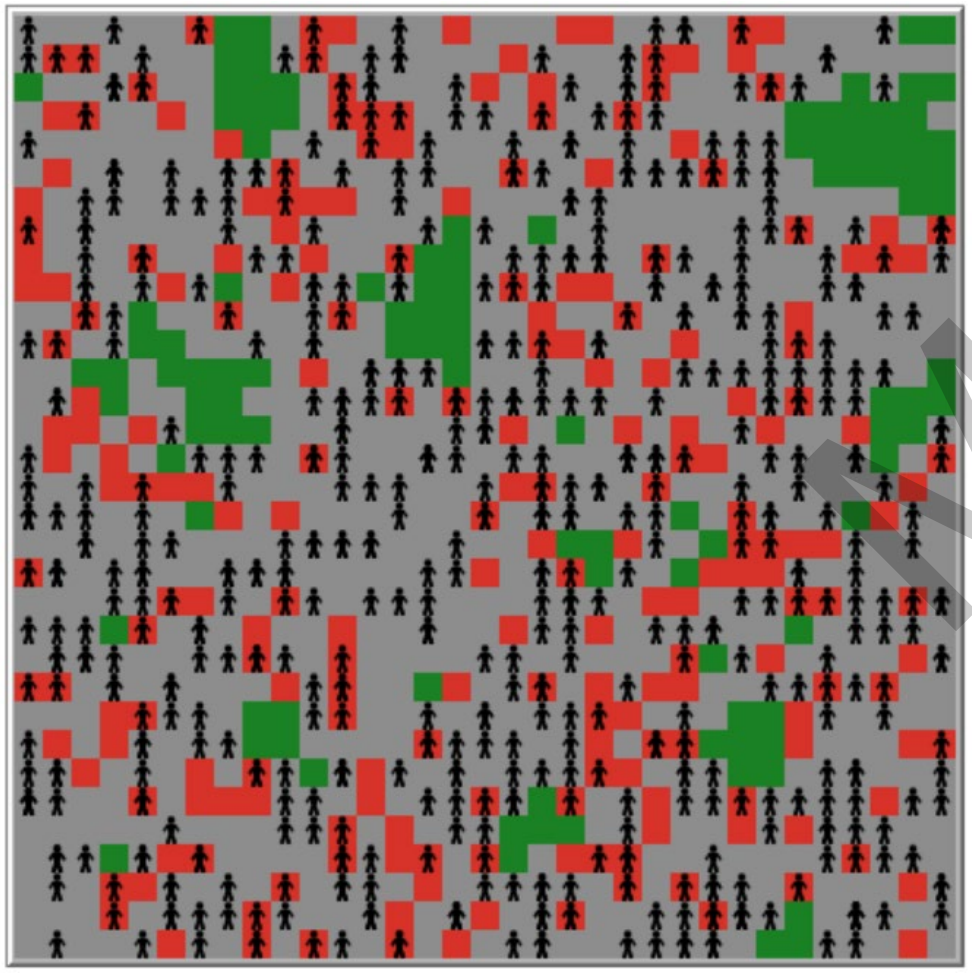
McClure M & Diuk-Wasser M Int J Environ Res Public Health. 2018;15: 1048

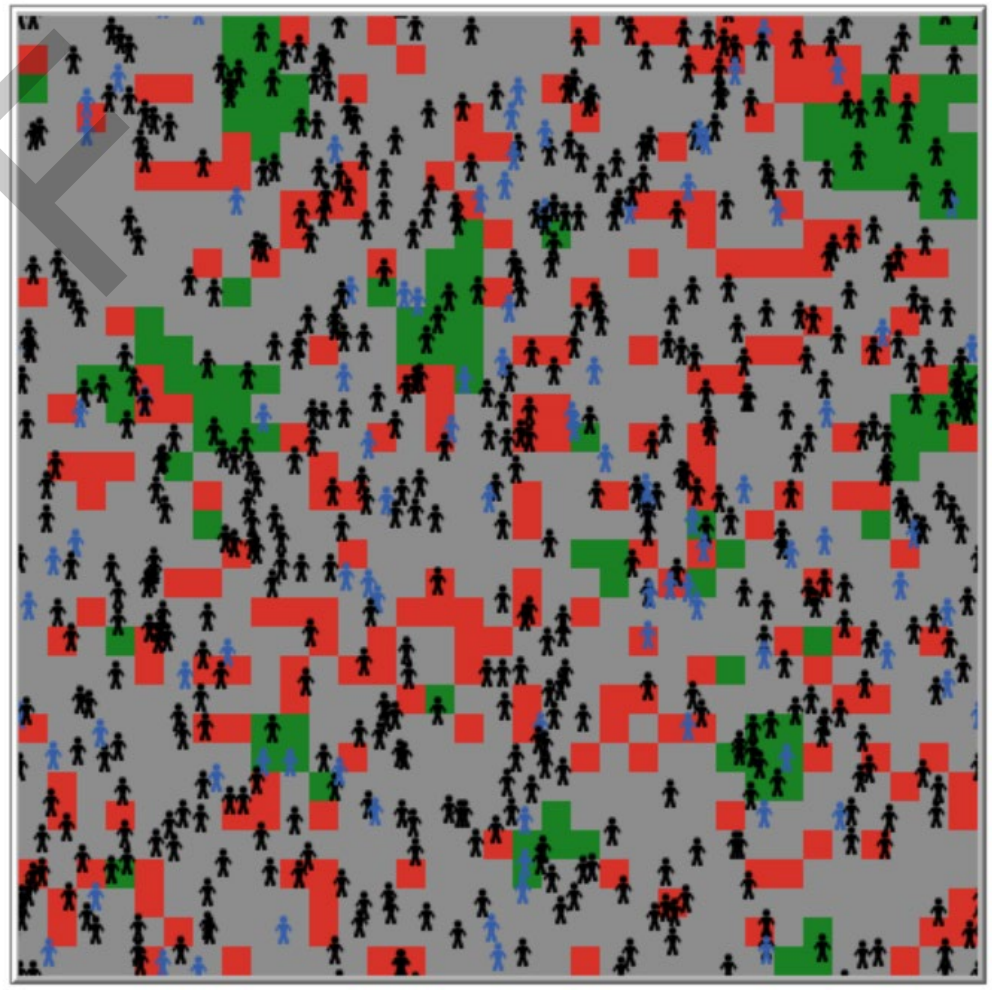
Suitable habitat density = 70%
Percolation probability= 0.45





Suitable habitat density = 10%
Percolation probability= 0.55

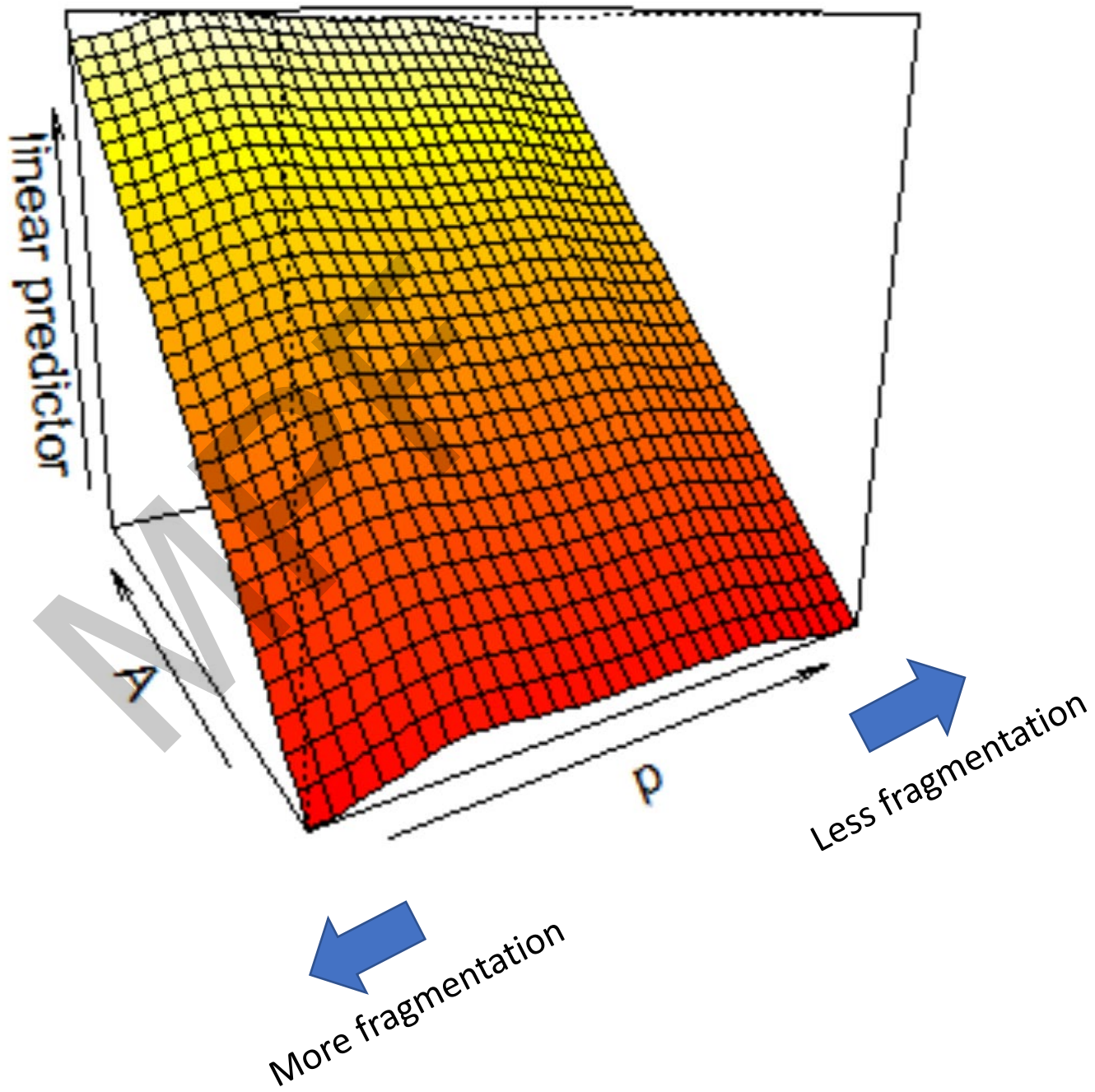


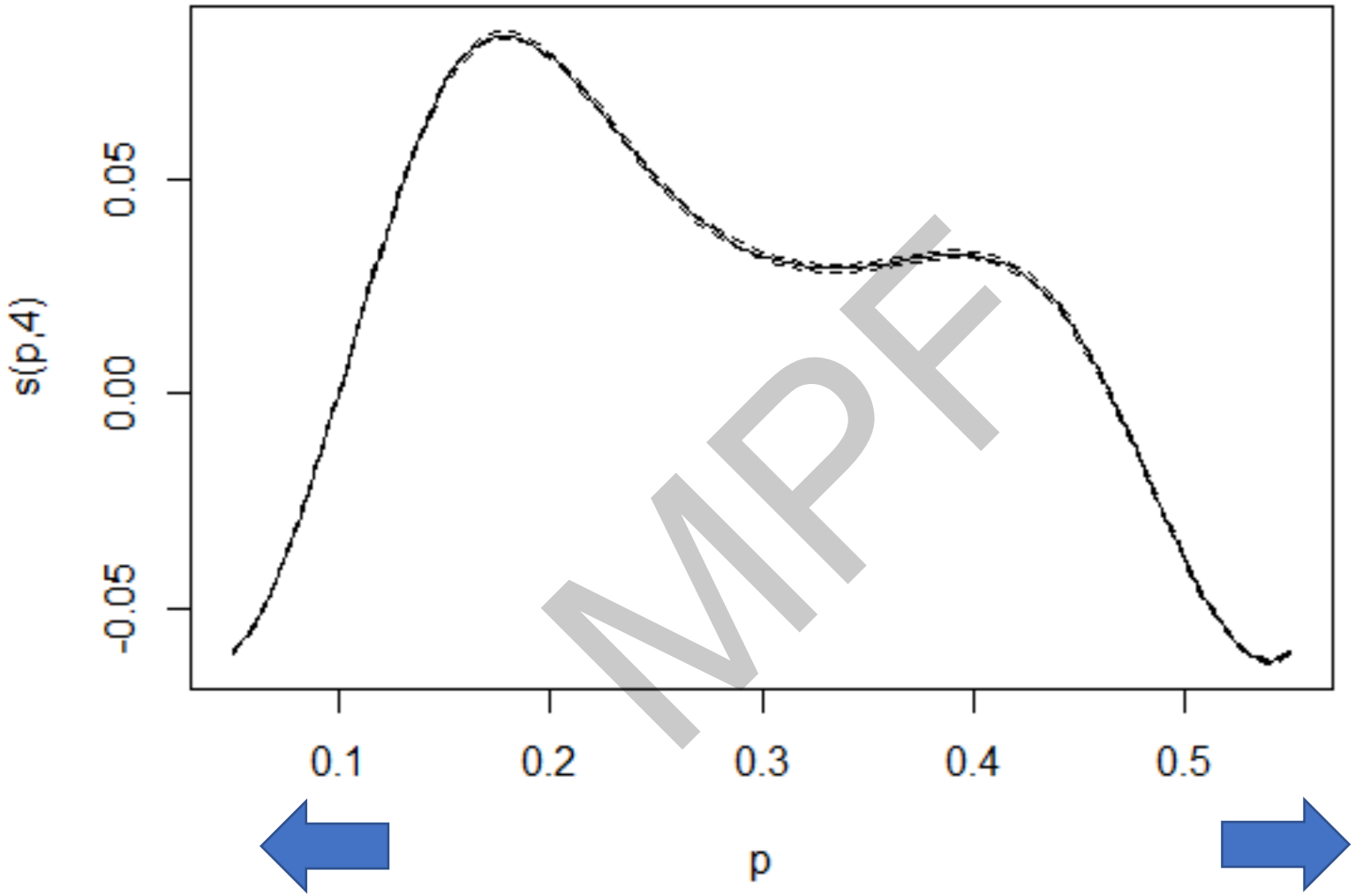


GAM
no interaction

Here is the independent effect of each variable adjusted by the other on the human-tick contact rate

Deviance explained = 64%

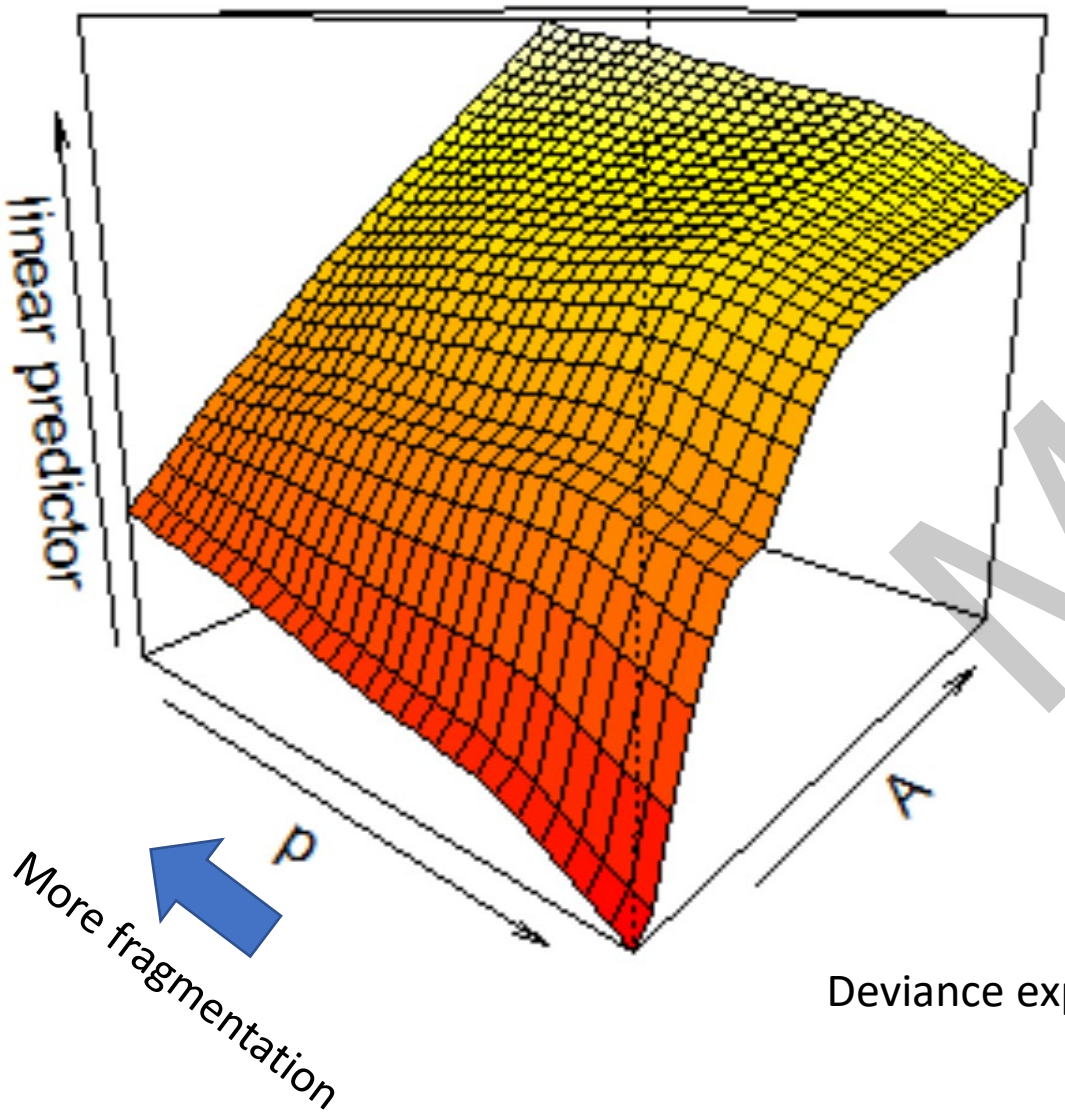




More fragmentation

Less fragmentation

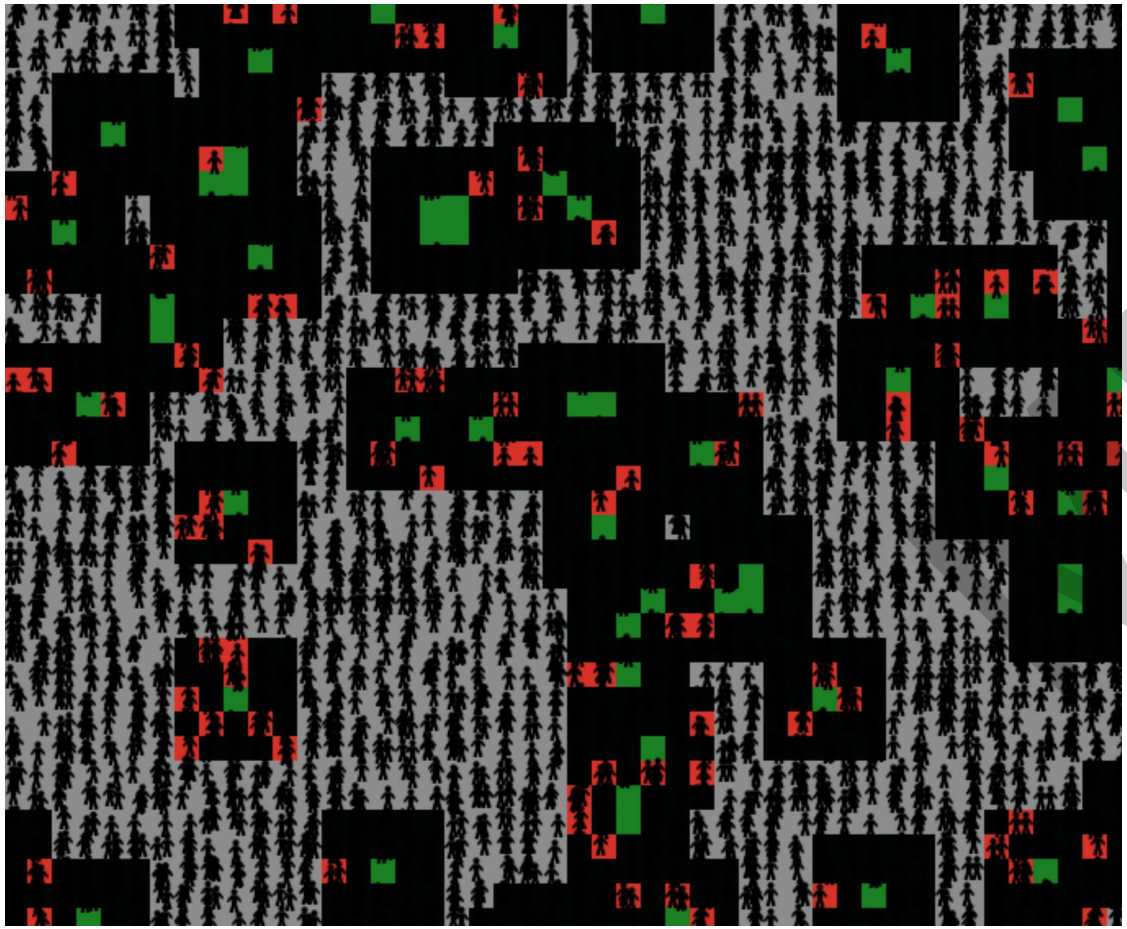
GAM with interaction

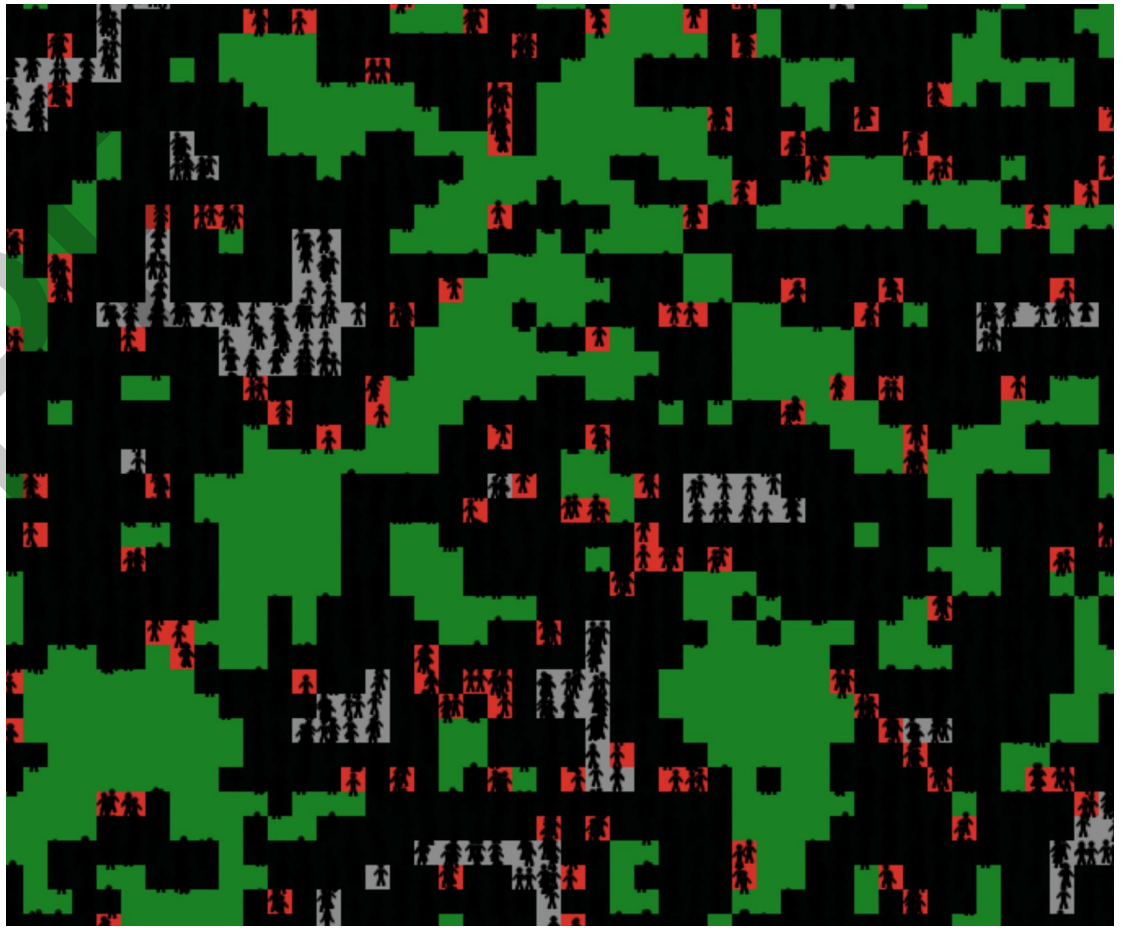


Human-tick contacts increased with forest cover and with fragmentation, but the effect of the forest cover decreased if it was less fragmented (i.e., large forest patches)

Deviance explained = 72.6%

And what about edges?





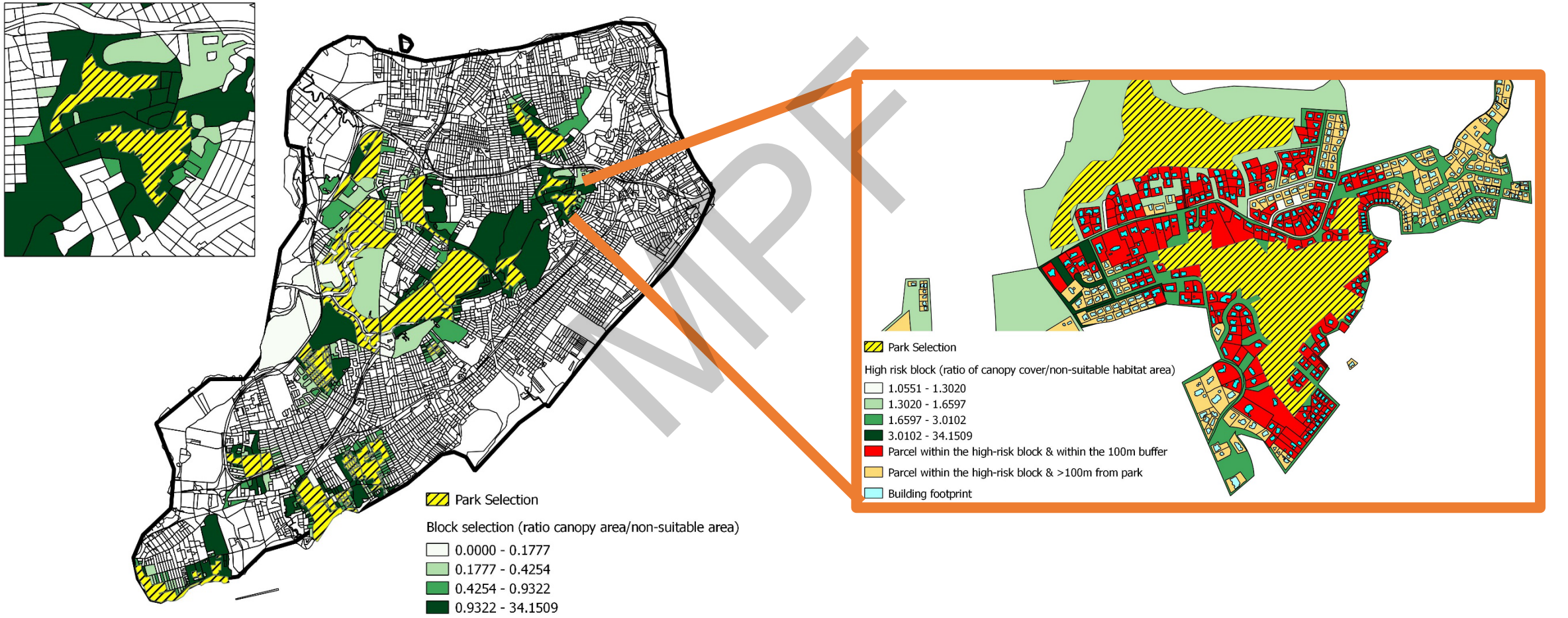
Future directions

1. Integrate data collected from the field into the ABM

2. Analyze activity and mobility patterns derived from the Tick App.

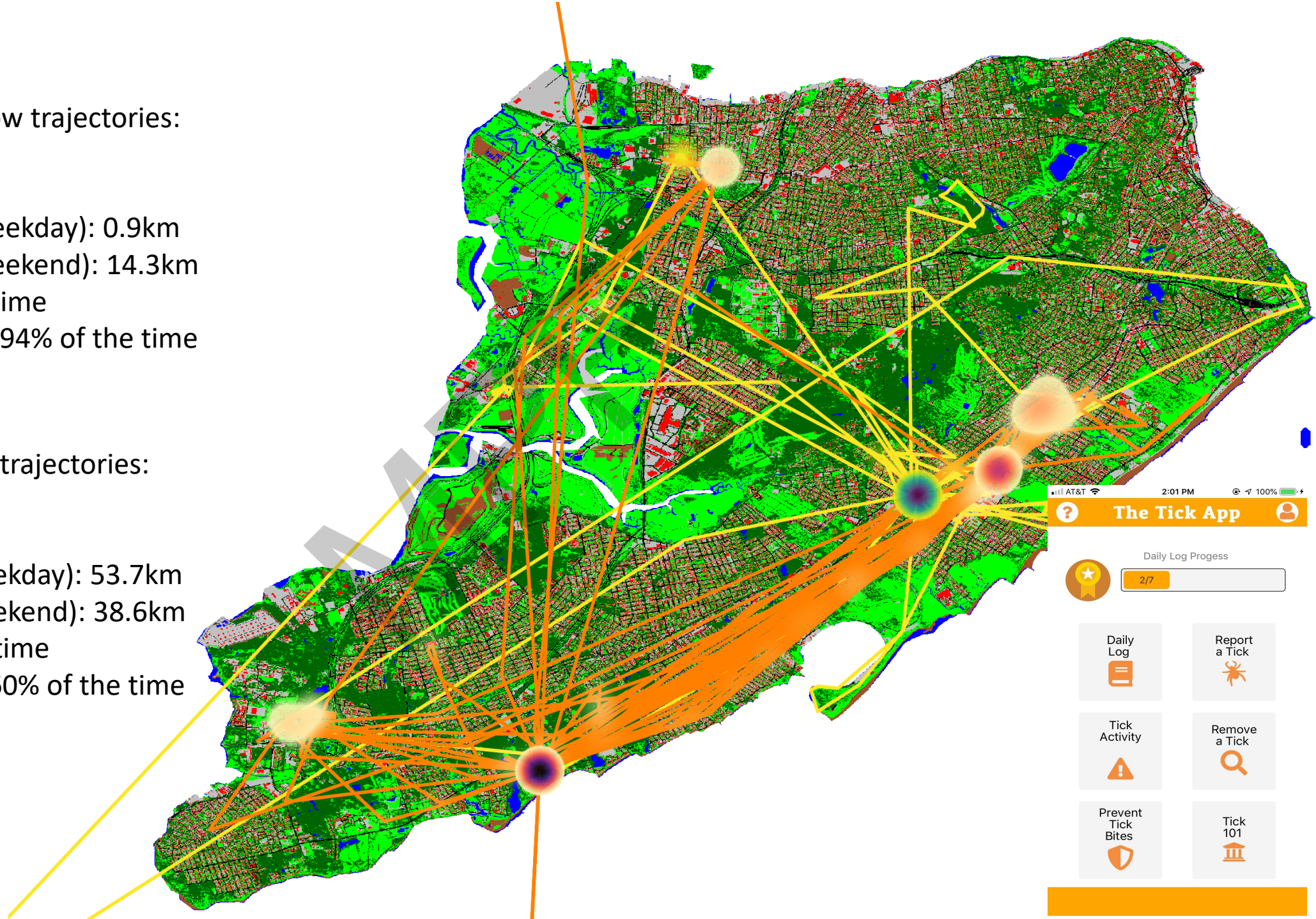
3. Assess feedback between the natural and human systems and simulate IPM interventions.

Household visits: Stratified, random cluster design



Person 1
Green-purple + yellow trajectories:
Female, 54 y.o.
Follow-up: 22 days
Median distance (weekday): 0.9km
Median distance (weekend): 14.3km
Forests = 5% of the time
Built environment = 94% of the time

Person 2
Pink-purple + orange trajectories:
Female, 61 y.o.
Follow-up: 35 days
Median distance (weekday): 53.7km
Median distance (weekend): 38.6km
Forests = 25% of the time
Built environment = 60% of the time



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Kacey Ernst (University of Arizona)
Mary Hayden (University of Colorado)
Holly Gaff (Old Dominion University)
Kevin Berry (University of Alaska)
Waheed Bajwa - New York City Department of Health & Mental Hygiene, Office of Vector Surveillance and Control
Sally Slavinski - New York City Department of Health and Mental Hygiene
Jennifer White - NY State Department of Health, State Epidemiologist
Anthony DeNicola - White Buffalo Inc.

Institutional support and funding:

NEVBD
NORTHEAST REGIONAL CENTER FOR EXCELLENCE IN VECTOR-BORNE DISEASES

NSF

Thank you

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