Modeling the spatiotemporal abundance of Aedes species and the risk of arboviral infection in Europe and the Americas

Agnese Zardini[1]

Francesco Menegale[1,2], Andrea Gobbi[3], Mattia Manica[1,4], Giorgio Guzzetta[1,4], Valeria d'Andrea[1], Valentina Marziano[1], Filippo Trentini[1,5], Fabrizio Montarsi[6], Beniamino Caputo[7], Angelo Solimini[7], Cecilia Marques-Toledo[8], André B.B. Wilke[9], Roberto Rosà[10,11], Giovanni Marini[4,10], Daniele Arnoldi[4,10], Ana Pastore y Piontti[12], Andrea Pugliese[2], Gioia Capelli[6], Alessandra della Torre[7], Mauro M Teixeira[8], John C. Beier[13], Annapaola Rizzoli[4,10], Alessandro Vespignani[12], Marco Ajelli[9], Stefano Merler[1,4], Piero Poletti[1,4]

[1] Center for Health Emergencies, Bruno Kessler Foundation, Trento, Italy
[2] Department of Mathematics, University of Trento, Trento, Italy
[3] Digital Industry Center, Bruno Kessler Foundation, Trento, Italy
[4] Epilab-JRU, FEM-FBK Joint Research Unit, Trento, Italy
[5] Dondena Centre for Research on Social Dynamics and Public Policy, Bocconi University, Milan, Italy
[6] Istituto Zooprofilattico Sperimentale delle Venezie, Legnaro, Padua, Italy
[7] Department of Public Health and Infectious Diseases, Sapienza university of Rome, Rome, Italy
[8] Department of Biochemistry and Immunology, Federal University of Minas Gerais, Belo Horizonte, Minas Gerais, Brazil
[9] Department of Epidemiology and Biostatistics, Indiana University School of Public Health, Bloomington, IN, USA
[10] Research and Innovation Centre, Fondazione Edmund Mach, Trento, Italy
[11] Center Agriculture Food Environment, University of Trento, Trento, Italy
[12] Laboratory for the Modeling of Biological and Socio-technical Systems, Northeastern University, Boston, MA, USA
[13] Department of Public Health Sciences, Miller School of Medicine, University of Miami, Miami, FL, USA

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Introduction

MOST OF APPROACHES

1. Focus on local epidemiological or entomological data
2. Estimate the mosquito habitat suitability, which do not provide quantitative estimates of transmission risks/seasonality

ASSUMPTIONS:

1. the local climate suitability determines the mosquito relative density
2. increase in the mosquito abundance as a consequence of persisting favorable temperature conditions over a certain period

1 Logistic regression to estimate the climate suitability for the mosquito presence

2 Mosquito captures as a function of the mean temperature over a time window

3 Absolute abundance of female adults per ha using the flight range and the capture rate

4 Transmission potential of CHIKV, DENV, and Zika

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Zardini et al. Lancet Planetary Health 2024

Climate suitability

Logistic regression model

- **Model:**

$$\sigma_i = \frac{1}{1 + e^{-\left(b_0 + \sum_{j=1}^{n} b_j Y_{i,j}\right)}}$$

- **Data:**

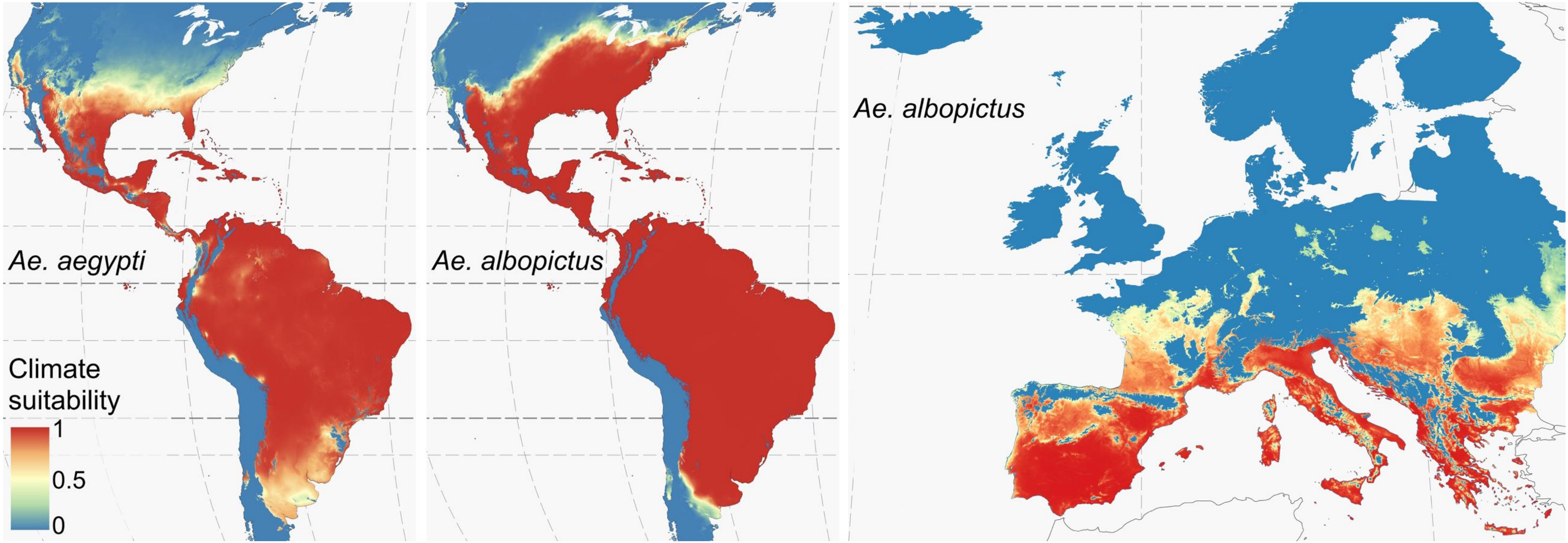
Presence-absence records for 1,892 US counties (Monaghan et al. 2019) and 4,372 European locations (ECDC)

Parameter	Description	Ae. aegypti		Ae. albopictus (Americas)		Ae. albopictus (Europe)	
		Estimate	p-value	Estimate	p-value	Estimate	p-value
b_0	Intercept	-0.3313192	0.8735	-10.204877	0.003	-17.45971	<0.001
b_1	Coeff. annual mean temperature	0.6406277	<0.001	0.876233	<0.001	0.2383233	<0.001
b_2	Coeff. maximum temperature of the warmest month	-0.2473132	0.001	-0.213569	0.126	0.5374626	<0.001
b_3	Coeff. annual precipitation	-0.0018763	<0.001	0.001792	0.040	0.0008732	<0.001
b_4	Coeff. precipitation in the warmest quarter	-	-	0.028052	<0.001	0.0048206	<0.001

Environmental mask suitability

Annual mean precipitation at least of 200 mm + Mosquitoes survive long enough to complete the gonotrophic cycle

Climate suitability



Seasonal population dynamics

Temperature modulation function

$$C(d) = \frac{L}{1 + e^{-k(\tilde{T}(d,w) - T_0)}}$$

where

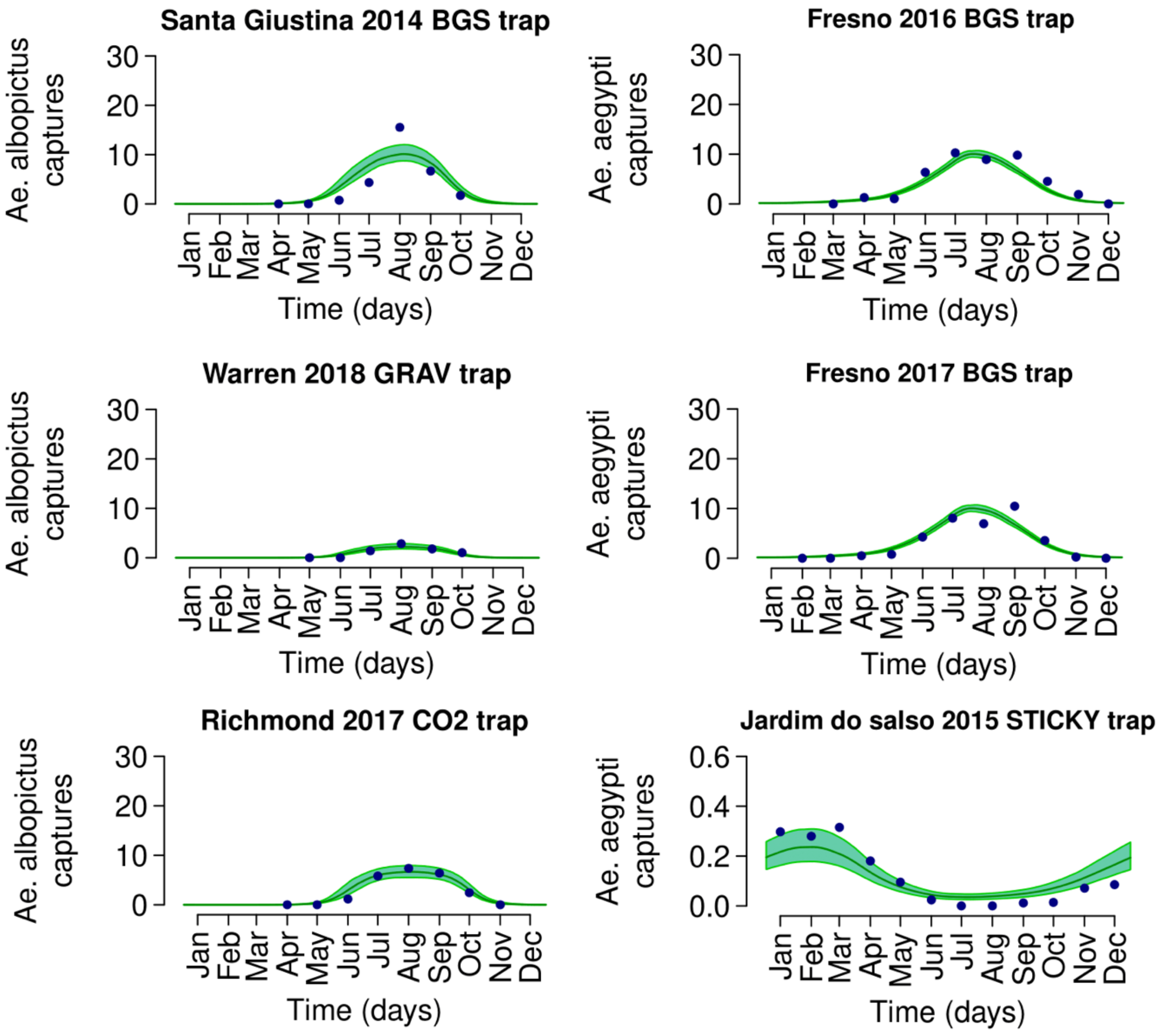
$$\tilde{T}(d,w) = \frac{1}{w} \sum_{j=d-w+1}^{d} T(j)$$

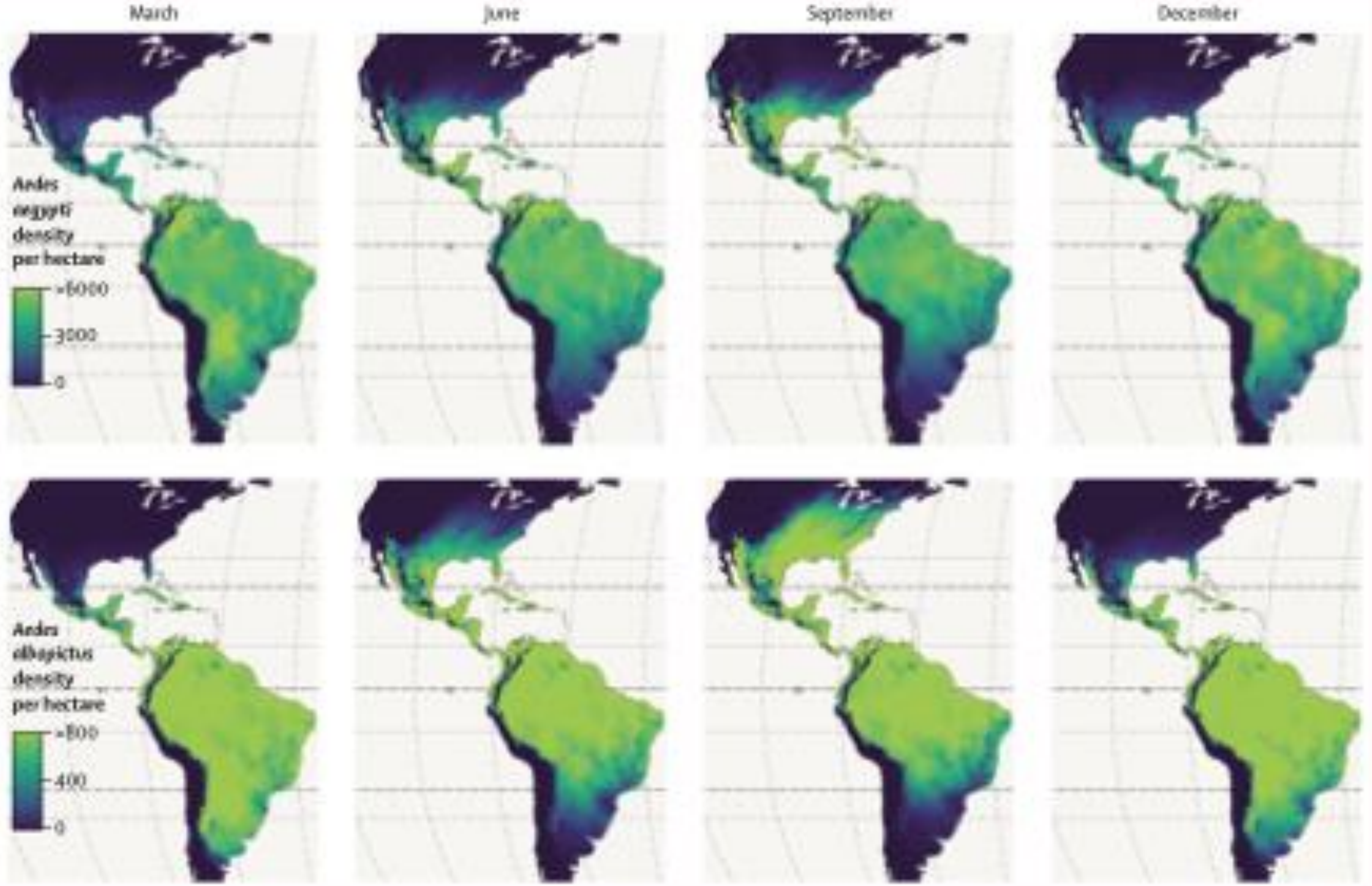
MCMC calibration based on capture data of female adults collected in 115 locations of Italy, US, Brazil

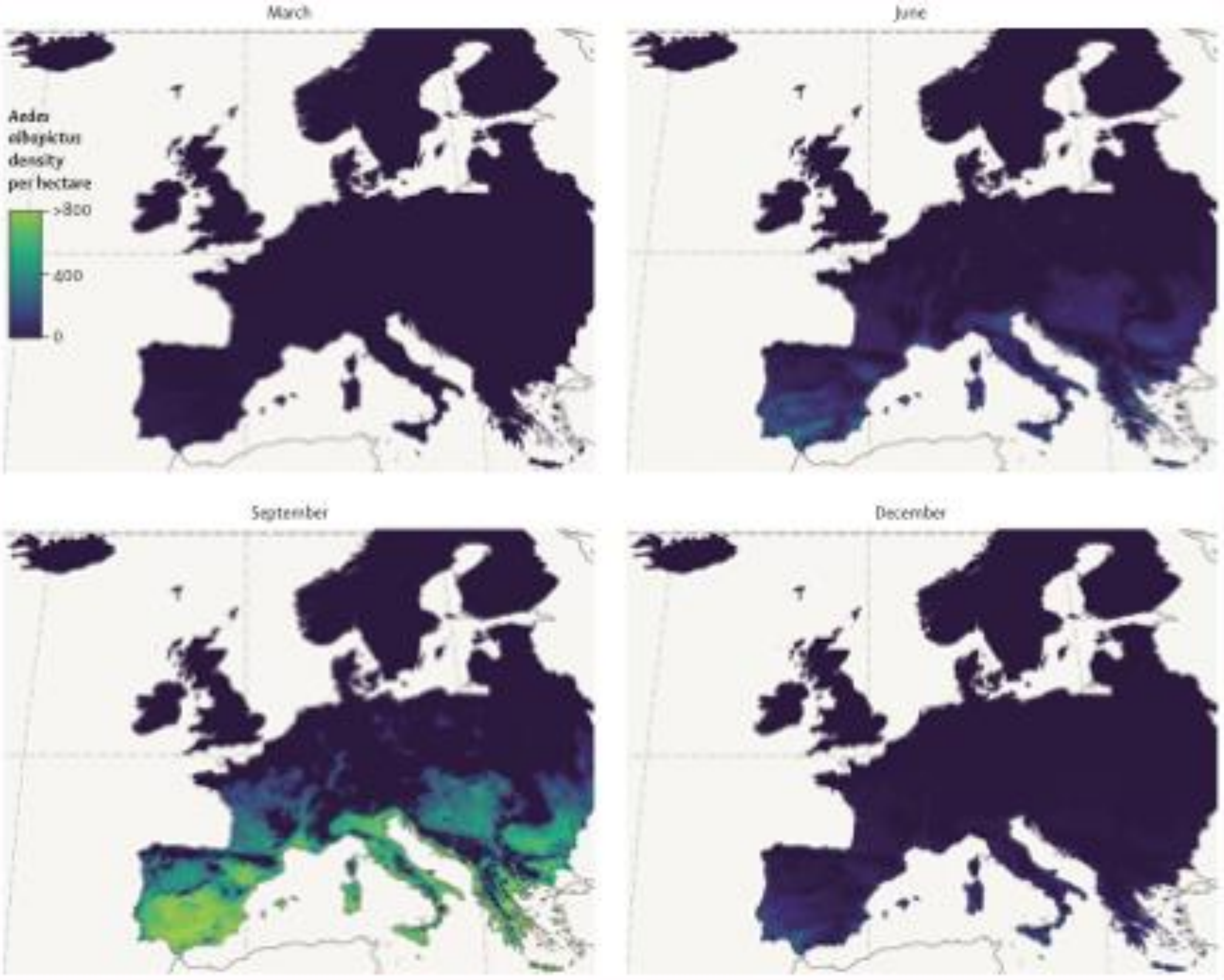
- $k,\ w,\ T_0$: site and trap independent
- $L = L_{i,tr} = \ \alpha_{tr}\ \sigma_i$
    - α_{tr} : trap dependent
    - σ_i : estimated climate suitability

Absolute abundance: flight range and trap specific capture rate

ILLUSTRATIVE FITS




March
June
September
December
Aedes aegypti density per hectare
>6000
3000
0
Aedes albopictus density per hectare
>800
400
0


March
June
September
December
Aedes albopictus density per hectare
>800
400
0

Transmission potential
reproduction number

Average number of mosquitoes infected by a single infectious human host in a population of fully susceptible mosquitoes and hosts:

$$R_{HV} = \chi_V \, \beta \, \phi \frac{1}{\gamma} \frac{N_V}{N_H} \frac{\omega_V}{\omega_V + \mu_V}$$

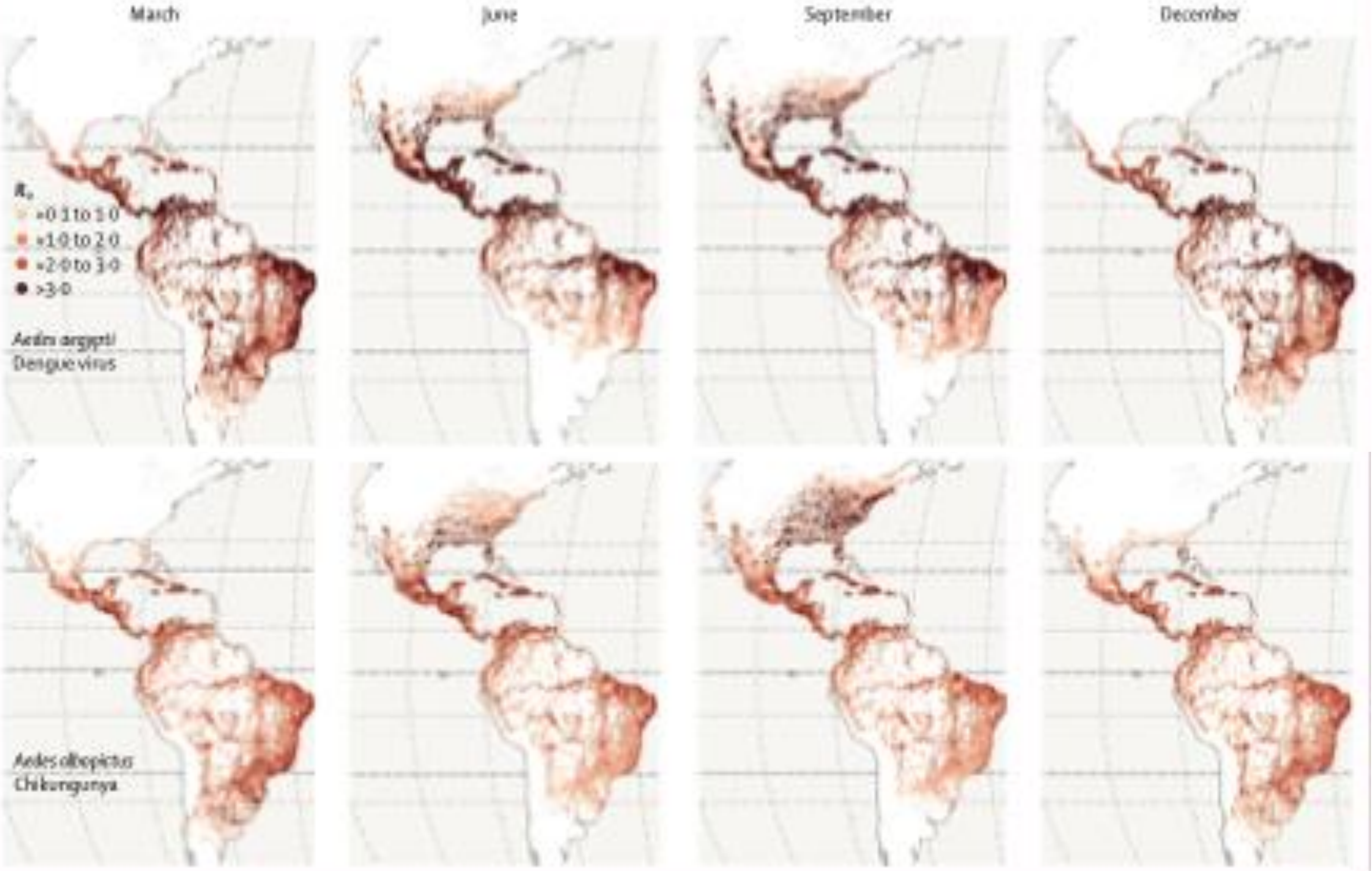
Average number of hosts infected by a single infectious mosquito introduced in a population of fully susceptible mosquitoes and hosts:

$$R_{VH} = \beta \, \phi \frac{\chi_H}{\mu_V}$$

Reproduction number:

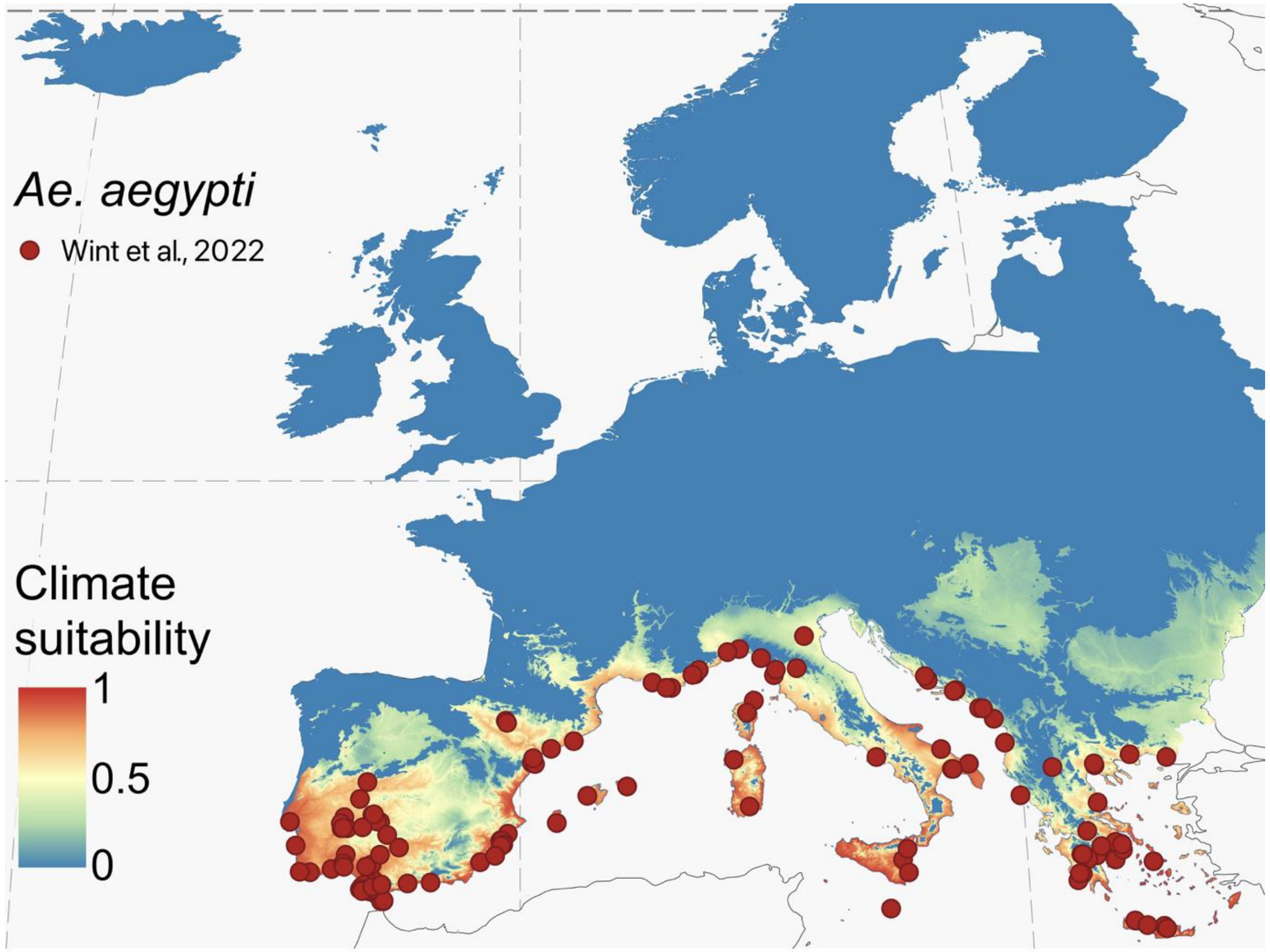
$$R_0 = R_{HV} \, R_{VH}$$

Diekmann O et al. 2009 (J R Soc Interface)
Lloyd AL et al. 2007 (J R Soc Interface)

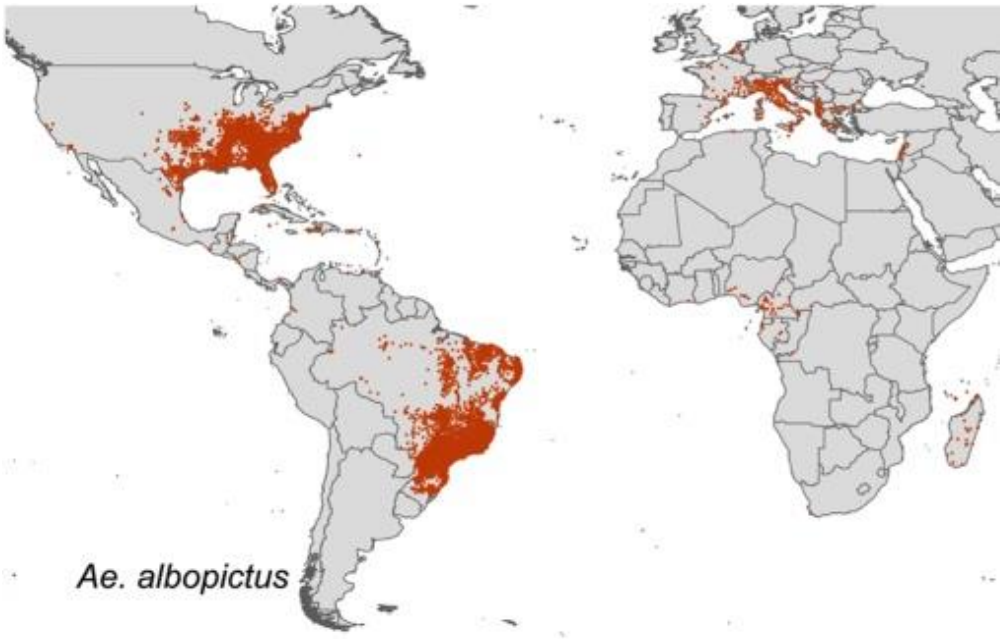

March
June
September
December
R_0
>0·1 to 1·0
>1·0 to 2·0
>2·0 to 3·0
>3·0
Aedes aegypti
Dengue virus
Aedes albopictus
Chikungunya

Model vs entomological evidence

Historical records for Ae. aegypti [1900-1955]

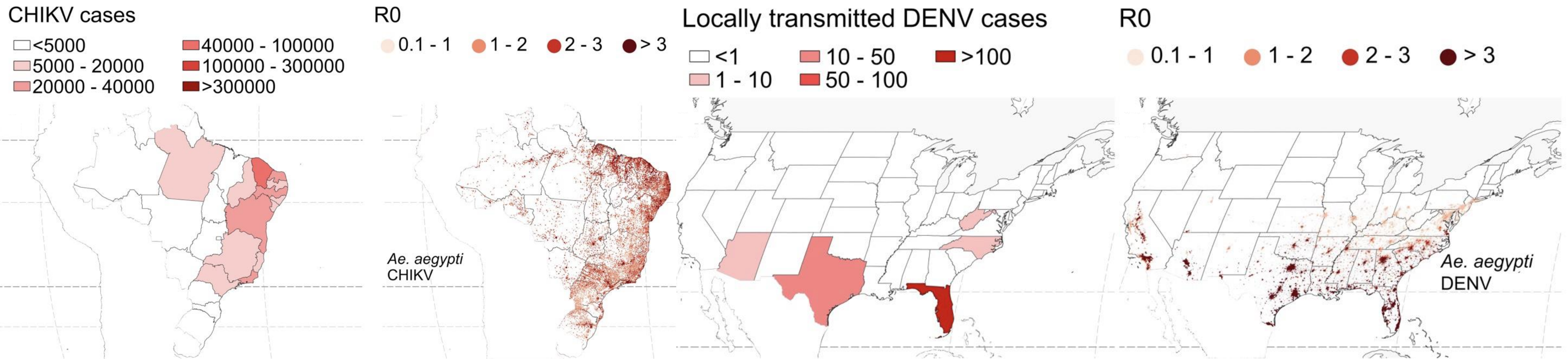


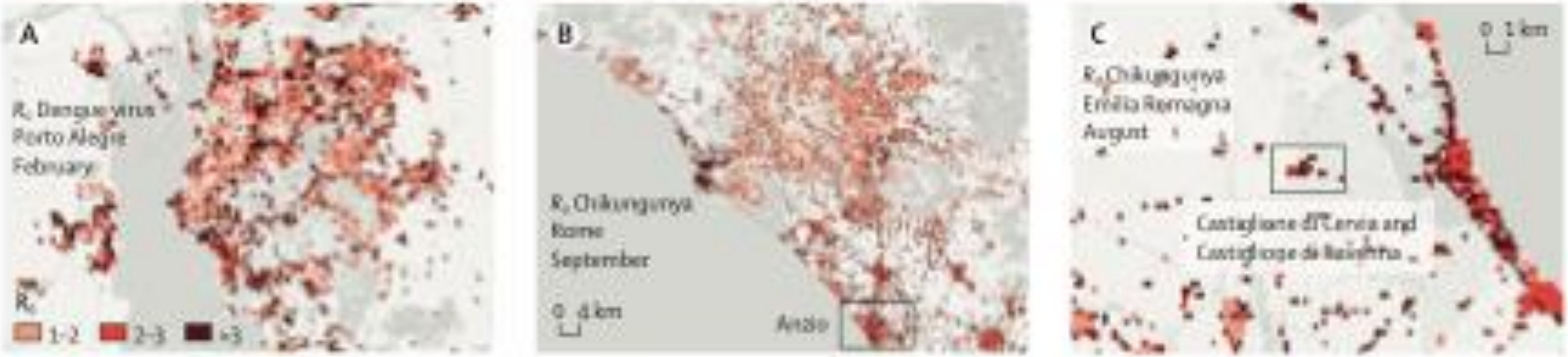
Occurrence records in Europe and the Americas [Kraemer et al. 2015]



	True Positive
Ae. albopictus	99%
Ae. aegypti	98%

Model vs epidemiological evidence

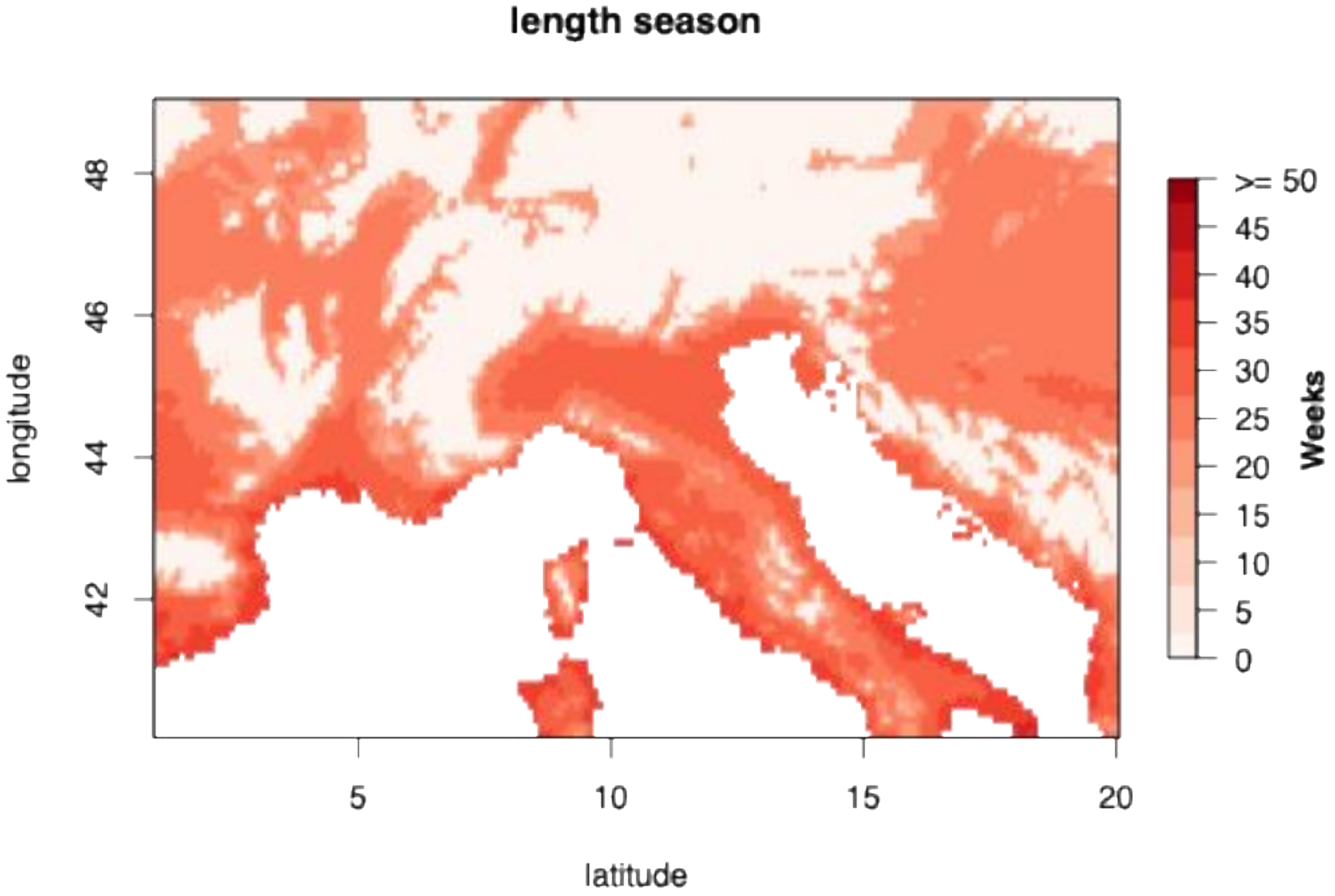




Modeling exercise

Standardized the abundance of Ae. albopictus with respect to the maximum value predicted in Bologna

Number of consecutive days associated with a standardized mosquito abundance > 0.05



Conclusions

- Innovative method to estimate the overall abundance of mosquitoes over time, based on freely available eco-climatic data
- Provide estimates in areas where entomological data are scarce or unavailable
- High temporal and spatial resolution

LIMITATIONS:

- Limited entomological data available for South America and Europe
- Climate suitability of the Americas calibrated against data aggregated at county level
- Dependence on estimates of capture rate
- Not account for progressive expansion and competition of mosquito species, and control measures
- Human mobility, level of immunity, case importations

Thank you for your attention

contact: zardini@fbk.eu

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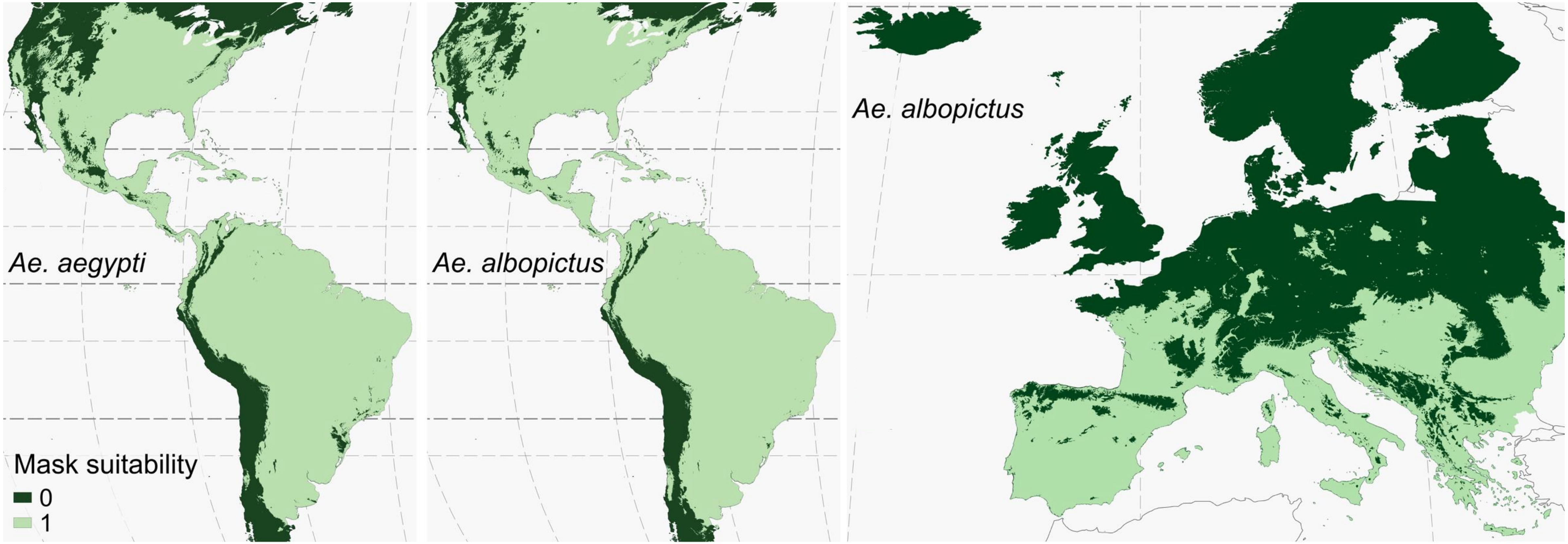
Francesco Menegale, Piero Poletti, Stefano Merler

Climate suitability

Environmental mask suitability

Annual mean precipitation at least of 200 mm **+** Mosquitoes survive long enough to complete the gonotrophic cycle



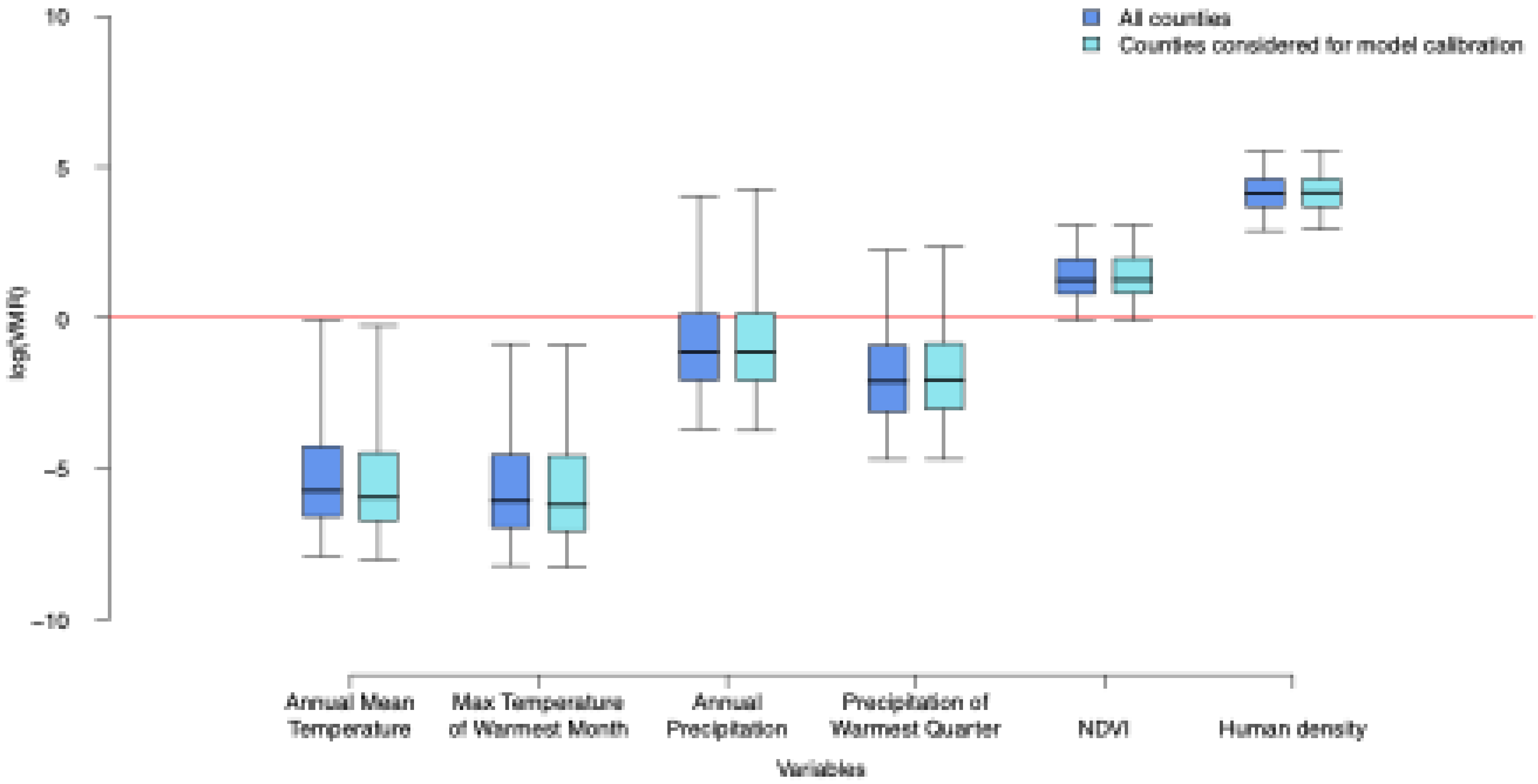


Figure S1. Distributions of the variance to mean ratio (VMR) across patches (1 km x 1 km) of different US counties for annual mean temperature, maximum temperature of warmest month, annual precipitation, precipitation of the warmest quarter, Normalized Difference Vegetation Index (NDVI), and human density. Distributions are displayed considering either all US counties or those counties considered for model calibration.[6] Black lines: median; boxes: interquartile range; whiskers: 95% CI.

Climate suitability

Logistic regression model

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- **Data:**

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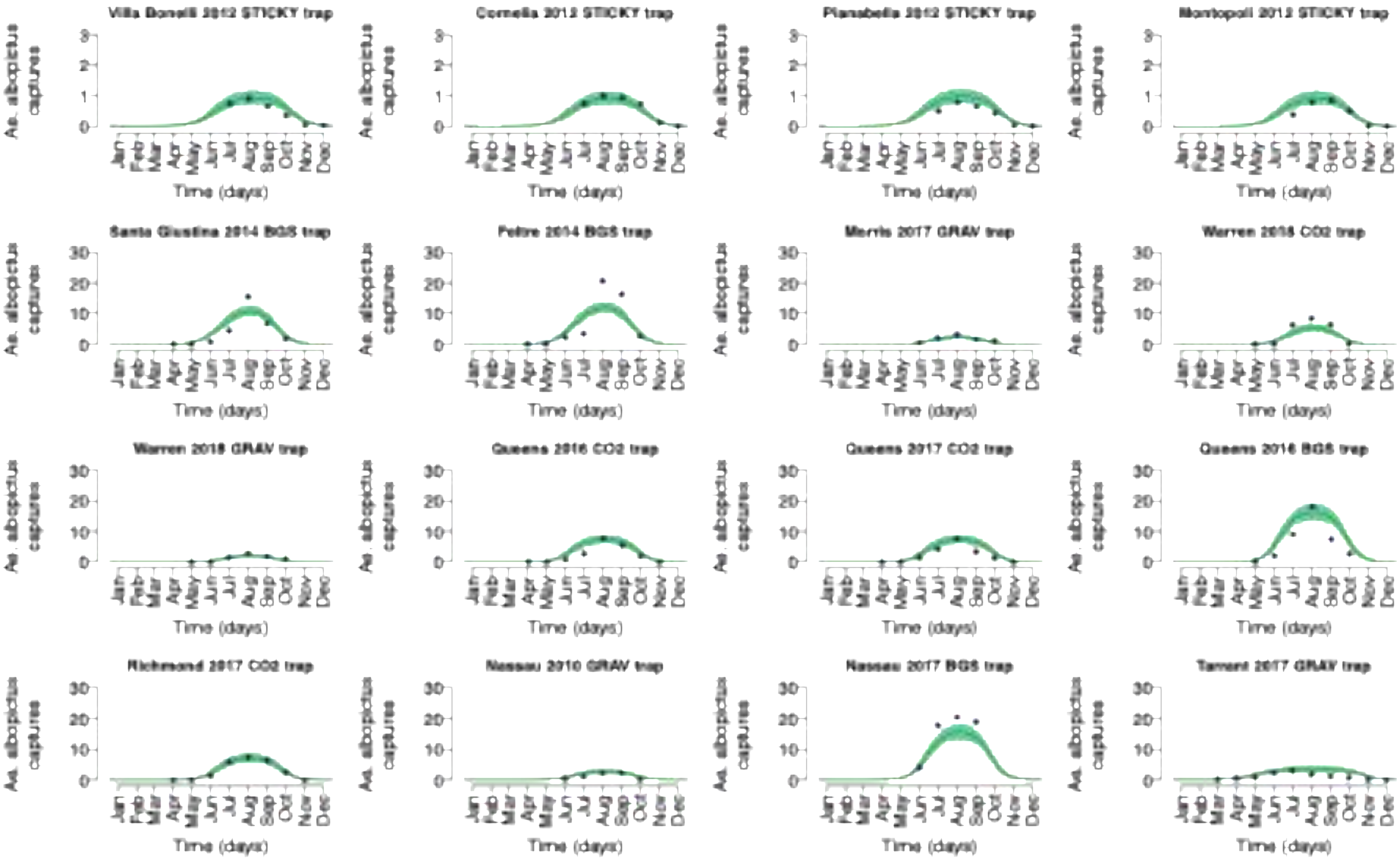
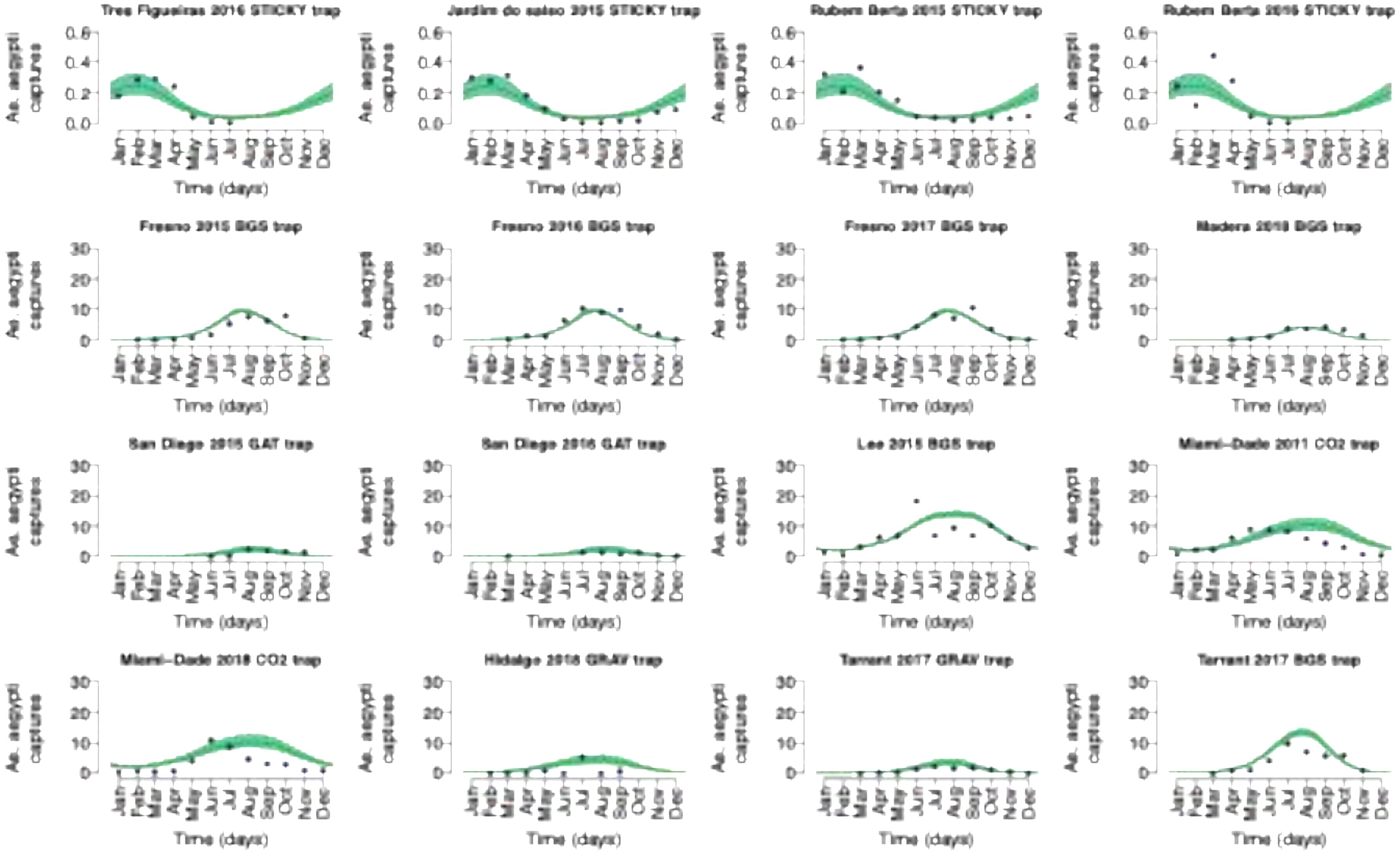
		Estimate	Std. error	p-value	Estimate	Std. error	p-value	Estimate	Std. error	p-value
b_0	Intercept	-0.3313192	2.0802373	0.8735	-10.204877	3.418939	0.003	-17.45971	0.8290	<0.001
b_1	Coeff. annual mean temperature	0.6406277	0.0580453	<0.001	0.876233	0.130634	<0.001	0.2383233	0.03409	<0.001
b_2	Coeff. maximum temperature of the warmest month	-0.2473132	0.0774989	0.001	-0.213569	0.139544	0.126	0.5374626	0.03245	<0.001
b_3	Coeff. annual precipitation	-0.0018763	0.0003827	<0.001	0.001792	0.000873	0.040	0.0008732	0.0002444	<0.001
b_4	Coeff. precipitation in the warmest quarter	-	-	-	0.028052	0.002873	<0.001	0.0048206	0.0008760	<0.001

	Reference	Threshold 0.5		Threshold 0.3		Threshold 0.7	
		True Positive	False Positive	True Positive	False Positive	True Positive	False Positive
Ae. albopictus (US)	Monaghan et al. 2019	99%	13%	99%	22%	98%	8%
Ae. albopictus (Europe)	ECDC	99%	38%	99%	46%	94%	29%
Ae. aegypti	Monaghan et al. 2019	67%	7%	76%	13%	49%	4%

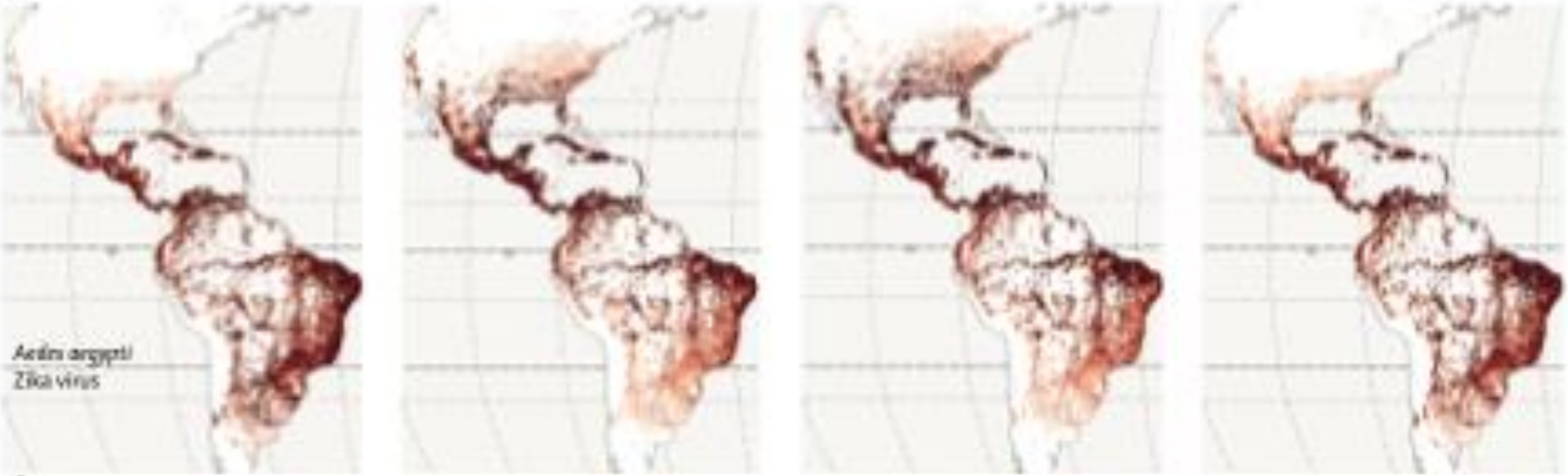
127 time series



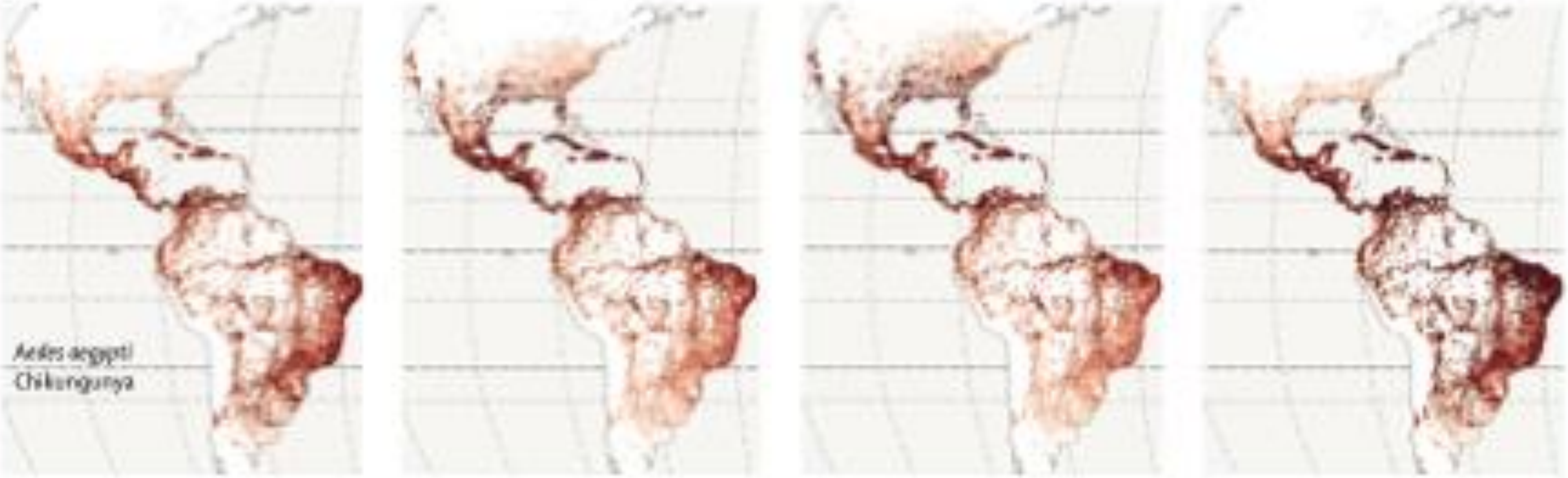
173 time series

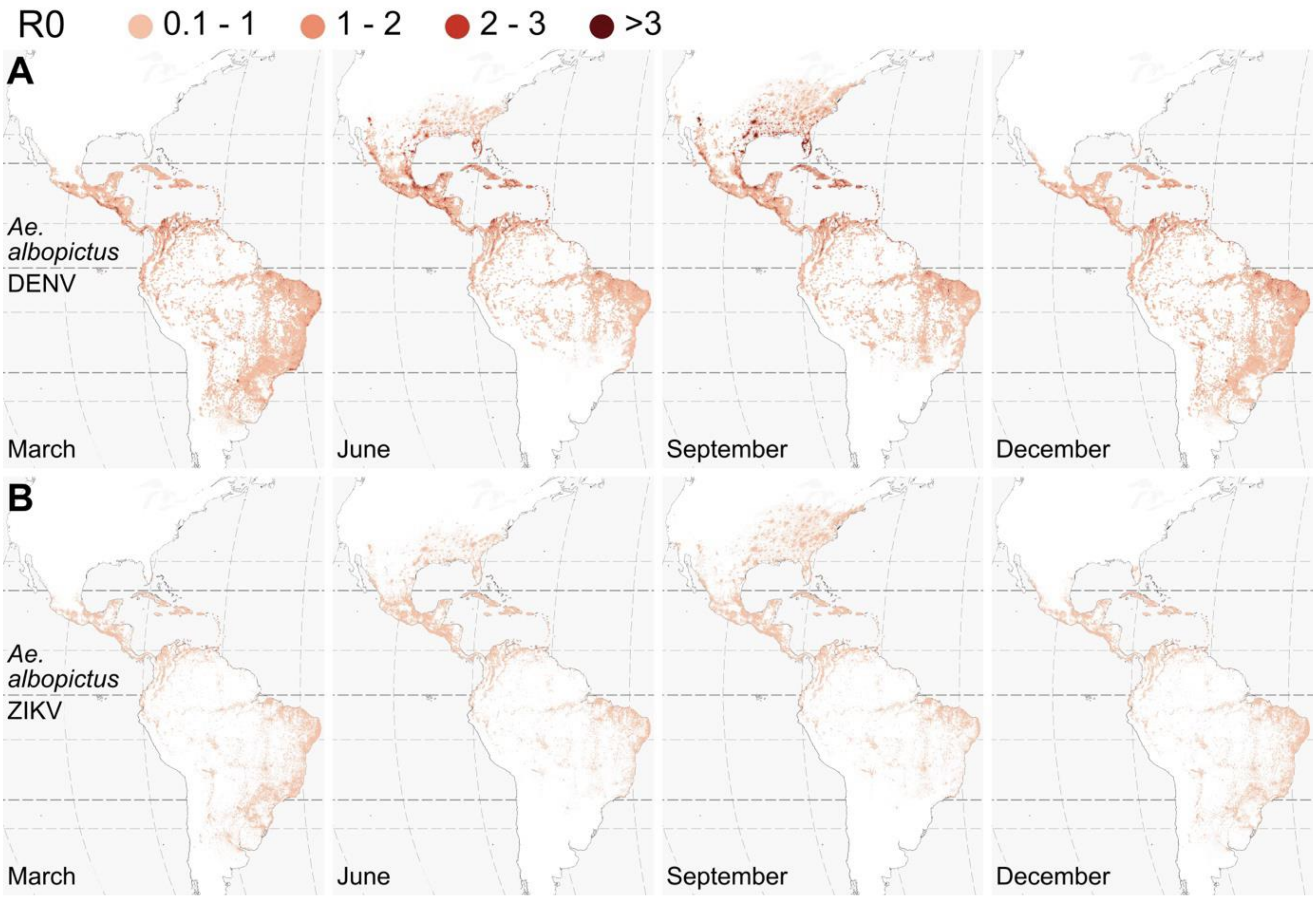


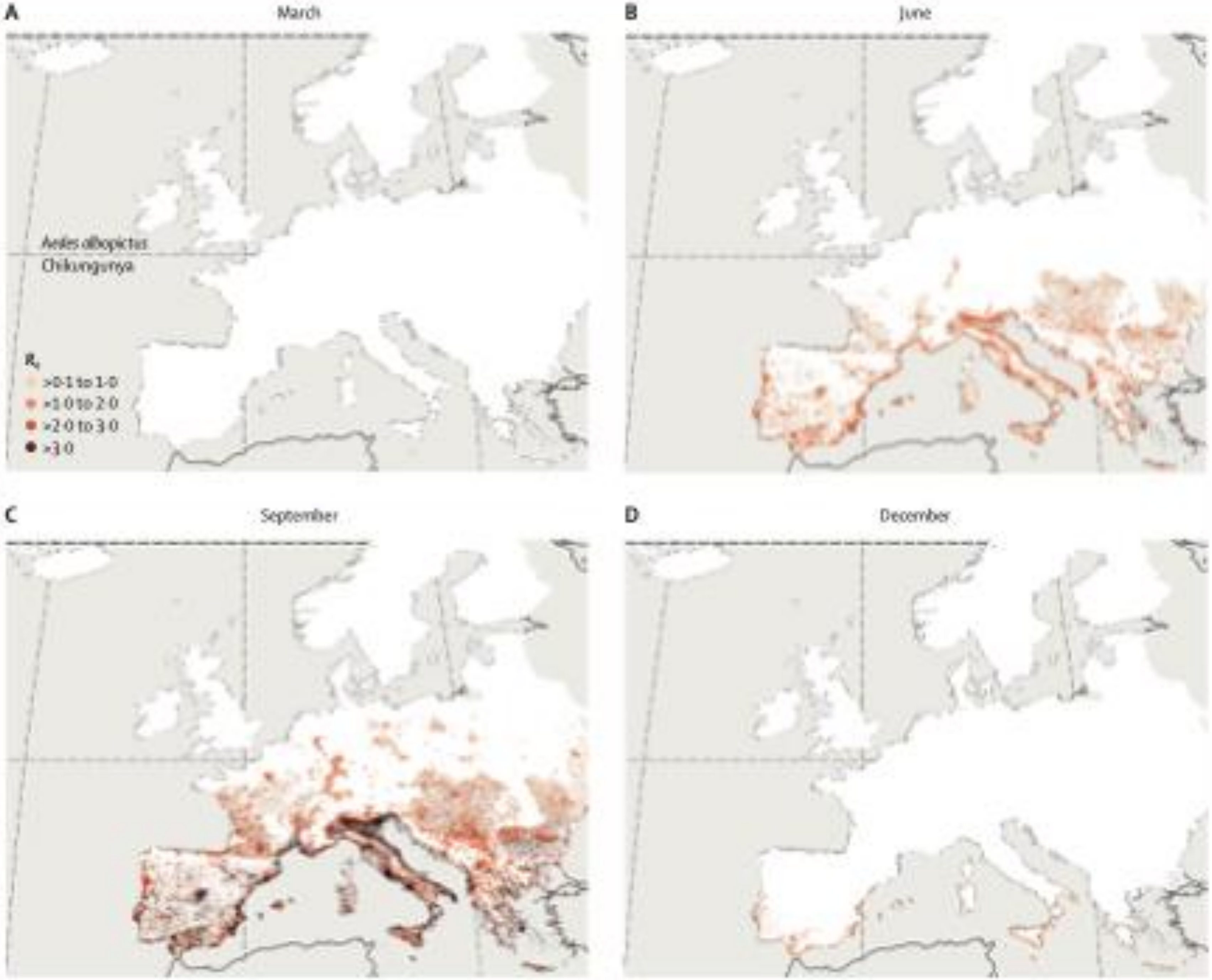
B

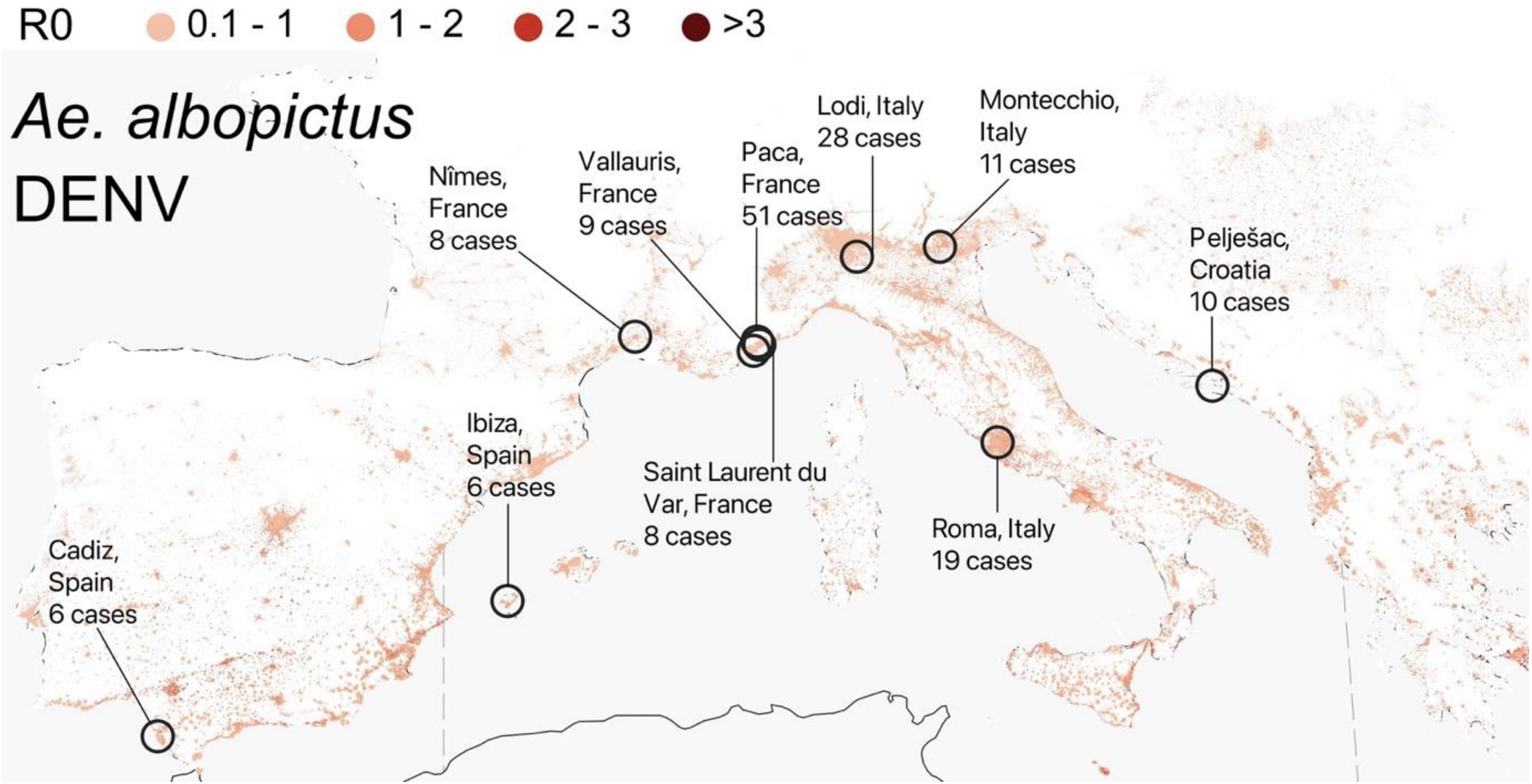


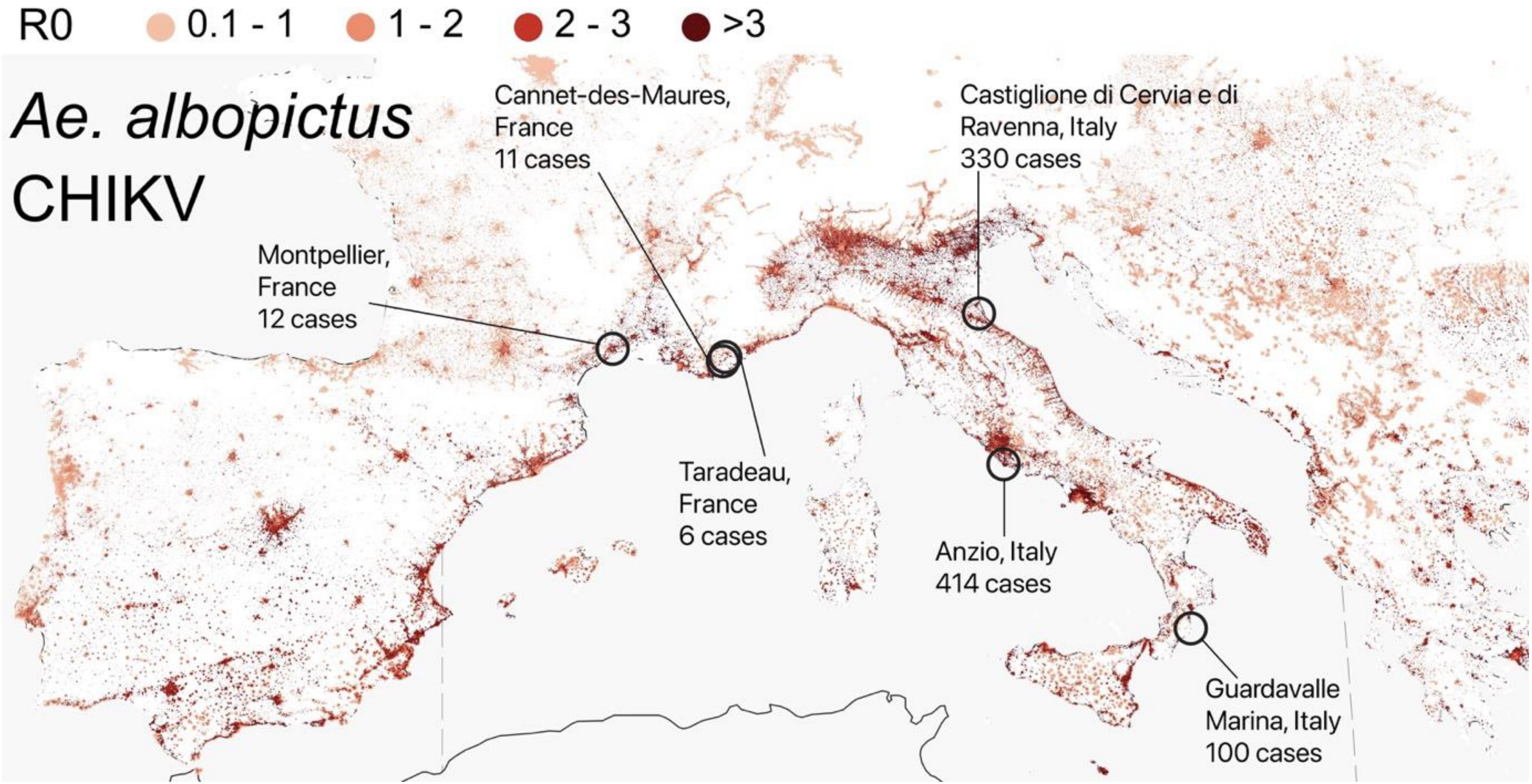
C




R0
0.1 - 1
1 - 2
2 - 3
>3
A
Ae. albopictus
DENV
March
June
September
December
B
Ae. albopictus
ZIKV
March
June
September
December


A
March
Aedes albopictus
Chikungunya
R_0
>0·1 to 1·0
>1·0 to 2·0
>2·0 to 3·0
>3·0
B
June
C
September
D
December


R0
0.1 - 1
1 - 2
2 - 3
>3
Ae. albopictus
DENV
Nîmes, France 8 cases
Vallauris, France 9 cases
Paca, France 51 cases
Lodi, Italy 28 cases
Montecchio, Italy 11 cases
Pelješac, Croatia 10 cases
Ibiza, Spain 6 cases
Saint Laurent du Var, France 8 cases
Roma, Italy 19 cases
Cadiz, Spain 6 cases


R0
0.1 - 1
1 - 2
2 - 3
>3
Ae. albopictus
CHIKV
Cannet-des-Maures, France
11 cases
Castiglione di Cervia e di Ravenna, Italy
330 cases
Montpellier, France
12 cases
Taradeau, France
6 cases
Anzio, Italy
414 cases
Guardavalle Marina, Italy
100 cases

transmission potential

duration epidemic risk

Number of consecutive days associated with an $R_0 > 1$