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Supplemental Material

Lyme Disease Risks in Europe under Multiple Uncertain Drivers of Change

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Supplemental figures

Figure S1 Deer population as a linear regressive function of habitat suitability in different regions. Deer (habitat) suitability indicates the capability of the cell to support the full carrying capacity, and was estimated as a multiplication of species presence, climate suitability and extent of suitable habitats. Individual data points refer to cell-level projections of deer density at the baseline and the regression lines indicate their linear relationship to deer suitability.

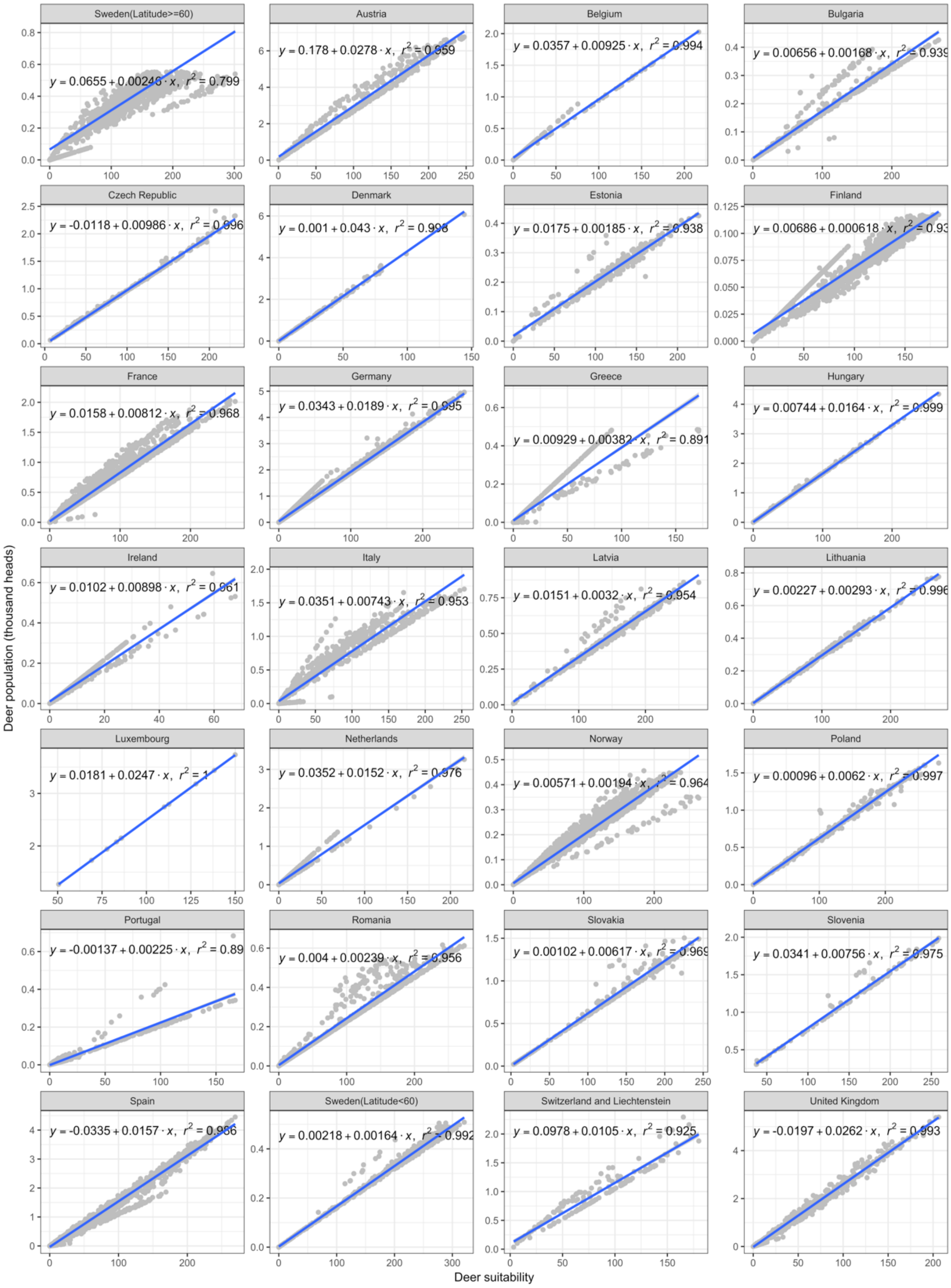


Figure S2 Projected monthly variation of the density of infected nymphs for (A) baseline and by the 2050s under the SSP1 x RCP2.6 (B) using the MPI-ESM-LR/REMO coupled climate model (B) and SSP4 x RCP4.5 using the HadGEM2-ES/RCA4 coupled climate model (C).

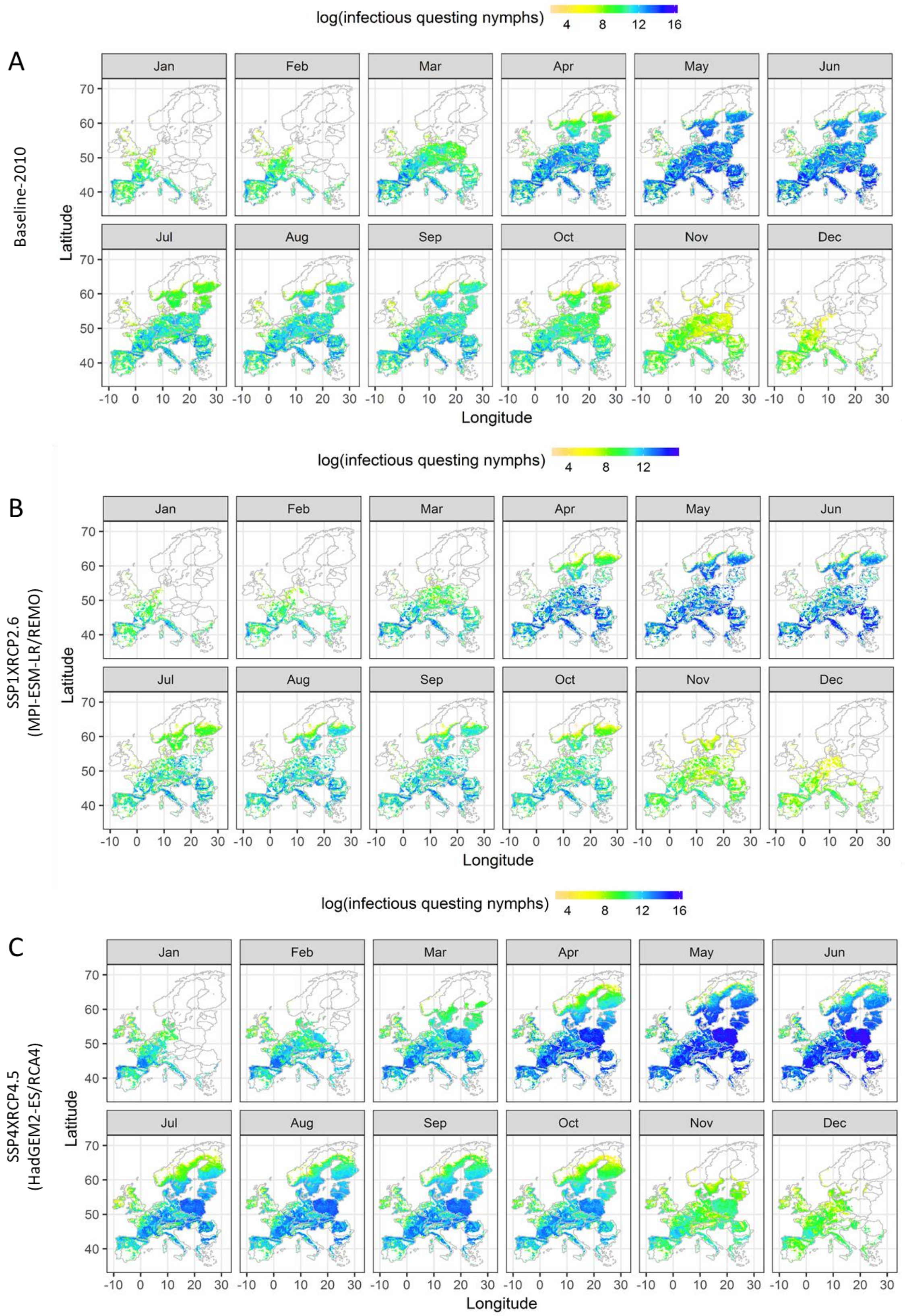


Figure S3 (A) Projected rates of active questing ticks under different temperatures in different European countries (Box plots = distributions of cell-level projections at different temperatures; blue line = mean value). (B) Projected monthly rates of active questing ticks in different European countries (Green line = larvae; Blue line = nymphs; Black line = female adults). (C) Projected monthly density of active questing ticks in different European countries (Green line = mean density of larvae/100; Blue line = mean density of nymphs/10; Black line = mean density of female adults). Country abbreviations are explained in Table S1.

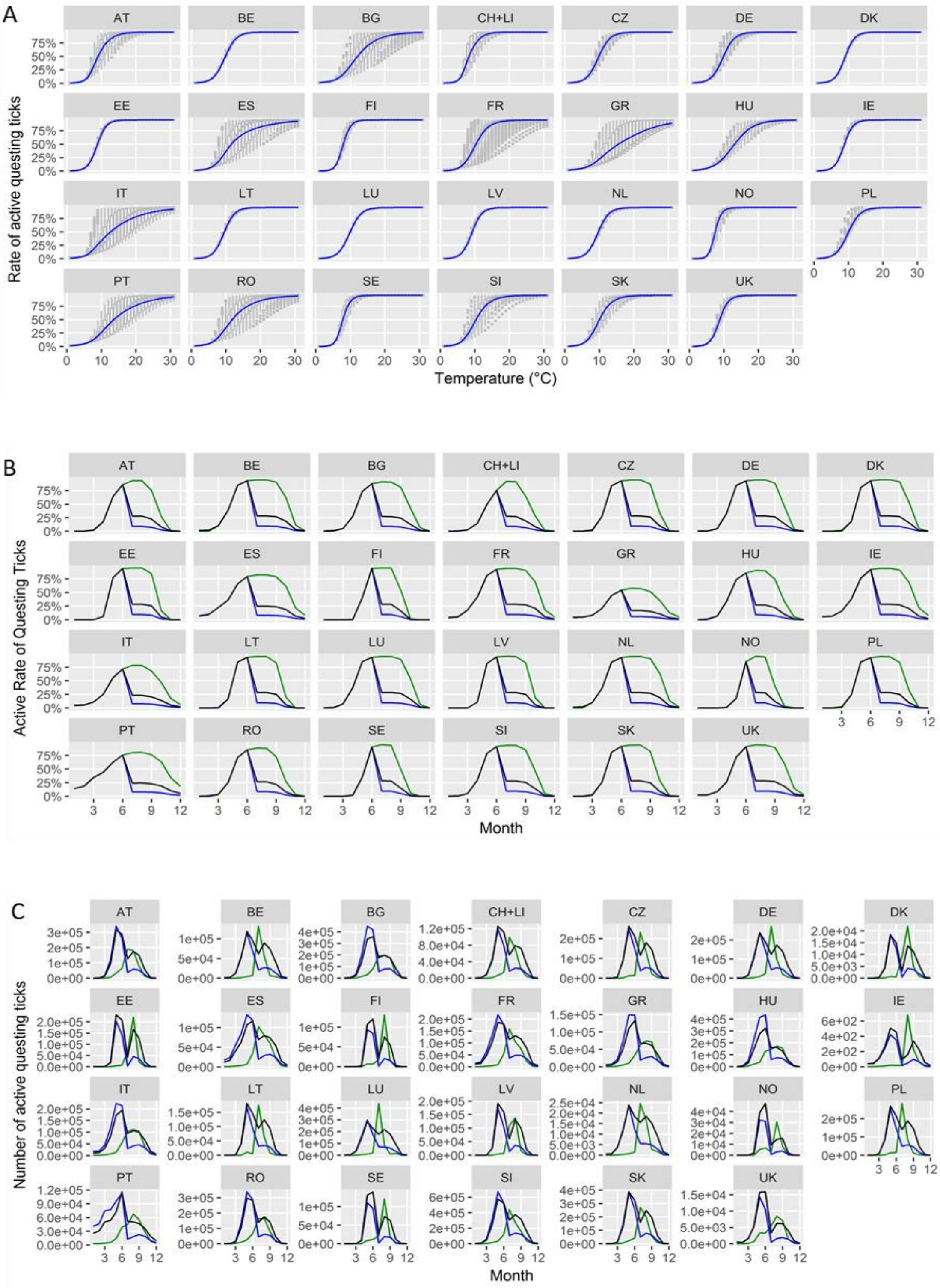


Figure S4 Monthly average daily mean temperature for (A) baseline based on the WATCH-WFDEI data, and the 2050s under RCP2.6 using the MPI-ESM-LR/REMO coupled climate model (B) and RCP4.5 using the HadGEM2-ES/RCA4 coupled climate model (C).

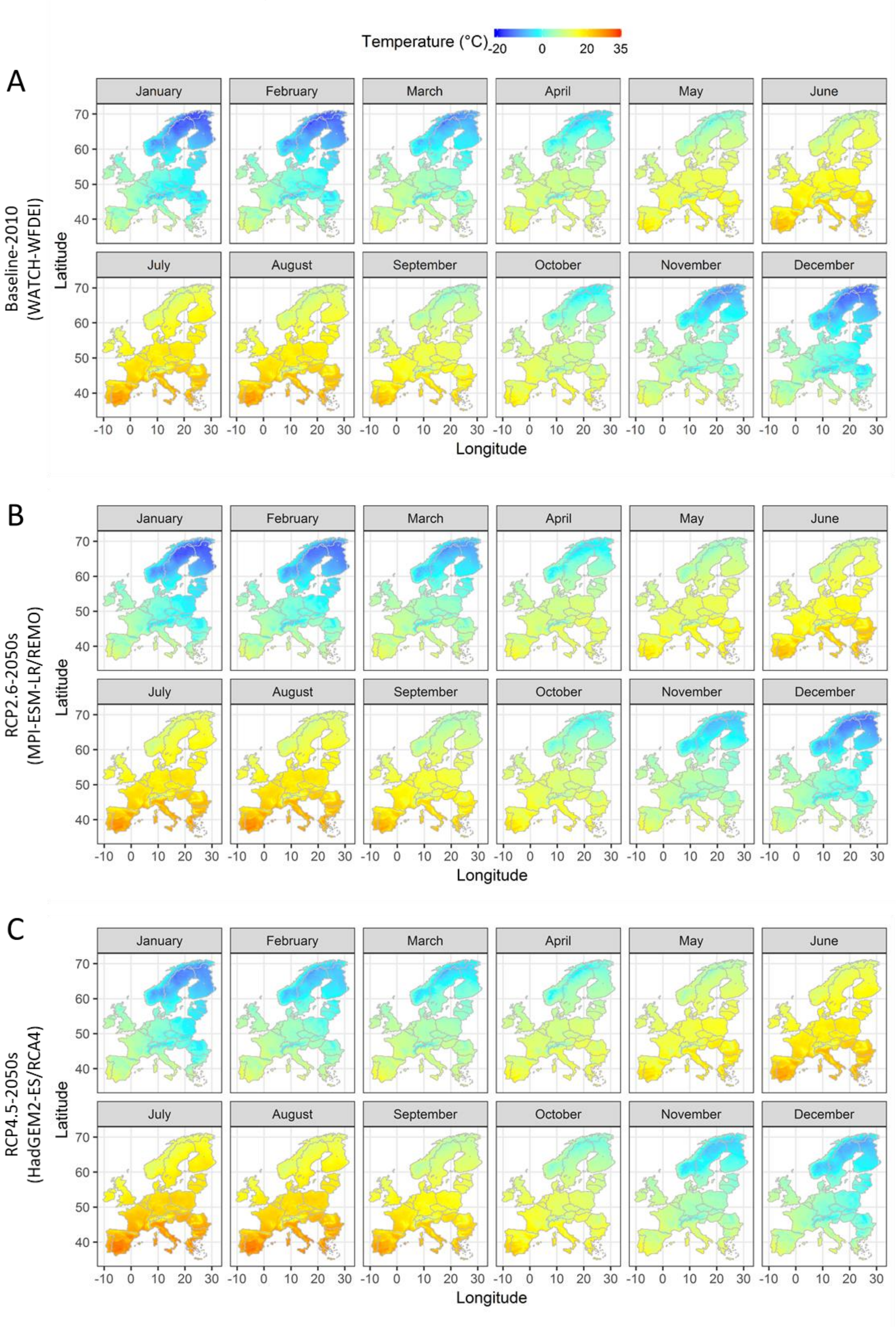


Figure S5 Patterns of habitats for (A) baseline and by the 2050s under the SSP1xRCP2.6 (B) and SSP4xRCP4.5 (C) scenarios.

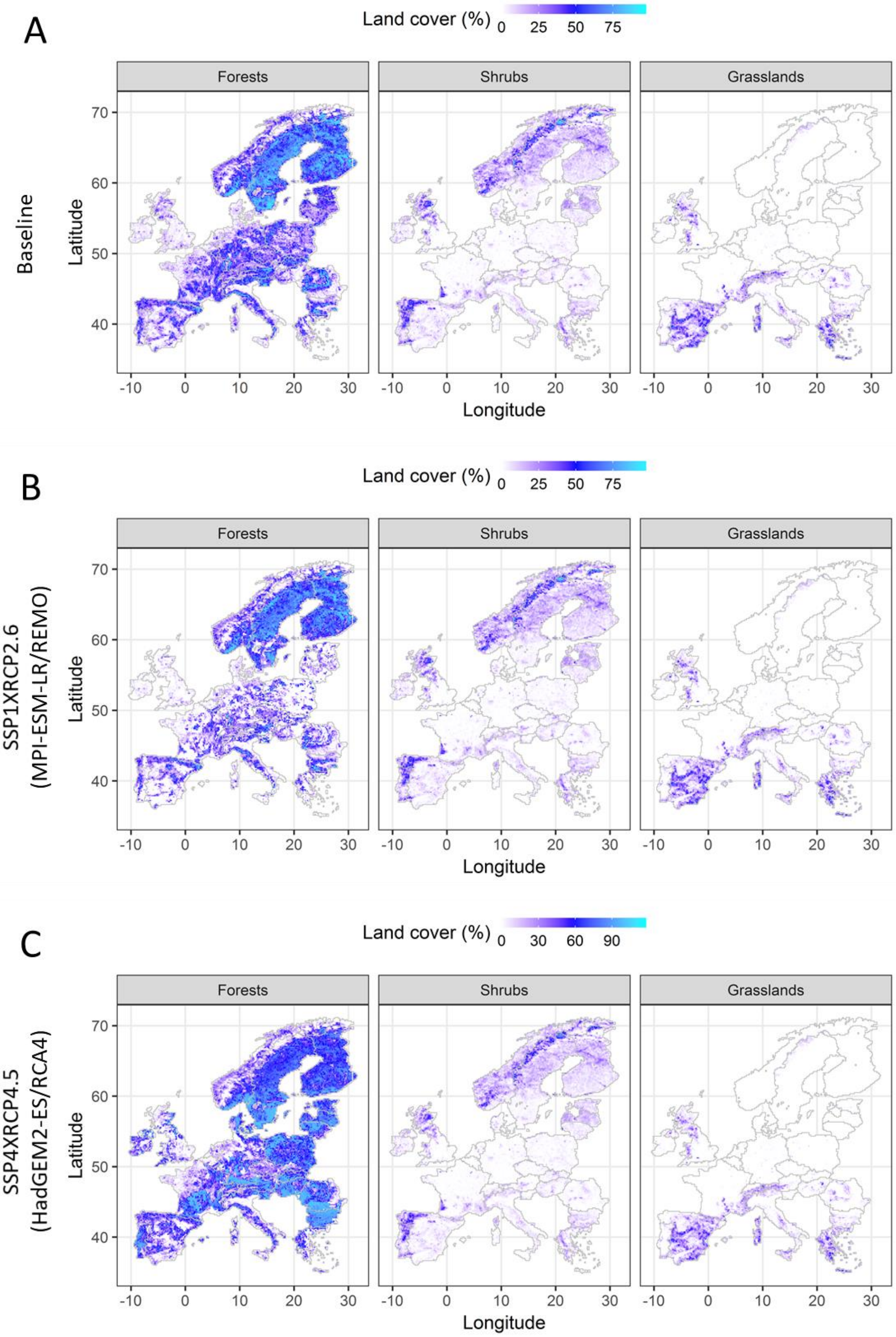


Figure S6 Density and distribution of deer (represent reproduction hosts) for (A) baseline and by the 2050s under the SSP1xRCP2.6 (B) and SSP4xRCP4.5 (C) scenarios. For species distribution: grey area refers to baseline observed presence (source: IUCN); pink area refers to the predicted presence.

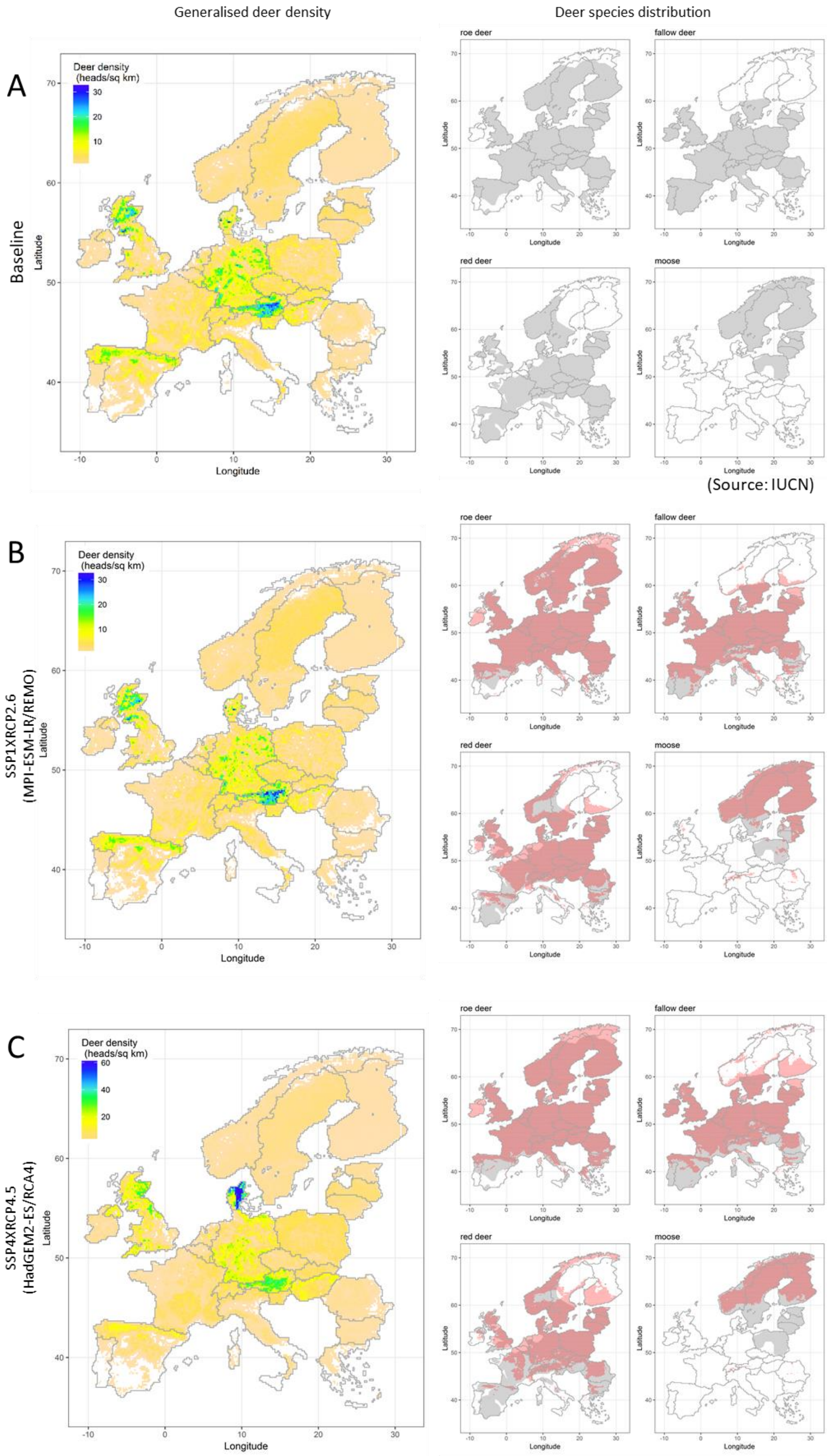
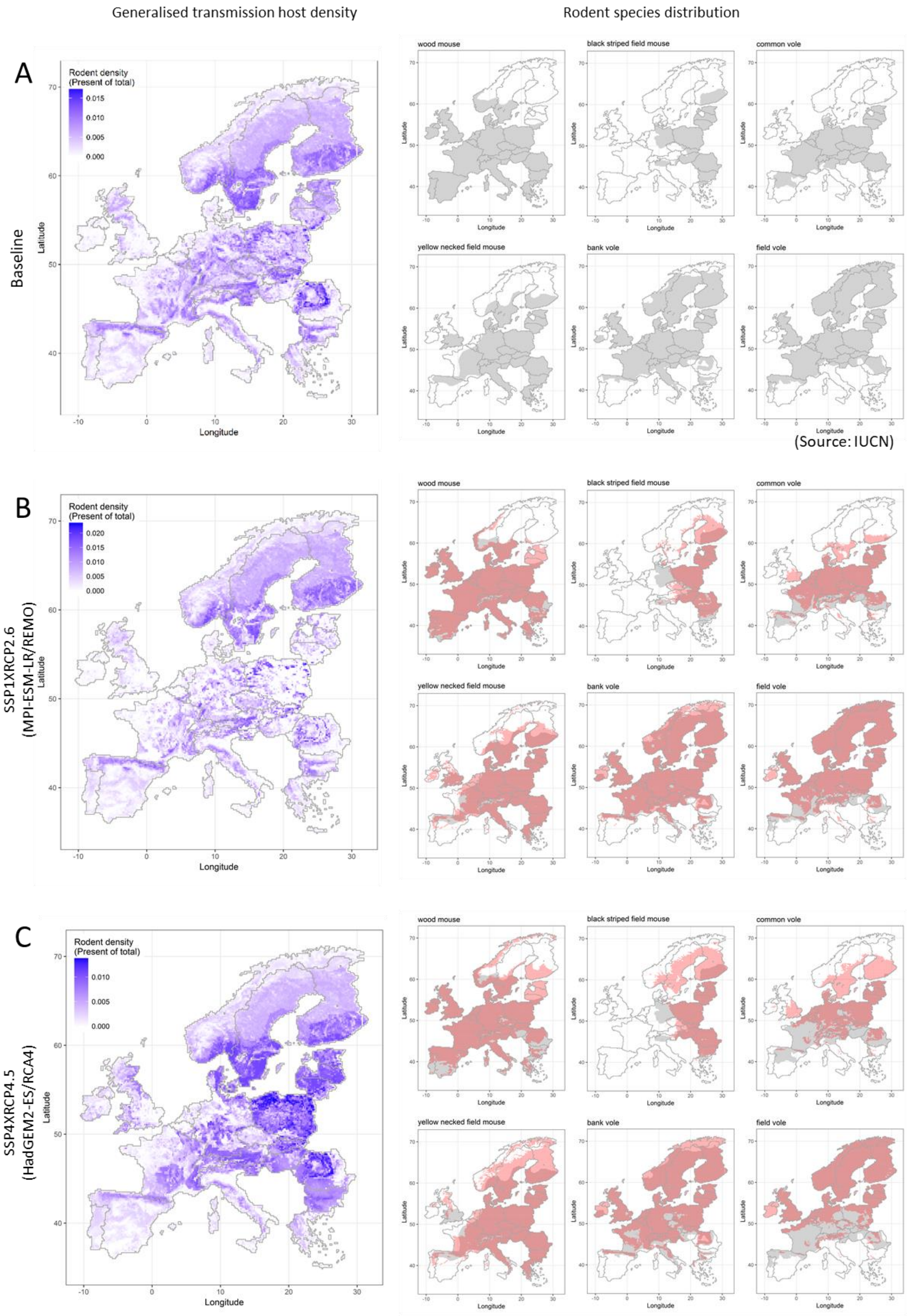


Figure S7 Projected density and distribution of rodents (represent tranmission hosts) for (A) baseline and by the 2050s under the SSP1xRCP2.6 (B) and SSP4xRCP4.5 (C) scenarios. For species distribution: grey area refers to baseline observed presence (source: IUCN); pink area refers to the predicted presence.



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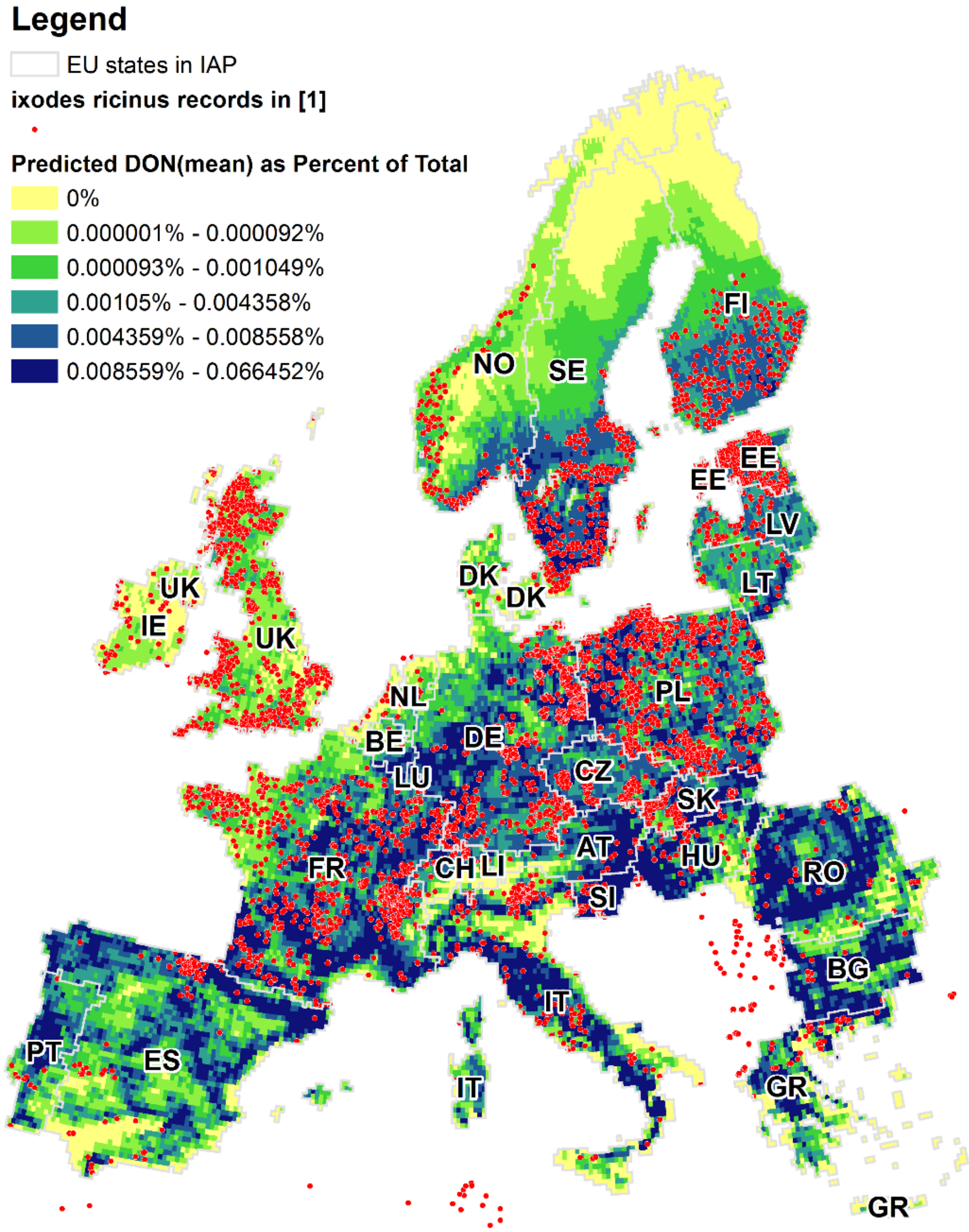


Figure S9 Comparison between the projected distribution of infected *Ixodes ricinus* nymphs in Spain (left panel) with the Lyme disease incidence distribution map generated based on Bonet Alavés et al. (2016) (right panel).

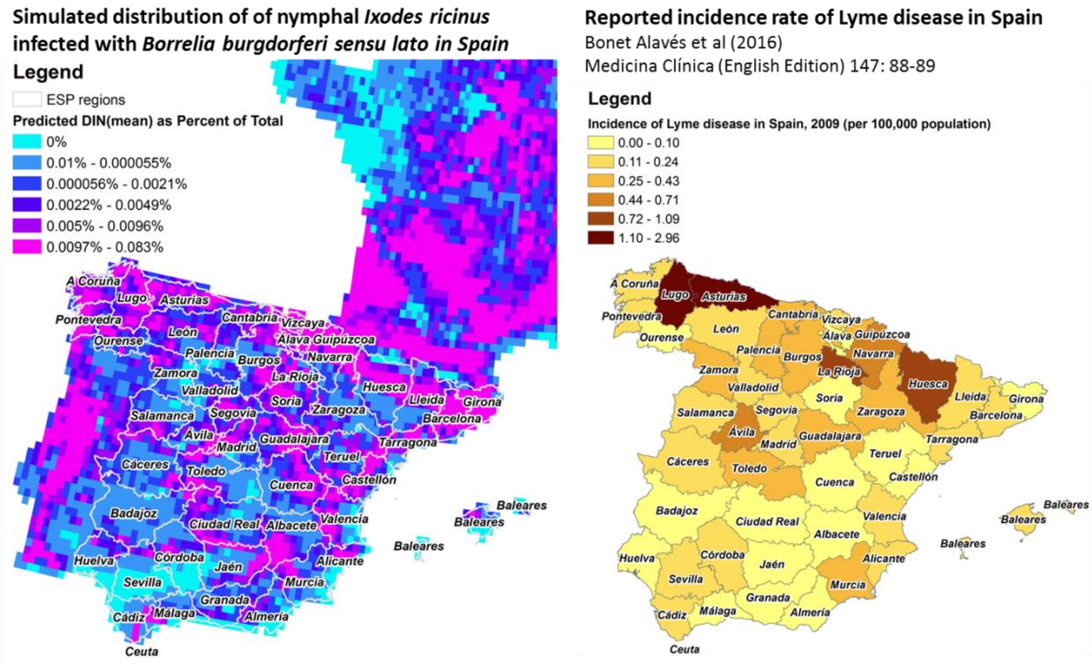
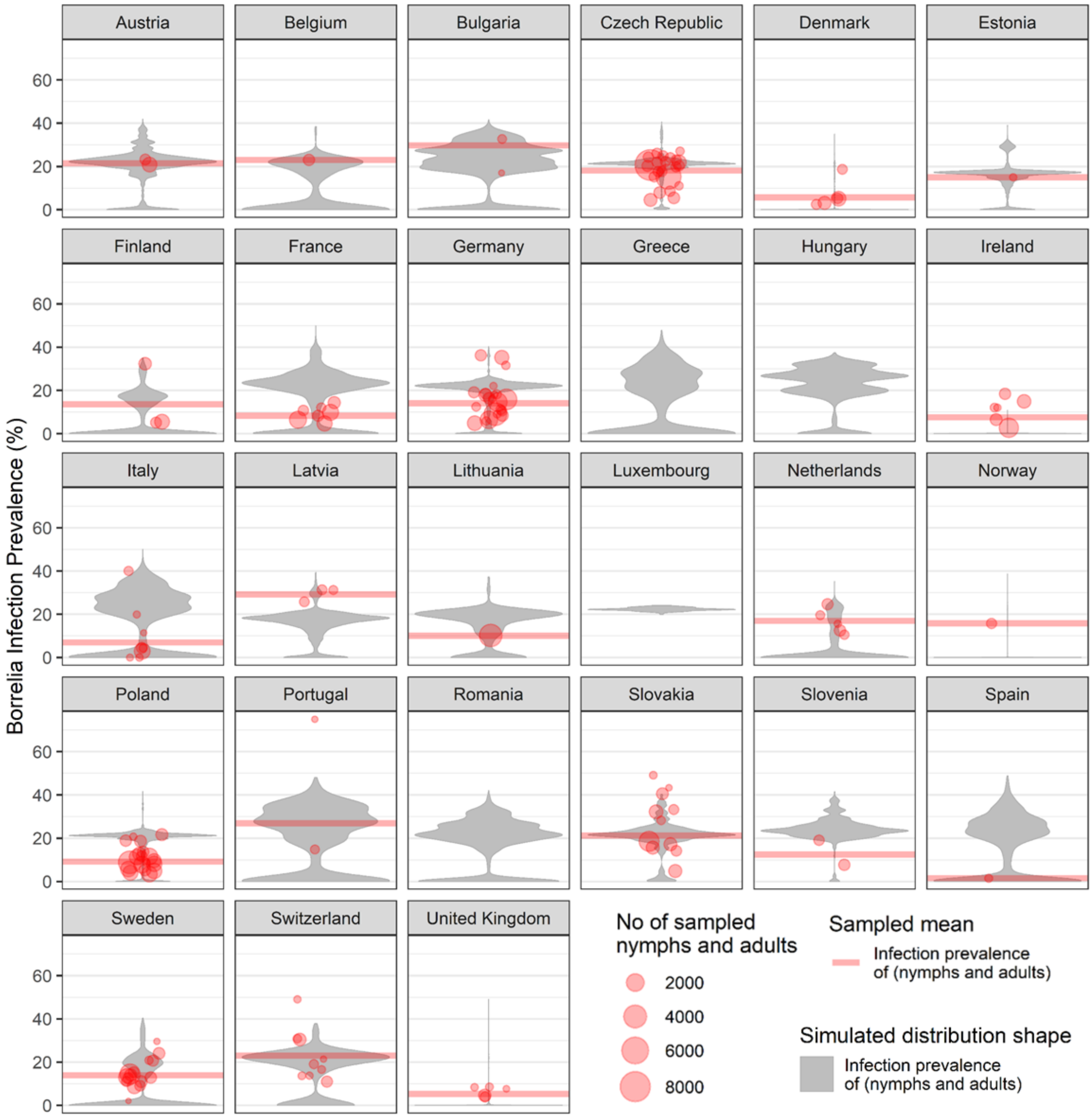


Figure S10 Comparison between the projected infection prevalence of nymphal and adult ticks with observed data in a literature review (Rauter and Hartung, 2005) in different European countries. The violin plots in Fig. S9D show the probability density at different predicted values of infection prevalence of combinations of adults and nymphs (grey). Red symbols (pies and lines) refer to the observed infection prevalence in the combined population of nymphs and adults from the articles reviewed in Rauter and Hartung (2005). Subplots without red pies or lines reflect that the observed data for the counties are missing from the review.



Supplemental tables

Table S1 Reproduction host (cervidae) population estimation in the European countries (in thousands)

State Code	Name	Roe deer	Red deer	Fallow deer	Moose	White-tailed deer	Sika deer	Ref	Total cervidae†
AT	Austria	1050	190	1.5	0.01		2.7	*	1244.21
BE	Belgium	60	10	0.2	0.03			*	70.23
BG	Bulgaria	57.2	16.3	3.7				a	77.2
CH	Switzerland	130	25				0.25	*	155.25
CZ	Czech Republic	293	23	19	0.03	0.4	6	*	341.53
DE	Germany	2400	150	150	0.05		3	*	2703.05
DK	Denmark	200	14	5.8			0.5	*	220.3
EE	Estonia	48.4	1.55		11.9			*	61.85
ES	Spain	600	900	100				*	1600
FI	Finland	30		0.6	93	55		*	179.8
FR	France	1200	120	12			1	*	1333
GR	Greece	50	0.65	0.4				*/est	51.05
HU	Hungary	316	74	21.6				*	411.7
IE	Ireland		4	10			25	*	39
IT	Italy	426	63	21				*	510
LI	Liechtenstein	0.8	0.4					c	1.2
LT	Lithuania	81.3	12.6					*	97.8
LU	Luxembourg	24	3.2					b	27.2
LV	Latvia	129.5	28.4		14.5			*	172.4
NL	Netherlands	60	2.7	1.15				*	63.95
NO	Norway	90	130		110			*	355
PL	Poland	692	141	13.1	3.9		0.1	*	850.1
PT	Portugal	5	20	3				*	28
RO	Romania	158.7	36.1	5.9				*	200.7
SE	Sweden	800	10	?	200			*	1010
SI	Slovenia	85	38	7.5	0.01			*	130.51
SK	Slovakia	150	14	0.3				*	164.3
UK	United Kingdom	450	420	152			27	*	1168.5

† Also includes Reindeer, White-tailed deer, Muntjac and Chinese water deer
* Book: European Ungulates and Their Management in the 21st Century, ref (Apollonio et al., 2010)
a Stoyanov, N. & Stoyanova, M. 2005. Geneva Timber and Forest Discussion Paper 38 Forest and Forest Products Country Profile: Republic of Bulgaria. United Nations, Geneva.
b Baghli, A., Moes, M. & Walzberg, C. 2007. Les corridors faunistiques du cerf (Cervus elaphus L.) au Luxembourg. Bull. Soc. Nat. luxemb., 108, 63–80.
c Meile, P., Sele, H., Bargetze, T., Ospelt, A., Hasler, M., Bühler, N., Malin, P., and Näscher, F. 2007. Wald- und Wildtiere. Beiträge zu Waldwirtschaft und Jagd in Liechtenstein. Gstöhl, E. Report: 1-24. Amt für Wald, Natur und Landschaft, Fürstentum Liechtenstein.

Table S2 Selected GCMs and RCMs for modelling climate change impacts

Climate change	Emission scenario	GCM	RCM	Projected increases in temperature (˚C) in Europe (2010-2070)
Low	RCP2.6	MPI-ESM-LR	REMO	0.62
Low	RCP2.6	NorESM1-M	RCA4	0.92
Low	RCP2.6	EC-EARTH	RCA4	1.07
Low	RCP4.5	MPI-ESM-LR	CCLM4	0.84
Intermediate	RCP4.5	GFDL-ESM2M	RCA4	1.50
Intermediate	RCP4.5	HadGEM2-ES	RCA4	2.31
Intermediate	RCP8.5	GFDL-ESM2M	RCA4	1.93
High	RCP8.5	IPSL-CM5A-MR	WRF	2.44
High	RCP8.5	HadGEM2-ES	RCA4	2.87
High	RCP8.5	CanESM2	CanRCM4	2.95

Table S3 Projected changes in overall DON (density of nymphs) and DIN (density of infected nymphs) under different scenarios. The greatest decrease and increase are highlighted in blue and red respectively.

Socio-economic scenarios	Climate scenario	GCM	RCM	ΔDIN	ΔDON
SSP1	RCP2.6	MPI-ESM-LR	REMO	-25%	-26%
SSP1	RCP2.6	NorESM1-M	RCA4	-6%	-7%
SSP1	RCP2.6	EC-EARTH	RCA4	-13%	-17%
SSP1	RCP4.5	MPI-ESM-LR	CCLM4	-16%	-20%
SSP1	RCP4.5	GFDL-ESM2M	RCA4	-13%	-16%
SSP1	RCP4.5	HadGEM2-ES	RCA4	42%	29%
SSP3	RCP4.5	MPI-ESM-LR	CCLM4	30%	21%
SSP3	RCP4.5	GFDL-ESM2M	RCA4	35%	29%
SSP3	RCP4.5	HadGEM2-ES	RCA4	82%	64%
SSP3	RCP8.5	GFDL-ESM2M	RCA4	47%	38%
SSP3	RCP8.5	IPSL-CM5A-MR	WRF	105%	87%
SSP3	RCP8.5	HadGEM2-ES	RCA4	100%	74%
SSP3	RCP8.5	CanESM2	CanRCM4	120%	90%
SSP4	RCP4.5	MPI-ESM-LR	CCLM4	132%	112%
SSP4	RCP4.5	GFDL-ESM2M	RCA4	144%	122%
SSP4	RCP4.5	HadGEM2-ES	RCA4	220%	182%
SSP5	RCP8.5	GFDL-ESM2M	RCA4	29%	21%
SSP5	RCP8.5	IPSL-CM5A-MR	WRF	80%	66%
SSP5	RCP8.5	HadGEM2-ES	RCA4	74%	51%
SSP5	RCP8.5	CanESM2	CanRCM4	100%	71%

Table S4 Projected changes in the drivers and risk indicators of Lyme disease for the European countries considered. Projections under the six combined scenarios of socio-economic (SSPs) and climate changes (RCPs) are summarised for different countries. Country abbreviations are explained in Table S3. Sub-regions of European regions are according to the Eurovoc, the EU's multilingual thesaurus. Risk drivers include: ΔT – increase in temperature (˚C); ΔF – change in forest coverage (%); ΔD – change in deer density (%); ΔH – change in transmission host density (%). Risk indicators include: ΔMD – change in infected nymphal tick density (ticks/km2); ΔwL – change in range of low risk area in winter (Dec-Jan) (%); ΔpH – change in range of high risk area in peak season (May-Jun) (%).

Region		SSP1 x RCP2.6							SSP1 x RCP4.5							SSP4 x RCP4.5							SSP3 x RCP4.5							SSP3 x RCP8.5							SSP5 x RCP8.5						
		ΔT	ΔF	ΔD	ΔH	ΔMD	ΔwL	ΔpH	ΔT	ΔF	ΔD	ΔH	ΔMD	ΔwL	ΔpH	ΔT	ΔF	ΔD	ΔH	ΔMD	ΔwL	ΔpH	ΔT	ΔF	ΔD	ΔH	ΔMD	ΔwL	ΔpH	ΔT	ΔF	ΔD	ΔH	ΔMD	ΔwL	ΔpH	ΔT	ΔF	ΔD	ΔH	ΔMD	ΔwL	ΔpH
North	NO	1.4	-1.2	0.0	0.0	1.E+03	0	0	1.9	-1.3	0.0	0.0	6.E+03	0	2	1.9	1.4	0.1	0.1	1.E+04	0	3	1.9	1.4	0.1	0.1	2.E+04	0	5	3.1	1.3	0.0	0.1	1.E+04	0	3	3.1	0.7	0.0	0.1	1.E+04	0	5
	FI	1.0	-1.9	0.1	0.0	1.E+04	0	3	1.9	-1.1	0.0	0.0	2.E+04	0	11	1.9	2.3	0.1	0.1	3.E+04	0	13	1.9	2.1	0.1	0.1	6.E+04	0	24	3.3	2.5	-0.1	0.0	3.E+04	0	13	3.3	-1.0	-0.1	0.0	5.E+04	0	22
	SE	1.2	-3.9	0.1	-0.1	3.E+03	0	0	1.9	-0.7	0.1	0.0	3.E+04	0	7	1.9	6.3	0.2	0.2	5.E+04	0	14	1.9	5.5	0.2	0.1	7.E+04	4	21	3.1	5.0	0.2	0.1	5.E+04	0	13	3.1	3.4	0.1	0.1	6.E+04	3	20
	EE	0.8	-17	-0.1	-0.4	-6.E+03	0	-23	1.5	4.5	0.1	0.1	6.E+04	0	13	1.5	17.7	0.4	0.4	1.E+05	0	21	1.5	17.5	0.4	0.4	2.E+05	0	23	2.8	17.3	0.2	0.3	1.E+05	0	21	2.8	13.9	0.1	0.2	2.E+05	0	22
	LV	0.6	-18	-0.2	-0.4	-2.E+04	0	-32	1.5	-9.5	-0.1	-0.2	7.E+03	0	-17	1.5	39.6	0.9	1.0	2.E+05	0	40	1.5	14.6	0.4	0.7	2.E+05	3	24	2.6	15.3	0.3	0.3	9.E+04	0	14	2.6	-0.2	0.0	-0.1	9.E+04	1	4
	DK	0.7	-1.0	0.0	-0.1	-3.E+01	0	1	1.2	-0.7	0.0	-0.1	2.E+03	0	1	1.2	49.8	4.5	5.7	2.E+05	38	81	1.2	13.6	1.9	1.5	9.E+04	22	33	2.1	15.4	2.2	1.8	7.E+04	13	32	2.1	13.0	1.9	1.5	7.E+04	21	31
	LT	0.6	-19	-0.2	-0.7	-4.E+04	0	-34	1.4	-19	-0.2	-0.7	-4.E+04	0	-33	1.4	43.6	1.4	1.4	2.E+05	0	49	1.4	6.4	0.3	0.7	8.E+04	0	7	2.5	-0.2	0.2	-0.2	5.E+04	0	13	2.5	-19	-0.2	-0.7	-3.E+03	0	-24
WEST	UK	0.6	-5.0	0.0	-0.3	-2.E+03	0	-2	0.9	-5.0	0.0	-0.3	-2.E+03	0	-2	0.9	13.2	0.9	0.7	5.E+04	27	24	0.9	-4.2	0.0	-0.3	1.E+04	9	4	1.5	-0.4	0.2	0.0	-7.E+01	1	-1	1.5	-3.4	0.0	-0.2	3.E+03	4	0
	IE	0.5	-2.3	0.0	-0.2	3.E-01	0	0	0.8	-2.3	0.0	-0.2	2.E+01	0	0	0.8	25.3	2.3	2.9	2.E+04	25	8	0.8	-2.0	0.0	-0.2	3.E+03	4	0	1.3	3.1	0.5	0.4	2.E+01	0	0	1.3	-0.7	0.1	0.0	5.E+02	1	0
	NL	0.4	-1.0	0.0	-0.1	-2.E+03	0	-2	1.0	-1.0	0.0	-0.1	4.E+03	5	2	1.0	27.7	2.6	2.7	1.E+05	51	50	1.0	-0.8	0.1	-0.1	1.E+04	7	3	1.7	-0.5	0.1	-0.1	4.E+03	5	2	1.7	-0.7	0.1	-0.1	8.E+03	7	3
	DE	0.4	-11	-0.1	-0.4	-4.E+04	1	-25	1.1	-12	-0.1	-0.4	-8.E+03	10	-22	1.1	17.6	0.6	0.5	2.E+05	25	12	1.1	-9.0	-0.1	-0.3	1.E+05	23	-12	1.9	-5.1	0.0	-0.3	5.E+03	11	-18	1.9	-6.8	-0.1	-0.3	9.E+04	22	-11
	BE+LU	0.4	-7.7	-0.1	-0.4	-2.E+04	6	-13	0.9	-7.7	-0.1	-0.4	-1.E+04	13	-10	0.9	11.0	0.5	0.4	6.E+04	37	12	0.9	-7.2	-0.1	-0.3	2.E+04	21	-8	1.7	-4.7	0.0	-0.3	-1.E+04	13	-10	1.7	-5.5	-0.1	-0.3	1.E+04	20	-9
	AT	0.8	-11	0.0	-0.2	-4.E+04	0	-15	1.6	-9.6	0.0	-0.2	6.E+03	0	-11	1.6	20.4	0.5	0.4	2.E+05	2	12	1.6	4.8	0.3	0.2	3.E+05	6	12	2.4	16.0	0.4	0.3	7.E+04	0	0	2.4	11.5	0.3	0.2	2.E+05	4	11
	CH+LI	1.0	-4.7	0.1	-0.1	-4.E+03	1	-6	1.8	-4.2	0.1	0.0	2.E+04	9	0	1.8	16.8	0.7	0.6	2.E+05	13	18	1.8	3.6	0.3	0.2	2.E+05	19	19	2.6	15.4	0.6	0.6	5.E+04	10	12	2.6	7.0	0.4	0.3	1.E+05	16	18
	FR	0.4	-9.9	-0.1	-0.4	-5.E+04	-6	-21	0.9	-8.2	-0.2	-0.4	-9.E+03	3	-13	0.9	15.3	0.5	0.4	2.E+05	27	12	0.9	-5.2	-0.1	-0.3	9.E+04	17	0	1.7	-0.8	0.0	-0.2	2.E+04	5	-10	1.7	2.9	0.0	-0.1	1.E+05	24	7
EAST	PL	0.6	-17	-0.2	-0.6	-2.E+04	0	-38	1.4	-16	-0.2	-0.5	4.E+04	0	-30	1.4	29.7	0.9	0.9	6.E+05	2	28	1.4	-5.4	-0.1	-0.2	3.E+05	3	-2	2.4	-5.4	-0.1	-0.2	1.E+05	0	-6	2.4	-8.0	-0.1	-0.3	2.E+05	4	-8
	CZ	0.5	-11	-0.1	-0.4	-3.E+04	0	-24	1.2	-11	-0.1	-0.4	-8.E+03	0	-19	1.2	0.4	0.0	-0.1	4.E+04	0	5	1.2	-7.2	-0.1	-0.2	7.E+04	1	-8	2.1	-7.9	-0.1	-0.3	6.E+03	0	-11	2.1	-8.4	-0.1	-0.4	6.E+04	1	-8
	SK	1.2	-12	-0.1	-0.3	2.E+03	0	-18	2.0	-8.6	-0.1	-0.3	1.E+05	0	-12	2.0	26.9	0.6	0.4	6.E+05	7	17	2.0	5.7	0.2	0.0	3.E+05	4	-3	2.8	4.4	0.1	-0.1	3.E+05	2	3	2.8	-0.1	0.0	-0.2	2.E+05	4	-4
	HU	0.9	-1.7	-0.1	-0.2	-2.E+04	0	-14	1.7	11.6	0.2	0.1	4.E+04	6	-10	1.7	55.5	1.7	1.7	7.E+05	50	18	1.7	39.1	1.1	0.8	8.E+04	27	-13	2.6	37.6	0.7	0.9	4.E+05	28	14	2.6	31.1	0.5	0.7	2.E+04	23	-19
	SI	0.6	-26	-0.2	-0.5	-1.E+05	2	-39	1.3	-23	-0.2	-0.5	-4.E+04	4	-35	1.3	15.2	0.2	0.1	4.E+05	17	2	1.3	10.5	0.1	0.1	5.E+05	32	-3	2.2	13.0	0.1	0.1	3.E+05	13	-3	2.2	8.7	0.1	0.0	4.E+05	29	-6
	RO	1.1	-8.6	-0.1	-0.3	1.E+04	0	-13	1.9	-8.2	-0.2	-0.3	2.E+04	2	-21	1.9	26.4	0.6	0.5	3.E+05	12	4	1.9	11.3	0.2	0.1	2.E+05	11	-12	2.9	20.6	0.4	0.3	2.E+05	7	-3	2.9	2.9	0.0	-0.1	5.E+04	5	-22
	BG	1.0	0.5	0.0	-0.1	7.E+03	12	-1	1.8	5.1	-0.1	-0.1	1.E+04	8	-16	1.8	47.9	0.6	0.8	3.E+05	32	-2	1.8	21.3	0.2	0.3	1.E+05	14	-28	2.8	22.5	0.1	0.3	1.E+05	16	-12	2.8	18.1	0.0	0.2	7.E+04	12	-29
SOUTH	IT	1.0	-5.9	-0.1	-0.2	2.E+03	0	-9	1.7	-4.9	-0.1	-0.2	6.E+03	-2	-11	1.7	4.4	0.1	0.1	7.E+04	5	-2	1.7	-2.0	0.0	-0.1	3.E+04	-7	-15	2.6	1.3	0.0	-0.1	2.E+04	0	-9	2.6	3.5	0.0	0.0	6.E+04	-6	-14
	ES	0.5	-4.0	-0.1	-0.2	-1.E+04	-6	-9	1.2	-2.0	-0.2	-0.2	7.E+03	-4	-5	1.2	10.4	0.0	0.0	7.E+04	6	4	1.2	0.7	-0.2	-0.1	6.E+04	3	-1	2.1	9.4	-0.2	-0.2	2.E+04	-2	-3	2.1	0.3	-0.3	-0.3	4.E+04	-2	-5
	PT	0.9	-5.1	-0.3	-0.2	-4.E+04	-19	-16	1.5	2.7	-0.4	-0.2	-2.E+04	-18	-14	1.5	31.1	-0.2	0.3	8.E+04	-7	-1	1.5	16.7	-0.3	0.1	3.E+03	-23	-16	2.4	19.0	-0.5	-0.1	3.E+04	-12	-7	2.4	13.4	-0.6	-0.2	-7.E+03	-24	-17
	GR	0.9	-4.4	-0.1	-0.2	-1.E+04	0	-6	1.6	-2.8	-0.2	-0.2	-2.E+04	-4	-11	1.6	9.1	0.0	0.1	5.E+04	4	-3	1.6	-1.5	-0.2	-0.2	-6.E+01	-3	-12	2.6	3.1	-0.2	-0.1	-2.E+04	-3	-10	2.6	-1.2	-0.3	-0.3	-2.E+04	-6	-15
Mean		**0.8**	**-8.1**	**-7.4**	**-26**	**-2.E+04**	**-0.3**	**-14**	**1.4**	**-5.2**	**-7.0**	**-22**	**8.E+03**	**1.3**	**-9.7**	**1.4**	**22**	**79**	**87**	**2.E+05**	**14**	**17**	**1.4**	**5.0**	**18**	**12**	**1.E+05**	**7.6**	**1.8**	**2.4**	**7.6**	**19**	**13**	**8.E+04**	**4.1**	**1.5**	**2.4**	**2.9**	**7.6**	**-0.7**	**9.E+04**	**6.3**	**-1.7**