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The dependence of urban tick and Lyme disease hazards on the hinterlands

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Table S1: Summary of the average density of nymphs (/100m^2 ±sd), nymphal infection prevalence (%) and Lyme disease hazard (density of infected nymphs) (/100m^2) in urban (109 site visits) and hinterland sites (112 site visits) for each city surveyed. In bold are the six cities in which we detected ticks in urban greenspaces.

	Hinterland			Urban		
	Nymph density	Infection prevalence	Lyme disease hazard	Nymph density	Infection prevalence	Lyme disease hazard
Burnley	0	-	0	0	-	0
Cannock	0	-	0	0	-	0
Carlisle	**22.3±37.2**	**4.7% (24/507)**	**1.06**	**0.1±1.2**	**0% (0/2)**	**0**
Dunfermline	**19.3±29.7**	**10.9% (33/302)**	**2.11**	**15.0±25.1**	**1.6% (4/253)**	**0.24**
Durham	0.1±0.12	-	0	0	-	0
Falkirk	**26.8±62.5**	**4.7% (16/339)**	**1.26**	**9.5±15.6**	**4.9% (9/184)**	**0.46**
Halifax	0	-	0	0	-	0
Harrogate	1.5±6.1	0% (0/55)	0	0	-	0
Inverness	**25.7±35.8**	**9.9% (57/573)**	**2.56**	**19.5±32.7**	**8.2% (28/343)**	**1.59**
Keighley	1.1±4.2	0% (0/8)	0	0	-	0
Kilmarnock	6.1±17.1	1.8% (1/56)	0.11	0	-	0
Kings Lynn	0.9±3.7	1.9% (1/54)	0.02	0	-	0
Macclesfield	0.1±1.1	0% (0/1)	0	0	-	0
Perth	**51.3±68.9**	**9.3% (60/644)**	**4.78**	**6.1±12.9**	**16.8% (17/101)**	**1.03**
Scarborough	**14.7±20.5**	**7.2% (22/306)**	**1.06**	**1.7±4.8**	**9.1% (2/22)**	**1.15**
Wrexham	0	-	0	0	-	0

Table S2: Outputs from the selected generalised linear mixed effects models. Models focussing on nymph density were analysed at the transect level (presence/absence of a nymph) and models focusing on Lyme disease hazard were analysed at the site/visit level (presence/absence of infected nymphs for each site/visit). Models used a binomial error distribution and included site, city and survey month as random intercepts. Delta AICc indicates the difference in AICc when removing the variable compared to the selected model (lower AICc is better fit).

Parameter	**Estimate (standard error)**	**Z value**	**p-value**	**Delta AICc**
Model: Differences in nymph density between urban greenspaces and hinterland woodlands				
Intercept	-3.40 (0.69)	-4.93	<0.001	
Type: urban (baseline: hinterland)	-2.55 (0.58)	-4.42	<0.001	17.5
Latitude	2.86 (0.62)	6.60	<0.001	14.2
Annual cumulative rainfall	-0.93 (0.59)	-1.59	0.11	0.6
Ground vegetation density	-0.20 (0.07)	-2.71	0.007	5.3
Year: 2023 (baseline: 2022)	0.93 (0.22)	4.23	<0.001	16.3
Model: Differences in Lyme disease hazard between urban greenspaces and hinterlands				
Intercept	-4.66 (3.07)	-1.52	0.13	
Type: urban (baseline: hinterland)	-12.13 (6.46)	-1.88	0.06	23.4
City latitude	8.20 (3.73)	2.20	0.03	6.4
Model: Effect of hinterland nymph density on urban greenspace tick density				
Intercept	-6.53 (1.00)	-6.52	<0.001	
Nymph density in hinterland	0.06 (0.01)	4.92	<0.001	21.8
Latitude	2.66 (0.94)	2.83	0.005	7.4
Veg density	-0.40 (0.15)	-2.68	0.007	5.8
Model: Effect of hinterland nymph density on urban greenspace Lyme disease hazard				
Intercept	-19.09 (6.56)	-2.91	0.004	
Nymph density in hinterland	14.12 (4.58)	3.08	0.002	9.1
Year: 2023 (baseline: 2022)	-16.94 (5.93)	-2.86	0.004	8.9
Model: Effect of hinterland landcover on urban greenspace nymph density				
Intercept	-6.52 (1.20)	-5.43	<0.001	
% Woodland cover	1.55 (0.89)	1.74	0.08	0.7
% built-up cover	-2.78 (1.19)	-2.33	0.02	5.8
Year: 2023	1.25 (0.35)	3.54	<0.001	10.6
Vegetation density	-0.50 (0.15)	-2.61	0.009	5.3
Model: Effect of hinterland landcover on urban greenspace Lyme disease hazard				
Intercept	-60.86 (21.72)	-1.80	0.005	
Year: 2023	-27.82 (8.62)	-3.23	0.001	10.0
Vegetation density	5.60 (2.78)	2.01	0.04	1.5
Model: Effect of city landcover on urban greenspace nymph density				

Intercept	-6.44 (1.16)	-5.56	<0.001	
Latitude	3.30 (1.10)	2.99	0.003	7.5
Year: 2023	1.20 (0.35)	3.44	<0.001	9.9
Vegetation density	-0.39 (0.15)	-2.57	0.01	5.0
Model: Effect of city on urban greenspace disease hazard				
Intercept	-60.86 (21.72)	-1.80	0.005	
Year: 2023	-27.82 (8.62)	-3.23	0.001	10.0
Vegetation density	5.60 (2.78)	2.01	0.04	1.5
Model: Effect of urban/hinterland connectivity on urban greenspace nymph density				
Intercept	-6.44 (1.16)	-5.56	<0.001	
Latitude	3.30 (1.10)	2.99	0.003	7.5
Year: 2023	1.20 (0.35)	3.44	<0.001	9.9
Vegetation density	-0.39 (0.15)	-2.57	0.01	5.0
Model: Effect of urban/hinterland connectivity on urban greenspace Lyme disease hazard				
Intercept	-60.86 (21.72)	-1.80	0.005	
Year: 2023	-27.82 (8.62)	-3.23	0.001	10.0
Vegetation density	5.60 (2.78)	2.01	0.04	1.5

Table S3: Summary of published study that investigated tick density, nymphal infection prevalence and Lyme disease hazard in the south of England between 2008 and 2018.

Urban area	Sites	Year	Larval density (/100m)	Nymph density (/100m)	Adult density (/100m)	Nymphal infection prevalence (%)	Lyme disease hazard (/100m)	Ref
Bath	14 sites	2017	0.06 (0-0.42)	0.13 (0-0.78)	0.02 (0-0.07)	7.14% (n=42) (0-7.7%)	0.02 (0-0.21)	[1]
Bristol	38 sites	2017	0	0.01 (0-0.57)	0.002 (0-0.03)	0	0	[1]
London	Brompton Park	2018	n.d	0	0	n.d	n.d	[2]
	Bushy Park	2013, 2018	0	1.99 (0.9-3.5)	0.003 (0-0.01)	0% (n=51)	0	[2,3]
	Green Park	2018	0	0	0	n.d	0	[2]
	Greenwich Park	2018	0	0	0	n.d	0	[2]
	Hampton Park	2013	0	0	0	n.d	0	[3]
	Hyde Park	2018	0	0	0	n.d	0	[2]
	Kensington Park	2018	0	0	0	n.d	0	[2]
	Regent Park	2018	0	0	0	n.d	0	[2]
	Richmond Park	2008-2018	134.8 (12.9-585)	18.98 (0-136)	0.46 (0-2)	5.4% (n=1146) (0-13%)	1.22	[2–8]
	St James Park	2018	0	0	0	n.d	0	[2]
	Wimbledon common	2013	0	0	0	n.d	0	[3]
Salisbury	25 sites	2013-2015	n.d	2.6	0.4	18.1% (n=349)	0.47	[9]
Southampton	20 sites	2017	0.28 (0-3.06)	0.31 (0-5.23)	0.03 (0-0.17)	4.06% (n=271) (0-33.3%)	0.13 (0-1.36)	[1]

Figure S1: Map representing the 16 UK cities that were surveyed for this study. The map contains public sector information licensed under the Open Government Licence v3.0 (UK outline). Source: ONS, Open Geography Portal.

Table S4: Number of visits, population size, cumulative annual rainfall, woodland cover (%), built-up cover (%) within the city (0 – 5 km from city centre) and in the hinterlands (5 – 10 km from city centre) and connectivity (least cost path) metrics for each city. In bold are the six cities in which we detected ticks in urban greenspaces.

				5 km		Between 5 and 10 km		
Urban area	Number of visits	Population size	Cumulative annual rainfall	% woodland	% built-up	% woodland	% built-up	Connectivity (LCP)
Burnley	1	73021	1314.5	15.6	25.5	11.1	11.1	0.48
Cannock	1	63054	691.86	25.4	26.1	26	23.4	0.1
Carlisle	**2**	**74281**	**918.8**	**11.5**	**19.7**	**11.7**	**10.1**	**0.38**
Dunfermline	**2**	**55480**	**1082.04**	**17.6**	**30**	**14.7**	**12.4**	**0.23**
Durham	1	48069	675.65	21.7	25.8	17.8	17.1	0.22
Falkirk	**2**	**103020**	**971.67**	**20.6**	**24.9**	**21**	**13.8**	**0.32**
Halifax	1	88134	1041.25	13.5	29.4	12.5	22.1	0.35
Harrogate	1	75070	646.93	20.6	35.1	21.3	19.9	0.32
Inverness	**2**	**47820**	**755.02**	**18.5**	**17.4**	**27.6**	**6.4**	**0.07**
Keighley	1	57345	1057.27	13.3	20	10.8	16.6	0.25
Kilmarnock	1	47400	980.8	18.3	22.4	20.8	16.2	0.3
Kings Lynn	1	47610	660.31	14.7	30.7	16.6	21.7	0.26
Macclesfield	2	64199	868.4	29.2	25.1	23.6	17.5	0.15
Perth	**2**	**47220**	**864.98**	**24.3**	**20**	**27.6**	**12.7**	**0.1**
Scarborough	**2**	**61285**	**635.58**	**18**	**26.7**	**18.5**	**14.5**	**0.2**
Wrexham	1	65200	728.74	13.2	24.1	15.4	15.8	0.26

Table S5: Cost values assigned to each UKCEH land cover class to create the cost raster layer for deer movement throughout the landscape. This cost matrix was used to generate the urban-hinterland interface connectivity metric. Cost values for each land cover class were computed based on published literature [10–14]

Land cover class	Cost value	Land cover class	Cost value		Cost value
Deciduous woodland	1	Fen	30	Supralittoral rock	100
Coniferous woodland	1	Heather	30	Supralittoral sediment	100
Arable	60	Heather grassland	30	Littoral rock	100
Improved grassland	40	Bog	30	Littoral sediment	100
Neutral grassland	30	Inland rock	40	Saltmarsh	300
Calcareous grassland	30	Saltwater	1000	Urban	1000
Acid grassland	30	Freshwater	1000	suburban	300

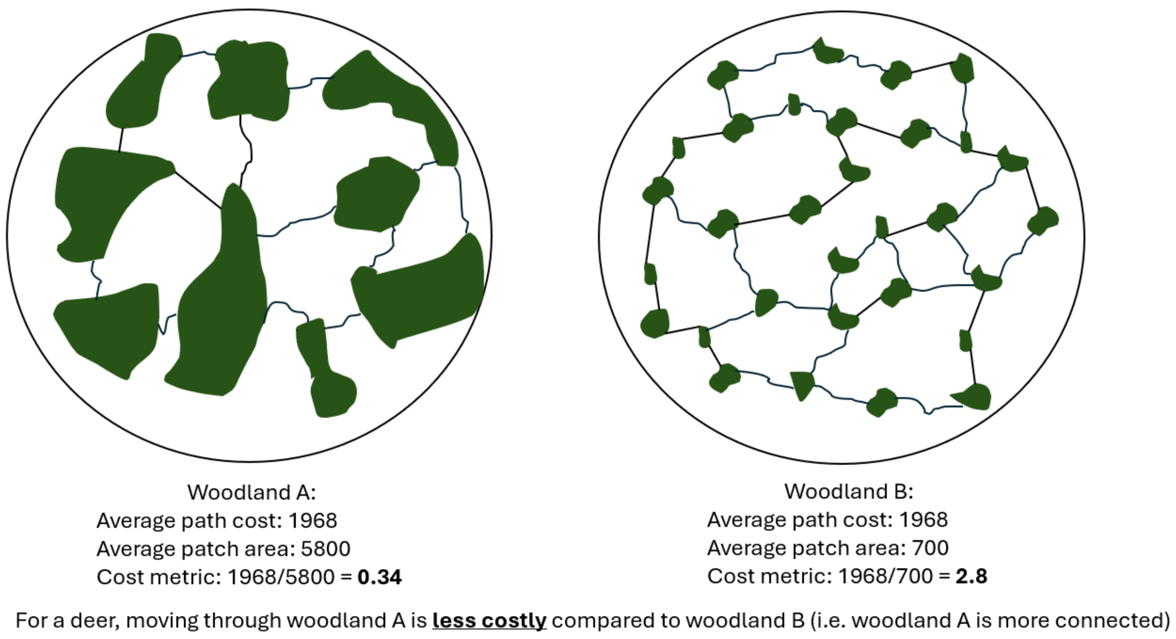

Figure S2: Examples explaining why we incorporated woodland patch area into our connectivity metrics. Fictional woodlands A and B both have the same average path cost however, we assume woodland A to be better connected for deer movement, as woodland patches are larger, which is why we decided to divide the average path cost by the average patch area.

Table S6: Table summarising the response variable, distribution, random effects and covariates for every generalised linear mixed effect model generated.

Response	distribution	Random effects	Covariates
Models: Differences in nymph density and Lyme disease hazard between urban greenspaces and hinterland woodlands			
Nymph presence at the transect level Presence of infected nymphs at the site/visit level	Binomial logit link	Town Site Month	Type (urban, hinterland) Year (2022, 2023) Ground vegetation density City latitude Annual cumulative rainfall Population size
Models: Effect of hinterland nymph density on urban greenspace nymph density and Lyme disease hazard			
Nymph presence at the transect level Presence of infected nymphs at the site/visit level	Binomial logit link	Town Site Month	DON hint Year (2022, 2023) City latitude Population size Annual cumulative rainfall Ground vegetation density
Models: Effect of hinterland landcover on urban greenspace nymph density and Lyme disease hazard			
Nymph presence at the transect level Presence of infected nymphs at the site/visit level	Binomial logit link	Town Site Month	Woodland cover hinterland Built-up cover hinterland Year (2022, 2023) Ground vegetation density Annual cumulative rainfall Population size
Models: Effect of city landcover on urban greenspace nymph density and Lyme disease hazard			
Nymph presence at the transect level Presence of infected nymphs at the site/visit level	Binomial logit link	Town Site Month	Woodland cover within town Built-up cover within town Year (2022, 2023) City latitude Ground vegetation density Year (2022, 2023) Population size Annual cumulative rainfall
Models: Effect of urban/hinterland connectivity on urban greenspace nymph density and Lyme disease hazard			
Nymph presence at the transect level Presence of infected nymphs at the site/visit level	Binomial logit link	Town Site Month	Connectivity interface City latitude Year (2022, 2023) Ground vegetation density Annual cumulative rainfall

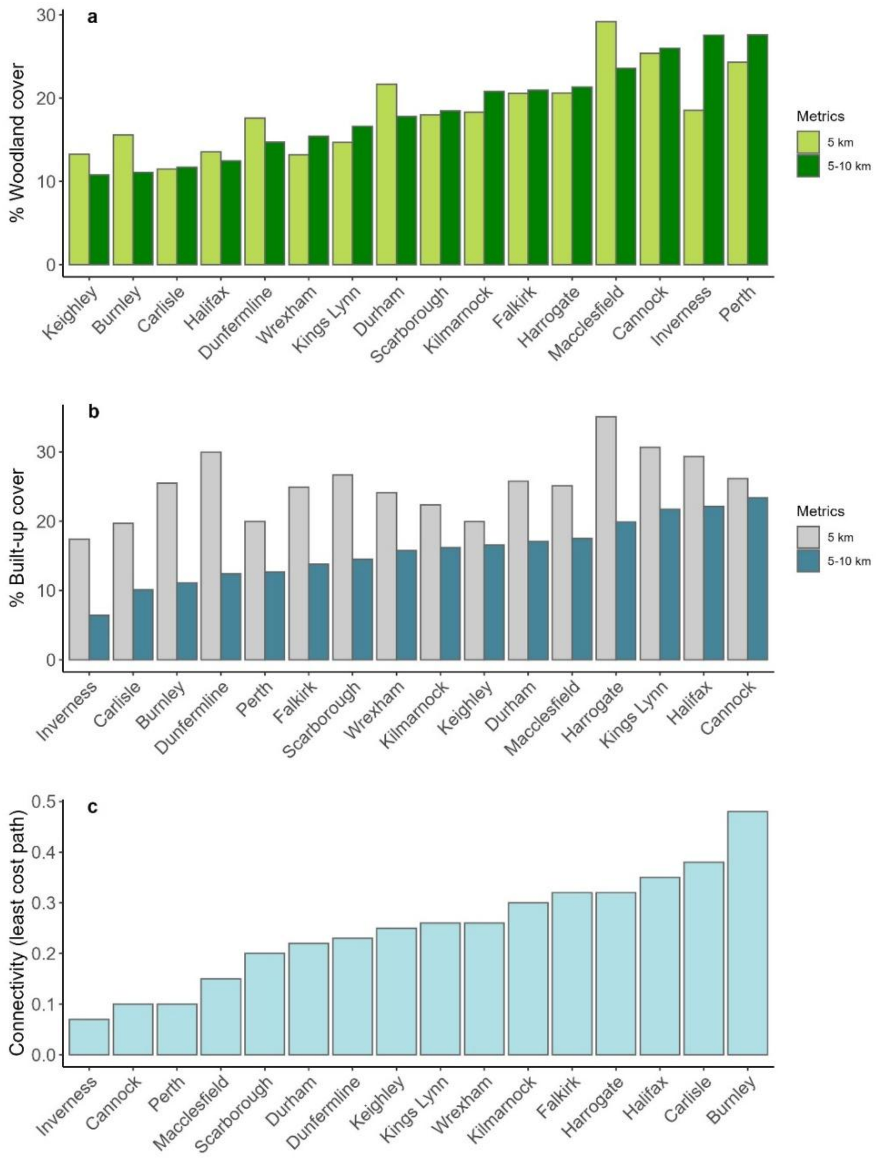

Figure S3: **The 16 cities were chosen to achieve a broad spread of (a) woodland cover (%) and (b) built-up cover (%) across hinterlands (in a ring 5 – 10 km of each city centre; darker bars).** Woodland (a) and built-up (b) covers are also shown within 5 km of each city centre, representing the area within and immediately adjacent to, each city (paler bars). Also shown is the **(c) connectivity metric (least cost path) of the urban-rural interface (a ring of 4 – 6 km of each city centre).** A low value indicates a more connected urban-rural interface (less costly for deer, as key tick hosts, to move through) and a high value represent a less connected (more costly) environment to move through. Landcover was extracted using the 2021 UKCEH landcover map[15].

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