

Supplementary Material

Does fragmentation contribute to the forest crisis in Germany?

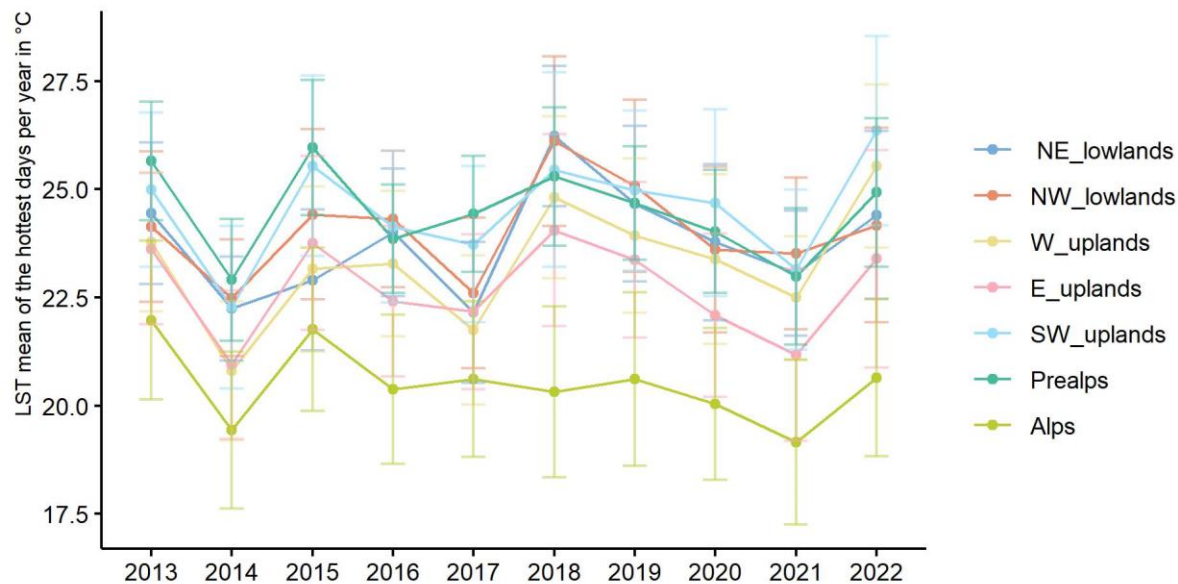
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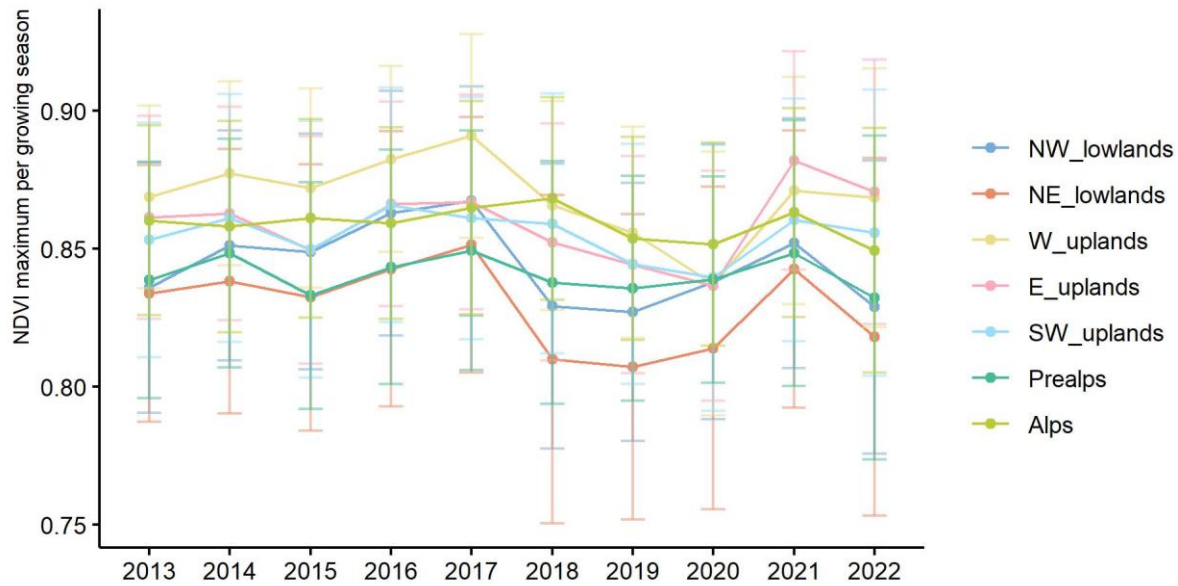
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Supplementary Figure 1. The LST (MODIS Aqua MYD11A1) mean value and standard deviation of forest areas (Hansen et al. 2013) in different ecoregions in Germany of the annual hottest days 2013-2022. The year 2022 shows extreme heat peaks, similar to the year 2018. The Alps show the same trends as other ecoregions at lower mean temperatures except for 2018, where the relatively cool mean temperature on hot days did not rise. In the Prealps, some of the highest mean temperatures are recorded in 2013 to 2015. The temperatures of the Southwest Uplands peak in 2022.



Supplementary Figure 2. The NDVI (MODIS Aqua MYD13A2) mean value and standard deviation of forest areas (Hansen et al. 2013) in different ecoregions in Germany per growing season (May-September) 2013-2022. The Uplands and the Alps record a higher mean greenness per growing season than the Lowlands and the Prealps. However, the decrease in vitality in 2018 and the following years are significant for all ecoregions.

Supplementary Table 1. Overview of area specifics for number of forest fragments, the size of the largest fragment, the area in km², forest area in km², the percentage forest cover and the days above 30 °C in forests in 2022.

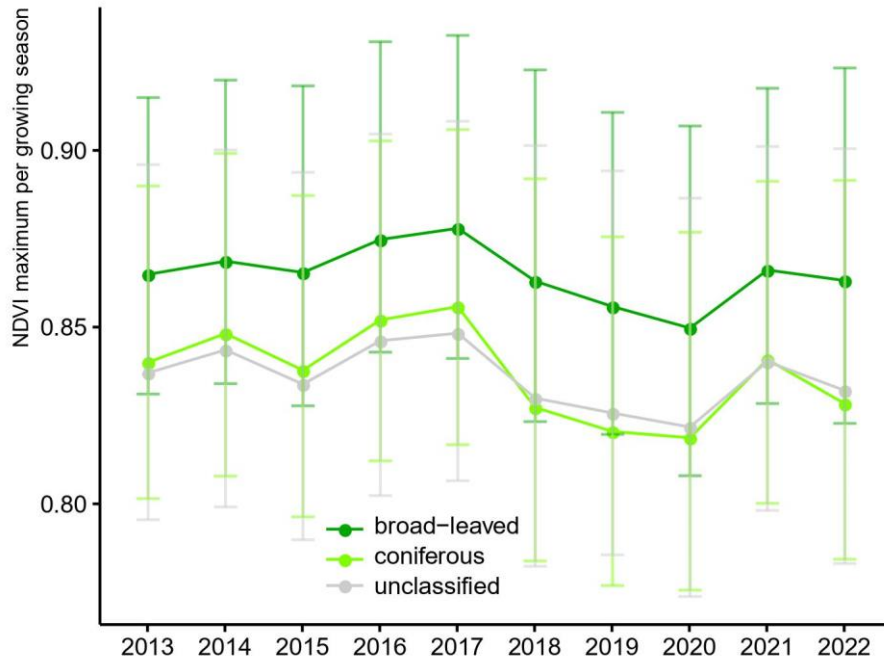
Area	No. of fragments	max size fragment in km ²	Area in km ²	Forest area in km ² * ¹	% forest cover	Days above 30°C in forests 2022* ²
Germany	1931934	3758	357588	98768.35	27.6* ¹	124
Alps	19106	1300	3816.30	2598.55	68.09	24
Prealps	238162	441	30636.16	8219.63	26.83	80
E_uplands	168553	1279	30528.82	11048.23	36.19	77
SW_uplands	259848	3758	63118.01	23382.1	37.05	107
W_uplands	433428	1372	57020.72	21960.29	38.51	91
NE_lowlands	335306	2369	76616.65	19911	25.99	96
NW_lowlands	477531	1134	71213.83	11408.29	16.02	92

*¹ based on Hansen et al. 2013 tree cover data at Landsat 30 m pixel resolution. The values differ from official statistics as they count forest areas without trees (and exclude some woodlands, urban forests that are no legal forest).

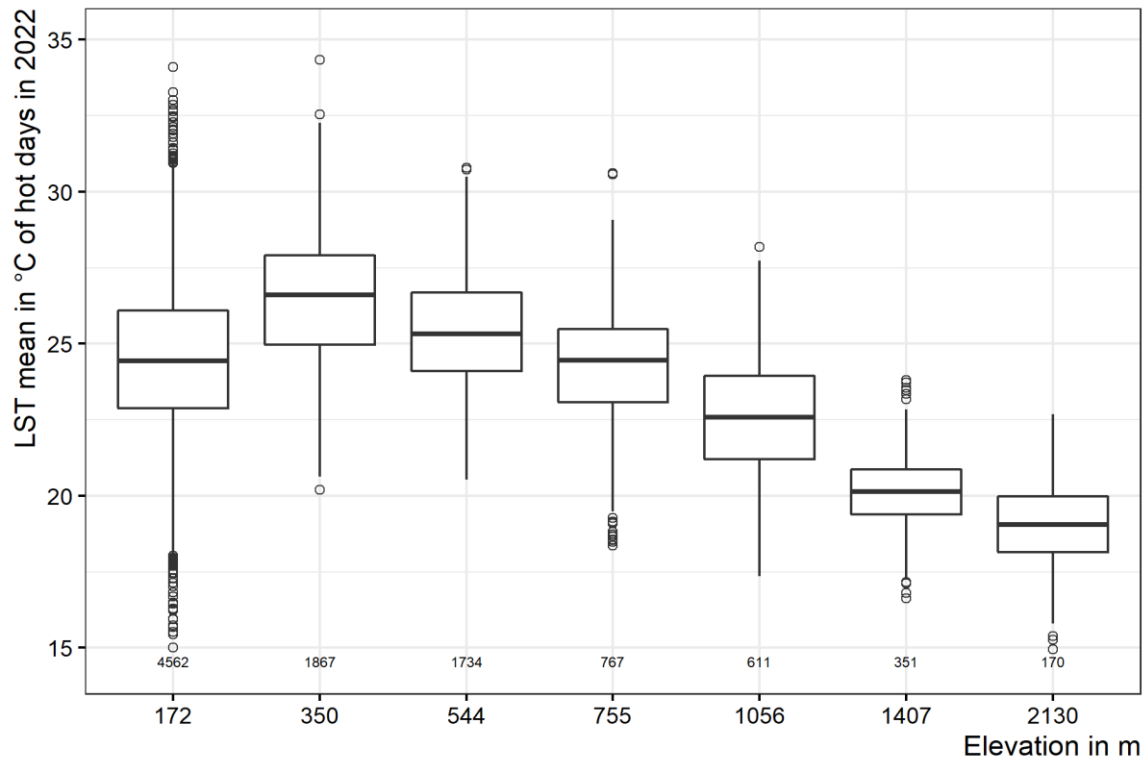
*² based on MODIS Aqua MYD11A1 Land surface temperature at 1 km spatial resolution.

Supplementary Table 2. Number of fragments (count), median values of Thiessen connectivity (TP), Land surface temperature (LST) and Normalized Difference Vegetation Index (NDVI) in different grouped forest fragments per ecoregion in Germany in 2022.

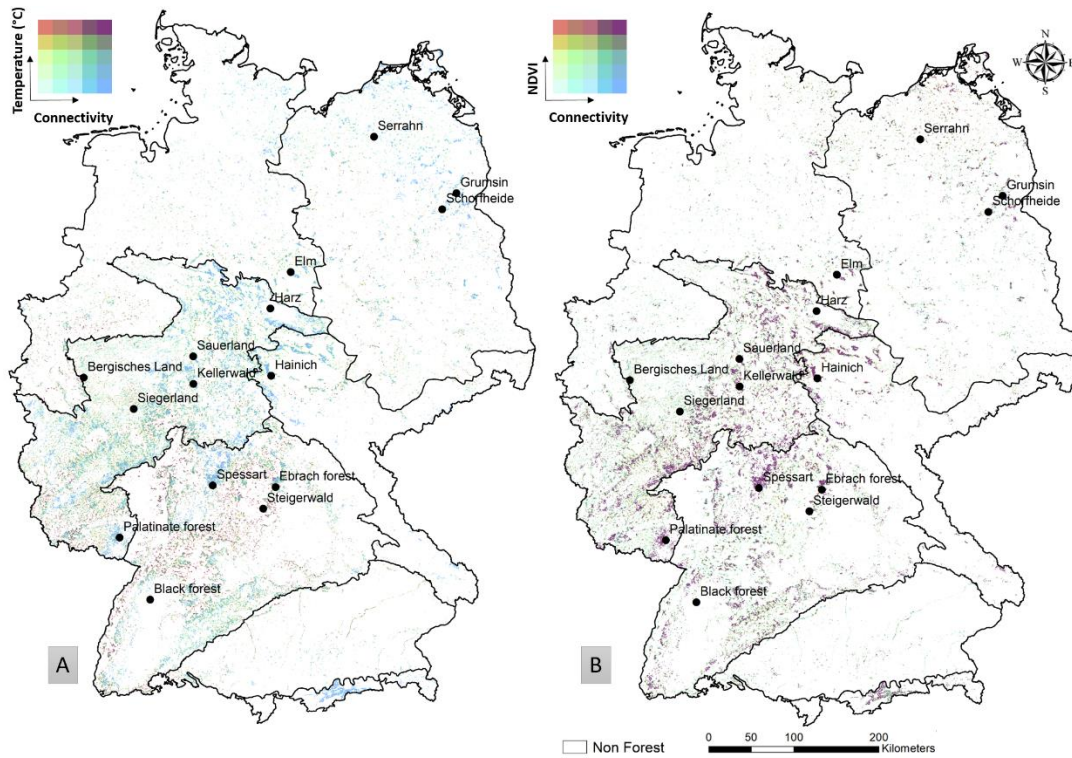
Ecoregion		Alps				Prealps			
Indicator		count	TP	LST	NDVI	Count	TP	LST	NDVI
Fragment	< 1 km	91380	0.52	22.22	0.83	2085292	0.41	26.84	0.80
	1-5 km	20085	0.70	21.75	0.83	1547516	0.76	26.23	0.82
	> 5 km	2627582	0.88	20.93	0.87	4707301	0.63	24.92	0.85
Ecoregion		E_uplands				SW_uplands			
Indicator		count	TP	LST	NDVI	Count	TP	LST	NDVI
Fragment	< 1 km	1334707	0.37	26.40	0.81	2498433	0.38	28.86	0.79
	1-5 km	1015713	0.60	25.72	0.86	2735707	0.61	28.04	0.82
	> 5 km	9152073	0.81	23.35	0.82	19456159	0.81	25.58	0.87
Ecoregion		NE_lowlands				NW_lowlands			
Indicator		count	TP	LST	NDVI	Count	TP	LST	NDVI
Fragment	< 1 km	3058691	0.31	26.93	0.78	3805222	0.34	26.65	0.77
	1-5 km	2538140	0.59	25.89	0.81	2082233	0.61	25.68	0.81
	> 5 km	15205831	0.81	24.48	0.82	5636453	0.78	24.26	0.83
Ecoregion		W_uplands							
Indicator		count	TP	LST	NDVI				
Fragment	< 1 km	3210310	0.41	26.93	0.81				
	1-5 km	2247157	0.61	26.49	0.84				
	> 5 km	17271998	0.77	24.84	0.87				



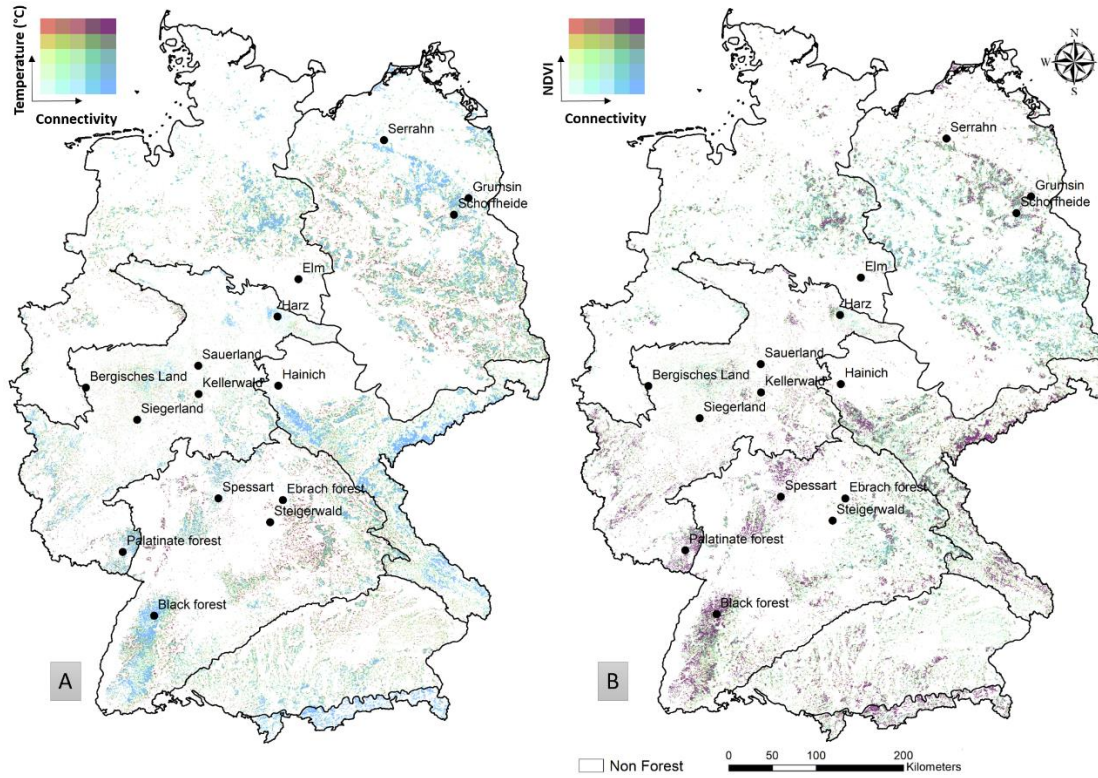
Supplementary Figure 3. Mean values of the maximum vitality (NDVI) per pixel in the growing season May to September of forest areas in Germany from 2013 to 2022 differentiated by broad-leaved forest, coniferous forest and unclassified forest areas. The standard deviations of the mean values are shown for each year and forest class.



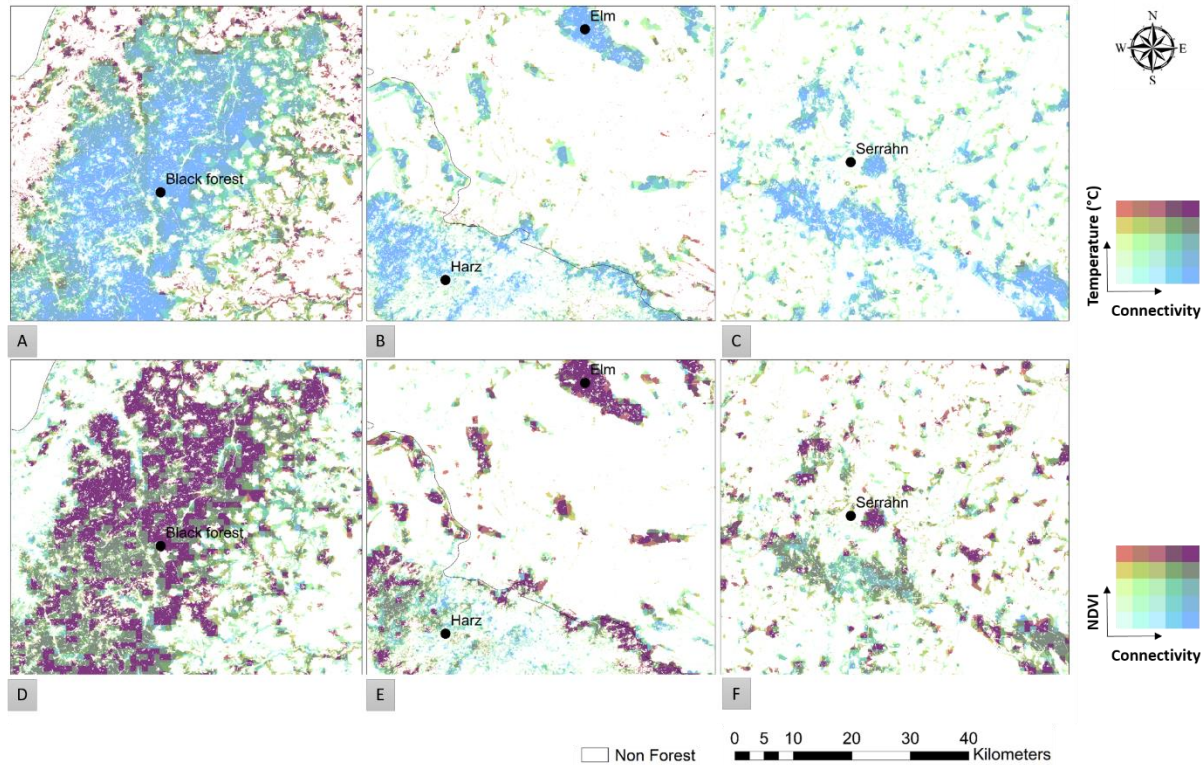
Supplementary Figure 4. Land surface temperature (MODIS Aqua MYD11A1) on hot days 2022 (at 1 km resolution of forested areas 2022 (Hansen et al. 2013, 30 m) and elevation based on the SRTM 30 m (NASA JPL 2020) with Jenks natural breaks for seven classes. The count of data points at 1 km resolution per elevation break is depicted above the x-axis. The higher the forest covered areas, the cooler the temperature on hot days.



Supplementary Figure 5. Bivariate maps of broadleaved tree covered areas in Germany 2022 and their relation between degree of fragmentation with temperatures and vegetation vitality. A) Thiessen Connectivity and Land surface temperature of hot days in 2022 (MODIS Aqua MYD11A1). B) Thiessen Connectivity and the maximum NDVI (MODIS Aqua MYD13A2) per growing season in 2022.



Supplementary Figure 6. Bivariate maps of coniferous tree covered areas in Germany 2022 and their relation between degree of fragmentation with temperatures and vegetation vitality. A) Thiessen Connectivity and Land surface temperature of hot days in 2022. B) Thiessen Connectivity and the maximum NDVI per growing season in 2022.



Supplementary Figure 7. Zoomed in view of some important locations depicted in bivariate maps of tree covered areas in Germany 2022. Subsets A, B and C shows the relation between Thiessen Connectivity and Land surface temperature of hot days in 2022. Subsets D, E and F shows the relation between Thiessen Connectivity and the maximum NDVI per growing season in 2022.

References

- Hansen, Matthew C., Peter V. Potapov, Rebecca Moore, Matt Hancher, S. A. A. Turubanova, Alexandra Tyukavina, David Thau, S. V. Stehman, S. J. Goetz, and Thomas R. Loveland. 2013. "High-Resolution Global Maps of 21st-Century Forest Cover Change." *Science* 342 (6160): 850–53. <https://doi.org/10.1126/science.1244693>.
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