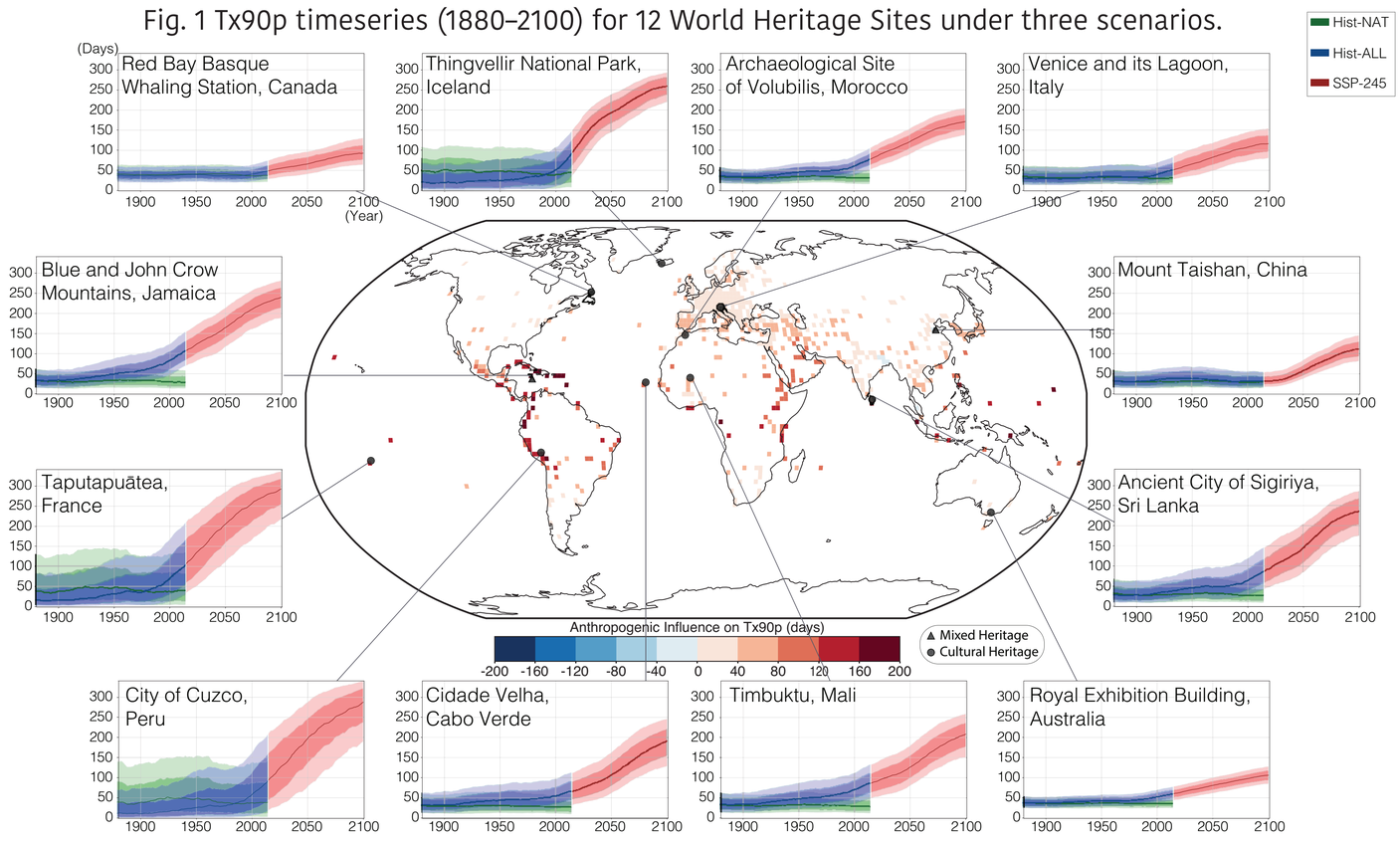
Humans have endangered their World Heritage Sites by amplifying extreme weather events

Site Trajectories of extreme heat events at 12 WHS

Fig. 1 Tx90p timeseries (1880–2100) for 12 World Heritage Sites under three scenarios.



Human activity has altered the occurrence of extreme weather events at World Heritage Sites. Using the large-ensemble climate simulations, we isolated anthropogenic impacts by comparing:

Factual simulations (real-world conditions with human drivers).

Natural-only simulations (counterfactual world that only simulates solar and volcanic activities).

Future scenarios (SSP2-4.5 intermediate emission future trajectory).

By calculating the extreme heat days exceeding 90th percentile of preindustrial maximum temperatures (Tx90p), we reveal:

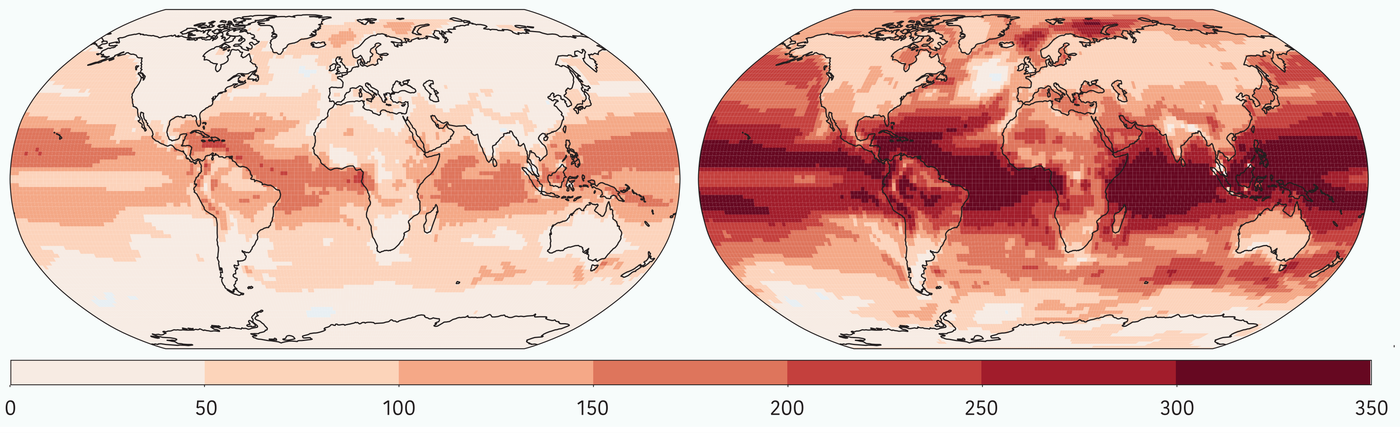
- All sites show anthropogenic heat increases, but magnitudes vary from 10 days to +200 days/year.
- Human impacts detected pre-1900 in most of the tropical sites (e.g., Blue Mountains in Jamaica).
- Even modest extreme temperature shifts can lead to heritage risks (e.g., the biodiversity change in Thingvellir, Iceland).

Global trends of extreme heat days (Tx90p)

Fig. 2 Global changes in extreme heat days (Tx90p) relative to pre-industrial baseline (1850-1900).

Extreme heat days (Tx90p) have incrased globally, with tropical heritage sites facing the greater increases. Compared to a pre-industrial baseline, we reveal:

- 2000–2014: Tropics gained 50–150 additional heat days due to human influence.
- 2070–2100 (SSP2-4.5): Projected >250 days/year across sub- and tropics, indicating the historic extremes will become the "new normal" (Fig. 2).



Regional exposures to drought days (CDD)

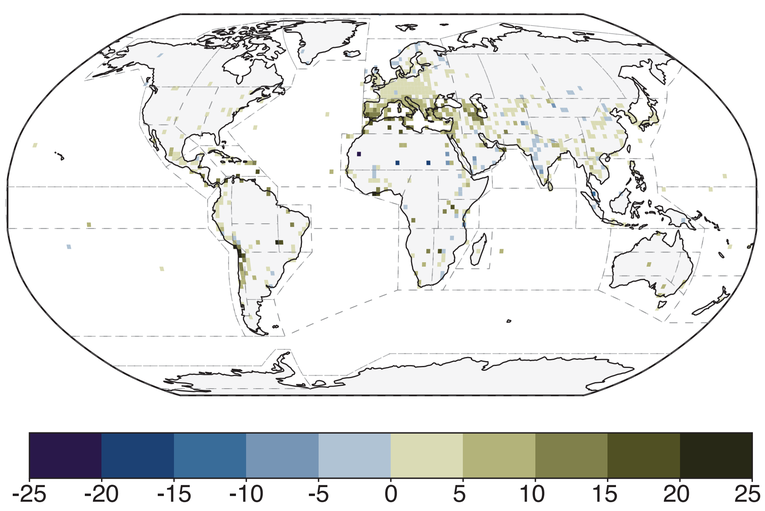


Fig. 3a: Anthropogenic contribution to consecutive drought days (CDD) at WHS grid cells.

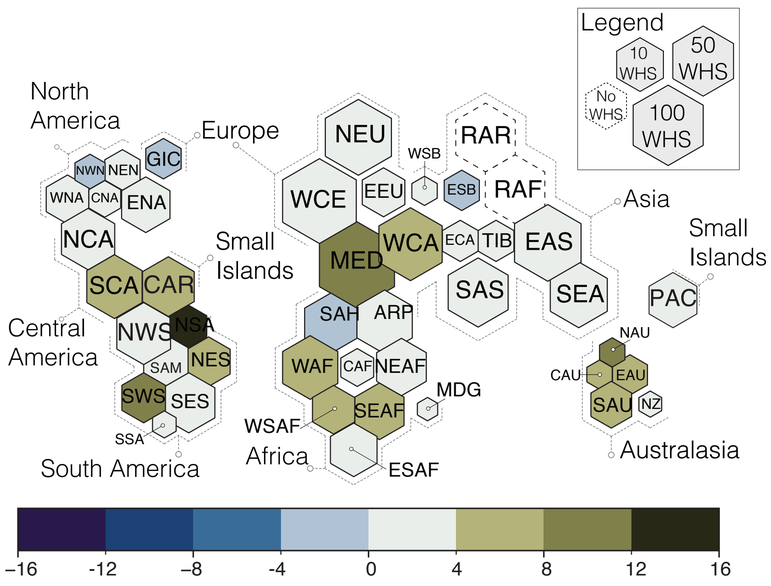


Fig. 3b: Regional averages of CDD changes, scaled by the number of WHS per IPCC-defined region.

We revealed the anthropogenic contribution to consecutive drought days (CDD): the longest sequence of days with <1 mm precipitation by comparing the factual and counterfactual scenarios at a regional scale.

Drought intensification disproportionately threatens heritage-rich regions, demanding urgent adaptation.

- Highest exposure: Mediterranean and West Asia (+8–12 drought days), impacting >200 WHS.
- Emerging risk in already-arid zone, e.g., South America and Australia (drying trend with fewer WHS).

Vulnerable WHS in the face of heavy rainfall events (R95p)

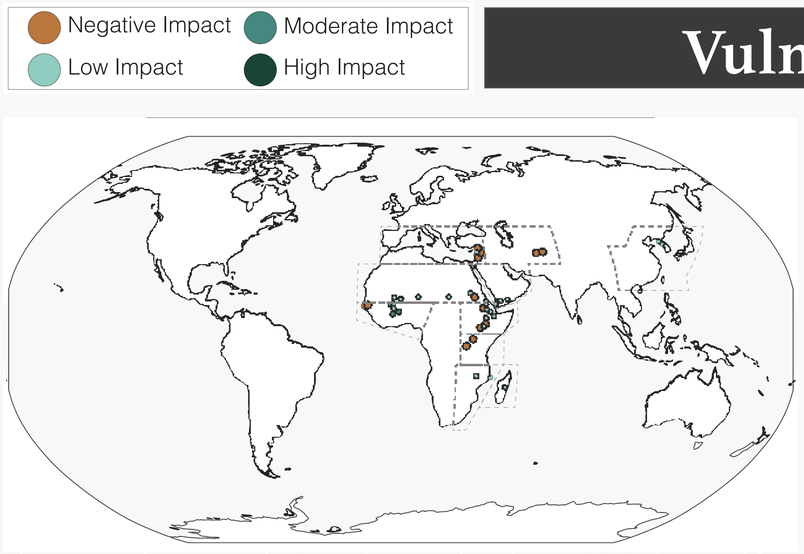


Fig. 4a: anthropogenic R95p impact levels at WHSs located in low-income countries.

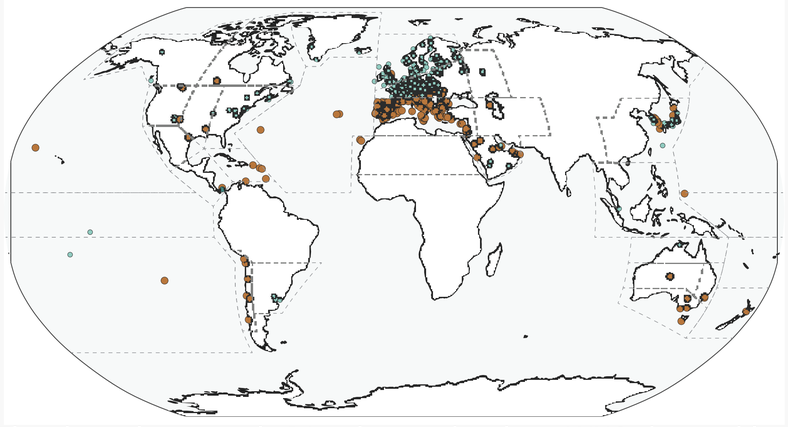


Fig. 4b: anthropogenic R95p impact levels at WHSs located in high-income countries.

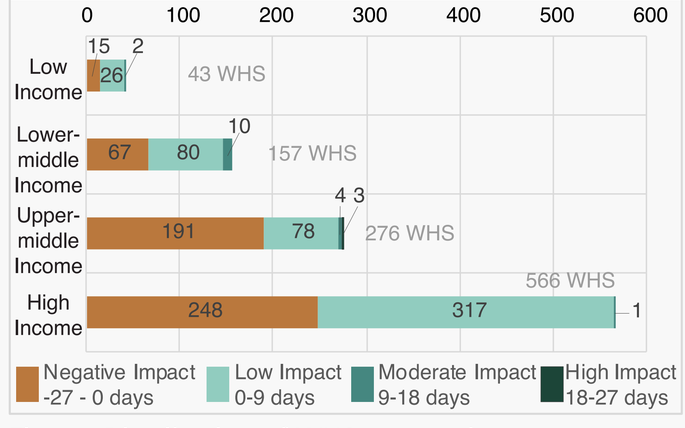


Fig. 4c: Distribution of WHSs across income categories by R95p impact level.

To assess vulnerability, we examined anthropogenic shifts in R95p: days when precipitation exceeds the 95th percentile of the preindustrial baseline, categorized by national income levels from World Bank data (Fig. 4a-c):

- Low-income countries: ~50% of WHS (28) face moderate-high rainfall increases. Limited adaptation capacity deepens inequalities.
- High-income countries: ~60% of WHS (317) show low impacts. Even have higher capabilities, these sites need nuanced investigations.

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