

# Solstice optimizes thermal growing season

## *Supplementary materials*

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Aug.-Dec. 2024

## Supplementary methods

All analyses were run on **R**, using the package **terra** for raster manipulation (Hijmans, 2024).

**Climate data** Daily mean temperatures from 1951 to 2020 were extracted from the ERA5-Land dataset, at a  $0.1^\circ$  spatial resolution (Muñoz Sabater et al., 2021). We sampled  $>500$  sites on a regular grid across Europe (see Figure 2 in the main text).

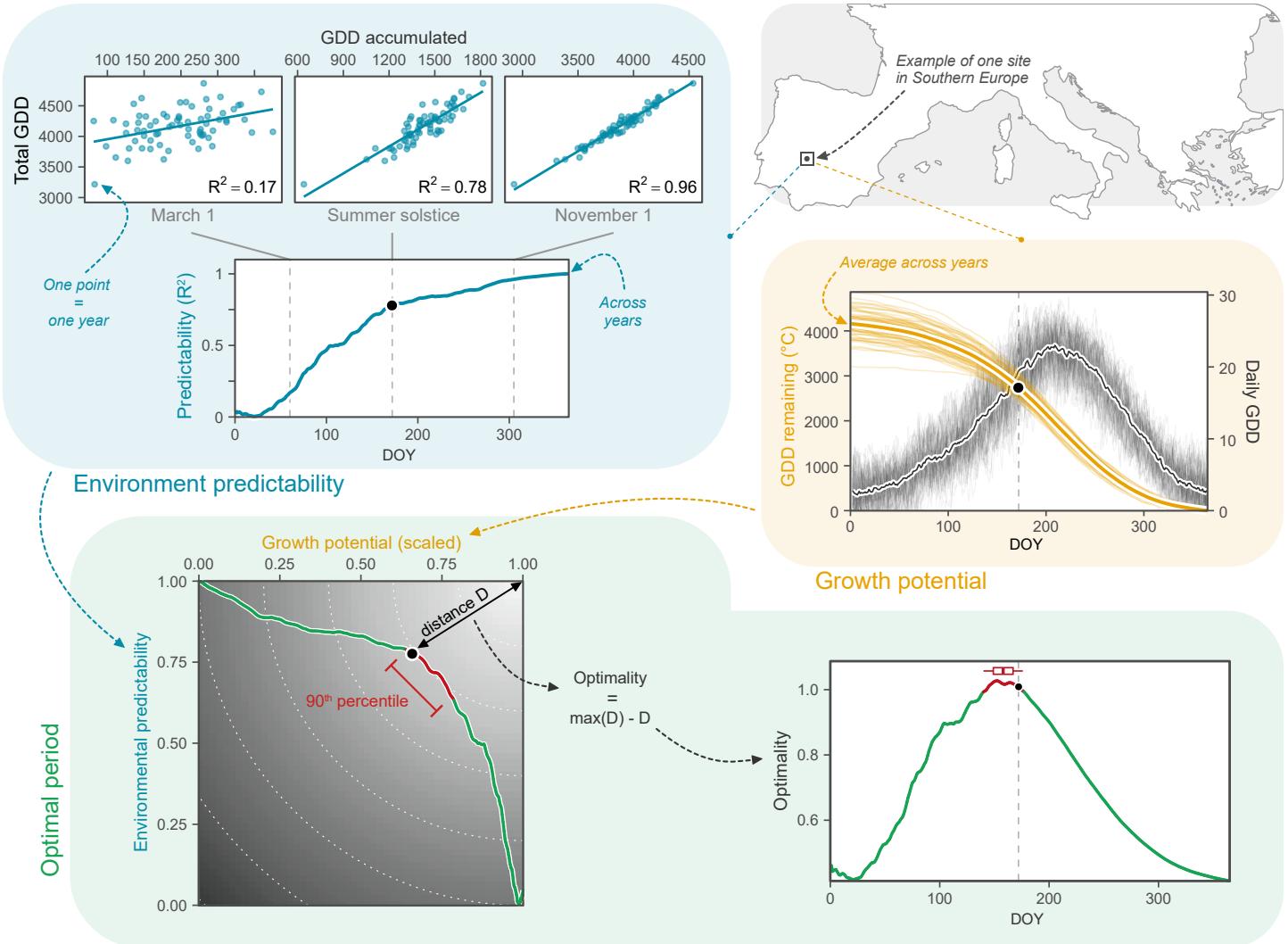
Following McMaster and Wilhelm (1997), we define growing degree-days at a day d ( $GDD_d$ ) as:

$$GDD_d = \begin{cases} 0 & \text{if } T_d < T_{lower} \\ T_{upper} - T_{lower} & \text{if } T_d > T_{upper} \\ T_d - T_{lower} & \text{otherwise} \end{cases} \quad (1)$$

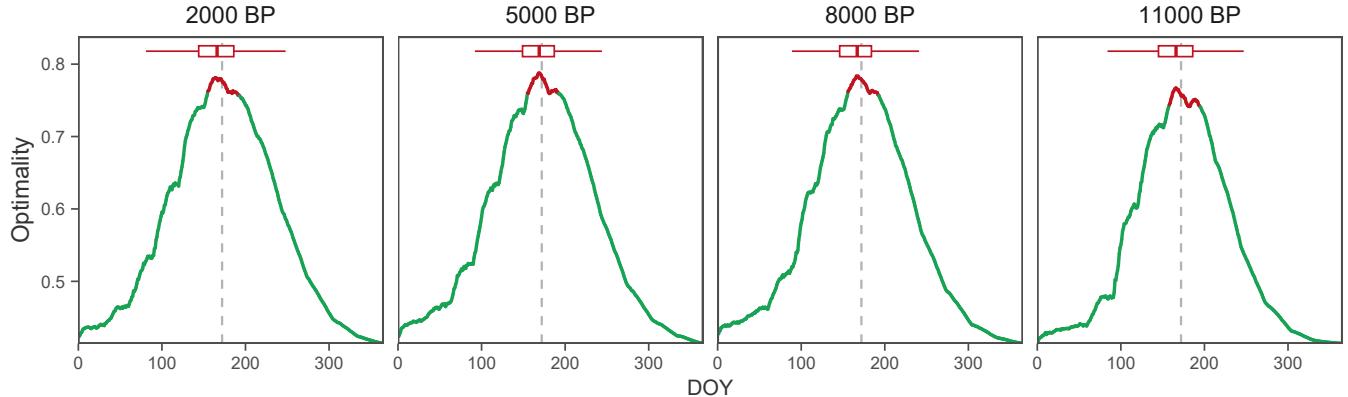
where  $T_d$  is the mean temperature at the day d, and  $T_{lower}/T_{upper}$  the lower/upper temperature thresholds (defining the range within which metabolism is likely active). Here, we chose  $T_{lower} = 5^\circ\text{C}$  and  $T_{upper} = 35^\circ\text{C}$ .

**Optimal period** For each day and each site, environmental predictability was computed as the  $R^2$  of the linear regression across years between total GDD and the GDD accumulated by that day (blue panel, Figure S1). Growth potential was defined as the remaining GDD to be accumulated from that day until the end of the year (yellow panel, Figure S1). While other trade-offs could be considered, this appears to be the most intuitive choice. Both environmental predictability and growth potential were computed for the entire year (January 1 to December 31), although the growing season is likely more restricted and varies across locations.

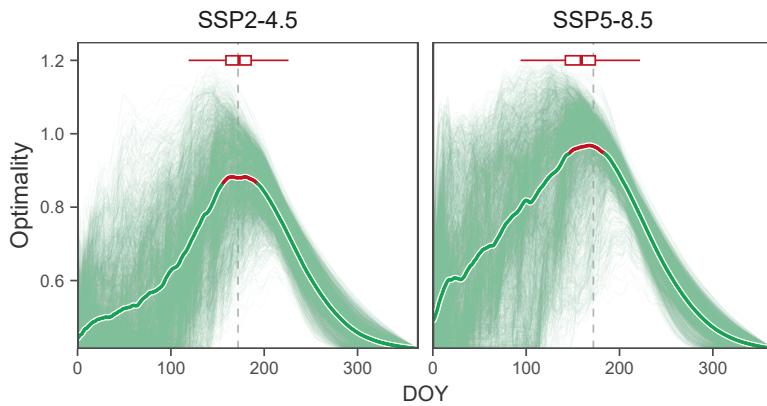
We computed an optimality measure based on the Euclidean distance  $D$  from the ideal point where both predictability and growth potential are maximized (green panel, Figure S1). Optimality was defined as  $\max(D) - D$  (where  $\max(D) \approx 1.414$ )—such that higher values correspond to more optimal days. Days were classified as optimal if they fell within the top 10% of the most optimal days.



**Figure S1: Workflow of the optimality analysis for one site in Southern Europe.**



**Figure S2: The average optimal trade-off between environmental predictability and growth potential is relatively stable across the Holocene.** Daily mean temperatures were obtained from [Van der Meersch et al. \(2024\)](#), in which daily data were generated with the GWGEN weather generator ([Sommer and Kaplan, 2017](#)) based on monthly paleosimulations from the HadCM3B-M2.1 coupled general circulation model ([Armstrong et al., 2019](#)). BP stand for "Before Present" (i.e. 1950).



**Figure S3: The future optimal trade-off between environmental predictability and growth potential (2071-2100)s.** Daily mean temperatures came from the last Coupled Model Intercomparison Project Phase 6 (CMIP6) climate projections, for 5 global climate models (GCMs) and 2 shared socio-economic pathways (SSPs). Model projections were downscaled to a  $0.1^\circ$  resolution with a statistical trend-preserving method (the cumulative distribution function transform), using the ERA5-Land reanalysis as a reference observational dataset between 1981 and 2010 ([Noël et al., 2022](#)). The five GCMs were GFDL-ESM4, IPSL-CM6A-LR, MPI-ESM1-2-HR, MRI-ESM2-0 and UKESM1-0-LL.

## References

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