Warming cues earlier flowering in *Protea* of subtropical Africa

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Phenology

- Phenology is the timing of life cycle events.
- Changes in phenology can affect ecosystem processes and biotic interactions, including impacts on animals that depend on plants for pollen, nectar, or fruit/seed

Phenology

Leaf out time

Phenology

Leaf out time

Flowering time

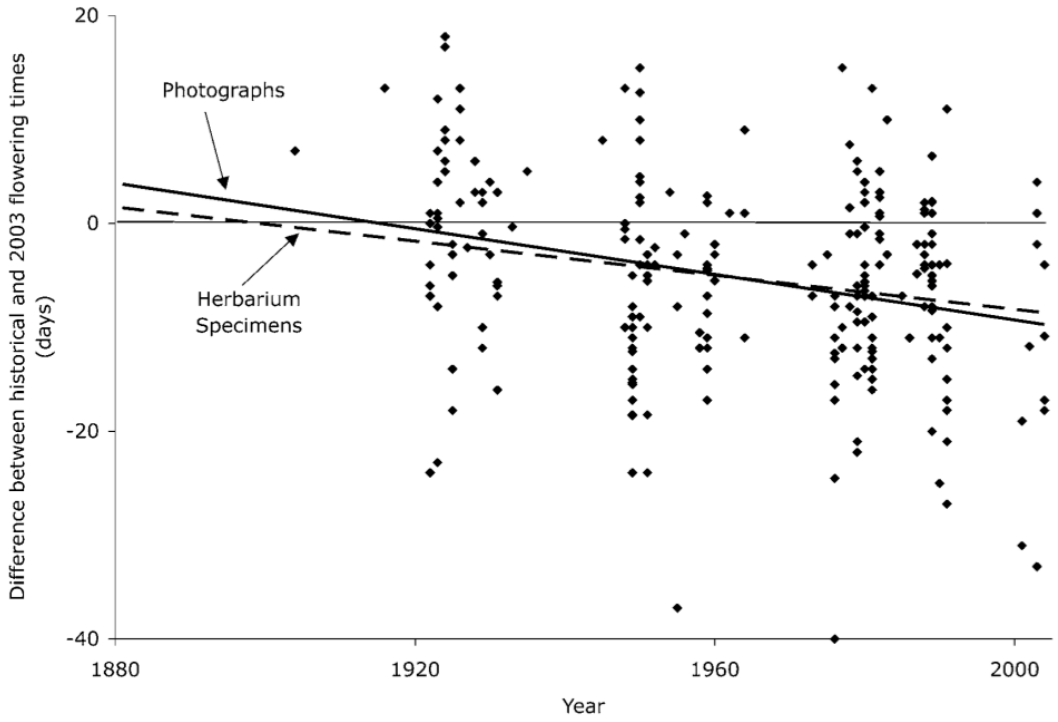
Phenology

Leaf out time

Flowering time

Animal migration

Flowering phenology: an example



Over 88 years, the Pink lady's slipper (*Cypripedium acaule*) in Concord MA flowered 5 days later in 1917 than in 2005!

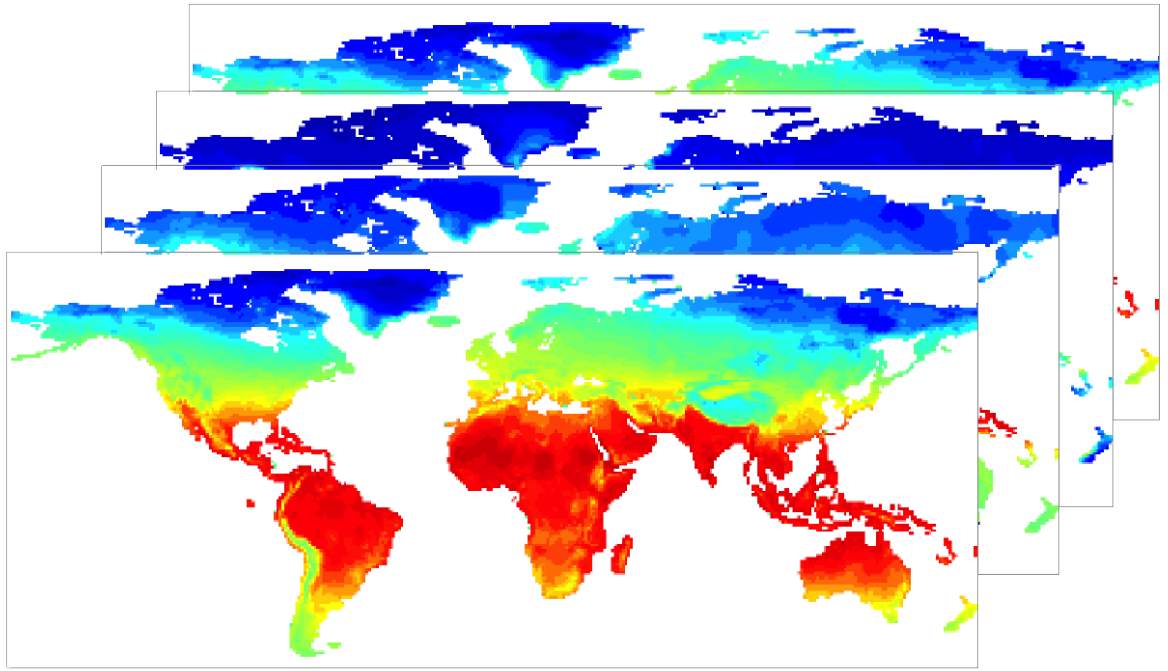
Primack RB et al. (2007) Using photographs to show the effects of climate change on flowering times. *Arnoldia* 65: 3-9.

Flowering time

Earlier

No change

Later



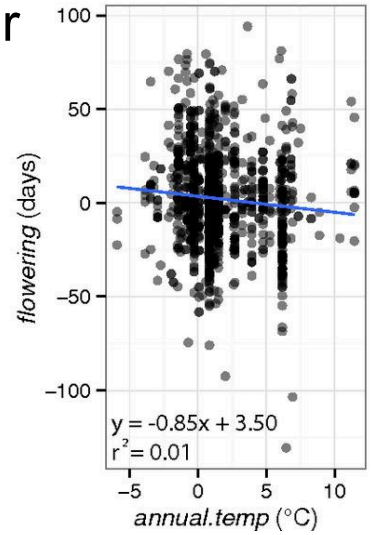
Under climate change, species respond in various ways

Flowering time

Earlier

No change

Later



Rhododendron adenogynum

For Himalayan *Rhododendron* over 125 y of collections, mean flowering advances with annual warming (2.27 days earlier per 1 °C warming)

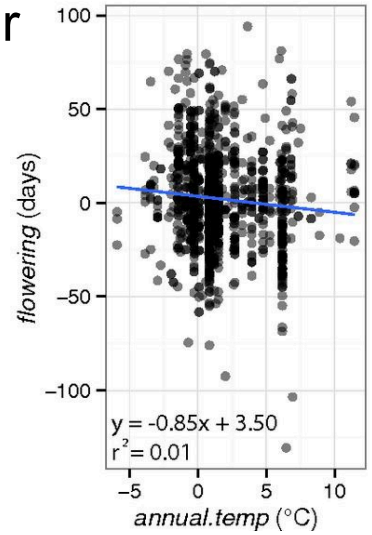
Hart R et al. (2014) *PNAS* 111: 10615-10619

Flowering time

Earlier

No change

Later



Rhododendron adenogynum

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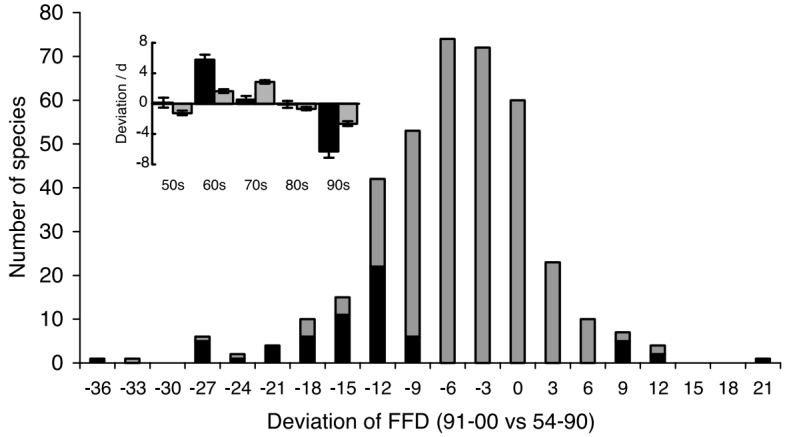
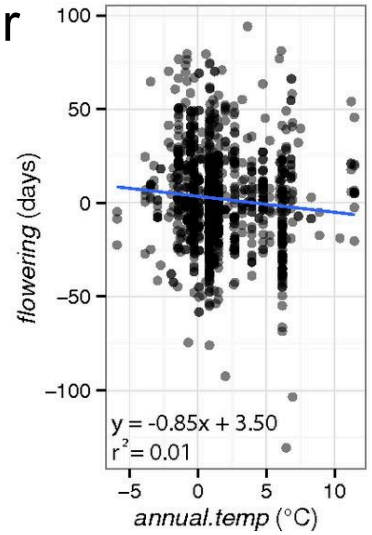
British plants



Fitter & Fitter 2002 *Science* 296: 1689–1691.

Flowering time

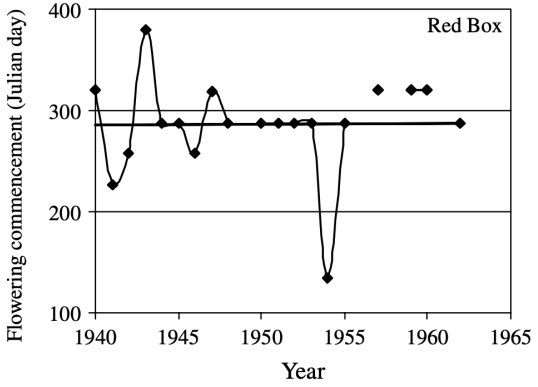
Earlier



Rhododendron adenogynum

Hart R et al. (2014) *PNAS* 111: 10615-10619

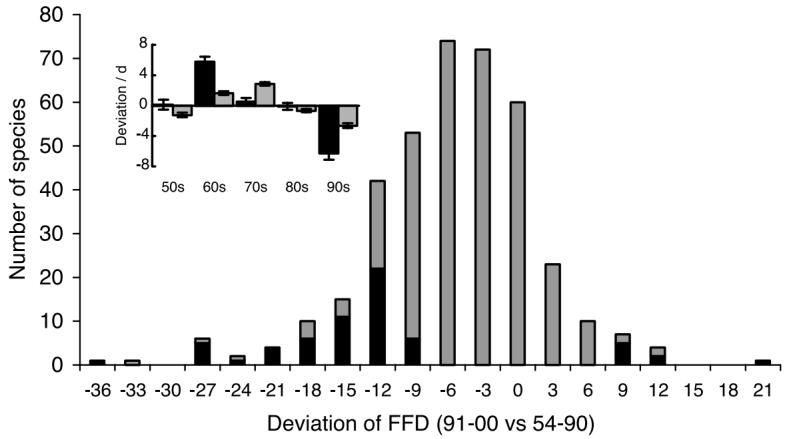
No change



Eucalyptus polyanthemos

Keatley MR et al. (2002) *Int J Climatol* 22: 1769–1780.

Later



Fitter & Fitter 2002 *Science* 296: 1689–1691.

Most of these studies focused on temperate species because of data availability

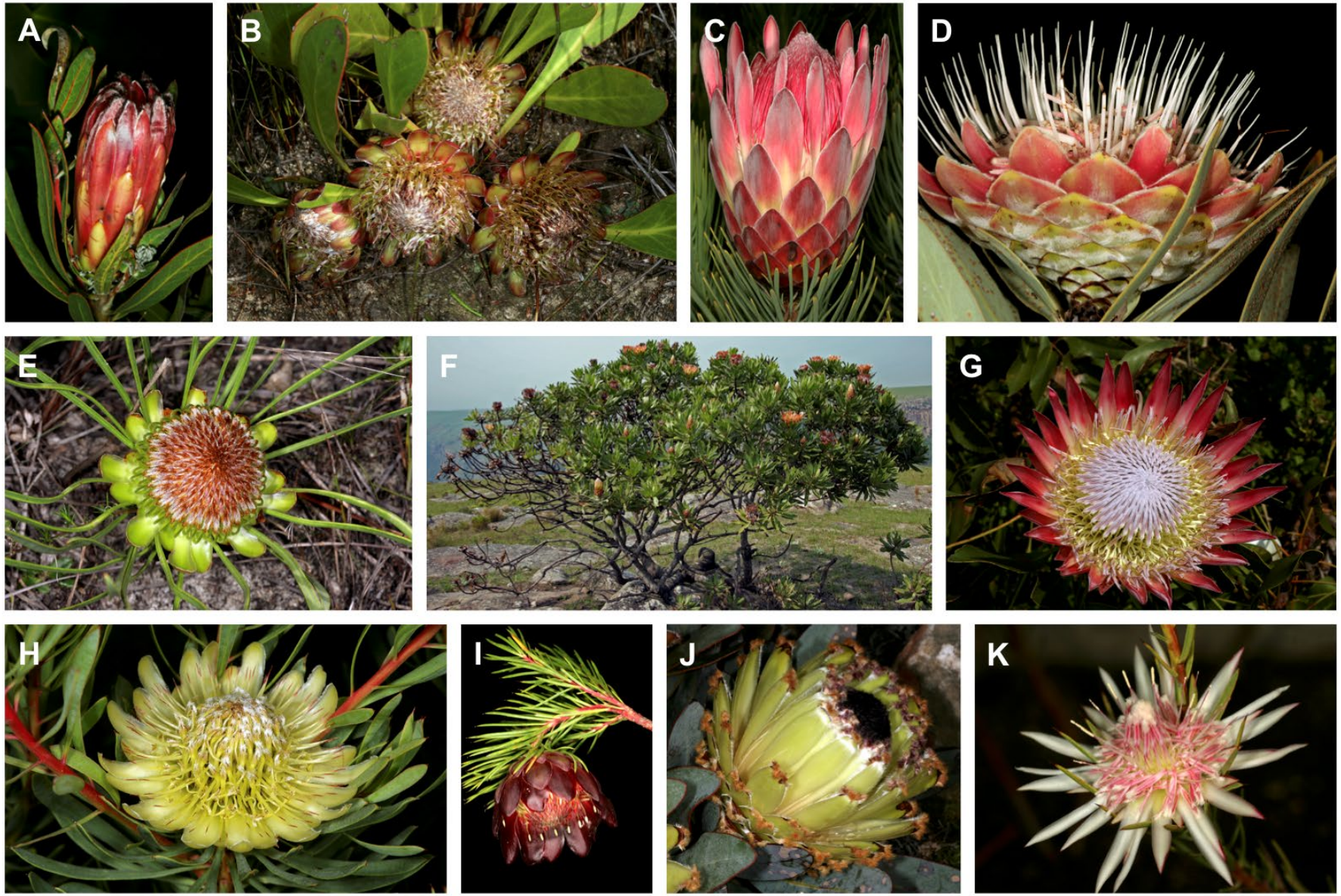
How about tropical and subtropical species?

Here, we use herbarium records to investigate phenological drivers for *Protea* (Proteaceae), an iconic flowering plant genus endemic to sub-Saharan Africa, with its center of diversity in southern Africa.

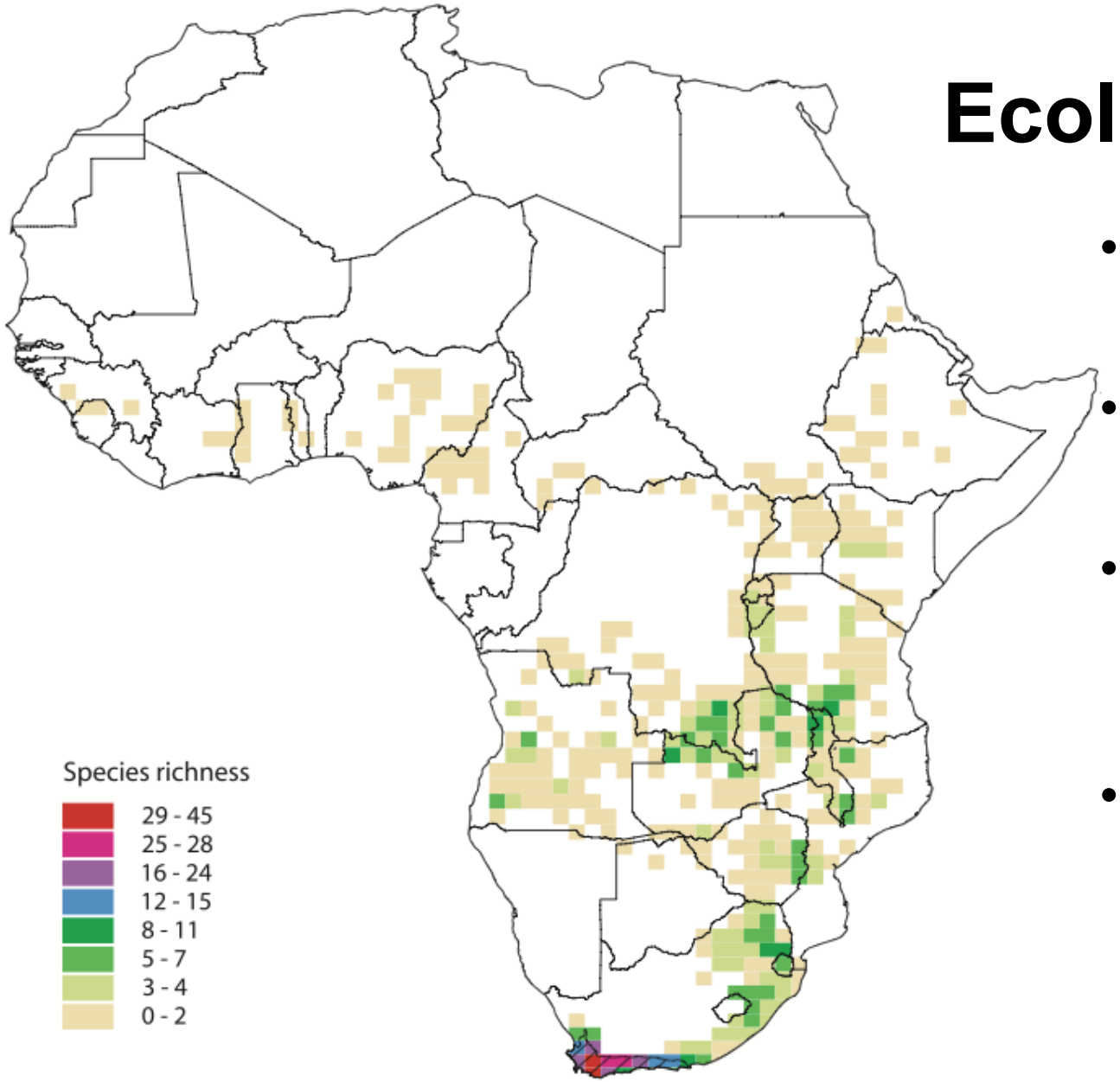
Protea comprises about 115 species

~70 are endemic to Cape Floristic Region

Widely used in horticulture as cut flowers



Ecology of *Protea* in CFR



- The CFR is subtropical, with mean temperatures from 15–18°C.
- Frost is restricted to inland valleys, and snow falls on mountains.
- The western regions receives rainfall in winter, but year-round in the east.
- Elsewhere, most *Protea* species fall in areas with summer rainfall.

Valente L et al. (2010) Diversification of the African genus *Protea* (Proteaceae) in the Cape Biodiversity hotspot and beyond: equal rate in different biomes. ***Evolution*** 64: 745-760.

Phenology of *Protea*

- The genus *Protea* is described as having a year-round flowering phenology.
- Each month of the year has multiple *Protea* species that are in full flower, with spring and summer being most common.

How to track phenological change for species with year-round flowering?

Rebelo AG (2008) *The Protea atlas of southern Africa*. South African National Biodiversity Institute, Kirstenbosch, South Africa.

Data from herbarium records

We used database of 1727 carefully vetted **herbarium specimens** representing 25 species collected between 1950 and 2011 to explore flowering phenology across time and space for *Protea*.

- Collection date
- Locality record (often represented as quarter degree grid cells [QDGC])
- Species identity
- flowering status (whether or not the specimen was in full flower).

Molecular phylogenetic tree derived from 8 gene regions

Flowering phenology from herbarium records

Peak flowering was assessed using the first- and second-order phenological scoring protocol of Yost et al. (2018).

- examine whether any reproductive structure is present
- determined whether flowers were in anthesis

Collection dates converted to Julian Day of Year (DOY; where January 1 = 1 DOY and February 1 = 32 DOY, and so on)

Each location's QDGC was converted to decimal degrees
e.g. QDGC 3419 AD = longitude 19.375 and latitude −34.375.

Yost JM et al. (2018) Digitization protocol for scoring reproductive phenology from herbarium specimens of seed plants. *Applications in Plant Sciences* 6: e1022

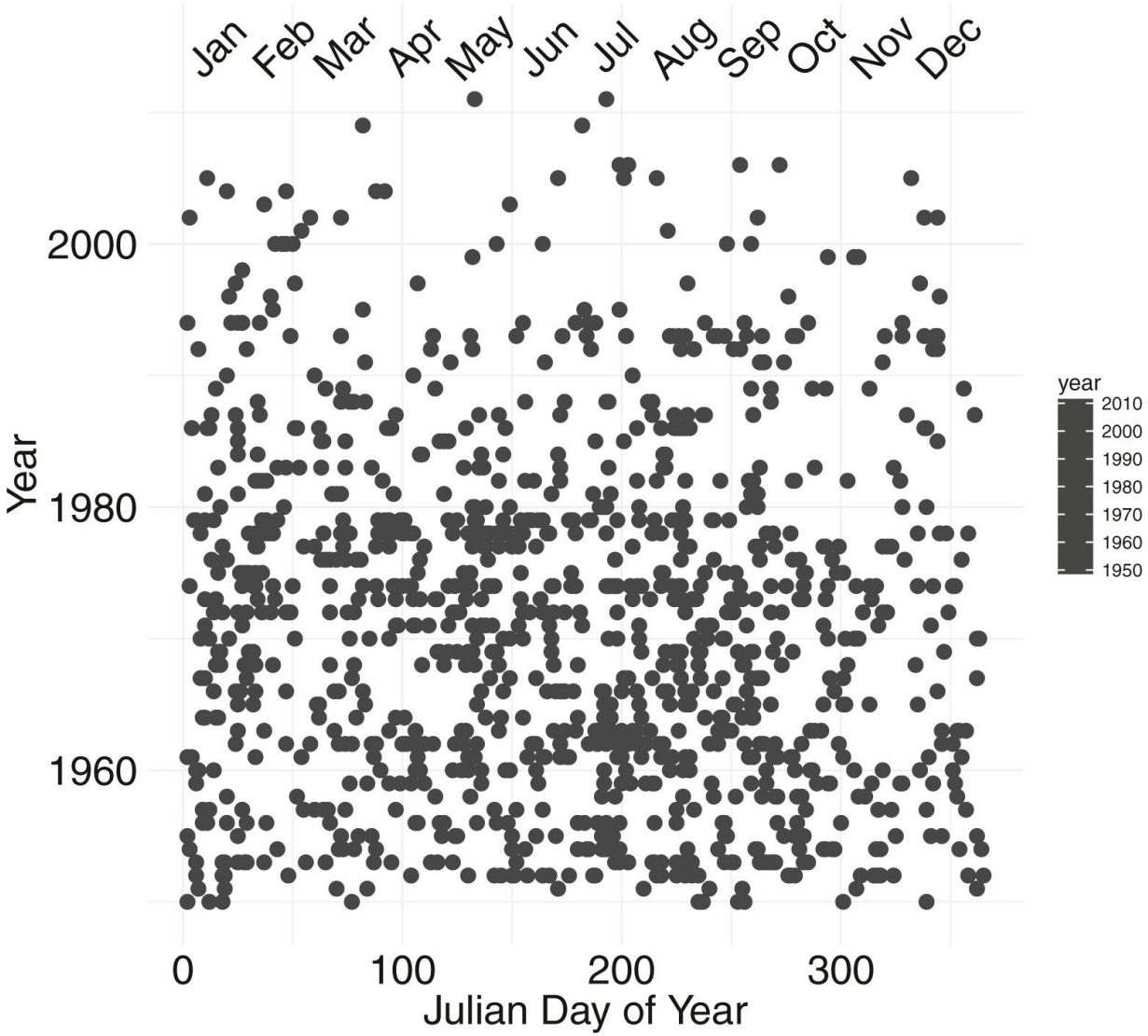
Aim and objectives

We explore flowering phenology across time & space for *Protea*. Specifically, we:

- characterize seasonal and geographic flowering phenology patterns across *Protea* species
- investigate how site-to-site and year-to-year variation in temperature and precipitation influence *Protea* flowering phenology
- test for phylogenetic conservatism in these climatic effects on phenology

RESULTS

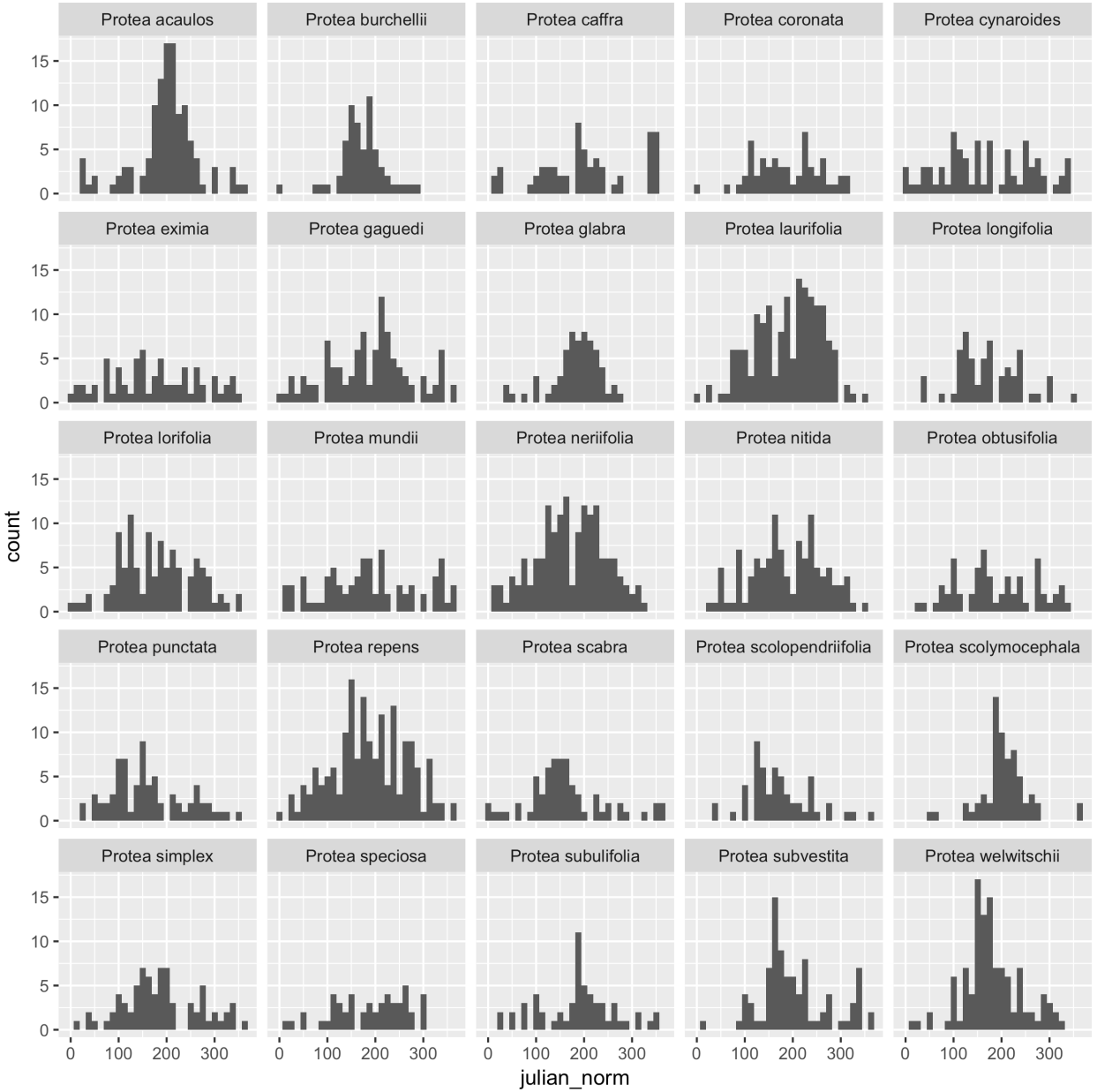
1. Temporally, specimens unevenly distributed across time



early years showing sparse records, and high density of collecting between 1960s and 1980s

Daru BH, Kling MM, Meineke EK & van Wyk AE (2019) Temperature controls phenology in continuously flowering *Protea* species of subtropical Africa. ***Applications in Plant Sciences*** 7: e1232

1. Temporally, specimens unevenly distributed across time



Frequency distribution of collection dates: as a proxy for flowering phenology.

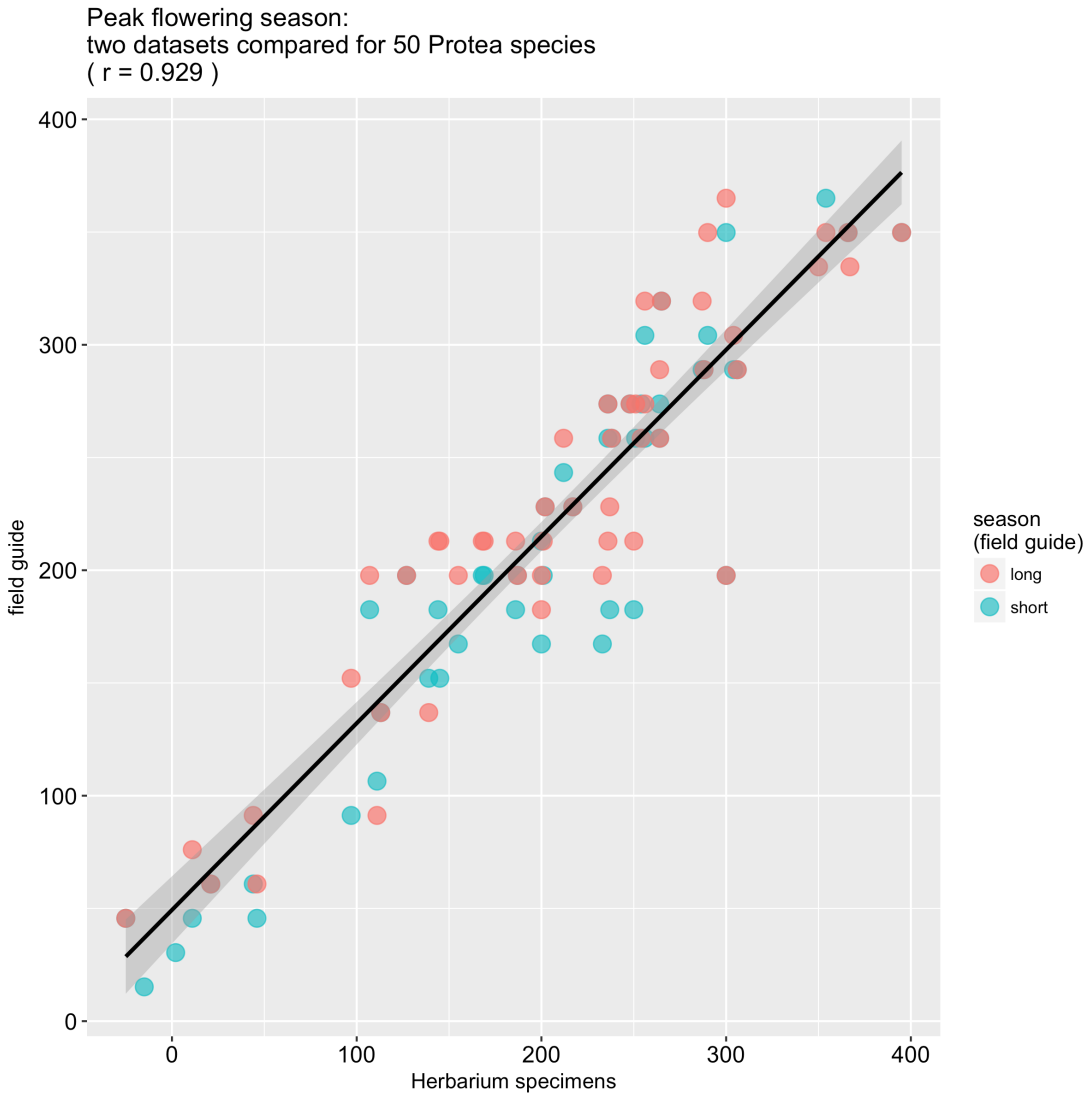
Used *sliding windows* to re-center each species' observations on periods of maximum and minimum flowering activity.

"peak season" = center of sliding 3-month window with largest # of occurrences

"low season" = center of sliding 6-month window with fewest # of occurrences

"aseasonality" = low season: peak season

1. Temporally, specimens unevenly distributed across time

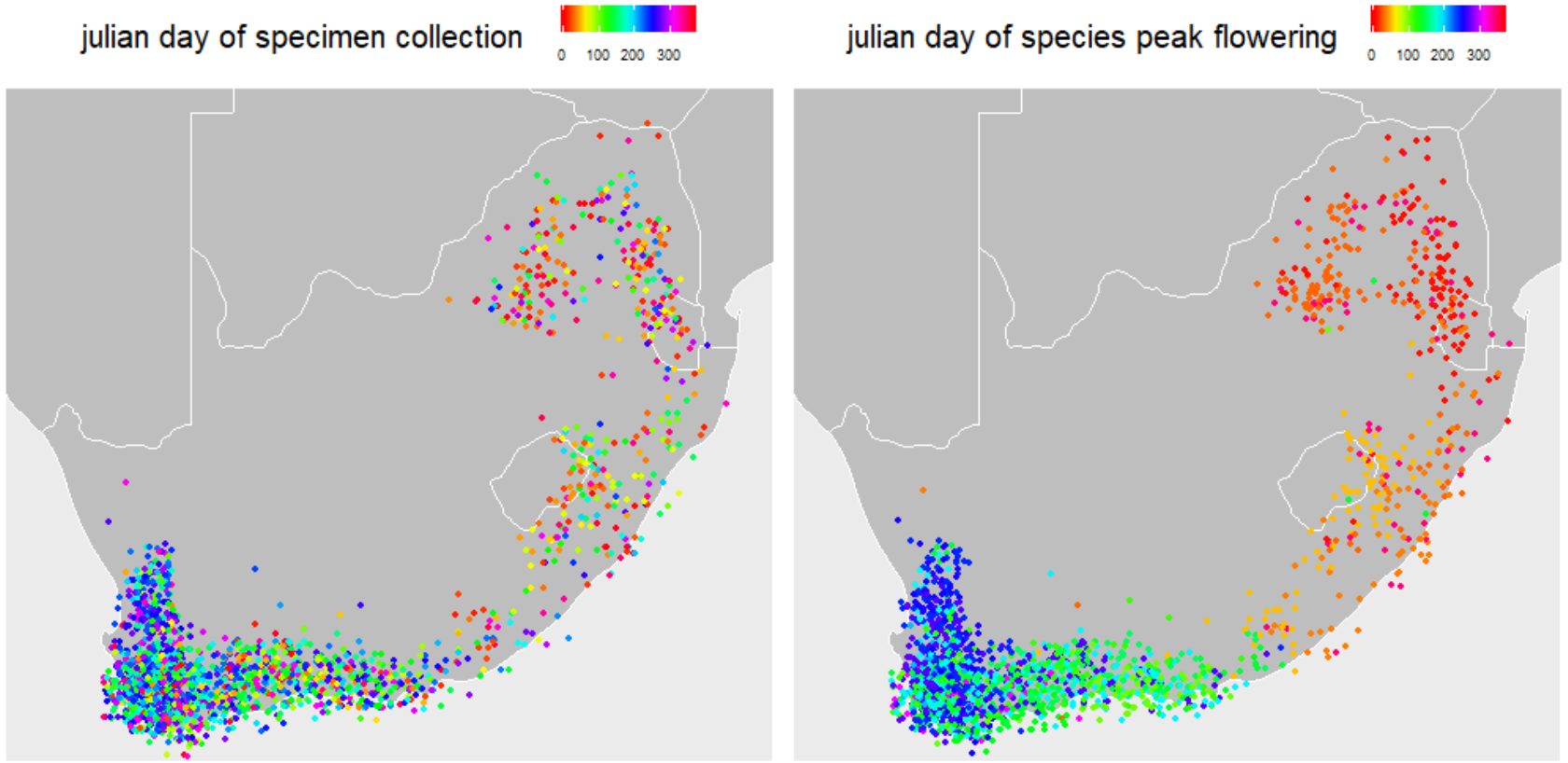


We found strong correlation between collection DOY from herbarium specimens and flowering time in the literature (Rebelo, 2008; r = 0.93)

supports our finding that collection dates on herbarium labels can serve as surrogate for flowering time in *Protea*.

Rebelo AG (2008) *The Protea atlas of southern Africa*. South African National Biodiversity Institute, Kirstenbosch, South Africa.

2. Spatial gradient in peak flowering season



In the Cape Floristic Region, flowering time tended to peak in the winter

whereas the non-Mediterranean regions show flowering during summer

Daru BH, Kling MM, Meineke EK & van Wyk AE (2019) Temperature controls phenology in continuously flowering *Protea* species of subtropical Africa. ***Applications in Plant Sciences*** 7: e1232

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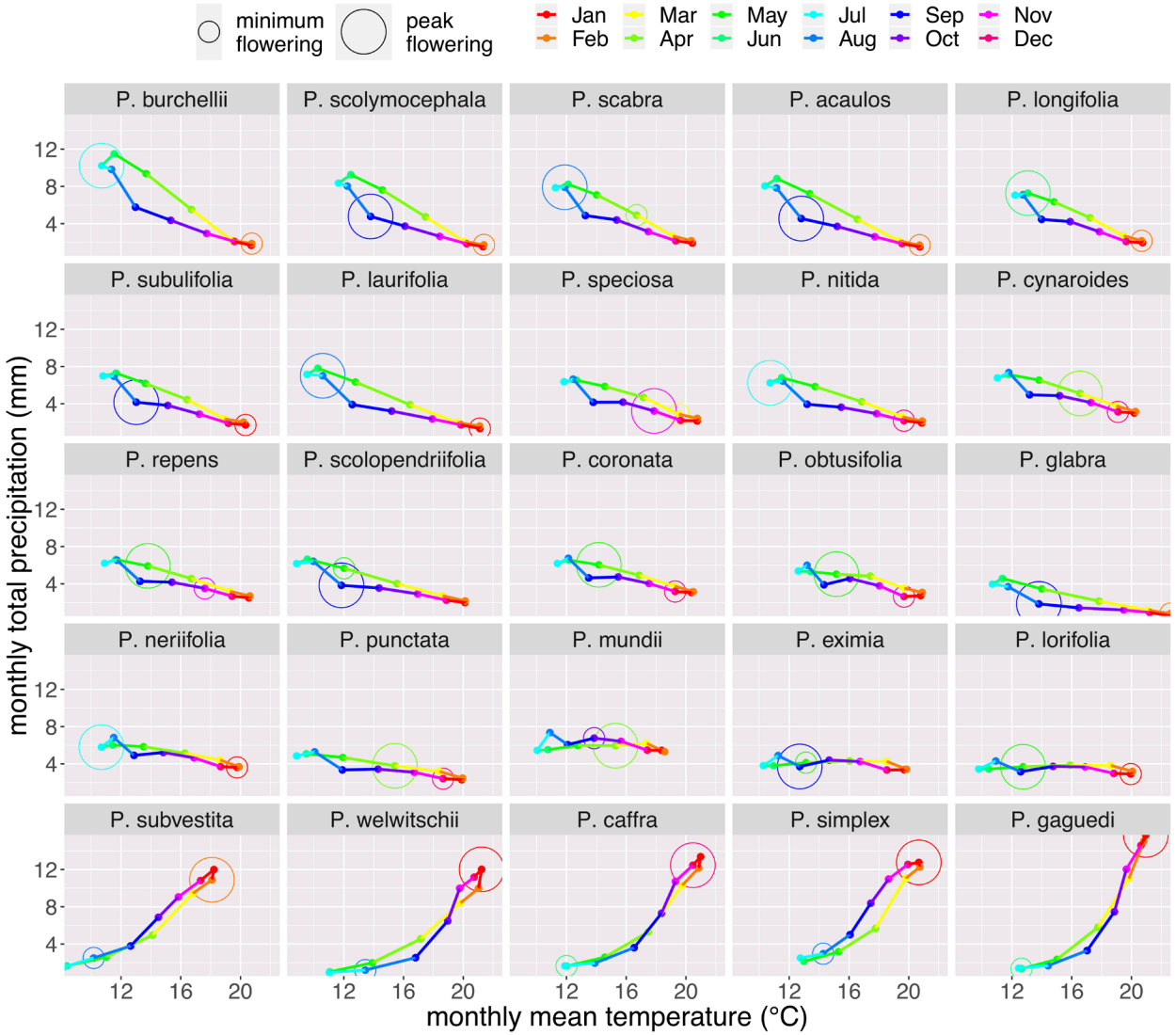


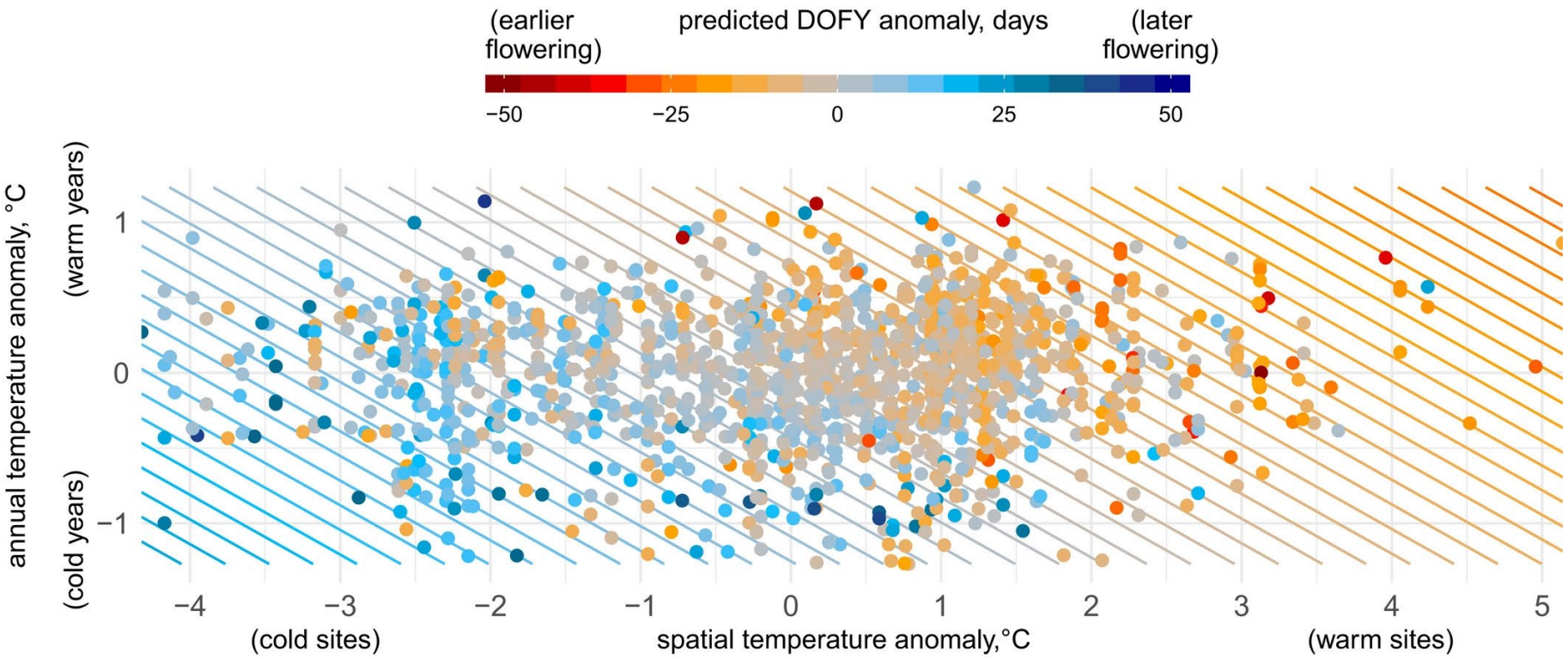
Monthly mean temperature and precipitation and peak and low flowering months for the 25 *Protea* species

In the Mediterranean-type Cape Floristic Region with wet winters and dry summers, flowering time tended to peak in the winter

whereas the non-Mediterranean regions show flowering during summer

Daru BH, Kling MM, Meineke EK & van Wyk AE (2019) Temperature controls phenology in continuously flowering *Protea* species of subtropical Africa. ***Applications in Plant Sciences*** 7: e1232

3. How does climate shape flowering phenology?

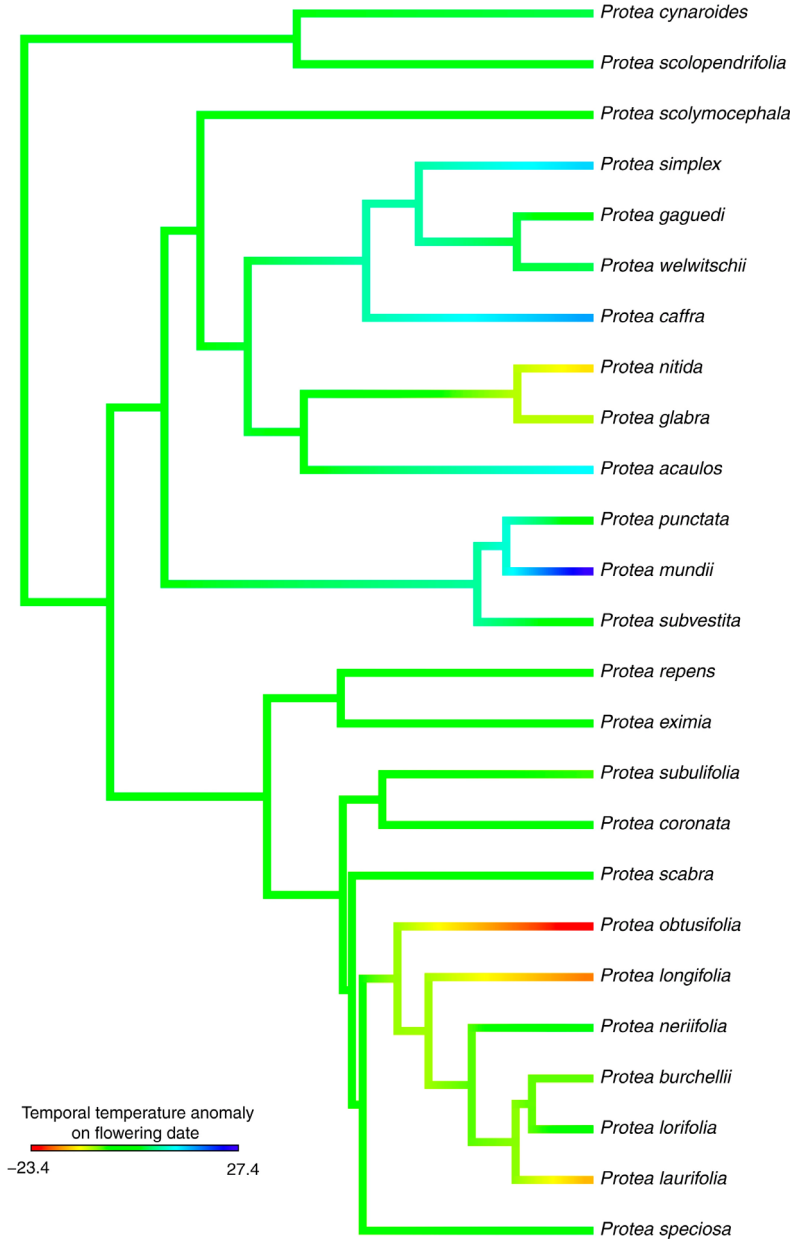


fitted model predictions of phenological responsiveness of *Protea*

In warmer parts of a species range, flowering advances by 3-5 days/°C (χ = 14.45, d.f. = 5, p = 0.013).

At the species level, 56% exhibited advancement in warmer years, e.g. *Protea cynaroides* showing greatest advancement of -9 days/°C

4. Is there evidence of phylogenetic signal in phenology?



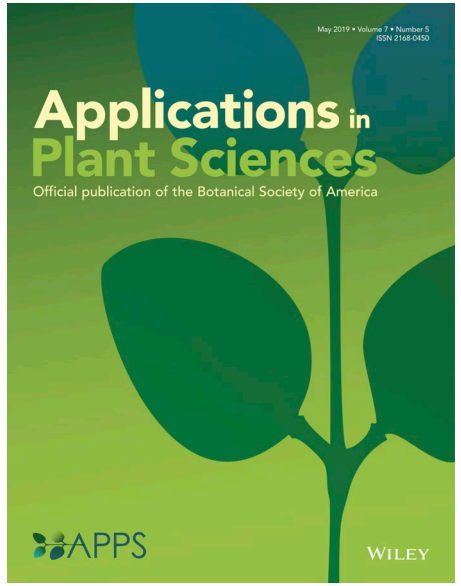
We found a significant, but weak phylogenetic signal

Species within lineages shift flowering time more similarly with climate than expected by chance (Abuoheif's C_{mean} = 0.05, $p < 0.01$; but both $\lambda = 0.00005$ and $K = 0.52$ [ns]).

Summary

- This study provides the first assessment of phenological responses to climate in Africa, within an area unrepresented by historic observational data
- Flowering in *Protea* species advanced by an average of 3–5 days per degree of temperature across both space and time
- Responses are phylogenetically pattern, such that closely related species tended to shift flowering time similarly with temperature.
- Our sliding window analysis can be of broader use across tropical and subtropical regions, where species tend to flower year-round.

THANK YOU



Recommended citation:
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