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Population ecology

Leaf morphology shift is not linked to climate change

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In a recent study, Guerin *et al*. [1] (Guerin, Wen and Lowe, hereafter GWL) used leaf width measurements from herbarium specimens of *Dodonaea viscosa* subsp. *angustissima* collected in South Australia to document two patterns. First, mean leaf width declined with increasing latitude. Latitude in their study region was strongly correlated with mean maximum temperature of the warmest month, such that leaf width declined as mean maximum temperature increased. This pattern is consistent with other studies that have documented predictable spatial variation in leaf morphology along gradients of temperature and moisture [2], implying that climate may exert a strong selection pressure on leaf morphology.

Second, the climate has warmed over recent decades in South Australia, with mean maximum temperature having increased by 1.2°C since 1950 [3]. Given that spatial variation in mean leaf width is linked to mean maximum temperature, GWL predicted that increasing temperature in recent decades should have caused mean leaf width to decline. They found that the herbarium specimens did show a significant decline in mean leaf width over time, concluding that leaf morphology had shifted in response to recent climate warming. The shift was large, with mean leaf width having declined 2 mm (*ca* 40%) since 1882, implying both a rapid and substantial response to climate warming. This is significant because it is one of the first examples of a morphological shift in a plant species in response to recent climate change [4], because the magnitude of the response is so large, and because finding this pattern in a shrub species that lives for several decades implies particularly rapid adaptation. Here I show that, while there is a decline in mean leaf width over time in herbarium specimens of *D. viscosa* subsp. *angustissima* in South Australia, all of the observed decline occurred prior to the onset of climate warming such that changes in leaf morphology are not linked to recent climate change.

Figure 1*a* shows the annual maximum temperature anomaly (relative to the 1961–1990 mean) for South Australia in the period for which data are available (1910–2011; data downloaded from http://www.bom.gov.au/cgi-bin/climate/change/timeseries.cgi?graph=tmax&area=saus&season=0112&ave_yr=0). Maximum temperature has increased over the last century, but a warming trend is apparent only since about 1950 [3]. To determine objectively when warming began, I fitted a broken-line regression model to the data [5], which identified a breakpoint in 1955 where the slope of the relationship between maximum temperature and year changed (see the electronic supplementary material for the R code used to produce figure 1). The regression line fitted for the 1910–1955 period had a negative slope but 95% CIs overlapped zero (figure 1*c*), implying no statistically significant trend towards warmer or cooler conditions during this period. In contrast, the regression line fitted for the 1956–2011 period had a positive slope with 95% CIs not overlapping zero, providing strong evidence that mean maximum temperature has increased since 1955.

If leaf width in *D. viscosa* subsp. *angustissima* has shifted in response to changes in temperature over time, as GWL argue, then the temperature trends in figure 1*a* imply the following: (i) given no significant trend towards warmer or cooler conditions before 1955, mean leaf width should not have changed substantially during this period; (ii) since 1955, the temperature has

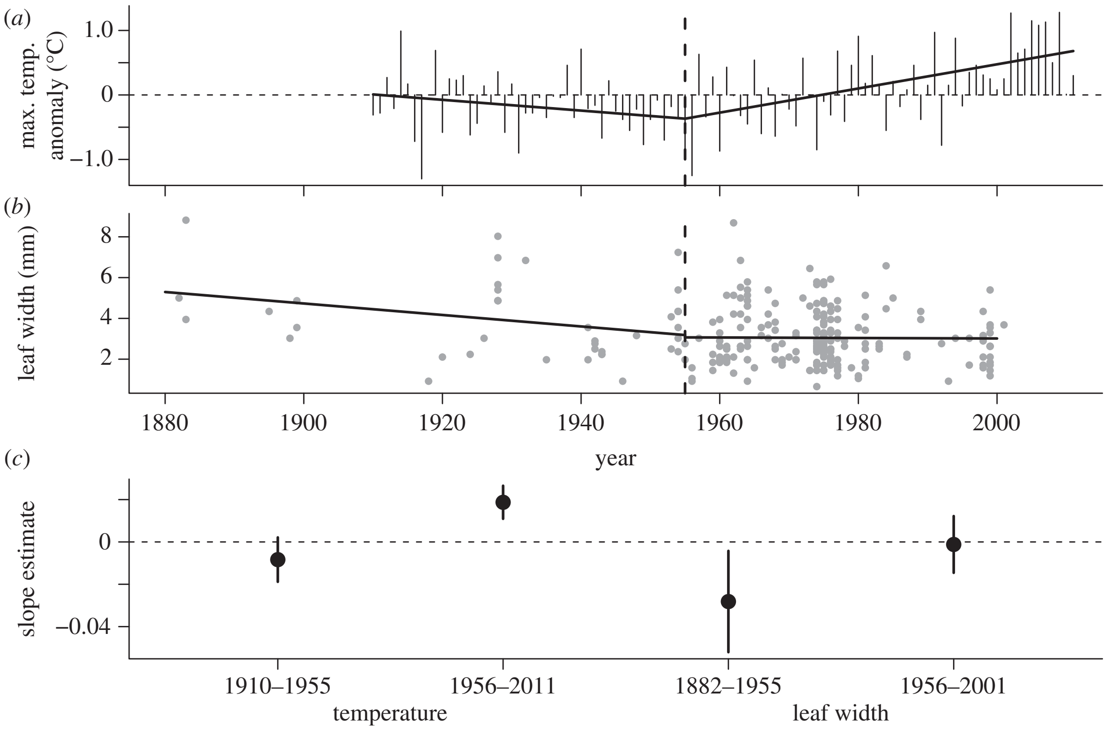

Figure 1. (*a*) Annual maximum temperature anomaly (relative to 1961–1990 mean) for South Australia (vertical bars) for the 1910–2011 period, with a broken-line regression model fitted to the data. The dashed vertical line is at 1955, marking the breakpoint where the slope of the regression line changes. (*b*) Leaf width versus year for 252 herbarium specimens (grey circles) with regression lines fitted to the data for the 1882–1955 and 1956–2001 periods. The dashed vertical line is at 1955. (*c*) Slope estimates for the regression lines shown in (*a*) and (*b*) and their 95% CIs.

increased steadily and mean leaf width should have correspondingly declined in this period.

To evaluate these predictions, I fitted two linear regression lines to the herbarium data for leaf width versus year—one for the collection period prior to and including 1955 (1882–1955), and one for the period after 1955 (1956–2001) (figure 1*b*; using the data in Guerin_Wen_Lowe_latitude_year_data.csv available as a data supplement in GWL, omitting two data points that had missing values for year, leaving 252 observations). I fitted the regression lines including both year and latitude as explanatory variables in the model to allow for any confounding of these variables. The slope of the regression line for year (having accounted for latitude) in the 1882–1955 period was negative with 95% CIs not overlapping zero (figure 1*c*), providing strong evidence that mean leaf width declined during this period in the herbarium samples. The decline was equivalent to that documented by GWL for the full collection period [1]: the slope of the regression line for year (−0.028) implied a reduction in mean leaf width of 2 mm (*ca* 40%) in the 73 years from 1882 to 1955. By contrast, in the 1956–2001 period, mean leaf width remained relatively constant. The slope of the regression line for this period was close to zero (−0.001) with 95% CIs overlapping zero (figure 1*c*), implying no significant trend towards wider or narrower leaves since 1955.

These outcomes are not consistent with the hypothesis that the observed shifts in leaf morphology are linked to climate change. The 2 mm decline in mean leaf width observed in the herbarium data occurred prior to 1955 before the onset of recent climate warming. Since 1955, when maximum temperature in South Australia has increased steadily, mean leaf width has remained constant. There is thus no evidence of a link between changes in mean leaf width and recent climate warming.

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