**Results**

Minimum temperatures, freezing events, and growing degree days

Overall winter and spring temperature data show a gradual warming trend since 1980 at our study site but with absolute low temperatures not changing. We found that the mean low temperatures have been warming through the leaf-out period with February, March, and April warming on average of 0.05° to 0.08C per year for a total of roughly 2.2-3.5°C increase (p<0.001). The daily low temperature has warmed since 1980 (p<0.008), but the record low temperature for each year has not significantly increased since 1980 (p=0.243). Since 1980, the study site has seen fewer days with a low temperature below -2°C in the first four months of the year (Figure 1, p<0.0001, R2 = 0.343, slope = 0.525). Additionally, the Julian date for the last freeze event has advanced since 1980 (p=0.03, R2=0.09, slope= -0.388). Collectively, mean low temperatures have increased at our site and freezing events have become less common but low temperature extremes have stayed largely constant since 1980.

The accumulated growing degree days up to the final freezing event has not changed since 1980 despite documented changes in minimum temperatures (Supp figure; p>0.05). AGDD differed greatly in 2022 and 2023 with AGDD increasing faster in 2023 than 2022. Compared against the long-term average pattern of AGDD since 1980, 2023 was considerably advanced and 2022 was fairly average.

Against the backdrop of long-term temperature changes, the leaf-out period (defined as February to April) in 2022 and 2023 highlight strong interannual variation in winter and spring temperatures. In 2022 there were 41 days below -2°C, with 2023 having only 17 days that reached the same temperature threshold. However, the last freeze in 2022 was on 20 April, much later than the long-term mean of 24 March, while 2023 was slightly earlier than the long-term mean on 19 March.

Phenology

The best model to describe differences in phenology included Julian date and year (Table 1). We found that phenology significantly advanced with Julian date (p<0.001) and that plants exited dormancy earlier in 2023 than in 2022 (p<0.001). Species did not feature in the best model for phenology despite *L.* *tulipifera* having earlier bud development than *A. saccharum* in both years. In 2022 buds for *A. saccharum* began showing signs of activity on 7 April and on 24 March in 2023 (Figure 2). For *F. grandifolia* activity in 2022 began on 15 March and in 2023 on 2 March, with *L. tulipifera* signs of activity observed in 2022 on 7 April and in 2023 on 2 March. Notably, the National Phenological Network reported that in the southeastern United States, spring in 2023 was approximately 20 days ahead of 30-year leaf index dates (1991-2020, USA National Phenology Network 2023) in and around our study site. In comparison, the spring in 2022 was in-line or behind the 30-year index for the southeastern United States.

Thoughts on GDD – We can use growing degree days to show few things and deal with the reviewers who focus on phenology. At our site, 2023 was obviously warmer than average, we find this whether we look at GDD or just mean temperature. We also see that the GDD before the date of the last freeze hasn’t changed since 1980. This means that the amount of warmth trees experience before the last freeze doesn’t seem to increase or decrease through time. If it had increased, then that would suggest phenology could be advancing (because it is forced through GDD) while late spring frost hasn’t changed.

A graph of a number of years

Description automatically generated

New Figure X: Accumulated growing degree days since January 1st for study years (2022 – dotted, 2023 – dashed) and long-term average from 1980-2021 (solid lines with SD[gray shaded area). 2023 being warmer than 2022 and long-term average. 2022 being a pretty average year.

A graph showing the number of years

Description automatically generated

Supplementary figure X: Accumulated growing degree days up until the last freezing date since 1980. For each year I found the last day with a 0C temperature and then calculated GDD up until that date.



GDD (top row) and Julian Day of year (bottom row) for phenophases 2 and 3 for each species in each sample year.