Thermal optima and heat stress reveal vulnerabilities in a common butterfly

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Background

Silver-spotted skipper (*Epargyreus clarus*)[1]

- Larvae eat many legume spp. (Fabaceae)
- Winters as pupa
- Occurs across North America (Fig. 2)
- Number of generations per year (voltinism) varies
    - more generations at lower latitudes
    - May interact with climate change[10]

Fig 1. Clockwise from top left: new silver-spotted skipper egg; egg later in development; hatchlings; adult butterflies

Climate change & generations

- ⇑ Higher accumulation of growing degree days (GDD)
- ⇓ Extreme weather and phenological mismatch[11,12]

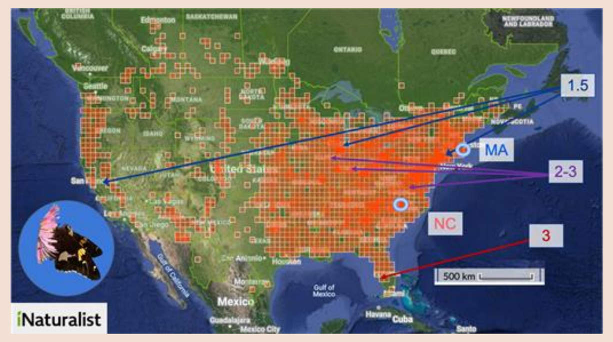


Fig. 2 Range map of silver-spotted skipper from iNaturalist[2] observations with MA and NC noted. Numbers on the right indicate number of generations, with 1.5 indicating a partial 2nd generation. Sources[1,3,4,5,6,7,8,9]

Adaptation Potential

- Thermal limits[10]
- Preserved obligate species interactions
    - e.g., larval host-plants, symbionts[12]
- Ability to add partial generations (bet-hedging)
- Longer growing season may increase voltinism

Methods

Silver-spotted skippers have been extensively studied in the DC region. To expand existing data[7], we collected eggs from populations (circled in map):

- south (NC)
- north (MA)

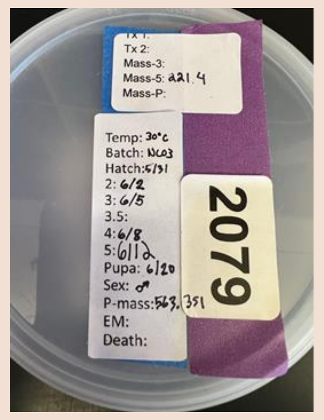


Fig. 3 Above: sample record of one individual's rearing temperature, source and development; left: final-instar silver-spotted skipper larva.

We measured

- growth and development
- the effect of diet on immune function (data not shown)
- survival and fitness,
- thermal performance.

To evaluate thermal performance, we reared individuals at five oscillating temperatures: 16C, 21C, 26C, 30C, 34C, all +/- 5C.

Results

Survival and Development

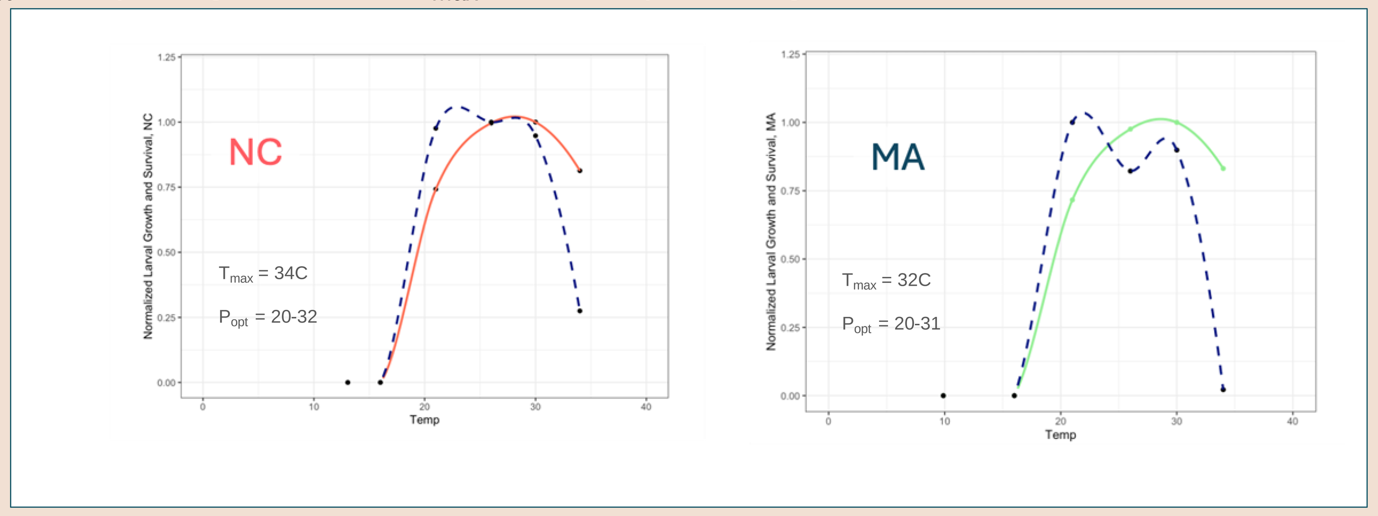
- At 16 +/- 5C, none survived to adulthood. Most died prior to the 2nd of five instars.
- Growth rate increased with temperature until 34 +/- 5C, at which, growth rate and survival fell.
- Growth at 30C was slightly higher vs 26 in MA cohort, and no different in NC.
- MA larvae grew more slowly and had higher mortality.

Diapause

- Most (90%) of MA pupae entered diapause. Those with direct development (n = 7) had faster growth.

Estimated thermal performance curves (TPC) Fig. 4

- Solid lines indicate relative growth rate at given temp (x); dashed lines indicate relative survival (y)
- Optimal performance in the temperature change where both curves >= 50%[13]
- T_{opt} is the peak growth rate; T_{max} is the temp where growth rate decreases



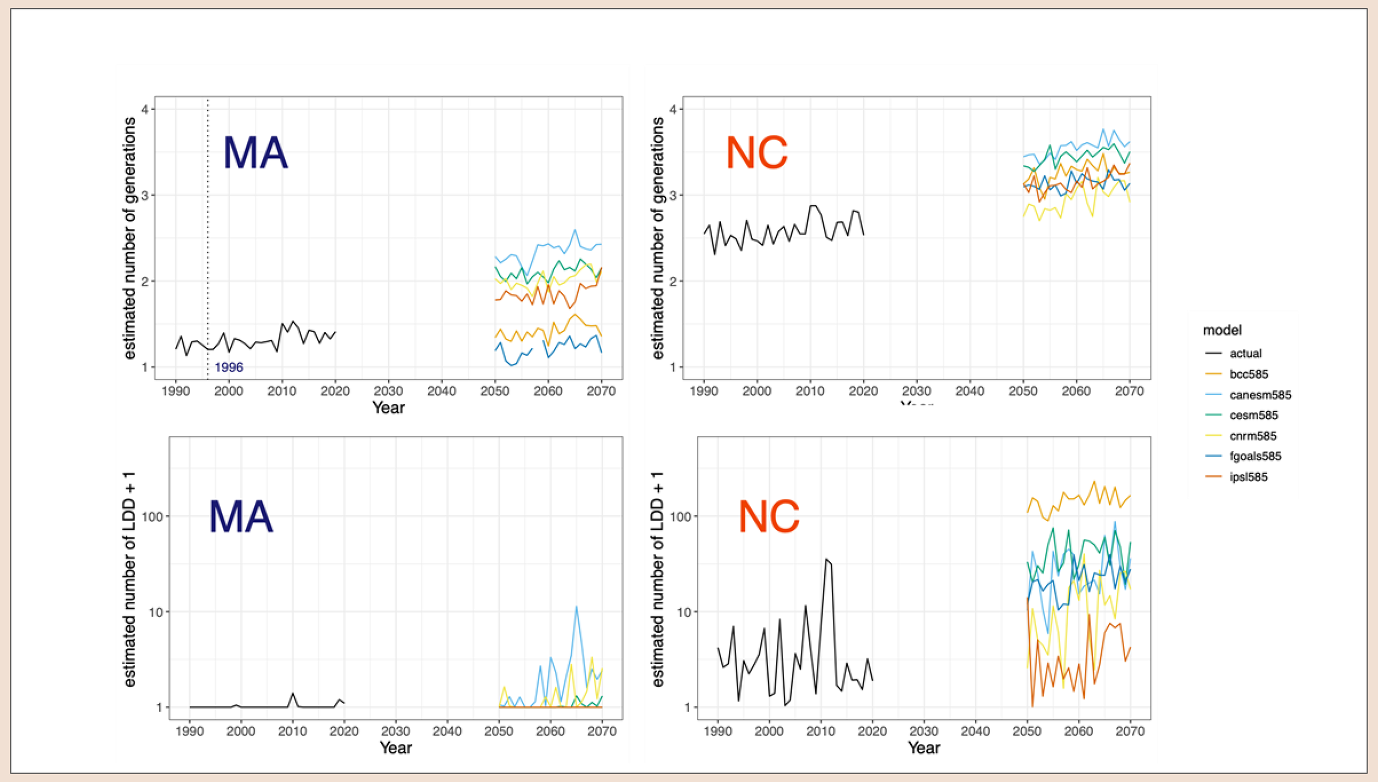


Figure 5: Forecasting

Top: total Growing Degree Days (GDD) calculated from thermal performance results accumulated between May 1-Sep 30 calculated from past temperature (1990-2020) and predicted future models (2050-2070). MA has 1-1.5 generations according to the model, with caveats; these may stay the same or increase in future. 1996 (the dashed line) is the first year that the last skipper observation in MA was later than August.[5] NC has had 2-3 generations, with 3-4 predicted in the future.

Bottom: total LDD (+1 for log scale) calculated as for GDD: LDD indicates heat stress accumulated above the GDD Tmax. MA experienced almost no LDD between 1990-2020, and is predicted to remain low. In contrast, NC has had cyclical years of high LDD, and the most extreme climate model predicts an increase to >100 LDD.

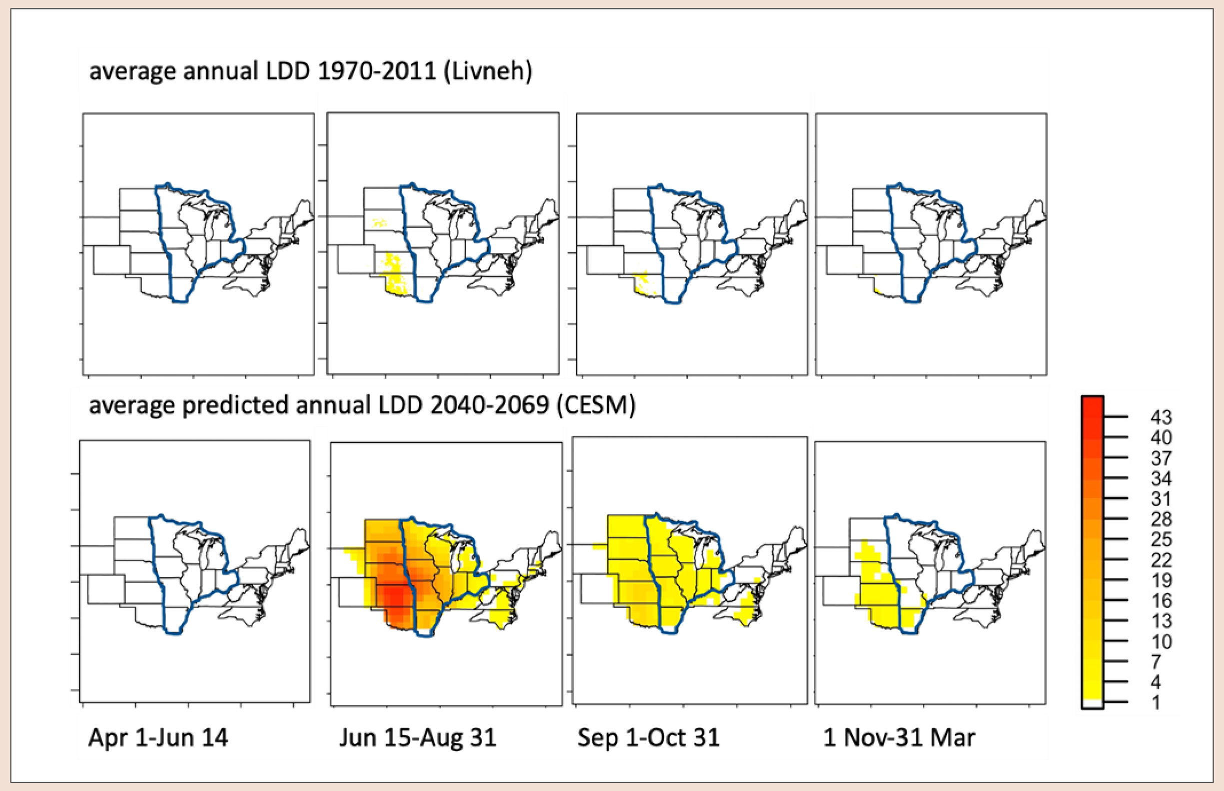


Fig. 6: Example of intended output. Thermal tolerance of *Speyeria idalia*. Color ramp indicates seasonal LDD averaged over the years indicated, for north-central USA. LDD are predicted to increase, especially in mid-summer. Data visualization by Naresh Neupane.

Conclusions & Ongoing Work

- In the future, developmental rate & # of generations could increase, or be blunted by LDD
- More work is needed to understand the effect of temperatures above the linear range.
  We do not yet understand the extent to which a species can tolerate LDD at any given developmental stage, and/or to what extent the sequence and intensity of GDD/LDD matter.

NEXT:

- Validate the phenology and generations predicted by GDD models using citizen science data, including decades of structured citizen science survey data
- Expand model to other areas of range and validate
- With the same citizen science data, investigate the role of other factors threatening butterfly populations

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