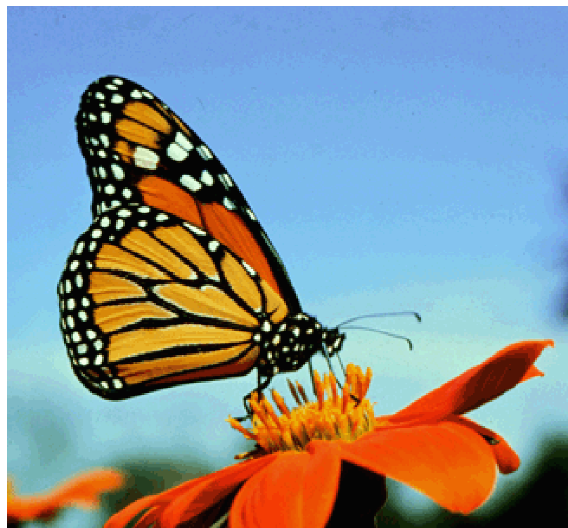
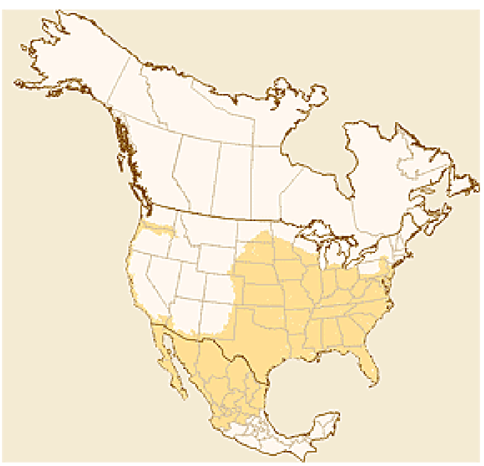
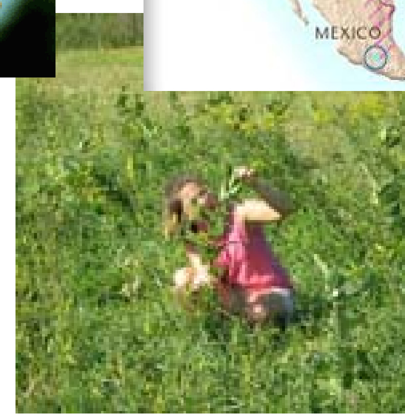
Tracking climate's impacts on butterflies using data from citizen scientists

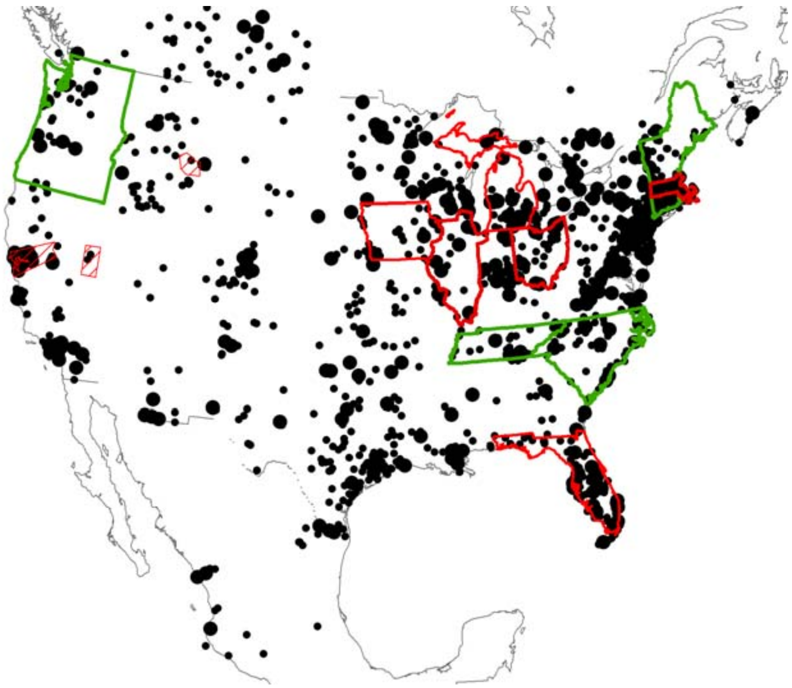
Leslie Ries, UMD, Biology and Socio-environmental Synthesis Center

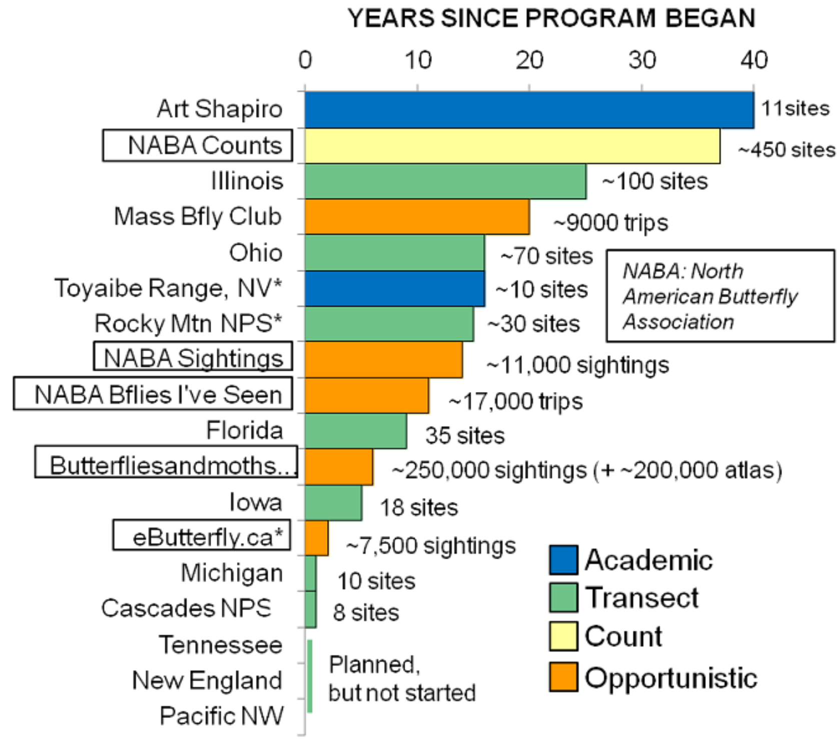






Butterfly monitoring programs are popular and growing in North America

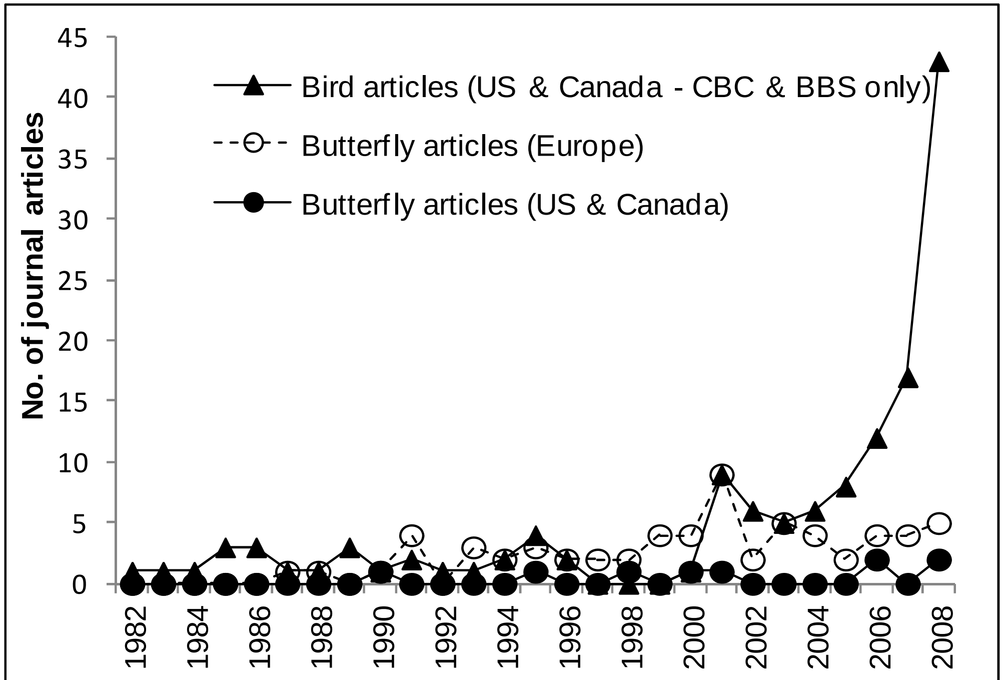




Thousands of butterfly surveys are conducted every year in North America…

…and new programs are emerging.

Yet these resources have received little use by the scientific community



The number of articles from monitoring data in refereed journals each year shows a lag in the development and analysis of butterfly data, especially in North America.

WHY?? Data are little known, hard to access and harder to use

<u>PROJECT OBJECTIVES:</u>

- Public access to monitoring data – for scientists and the general public
- Visualization tools for data exploration
  - Maps
  - Population Trends
- Knowledgebase for North American butterflies (US, Can)
  - Life history, ecological and morphological data
  - Photos
  - Parameter values from published studies
- Analytical approaches for invertebrate monitoring data

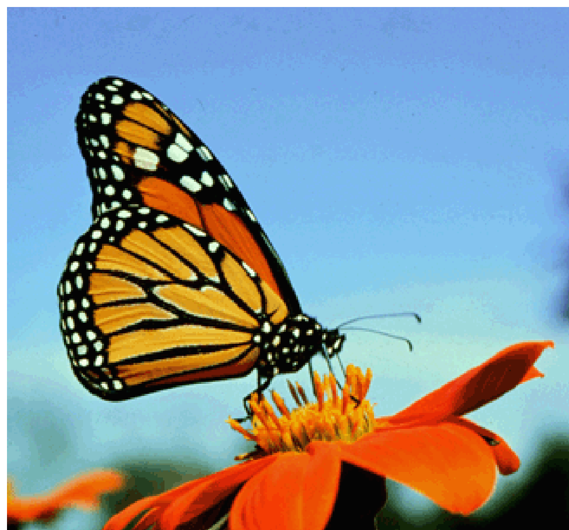
- Goal 1: To include all North American butterfly monitoring projects in our network
- Goal 2: To standardize protocols and data as much as possible
- Goal 3: To develop or enhance data management systems
- Goal 4: To build data download, visualization, and analytical tools
- Goal 5: To expand program participation

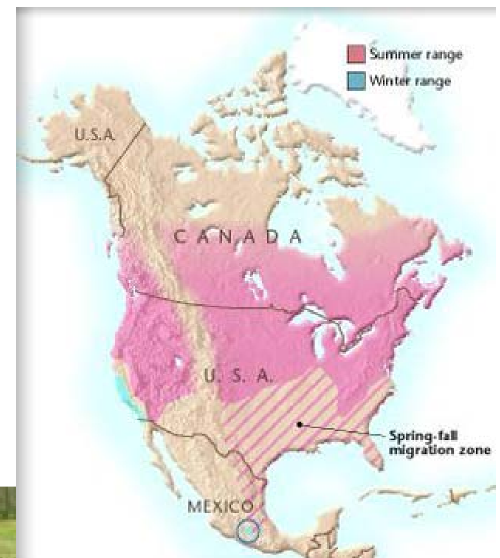
OPPORTUNITIES FOR COLLABORATION:

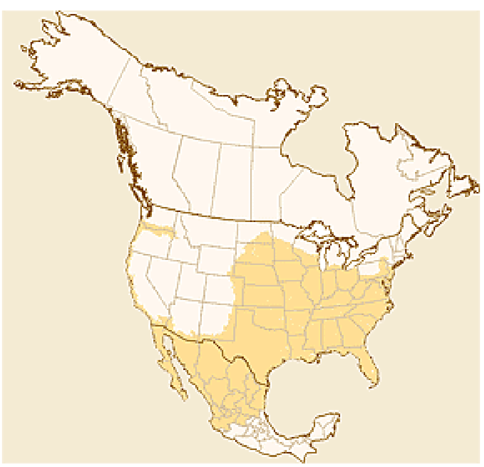
- Use of data for graduate or undergraduate research projects
- Incorporating resources in classroom exercises to introduce “big data approaches”

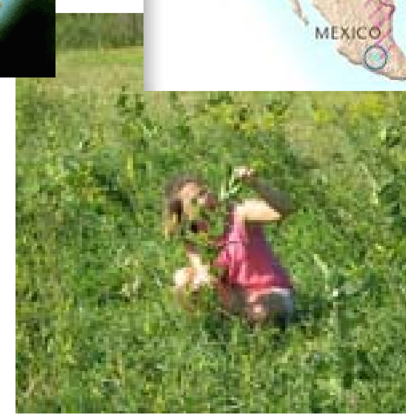
Tracking climate's impacts on butterflies using data from citizen scientists

Leslie Ries, UMD, Biology and Socio-environmental Synthesis Center







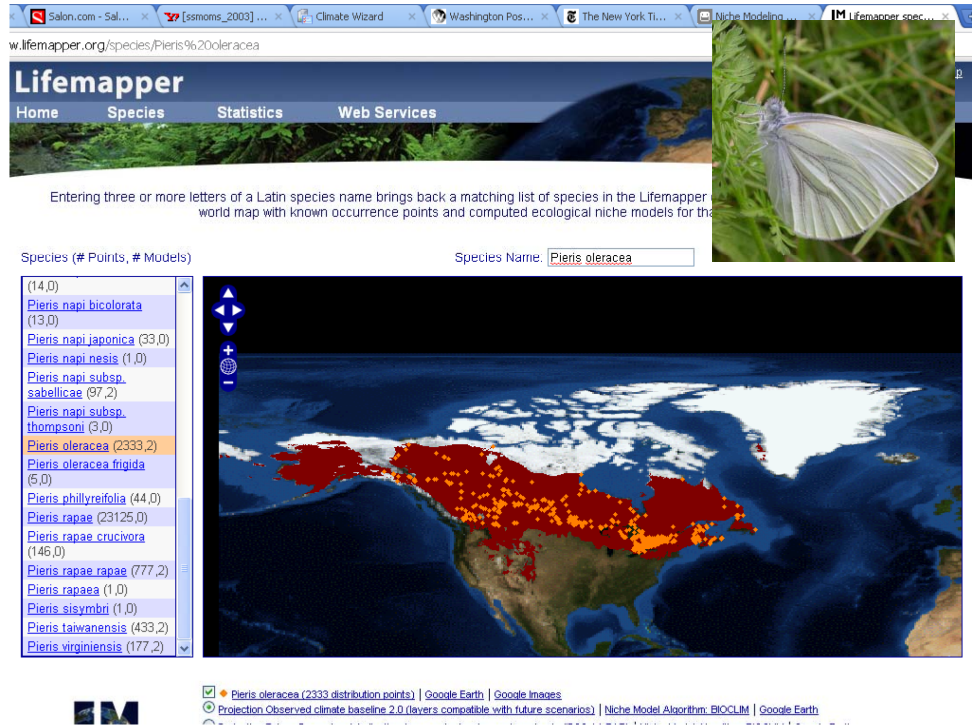


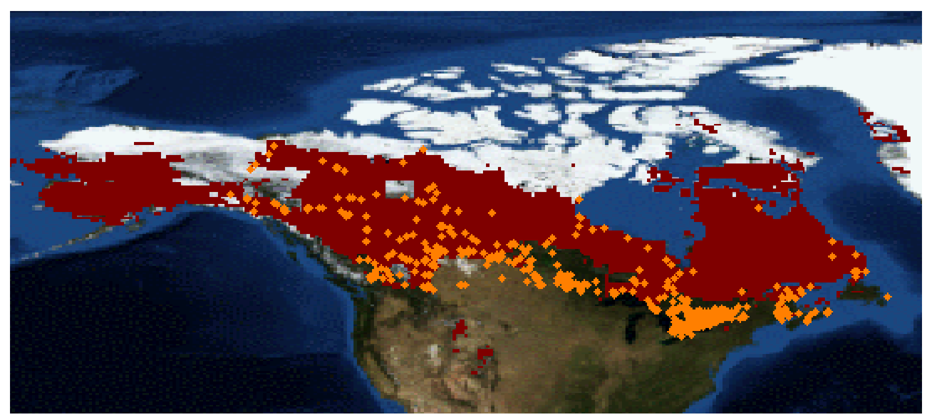
How does climate impact butterflies?

- Changing climates can enhance growth or challenge the physiological tolerances
- Changing climates can shift the distribution or emergence timing of interacting species
  - host or nectar plants, natural enemies or mutualists
- These dynamics can combine to shift range distributions or impact population numbers
- Climate vignettes
  - Using mechanistic species distribution models to predict current range limits:
    - Sachem butterflies
    - Monarch butterflies
  - How does climate influence yearly fluctuations in monarch numbers?
  - Can climate induce phenological mismatches in migrating monarchs and their host plants?

Correlative Species Distribution Models (SDMs)

- Correlative SDMS use known occurrences to identify current ranges and infer underlying environmental correlates
- Assuming that those correlates are driving current ranges, researchers can predict future range limits under different climate scenarios
- BENEFITS:
    - Long history of model development
    - Availability of digitized museum records and new sightings data allows models to be applied for a diverse group of organisms
- DRAWBACKS:
    - Occurrence records lack information on absences, abundances, or changes through time
    - Correlative approaches provide weak evidence for causation
    - There is usually no independent data set to test model predictions





Mechanistic SDMs make predictions based on physiological or other mechanistic data

• Mechanistic models can be used to translate environmental conditions (often thermal constraints to growth or energetics) into biologically relevant metrics (survivorship or fecundity) and thus predict distributions at large scales.

• BENEFITS:
  - • Specific mechanisms are identified *a priori*
  - • Allows independent distribution data to test predictions and identify specific weaknesses and strengths of the models

•DRAWBACKS:
  - • Lack of data for most organisms
  - • Short history of model development
  - • Lack of model transferability between organisms
  - •“Canned” climate layers may not include appropriate information

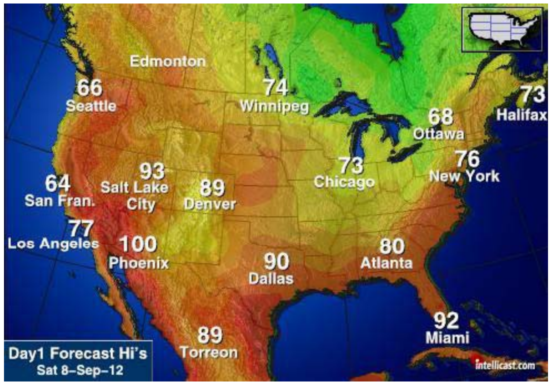
Goal: Predict current (and future) distributions

- Take laboratory-measured temperature tolerances and how they impact growth and survivorship
- Obtain climate data to estimate how the climate environment would translate into growth
- Use that to predict the range and also the predicted abundance gradients within that range

GDD calculations

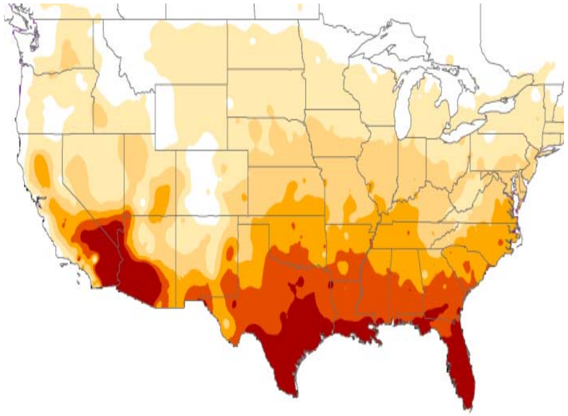
+

Daily highs and lows (1990-2009)



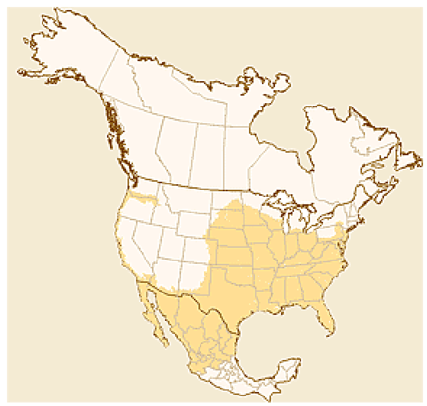
=

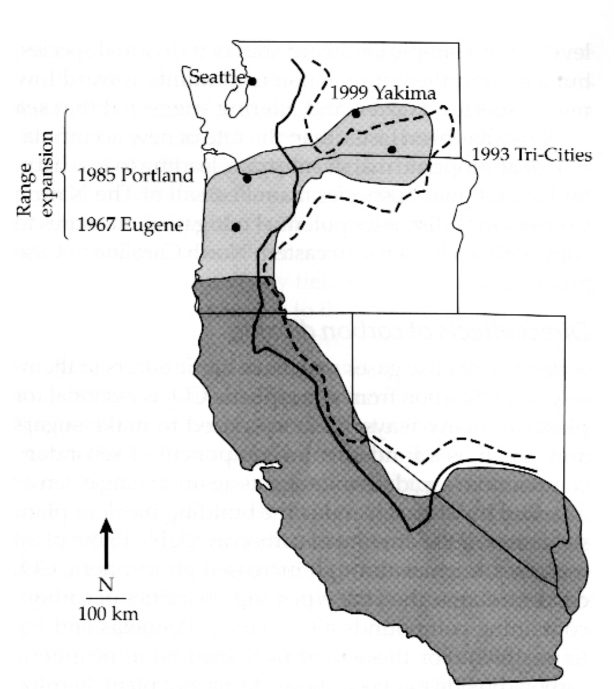
Predicted number of generations



Modeling the distribution of the sachem butterfly using mechanistic models

- Leslie Ries[1], Jessica Turner[1], Lisa Crozier[2], and Thomas Mueller[1]
- [1]University of Maryland
- [2]NOAA NW Fisheries Center





- The sachem butterfly (*Atalopedes campestris*) recently expanded its range into Washington state.
- Winter temperatures had been rising in the area

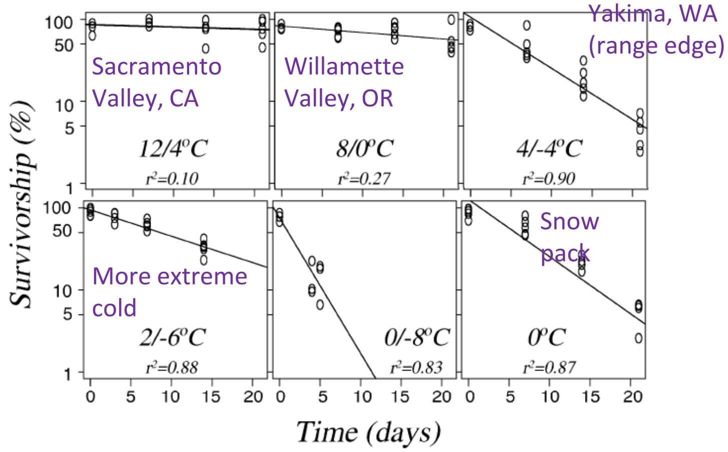
Natural history notes: a common, open-area species that uses several grasses, including common grasses such as Bermuda and crab grass

Her model focused on overwinter survival, but included summer recruitment as well

Laboratory experiments

Exposed larvae to environment mimicking January high/low temps:

Crozier 2003



$$\lambda = \varphi[T_w(L,t)]R[T_s(L,t)].$$

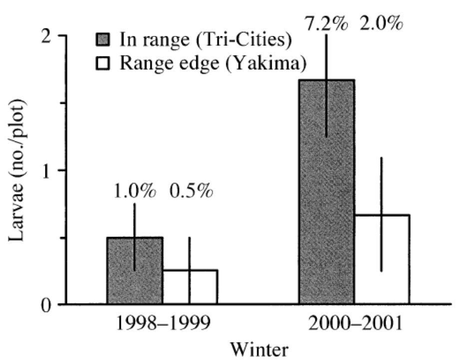
Annual growth — Winter survivorship — Summer Recruitment

Winter survivorship is a function of mean January temperature

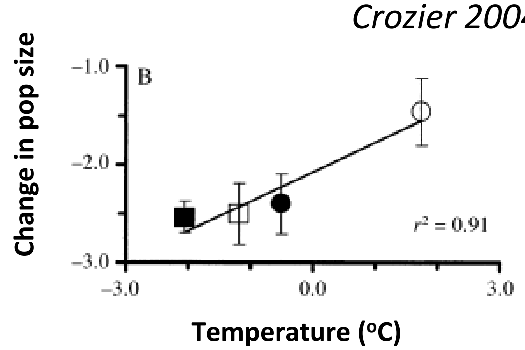
Summer recruitment is based on growing degree days

Field studies (experimental and observational)

Transplanted larvae and observed survivorship and tracked population growth.



Crozier 2004



Focus of model development was definitely on cold limitations

Sachem model projections

Model is based on field and lab experiments

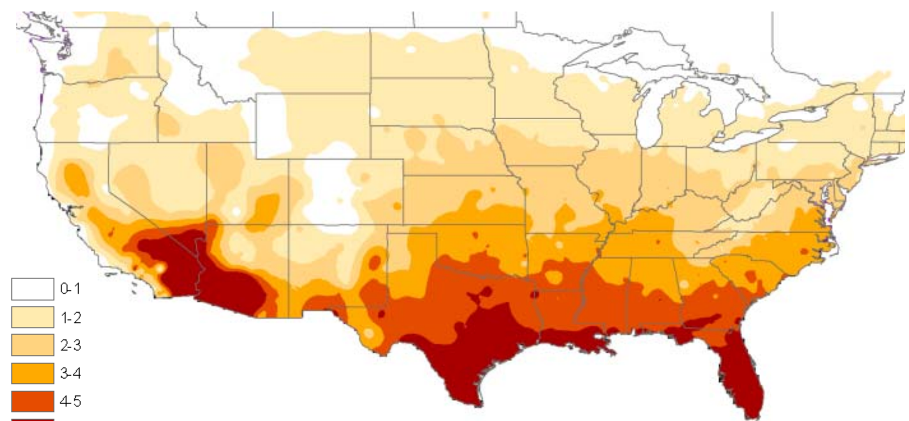
$$\underline{\lambda} = \underline{\varphi[T_w(L,t)]}\,\underline{R[T_s(L,t)]}.$$

Annual growth — Winter survivorship — Summer Recruitment

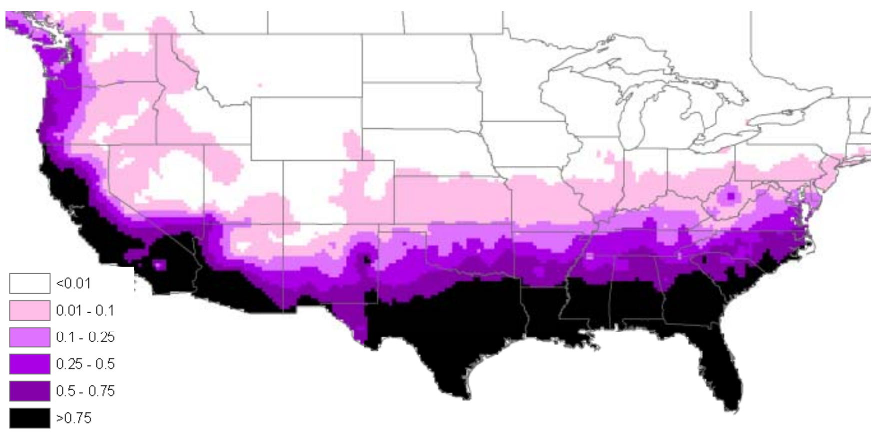
Winter survivorship is a function of mean January temperature

Summer recruitment is based on growing degree days

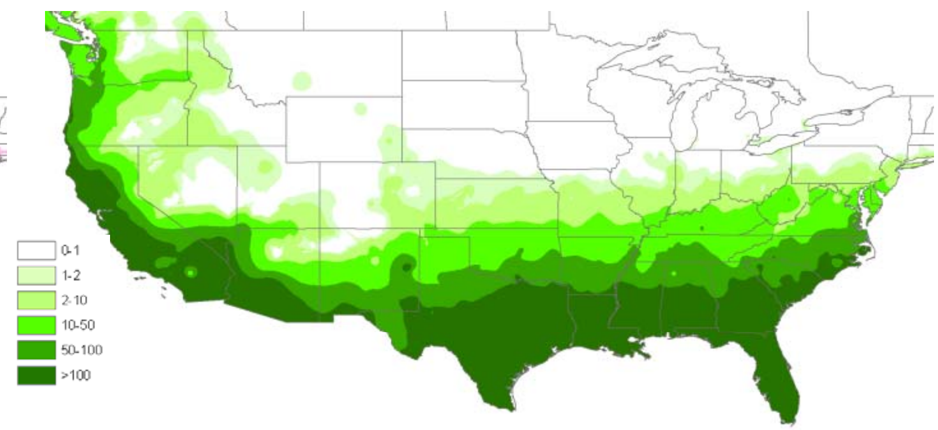
Predicted summer recruitment



Predicted winter survivorship: Φ

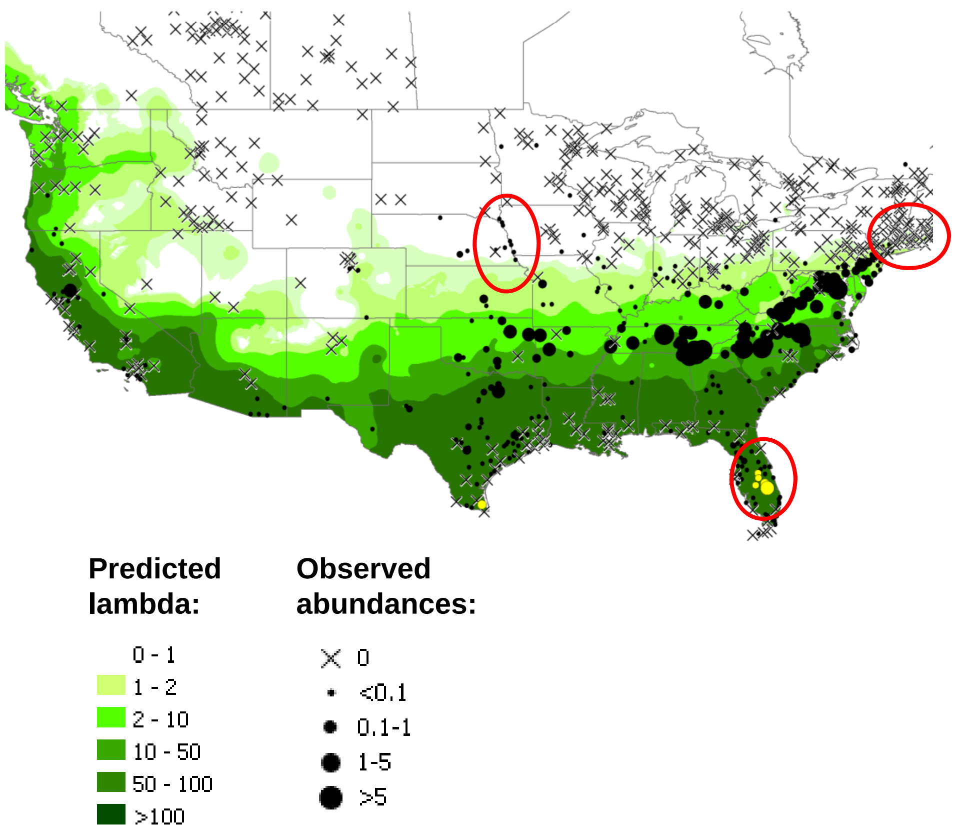


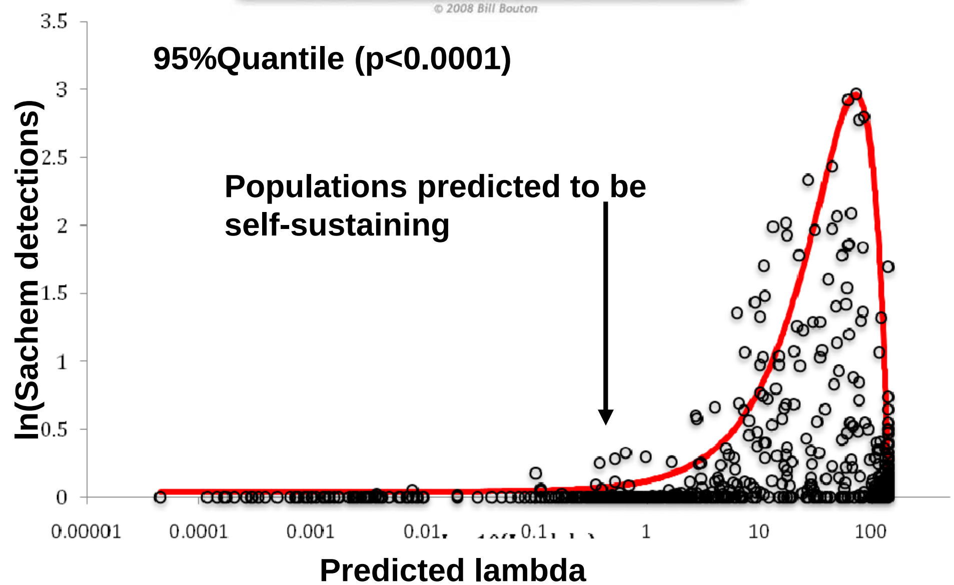
Predicted λ



Predictions based on NOAA weather station data (1990-2009 average)

Comparing observed distributions to a mechanistic model for the sachem butterfly (*Atalopedes campestris*)



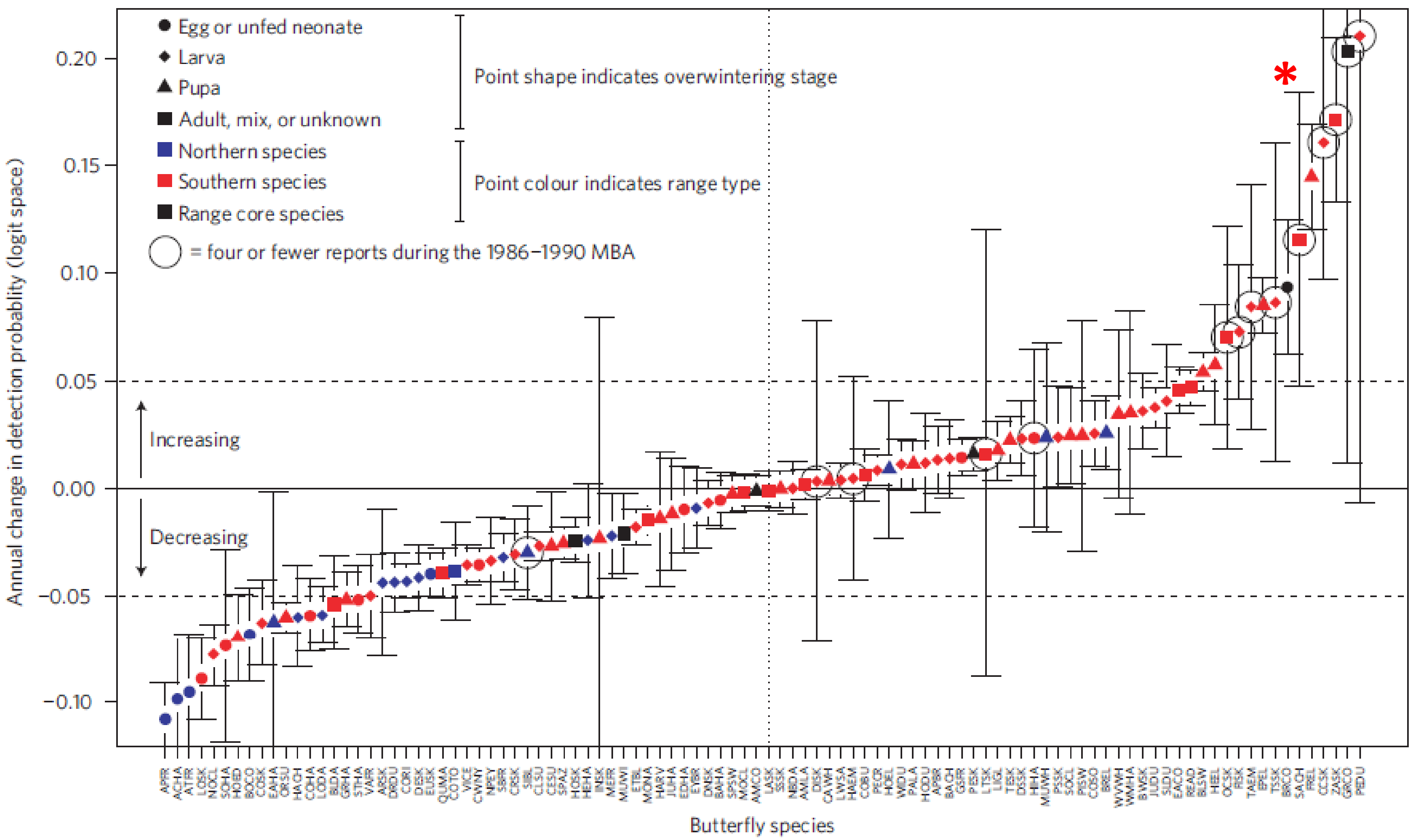


Turner, Ries, Mueller, and Crozier, in prep

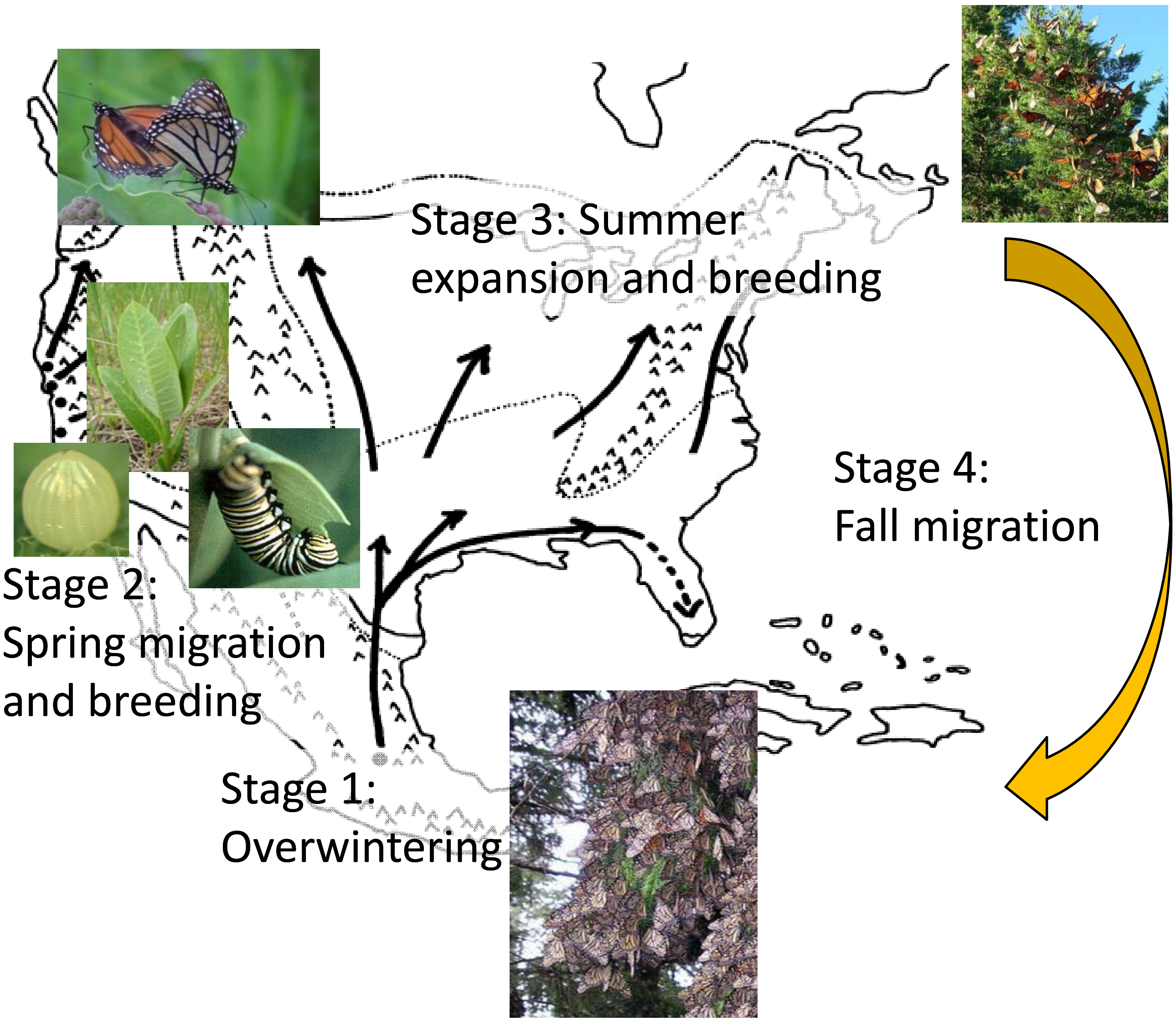
The model does a fairly good job at capturing the limiting factors of cold, and could be used to predict range expansions (expanding northward) – but the model needs to be improved before we could predict negative impacts of warming at the southern boundaries

One study shows the sachem increasing in MA

Breed et al. 2012. Nature Climate Change

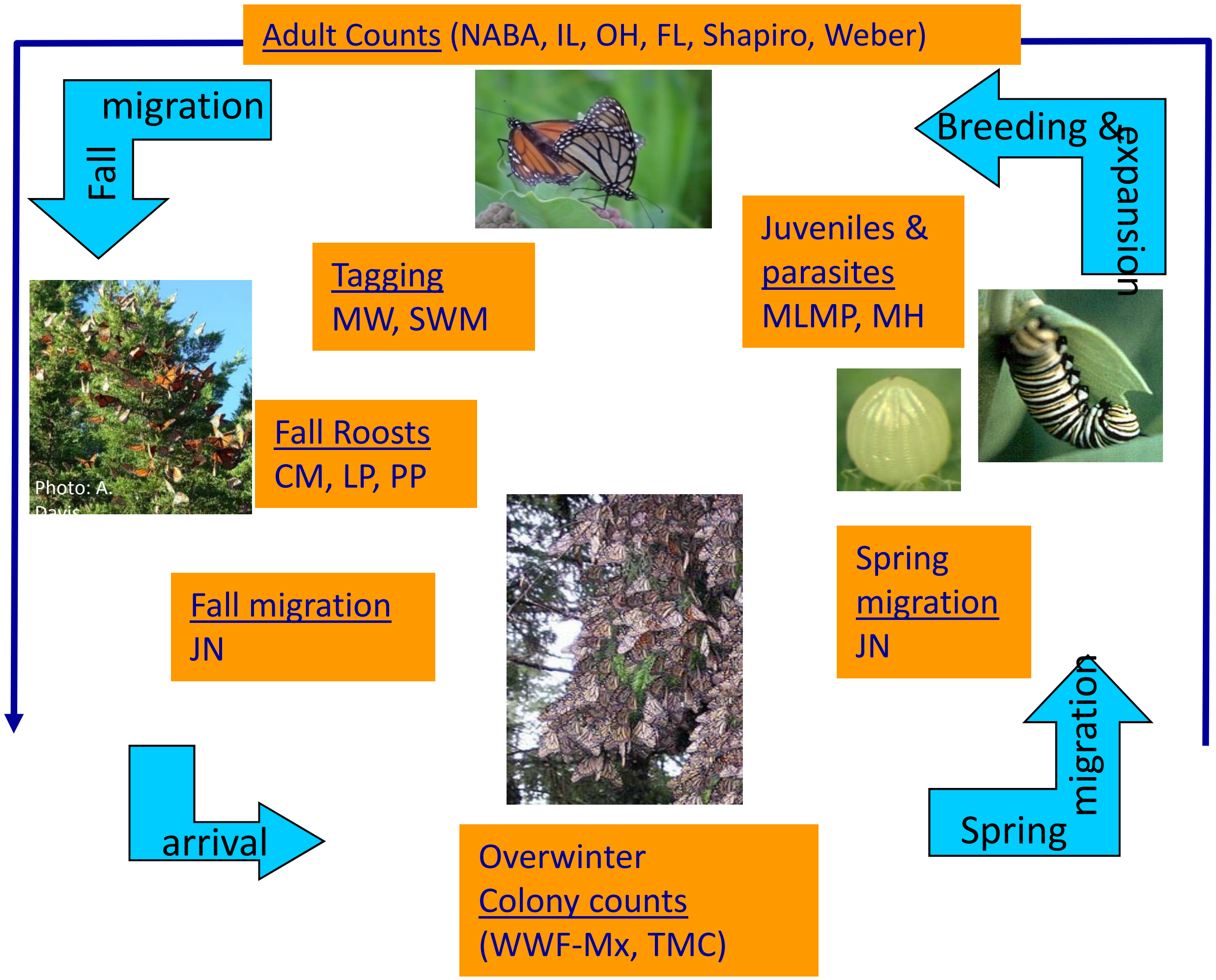


Monarchs have a complex migratory cycle that makes tracking climate impacts challenging



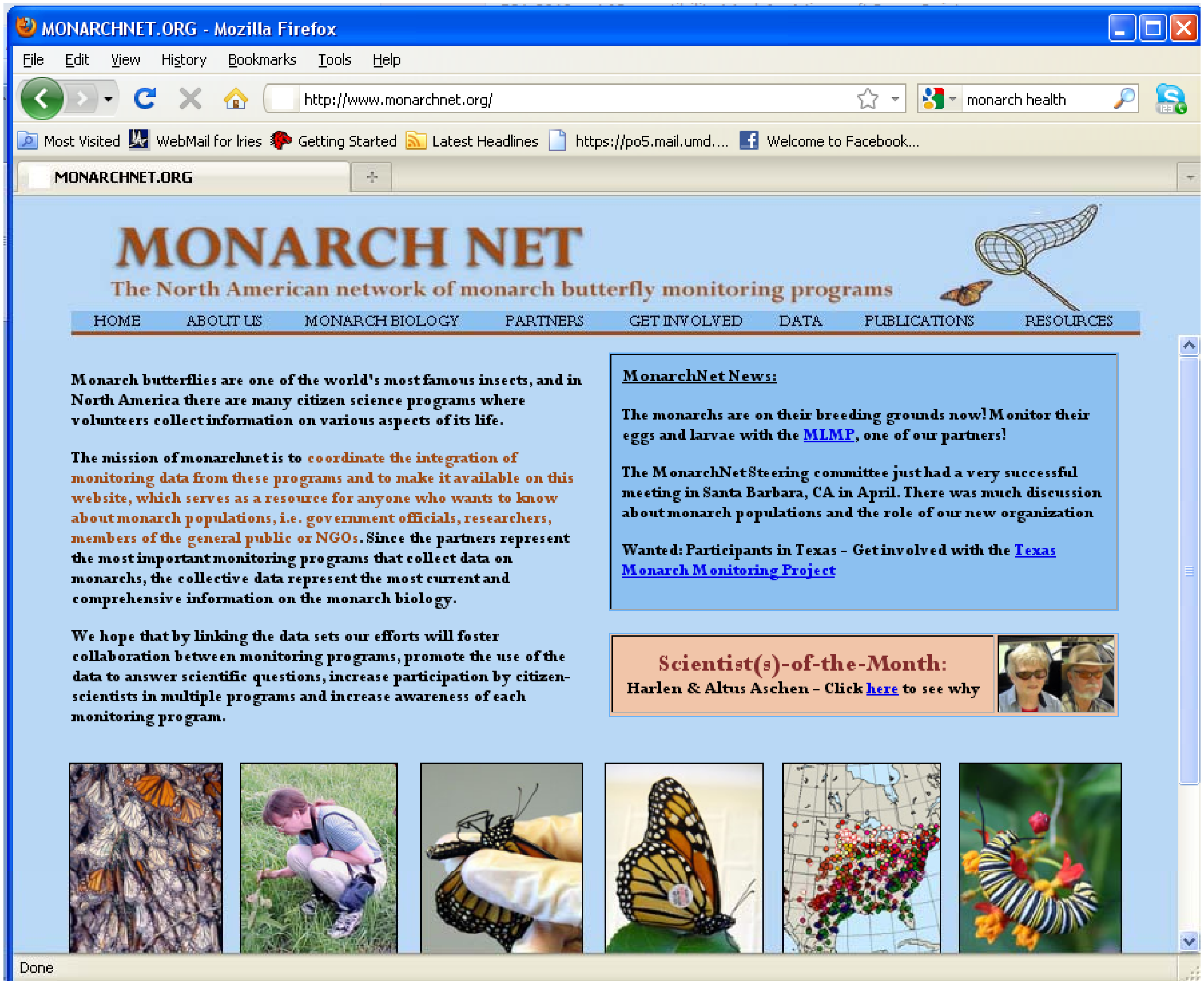
- *Dynamics in one stage have carry-over effects into subsequent stages*

Monarchs are one of the most intensively monitored species



MONITORING PROGRAMS
NABA: North American Butterfly Association count program
IL: Illinois monitoring network
OH: Ohio monitoring network
Shapiro: No. CA monitoring program
Weber: MN monitoring site
MLMP: Monarch Larvae Monitoring Project
MH: Monarch Health
JN: Journey North
WWF-Mx: World Wildlife Fund in Mexico
TMC: Thanksgiving Monarch Counts
MW: MonarchWatch
SWM: Southwest Monarchs
CM: Cape May roost monitoring
LP: Long Point roost monitoring
PP: Peninsula Point roost monitoring

A new partnership among multiple programs: Monarch Net

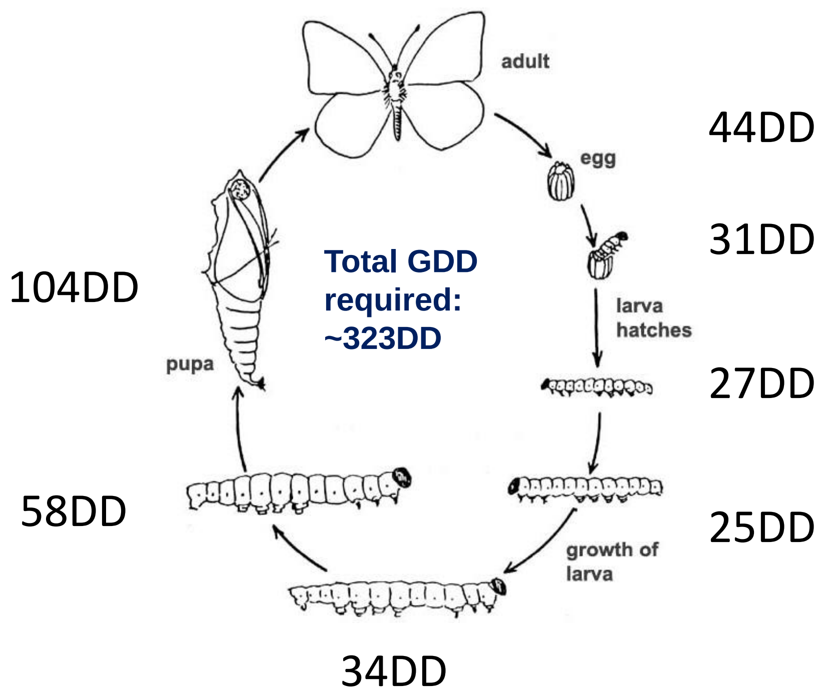


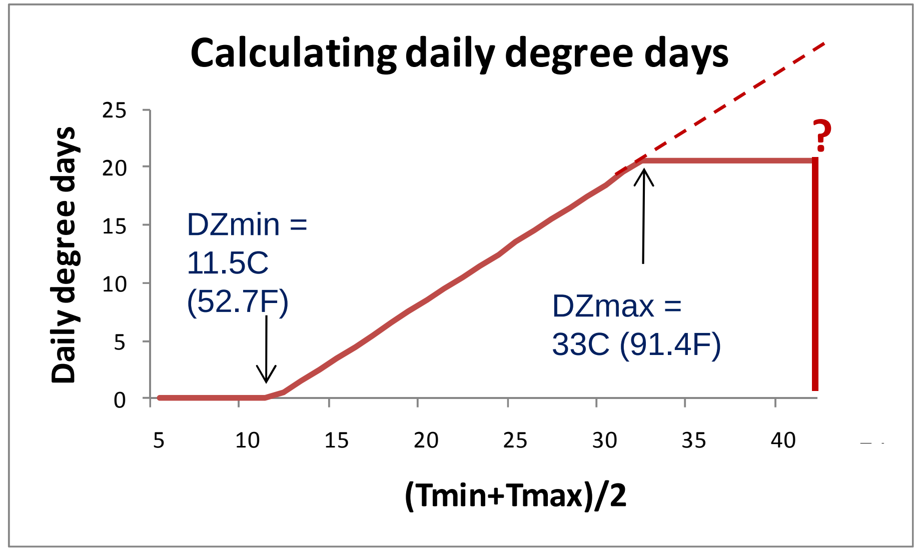
www.monarchnet.org

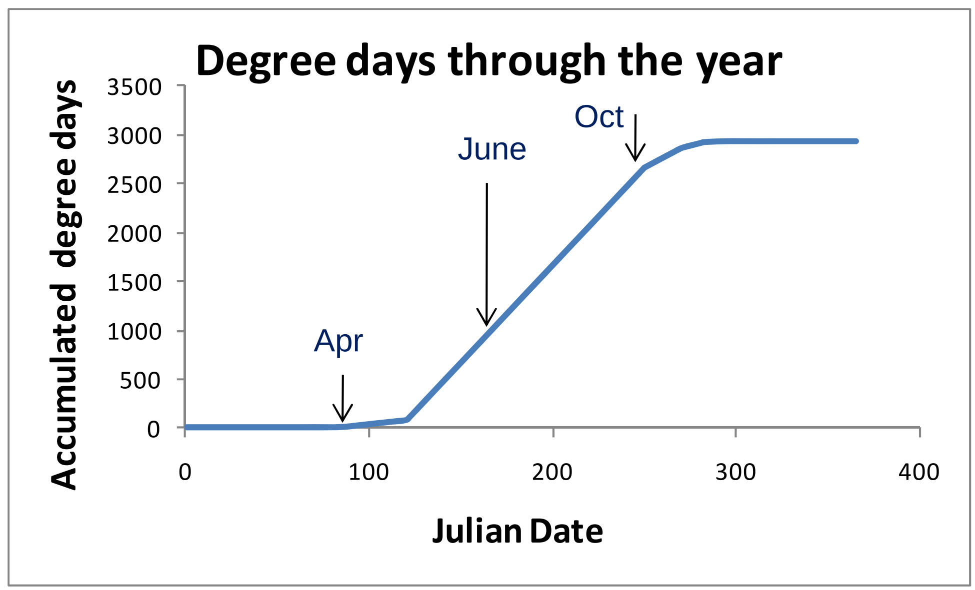
Growing Degree Days (GDD)

- Growing degree days are used to estimate the amount of thermal energy available for growth.
- A minimum temperature at which growth can begin is determined (DZmin), and each degree above that is considered a "degree day"
  - In some cases, a maximum temperature is set (DZmax) after which degree days are no longer accumulated

Zalucki 1982

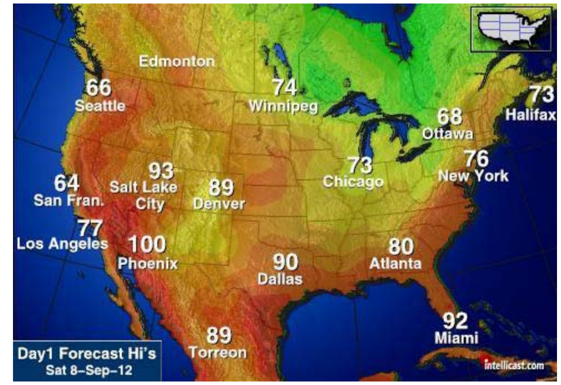






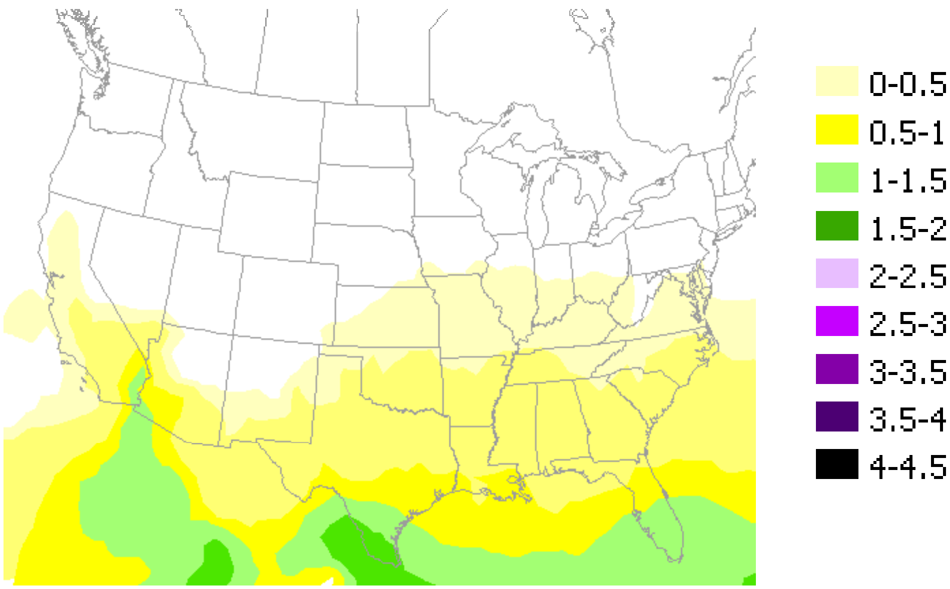
Building the distribution model

Take laboratory-measured temperature tolerances and intersect with spatial patterns of heat accumulation throughout eastern North America to predict number of generations that could be produced in spring and summer

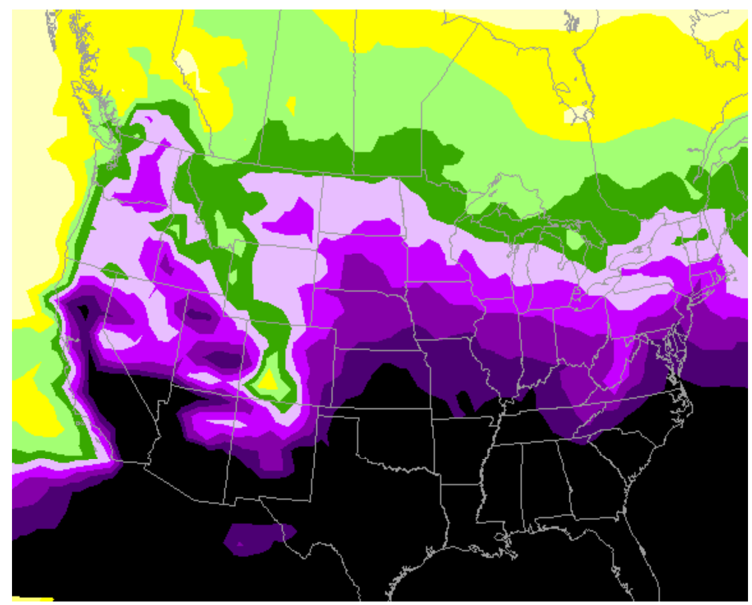


Predicted number of generations (1990-2009)

Spring (Mar-Apr)



Summer (May-Aug)

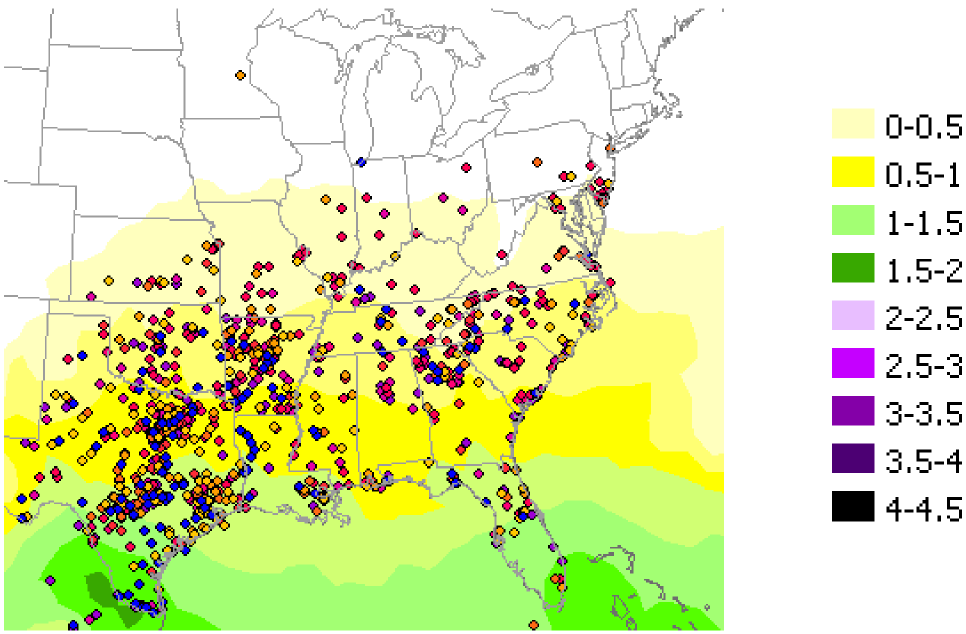


Testing the distribution model

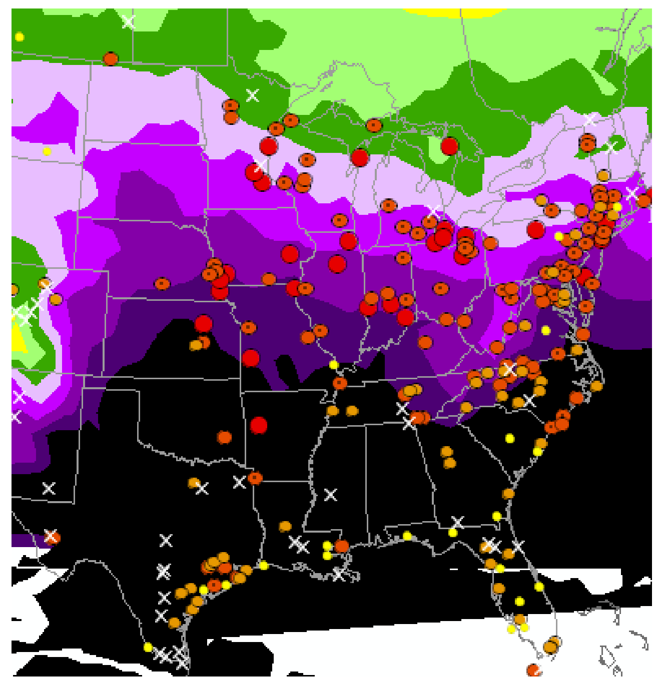
Compare the distribution and relative abundance of monarchs based on the number of generations predicted by the model.

Observed distribution of monarch populations

Spring (Mar-Apr) - JN



Summer (May-Aug)-NABA



Accounting for the potentially negative impacts of excessive heat

- Lethal and sub-lethal temperature effects were tested in a laboratory setting (*Betalden et al., in prep)*
- Larvae at various stages were exposed to potentially lethal or sublethal temperatures for a different number of days
  - 38C (100.4F), 40C (104F), 42C (107.6F), 44C (111.2F) and a control (30C, 86F)
  - First, Third, Fifth instars exposed
  - Exposed for 1, 2, 4, or 6 days
  - Nighttime temperatures were kept at 25C

- Larvae were reared to determine survivorship rates and total development time (in degree days)

Results: Survivorship rates
(*Betalden et al., in prep)*

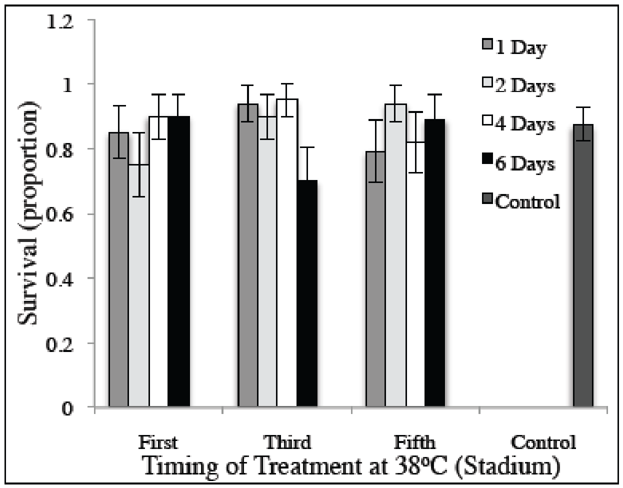


Figure 1a:

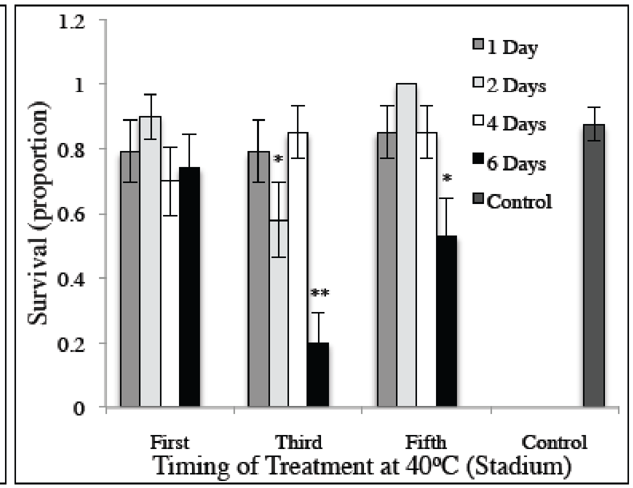


Figure 1b:

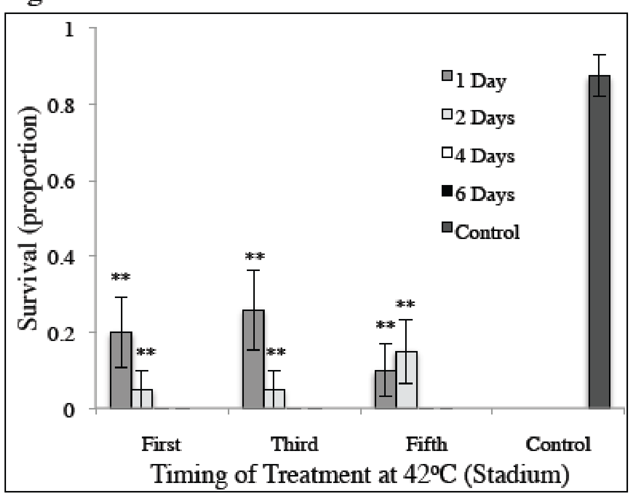


Figure 1c:

- Survivorship begins to decline for the 40C treatment only when larvae are exposed for 6 days (and only for 3rd and 5th instars)
- Survivorship is very low overall at 42C
- No individuals in the 44C treatment survived

Results: Development Time
(*Betalden et al., in prep)*

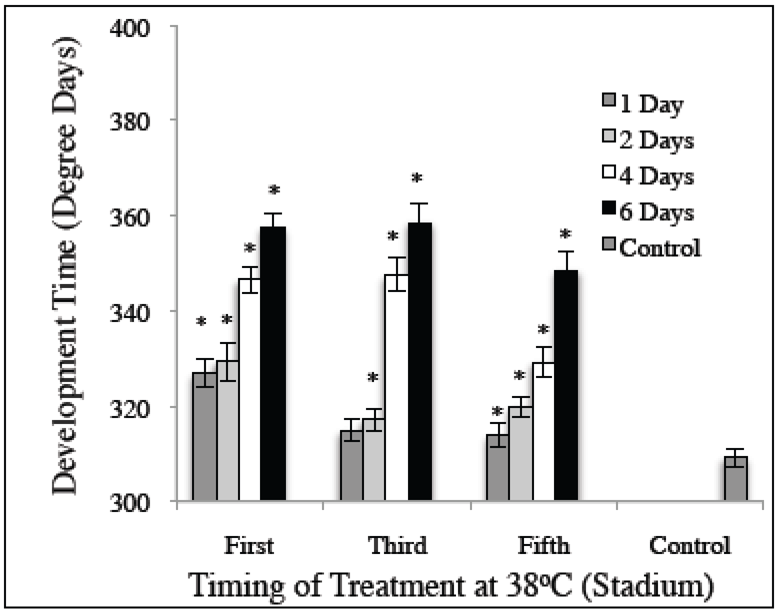


Figure 3a:

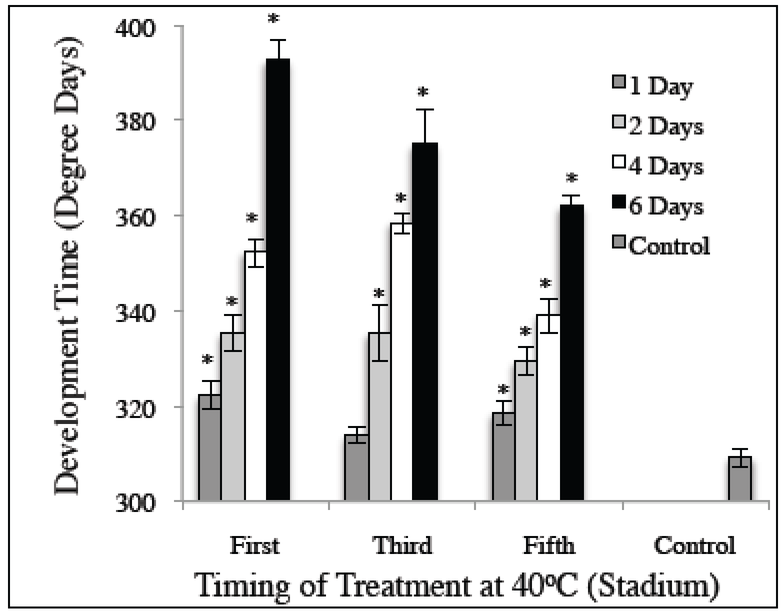
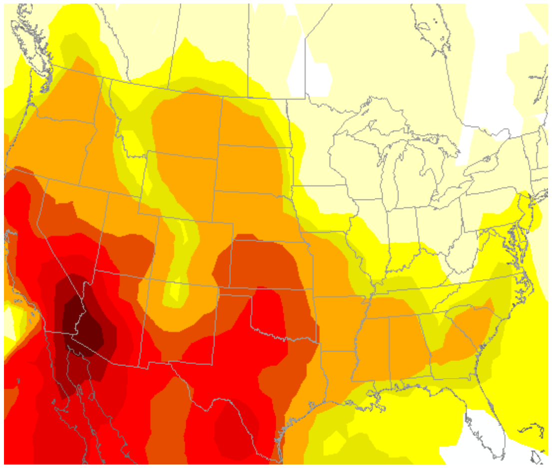


Figure 3b:

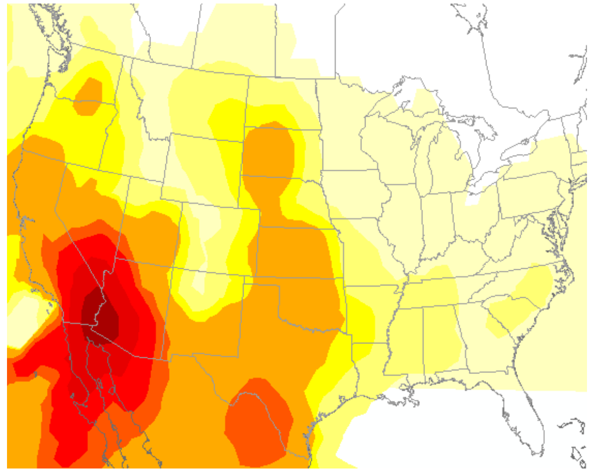
- Development time increases as individuals are exposed to higher temperatures for longer periods of time
- There is a treatment effect even for individuals exposed for 1 day (suggesting sublethal effects may occur at lower temperatures)

Preliminary examination: lethal and sub-lethal zones

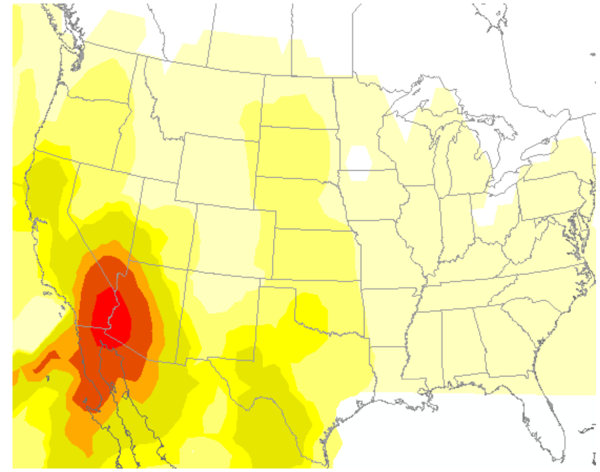
ABOVE 38



ABOVE 40



ABOVE 42

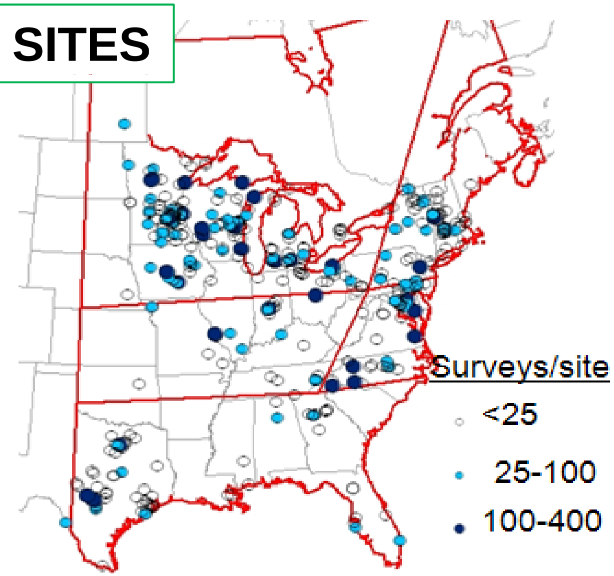


AVG NUMBER OF DAYS

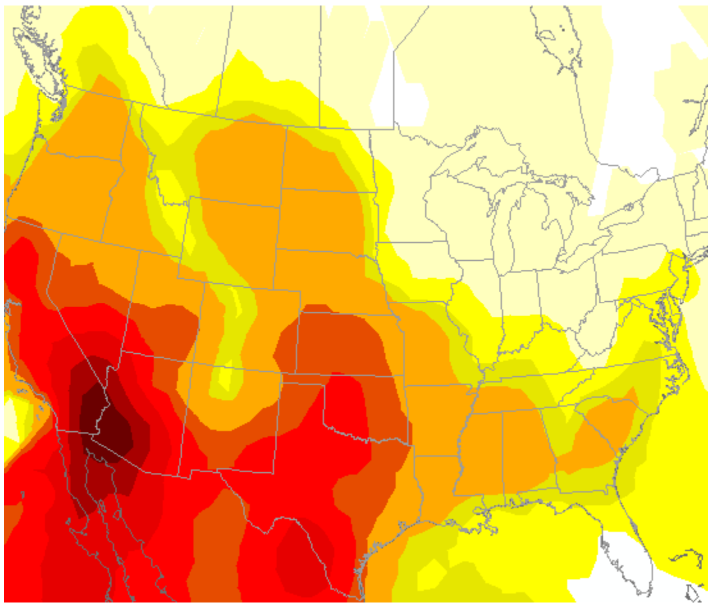
- 0 - 0.00001
- 0.00001 - 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 5
- 5 - 10
- 10 - 25
- 25 - 50
- 50 - 75
- 75 - 150

- Lethal and sub-lethal temperatures seem to correspond to limits in population densities, especially in the midwest
- Next up:
  - Comparing lethal temperatures to larval development observed in the field

MLMP SITES

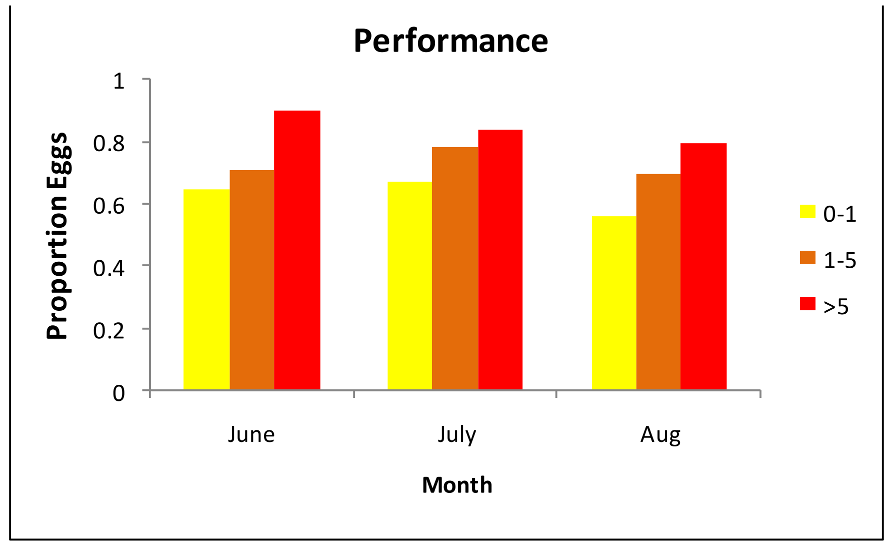


Preference and performance relative to mean number of days >38C

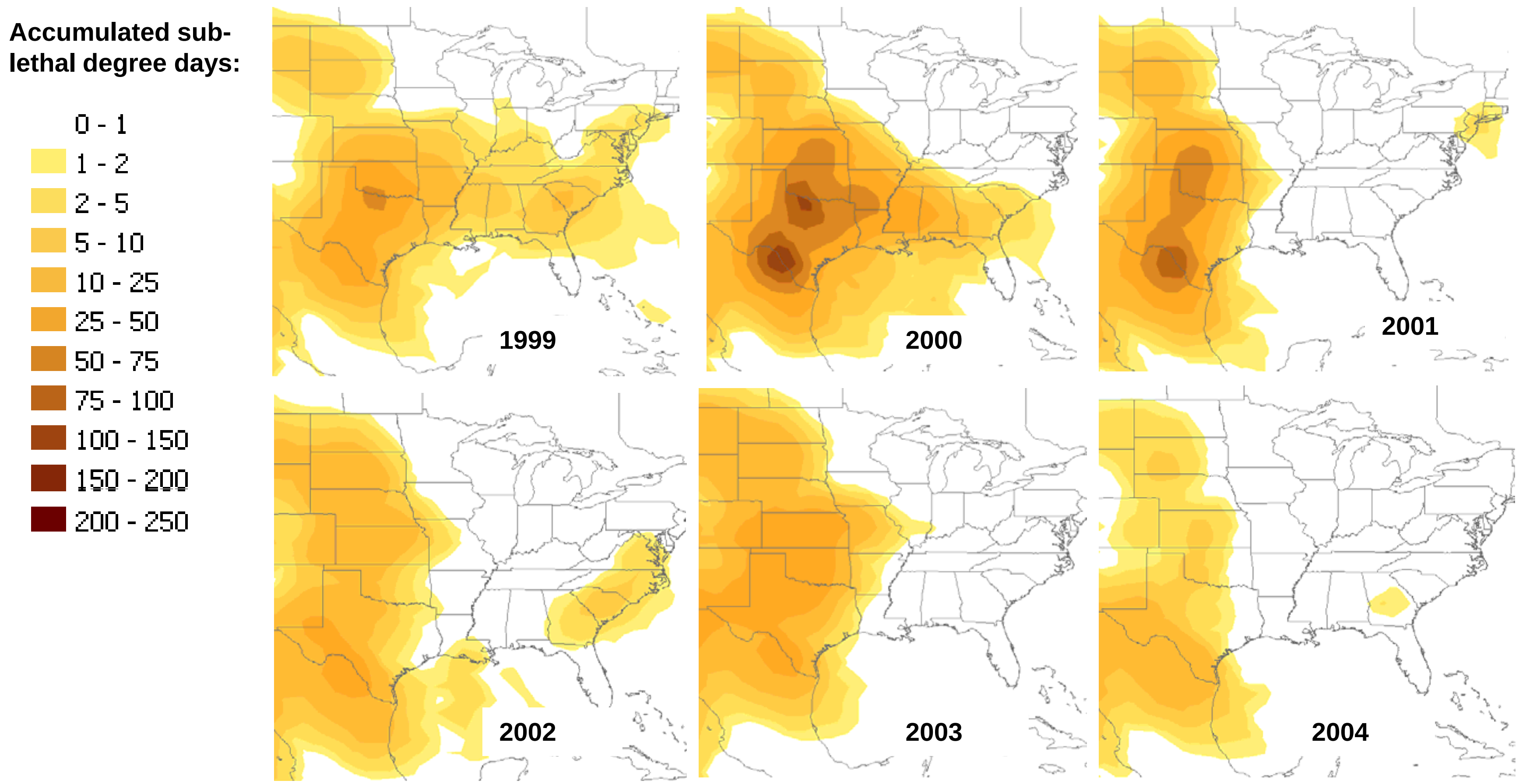


0 - 0.00001
0.00001 - 0.1
0.1 - 0.5
0.5 - 1
1 - 5
5 - 10
10 - 25
25 - 50
50 - 75
75 - 150

Mean number of days with temps >38C

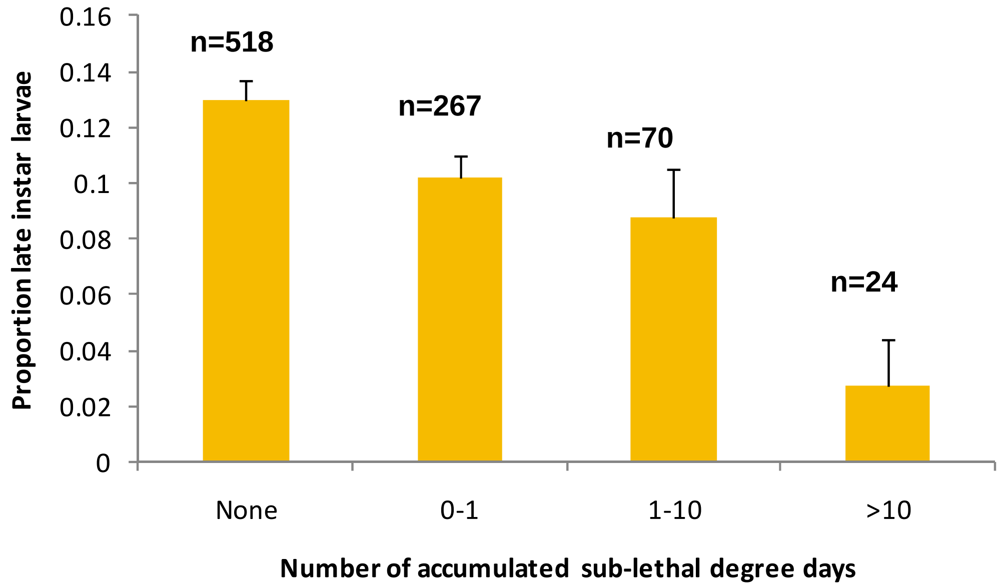


Our ultimate goal: take into account spatiotemporal patterns of temperature



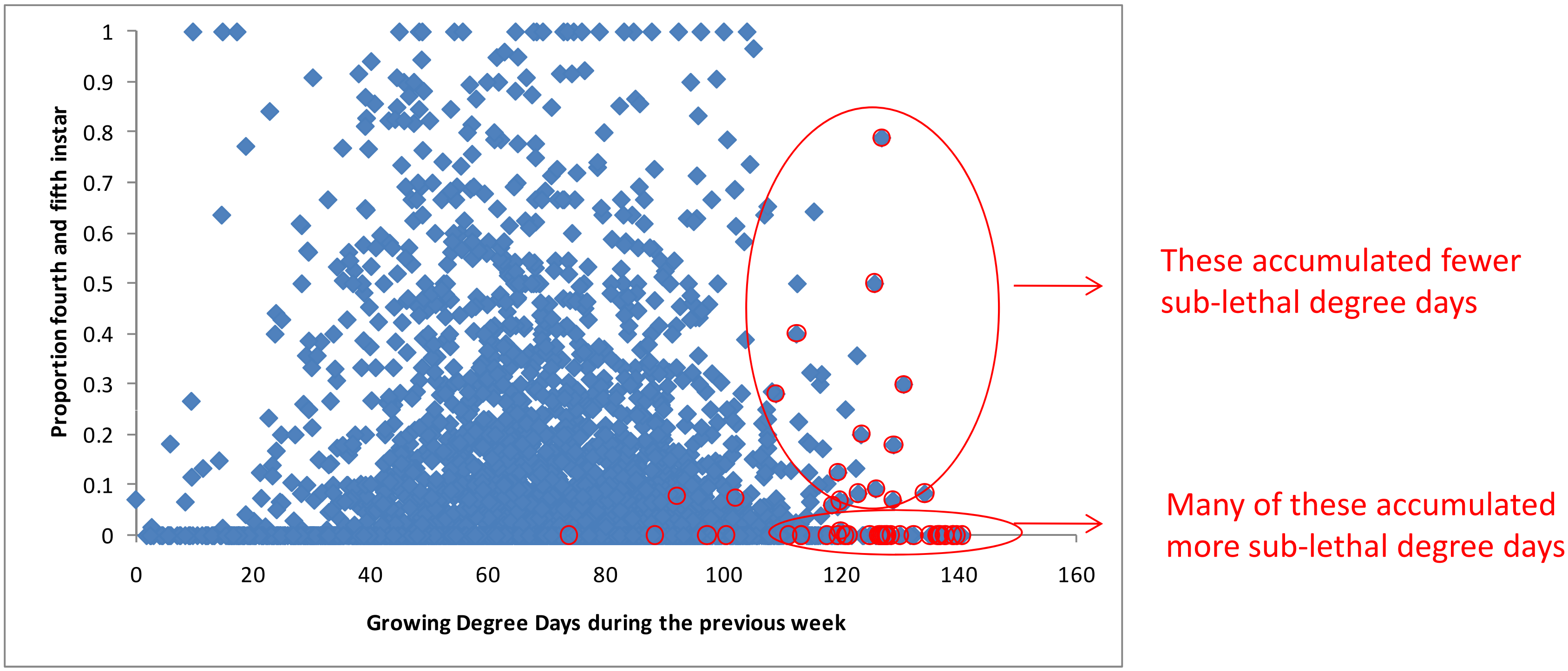
- These are accumulated over the main summer growing season (2 months)
- To truly test the impacts of sub-lethal and lethal temperatures, we need to tie temperature events to survey dates

Relationship between development and accumulated sub-lethal degree days



- <u>Next steps</u>
- Relate proportion of late instar larvae to sub-lethal temperatures in the preceding two weeks
- Examine relationship between parasitism rates and sub-lethal temperatures

Relationship between development and growing degree days accumulated during the previous 7 days



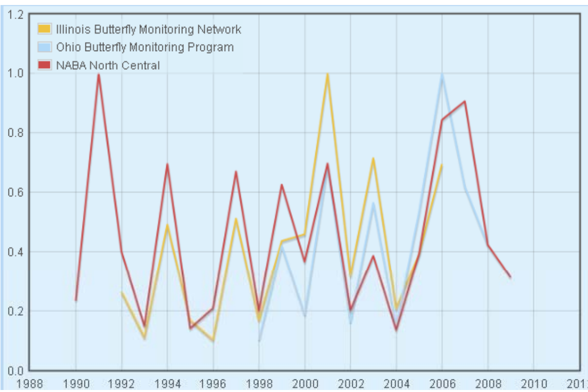
Surveys that accumulated *any* sub-lethal degree days are circled in red

SDM Summary

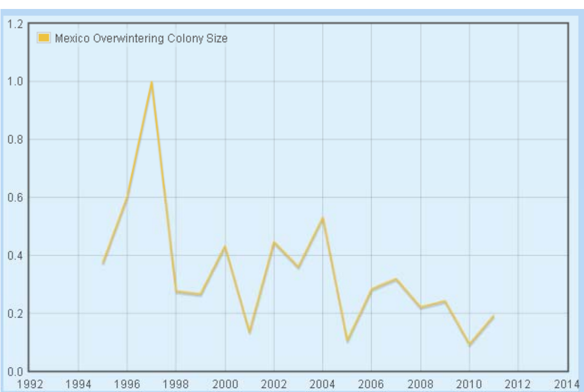
- Laboratory studies of physiological tolerances were able to be applied at continental scales and offered informative predictions about current distributions
  - For both monarchs and the sachem, intolerance to heat turned out to be an important factor
  - This suggests that models of growing degree days could be improved by adjusting for sub-lethal or lethal heat effects – this will require more laboratory work describing tolerances to higher temperatures
  - Results from these models could be used to make a priori predictions about responses to global climate change
- Our ability to use mechanistic models to explore how climate impacts range is dependent on access to mechanistic data
  - Global, long-term climate data offers the ability to explore the influence of the thermal landscape at many spatiotemporal scales
  - We are limited by mechanistic data describing responses to different thermal conditions, but these data are attainable
  - Citizen-science programs offer opportunities to test predictions at appropriate spatiotemporal scales

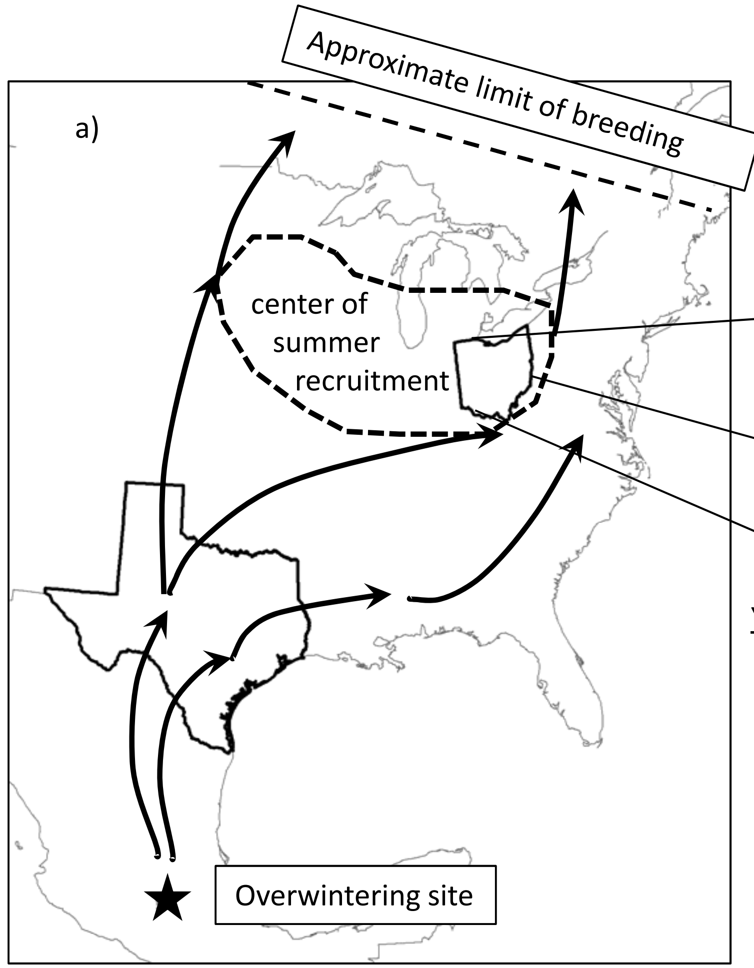
Tracking climate's impacts on population fluctuations of the migratory monarch butterfly

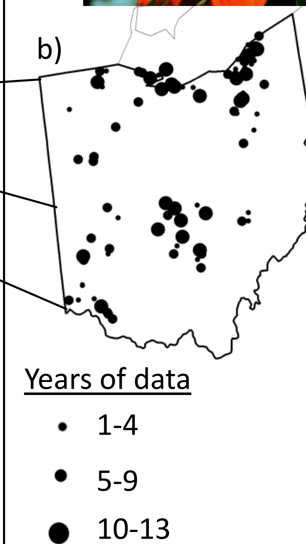
SUMMER MONITORING DATA

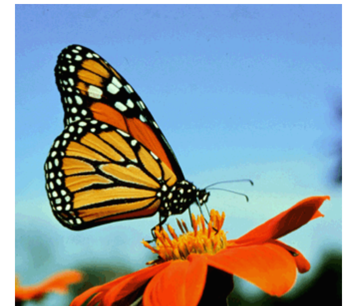


WINTER MONITORING DATA



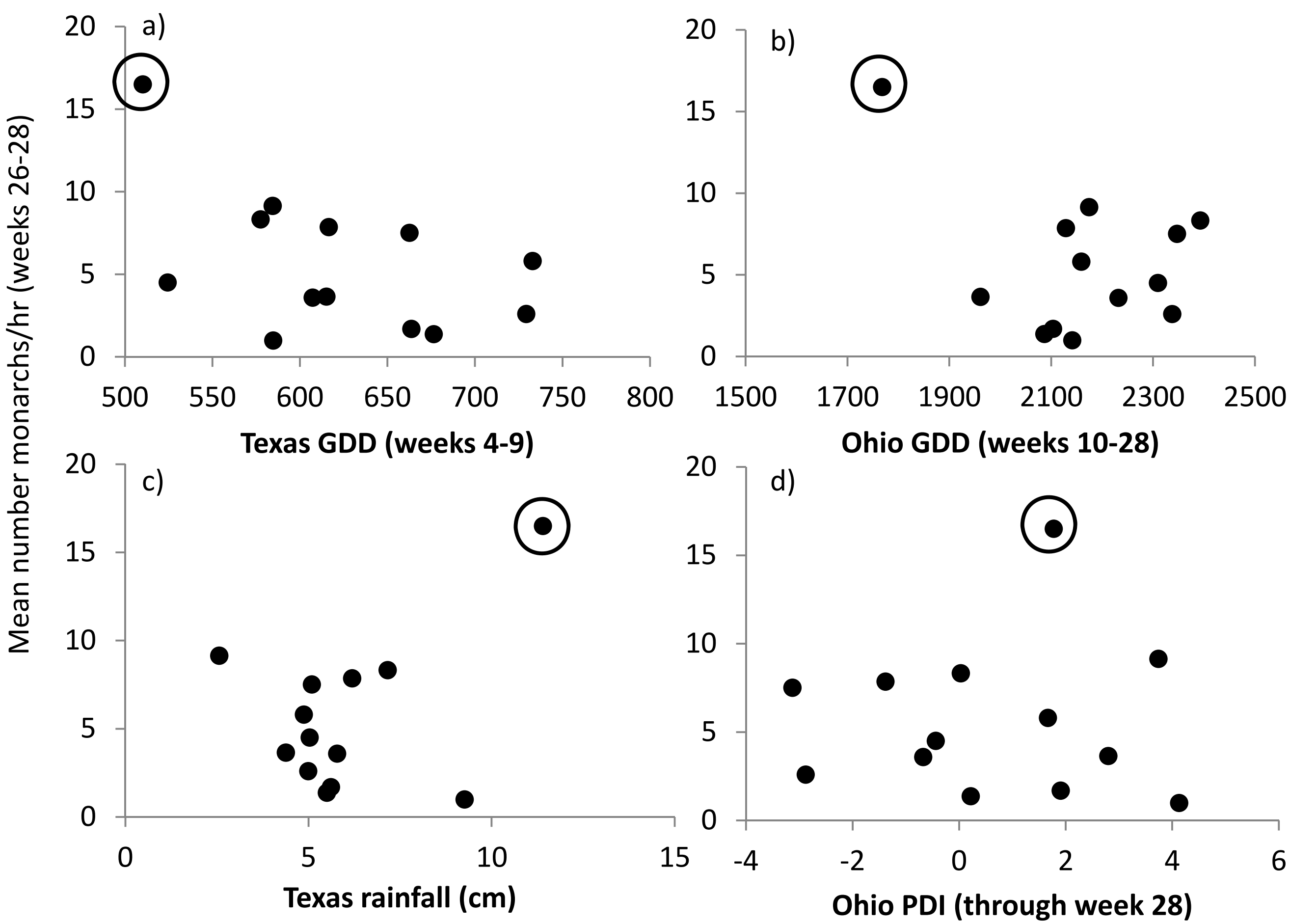




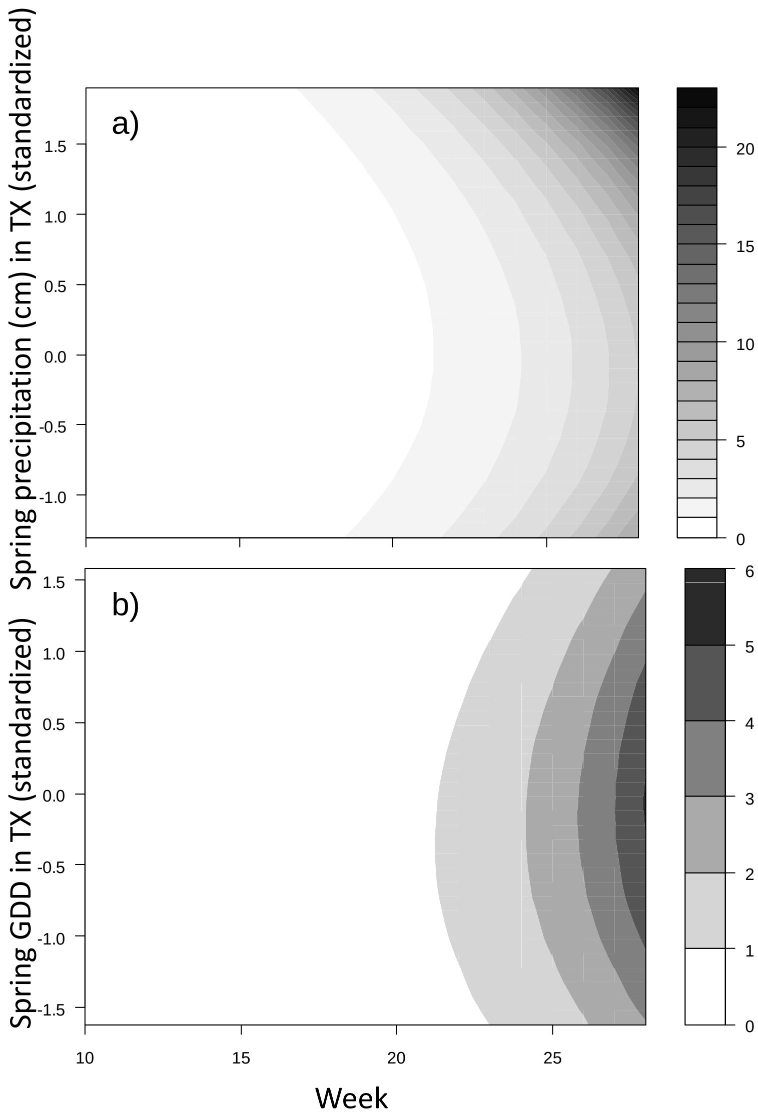


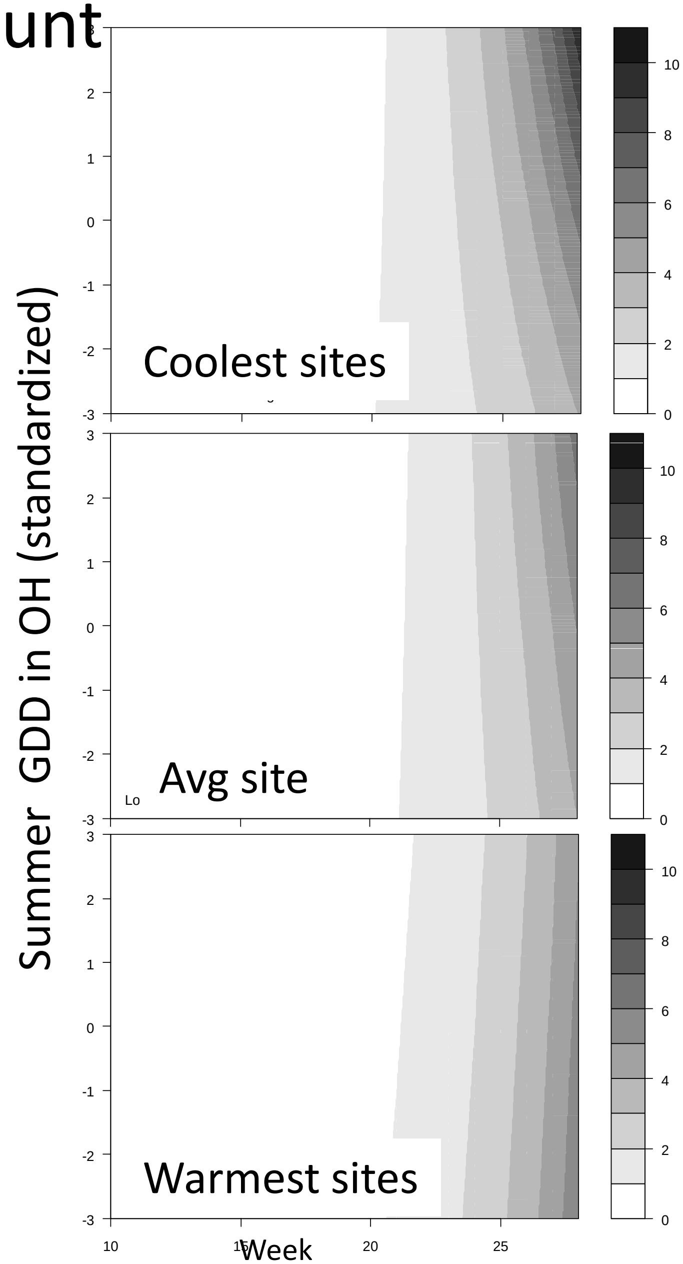
Zipkin et al. 2012, Global Change Biology (18): 3039-3049

Patterns based on simple state-wide metrics aren’t informative



Meaningful patterns emerge when factors are evaluated in a multiple regression framework, taking site characteristics into account



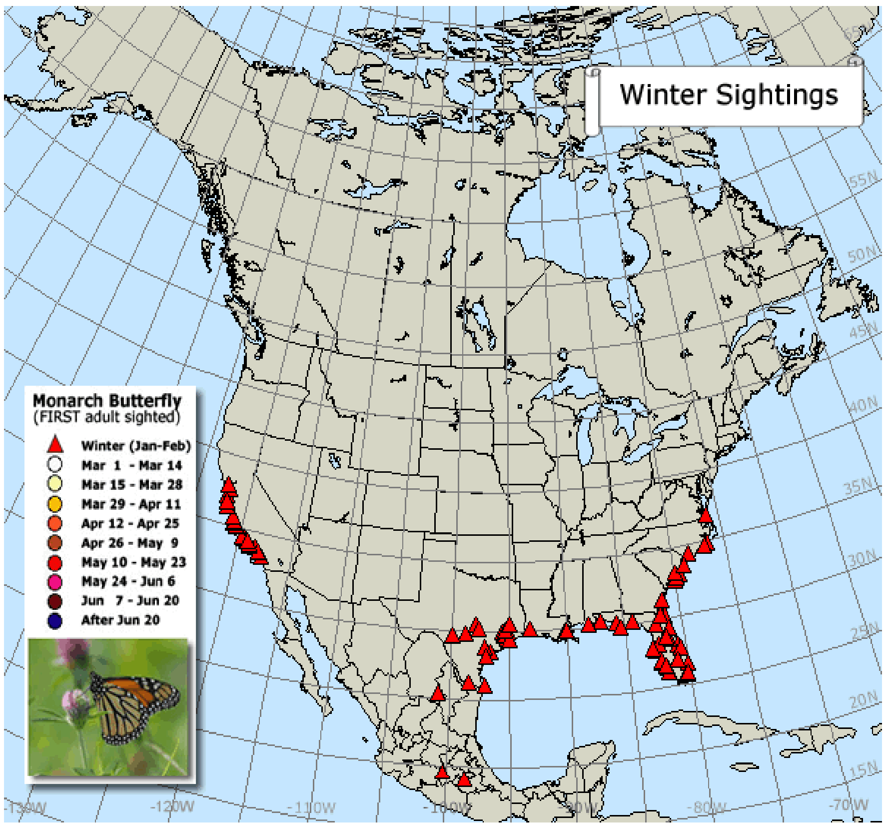


Population summary

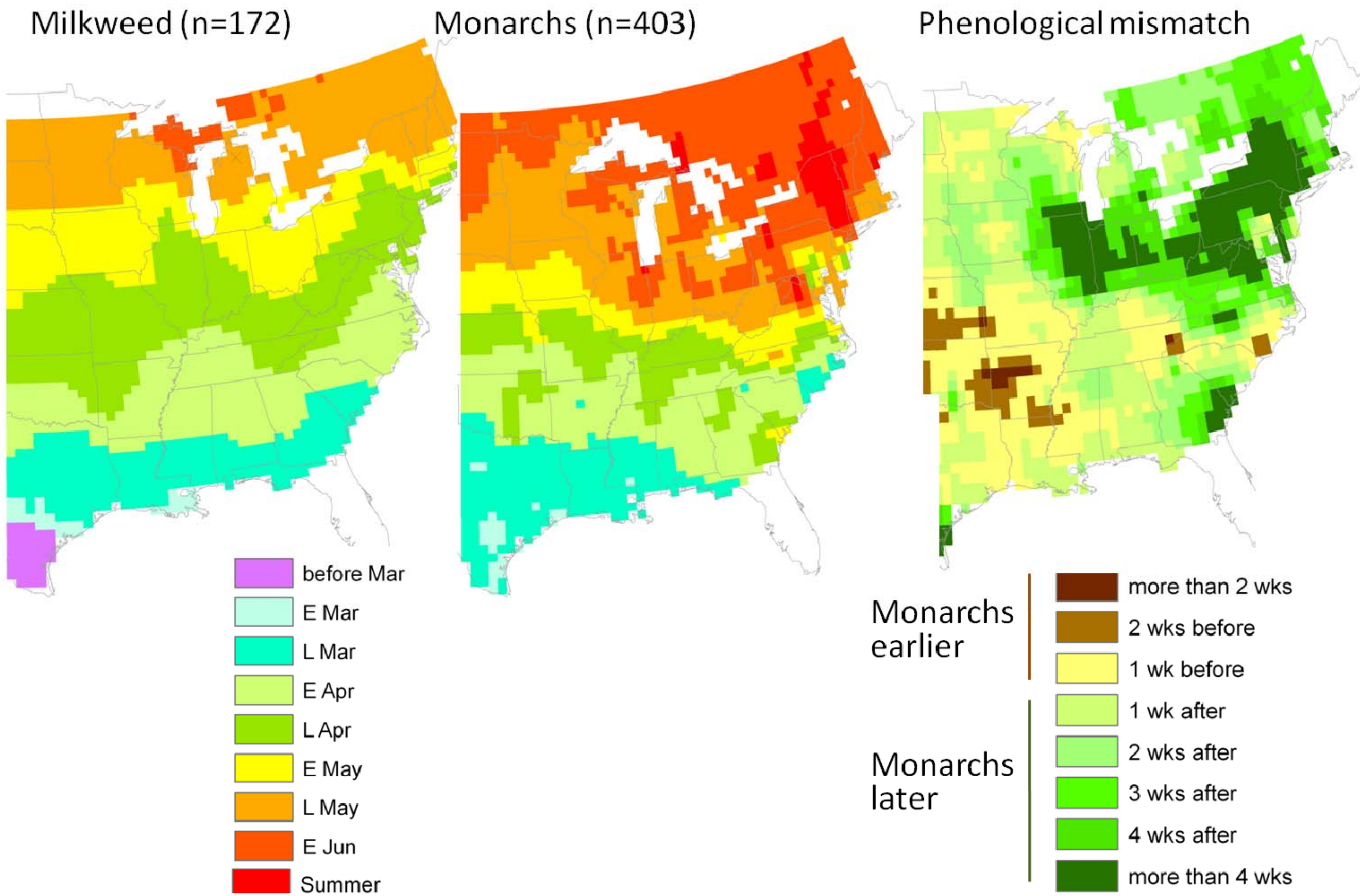
- Climate can explain at least some of the year-to-year variability in population
  - Spring precipitation is one important driving factor
  - Intermediate spring and summer temperatures seem to be optimal
- These results dovetail with another analysis that shows that the amount of population growth in the main northern recruitment zones is related to how many butterflies arrive from the south in the late spring
- Climate is one important factor impacting numbers but probably doesn’t explain the decline observed in Mexico

Could climate impact the phenological linkage between milkweeds and monarchs

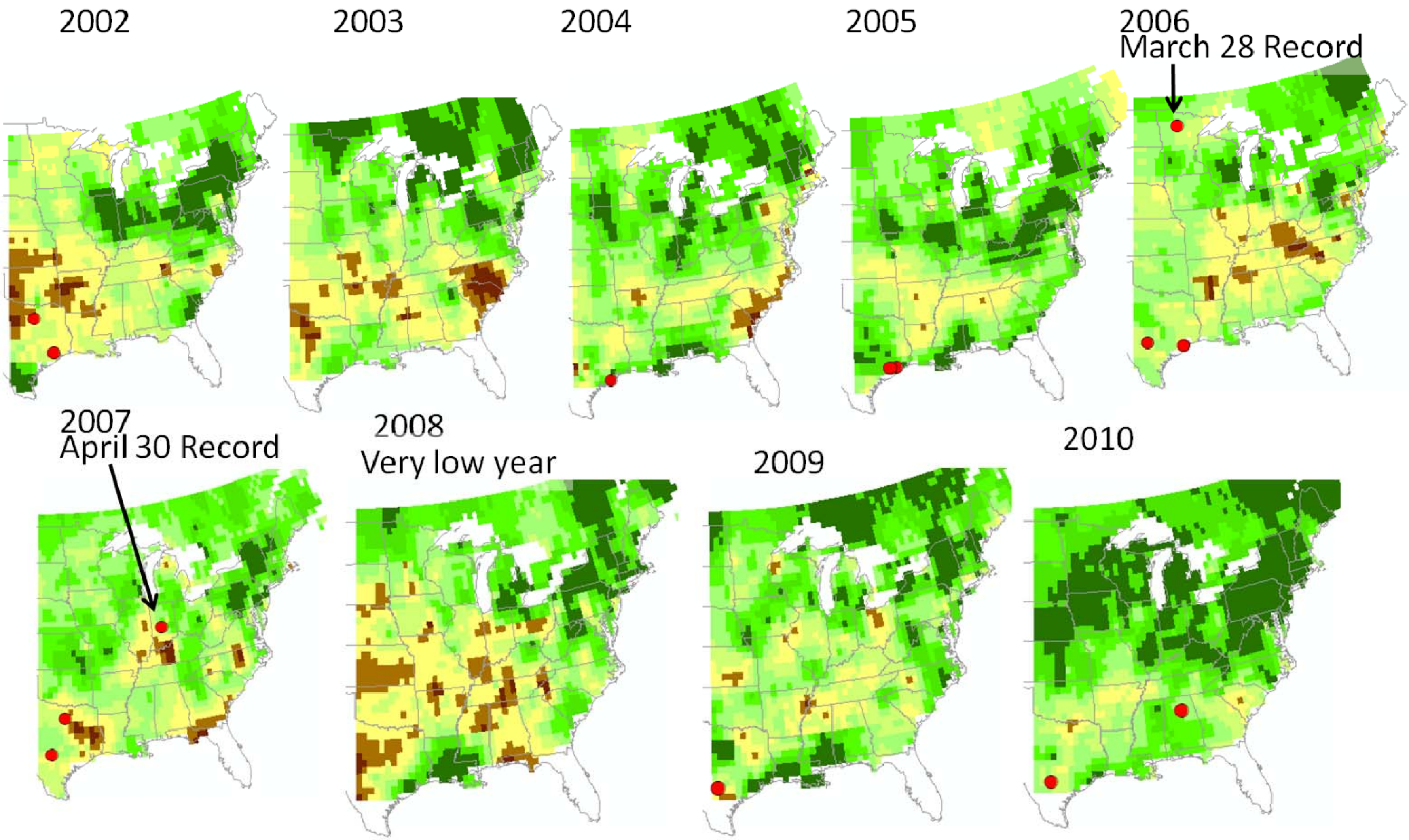
<u>Data source: Journey North</u>



Arrival dates - 2001



Arrival mismatches are leading to at least anecdotal incidents of egg loading



Take home messages

- Using models that link physiological tolerance data to large-scale distributions is a powerful way to tease out the complex interactions between climate and ecology
- Future mechanistic studies should focus on how increased temperatures may impact development
- We could not possibly explore these questions in a rigorous way without a data stream from large networks of citizen scientists

Public access and visualization

- Access and visualization tools for NABA and hopefully regional programs as well
  - Maps and trend graphs
  - Local lists of species (sorted by abundance)