First Flight of the Monarchs
Which Climatic Factors best explain changing Phenology of Monarch Butterflies *Danaus plexippus*
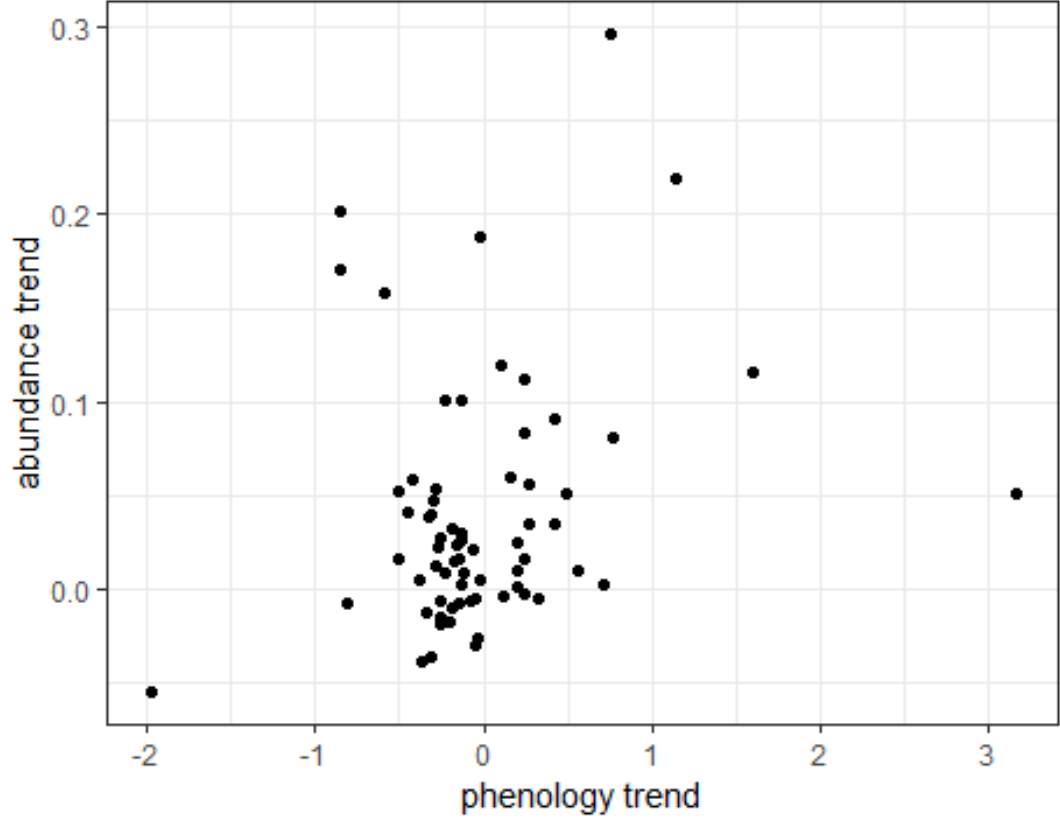
Introduction

Many plant and animal species depend on environmental triggers for the timing of life stage events. This cyclic change in species behavior or development is known as phenology. It is observed in many species and is a process which ensures that individuals will be able to take advantage of key resources or can mate with conspecifics. Phenology timing is especially important for species in temperate zones which often respond to seasonal variation. Such stimuli include thresholds for temperature, moisture etc.

The climatic variables responsible for the phenology of these species are changing due to the greenhouse effect and global climate change. Rising global temperatures and erratic weather patterns have been shown to significantly impact the abundance, distribution and phenology of certain species. Broad ecological studies of entire ecosystems' phenology have revealed the advance of spring & summer-associated phenomena in plants and animals to be a couple of days.
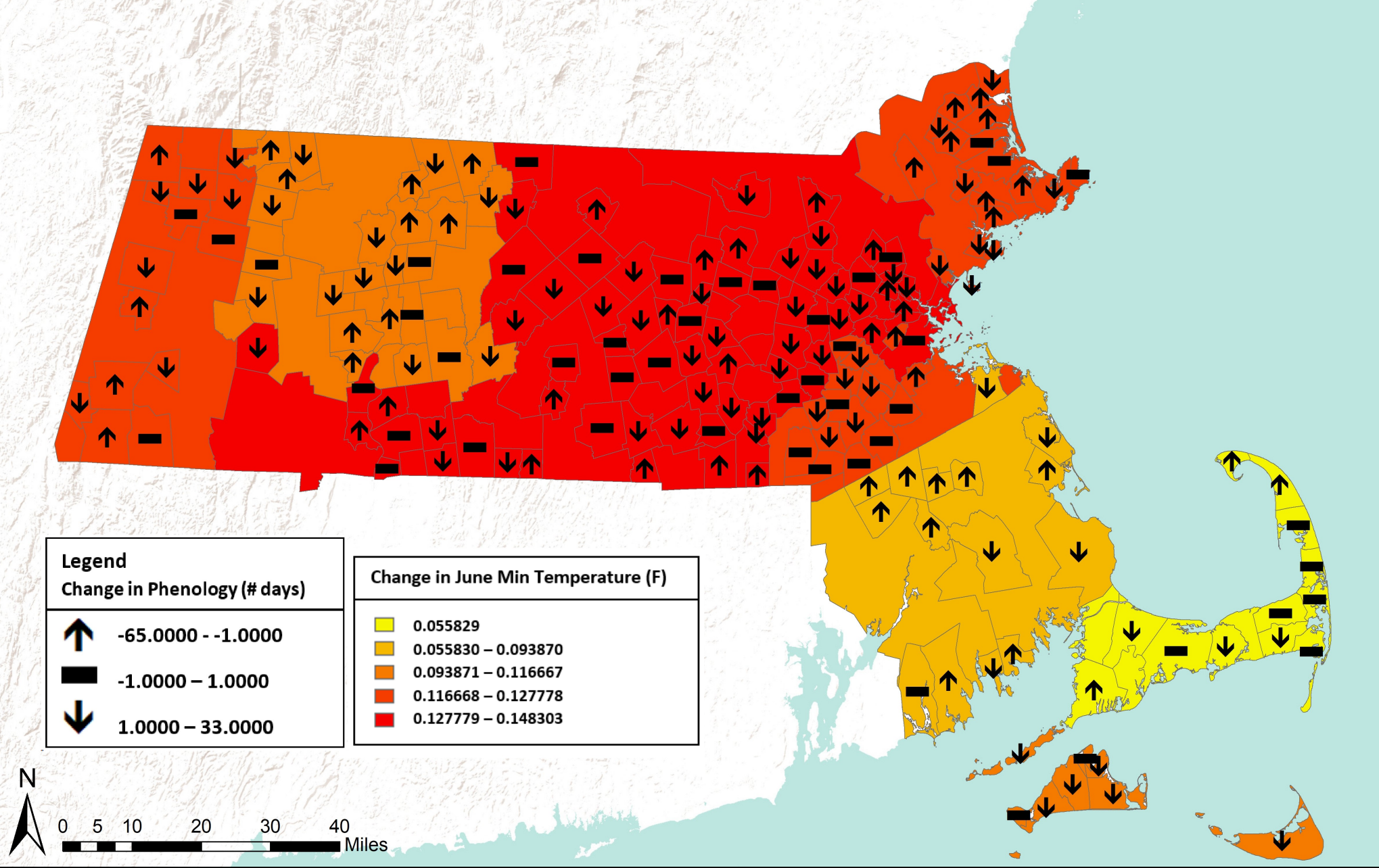
Many species of Butterfly *Lepidoptera* are specialists, dependent on certain host plants as both larvae and adults. Because plant species are only available at certain times of the year, larval and adult emergence times are linked with their ability to access these resources and consequently individual fitness. Under circumstances where butterfly phenology diverges from that of host plants it can be a critical threat for the population survival. For species of butterflies in Massachusetts there is a significant correlation between the observed trends in abundance and phenology.

The Monarch *Danaus plexippus* is a charismatic species of butterfly widespread throughout North America. Environmental factors affect Monarch emergence as well as their migratory patterns. Formerly very common, they have seen massive population declines estimated by the Xerces Society at a over 80% in their wintering territory. The largest contributor of this decline is likely the loss of suitable habitat containing their hostplant, Milkweed *Asclepias*. Although it isn't the primary contributor to Monarch population declines, it is essential to understand which climatic factors have the greatest impact on the phenology of the species as it has been linked to trends in abundance of other species.
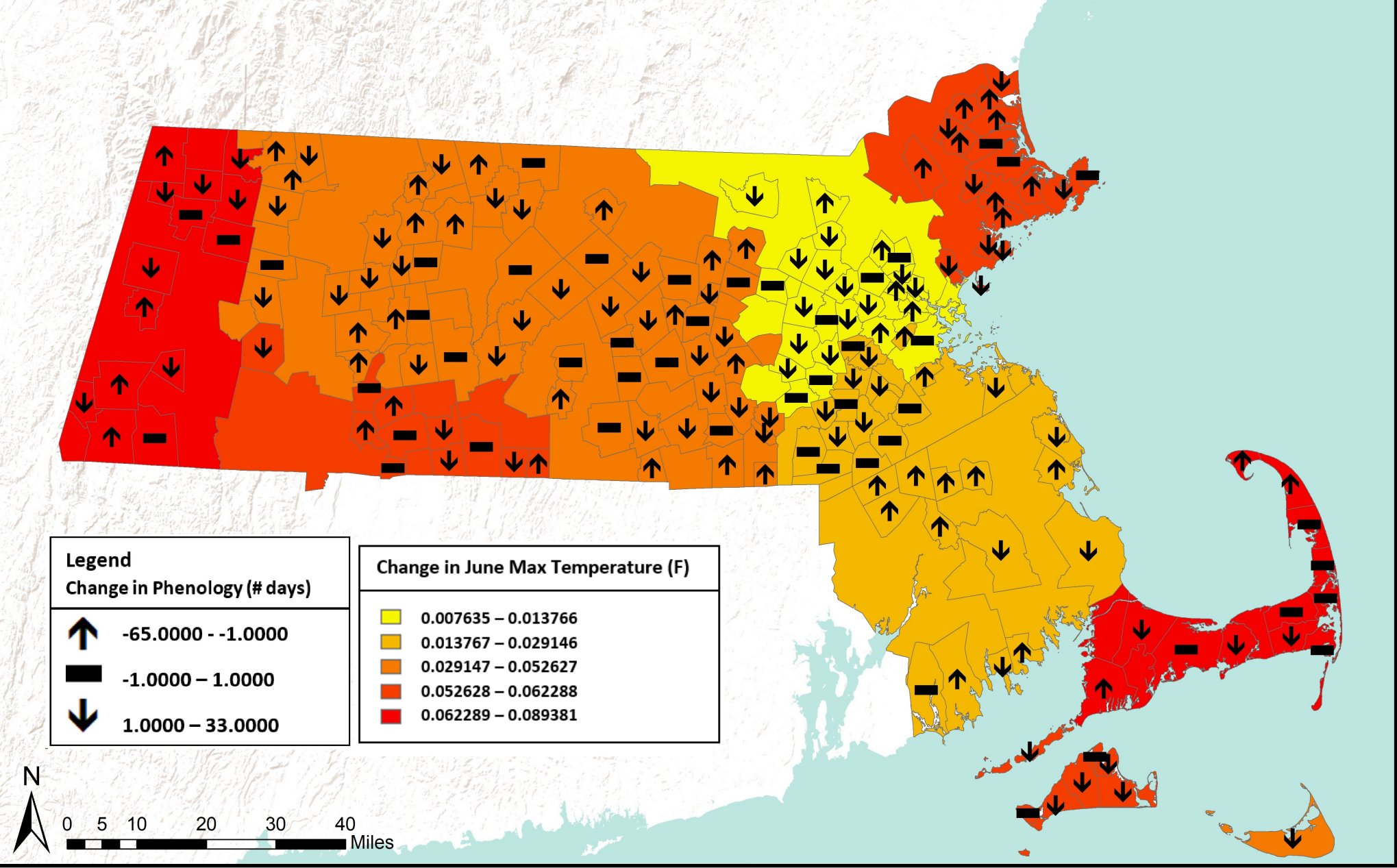
Trends in the Phenology and Abundance of Massachusetts Butterflies
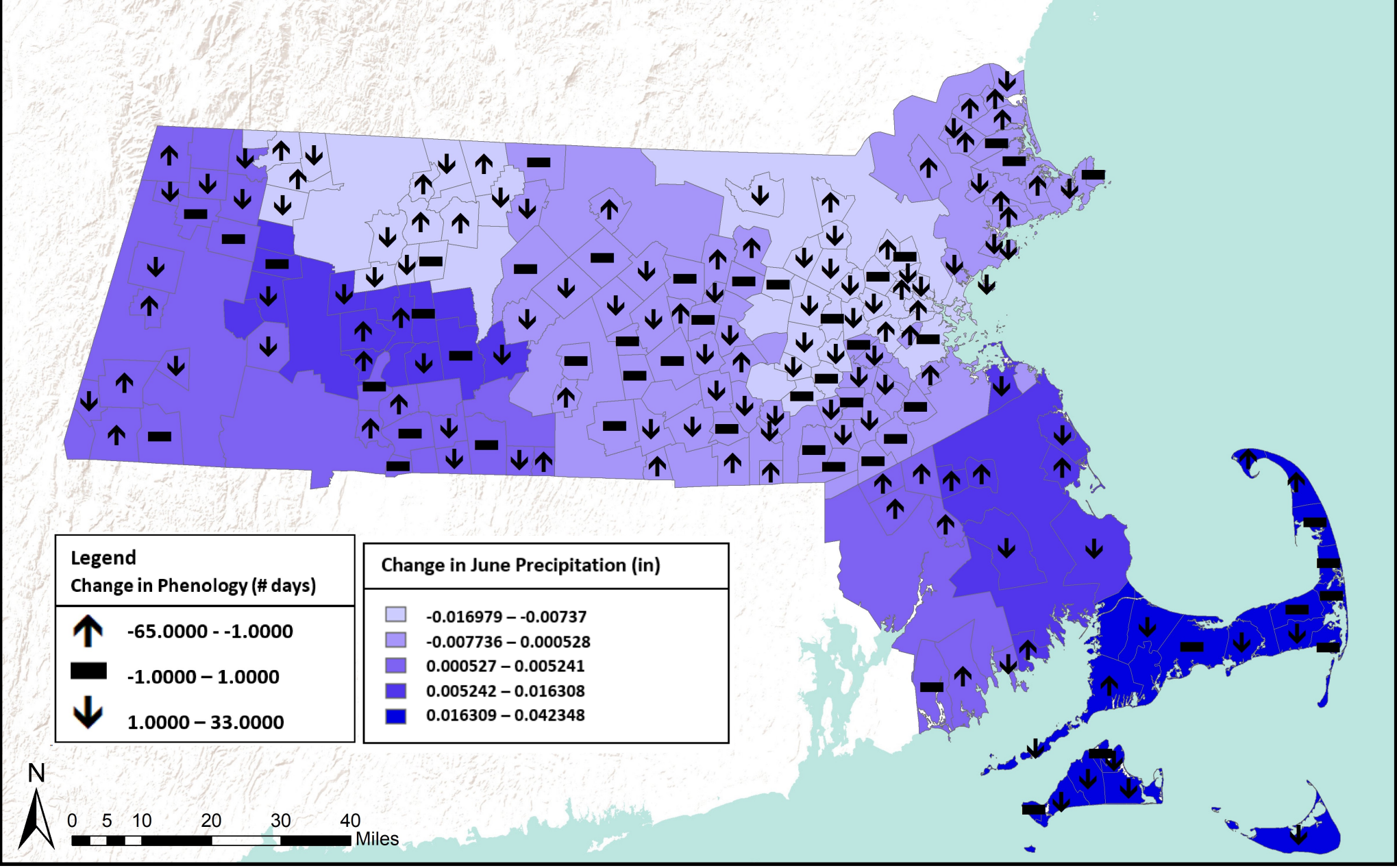

Min Temperature Change

Legend
Change in Phenology (# days)
↑ -65.0000 - -1.0000
▬ -1.0000 - 1.0000
↓ 1.0000 - 33.0000

Change in June Min Temperature (F)
0.055829
0.055830 - 0.093870
0.093871 - 0.116667
0.116668 - 0.127778
0.127779 - 0.148303

Maximum Temperature Change

Legend
Change in Phenology (# days)
↑ -65.0000 - -1.0000
▬ -1.0000 - 1.0000
↓ 1.0000 - 33.0000

Change in June Max Temperature (F)
0.007685 - 0.013766
0.013767 - 0.029146
0.029147 - 0.052627
0.052628 - 0.062288
0.062289 - 0.089381

Precipitation Change

Legend
Change in Phenology (# days)
↑ -65.0000 - -1.0000
▬ -1.0000 - 1.0000
↓ 1.0000 - 33.0000

Change in June Precipitation (in)
-0.016979 - -0.00737
-0.007736 - 0.000528
0.000529 - 0.005241
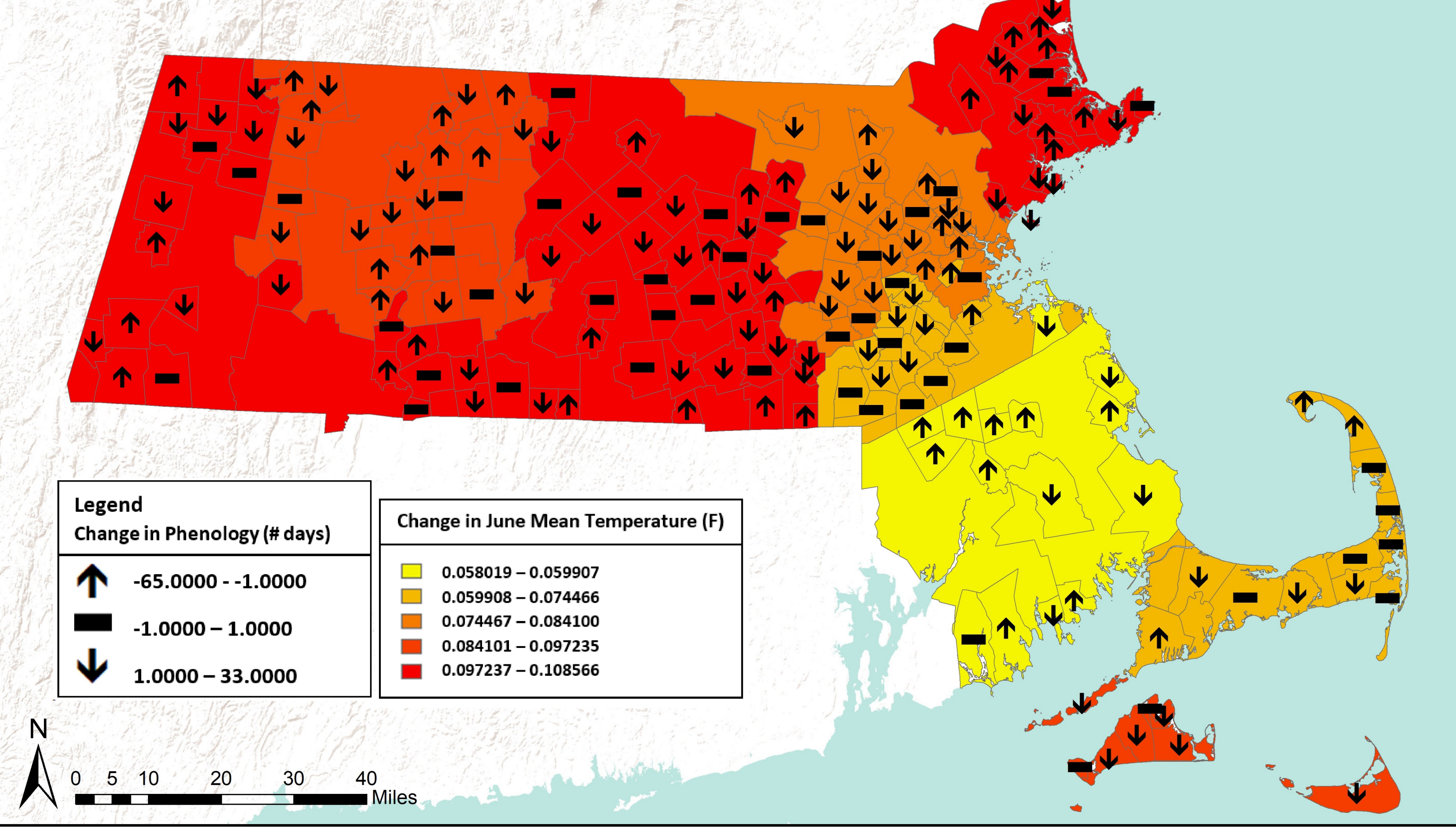0.005242 - 0.016308
0.016309 - 0.042348

Methodology

Butterflies are a unique group of insects in that they're easily identifiable. Citizen Scientists across the state of Massachusetts have been collecting records of butterfly sightings of many species for many decades. The Massachusetts Butterfly Club (MBC) has detailed records going as far back as 1990 on sightings of Monarch butterflies in each town in the state of Massachusetts. Populations of Monarch adults that emerge in June are the offspring of those who have returned from the annual southern migrations. These data were compiled by town and the linear change in the date of the year when the first sighting occurred was the metric of change in phenology.

Climate Data from the PRISM Climate Group was used to evaluate the change of certain environmental variables. Yearly data on the temperature and precipitation levels of June (the month where Monarchs tend to emerge) were used across counties. The climatic factors considered included the change in minimum temperature in June (Fº) the change in average temperature in June, the change in maximum temperature in June and change of precipitation in June (in) from 1990-2017.

Exploratory Regression was used to find across all towns in MA which climatic variables are most likely responsible for phenology patterns. This tool compiles the phenology change across towns and determines the most likely climatic factors (minimum temperature, maximum temperature, mean temperature or precipitation) responsible for the trends in phenology during the time period studied.

June Mean Temperature change and first Monarch Sightings

Legend
Change in Phenology (# days)
↑ -65.0000 - -1.0000
▬ -1.0000 - 1.0000
↓ 1.0000 - 33.0000

Change in June Mean Temperature (F)
0.058019 - 0.059907
0.059908 - 0.074466
0.074467 - 0.084100
0.084101 - 0.097235
0.097237 - 0.108566

0 5 10 20 30 40 Miles

Results

The climatic factor which the highest likelihood of predicting the changes we observed in monarch populations was the mean change in temperature from 1990 to 2017. This was followed closely by a combined minimum and maximum temperature change model. However, the variation observed in Monarch Phenology was not well explained by any of the models. There are multiple reasons this may be the case; there could be variation due to the fact that the MBC records of the first-month sightings are dependent on observations and not every site is monitored on a daily basis and therefore detecting phenology shifts which are observed on the order of days from one year to the next

Exploratory Regression Results

Parameters	AICc	Δ AICc	Adj R²
temperature mean change	3426.047	0	0.04959
temperature minimum change & temperature maximum change	3429.901	3.85	0.043723
temperature minimum change & precipitation change	3438.881	12.83	0.024831
temperature mean change & precipitation change	3440.480	14.43	0.021418
temperature minimum change	3443.209	17.16	0.013381
temperature mean change	3445.671	19.62	0.008075

Graphs represent the changes in phenology as arrows indicating, for each town for which there is substantial data, either advancing or retreating phenology (earlier and later dates respectively). Climatic variables are colored and demonstrate, at the county level, the changes observed at the county level. Phenology itself is variable among locations , but trends can be seen across the state where more butterflies in towns along the coast of the state (Essex, Bristol and Plymouth Counties) show advanced phenology more frequently.

Conclusion

The mean change in temperature across the time of the study was, among the factors examined in this study, the greatest predictor of adult Monarch emergence. This is possible because temperature is a strong indicator of seasonal change in temperate zones and is can be the ultimate mechanism through which Monarchs' emergence is determined. It would ensure under consistent cyclic seasons that they would emerge when resources and mates are available.

It is possible none of the factors studied here have a strong consequential impact on the development. It as been shown that migration patterns in Monarchs are determined by duration of light such that they orient their flights based on a time-compensated compass. It is possible a similar mechanism is what triggers larval emergence behavior as well. Further Investigation as to the exact determinant of phenology could reveal the determinant for this phenomenon.

It would also be valuable to explore whether the Monarch's hostplant, Milkweed, itself is correlated to any of the climatic factors examined in this study. Studies of Milkweed could reveal if there is some correlation between it and local Monarch emergence and abundance to see if some diversion in phenology and if that is affecting population levels. Continued studies on Monarch emergence will help provide conservationists with the understanding necessary to implement necessary management practices to protect this threatened species.

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Intro to GIS | GIS 101
Data Sources:
The Massachusetts Butterfly Club, PRISM Climate Group (NACSE), MassGIS

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Limitations

The climatic factor which the highest likelihood of predicting the changes we observed in monarch populations was the mean change in temperature from 1990 to 2017. This was followed closely by a combined minimum and maximum temperature change model. However, the variation observed in Monarch Phenology was not well explained by any of the models.

There are multiple reasons this may be the case; there could be variation due to the fact that the MBC records of the first-month sightings are dependent on observations and not every site is monitored on a daily basis and therefore detecting phenology shifts which are observed on the order of days from one year to the next.

The time series also might have been too short and the variation from year to year to great to detect a long term change. Continued observations will provide greater power to determine whether the butterflies emerge in response to climatic factors explored in this study