Annual first flowering dates of *Clintonia borealis*, *Saxifraga oppositifolia*, *Dryas integrifolia*, *Arctostaphylos uva-ursi*, and *Rhododendron groenlandicum* occur earlier as seasonal average temperatures increase

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Abstract

The timing of life history events in plants such as annual first flowering dates must occur when climatic conditions are favourable. Recent rapid climate change, however, is altering conditions such as temperature and humidity and triggering a shift in the flowering time of many plant species. We examined the annual first flowering dates of *Clintonia borealis*, *Saxifraga oppositifolia*, *Dryas integrifolia*, *Arctostaphylos uva-ursi*, and *Rhododendron groenlandicum* over a 13-year period (2004–2017) across the four islands Ile du Fantome, Ile du Havre, Grosse Ile au Marteau, and Petite Ile au Marteau in Mingan Archipelago National Park Reserve in Quebec to determine whether increases in seasonal average temperatures (April to July) explain the change in first flowering date in these plants. Our results show that temperature and humidity have a significant positive correlation. We also found that mean annual temperatures have a significant effect on first flowering dates such that there is a significant difference in the first flowering date of each species. However, mean annual temperatures had the same effect on first flowering dates across different plant species.

1. Introduction

Since *phenology*, the timing of life history events, is sensitive to environmental conditions, much can be learned about the impacts of climate change by tracking these phenological events over time (Panchen & Gorelick, 2017). In plants, some examples of phenological events that have been studied include first flowering date, length of growing seasons from leaf unfolding to leaf colouring, and fruiting times (Panchen & Gorelick, 2017). The data required for phenological research is often difficult to obtain as it must be collected from a long-term scientific experiment over many years in a singular habitat (Panchen & Gorelick, 2017). In this study, we examine one such phenological event–first flowering date–over a 13-year period for *Clintonia* *borealis*, *Saxifraga oppositifolia*, *Dryas integrifolia*, *Arctostaphylos uva-ursi*, and *Rhododendron groenlandicum* in Mingan, Quebec.

Various studies have been conducted to determine the effects of climate change on plant phenology. For example, in a study done in England from 1954 to 1989, 146 out of the 243 species showed earlier flowering with increasing temperatures (Fitter et al., 1995). Many other studies done today focusing on temperature and flowering have shown a similar result. This is because a plant's flowering time is expected to coincide with favourable growing temperatures to maximize fitness and prolong the survival of the species. However, most research describing this effect in Canada takes place in the Arctic. In the Arctic Archipelago of Canada in Nunavut, a study has shown that all but two of the 23 species they observed showed earlier flowering times with warmer mean June temperatures (Panchen & Gorelick, 2017). To our knowledge, studies concerning the boreal biome of Canada such as in the Mingan Archipelago are limited (Belland & Schofield, 1992).

Mingan Archipelago National Park Reserve is located in Mingan, Quebec, which is found north of the Gulf of the St. Lawrence, and encompasses over 900 islands including the ones in our study: Ile du Fantome, Ile du Havre, Grosse Ile au Marteau, and Petite Ile au Marteau (Belland & Schofield, 1992). The park belongs to the Boreal Forest Region and 9 habitat types were recognized among the islands: forested cliff, low elevation exposed cliff, closed crown forest, alpine heathland, unclassified heathland, ombrotrophic bog, fen, unclassified peatland, and low elevation stream gully (Belland & Schofield, 1992). This region is characterised by a temperate maritime climate with short growing seasons and long winters (Belland & Schofield, 1992). Additionally, it is home to a diverse array of wildlife and fauna, including *Clintonia borealis*, *Saxifraga oppositifolia*, *Dryas integrifolia*, *Arctostaphylos uva-ursi*, and *Rhododendron groenlandicum*.

Figure 1. Map of islands in Mingan Archipelago National Park Reserve, including the Ile du Fantome, Ile du Havre, Grosse Ile au Marteau, and Petite Ile au Marteau (from https://parks.canada.ca/pn-np/qc/mingan/visit/Cartes_Maps).

Clintonia borealis, *Saxifraga oppositifolia*, *Dryas integrifolia*, *Arctostaphylos uva-ursi*, and *Rhododendron groenlandicum* are also important outside of scientific research. *Clintonia borealis* (Blue-Bead Lily), is a common plant in the boreal forests of Quebec, blooming between May and June (Caron, 2015). Its habitat is moist deciduous or mixed coniferous woodlands (Caron, 2015). As a medicinal plant, it has mainly been studied for its antifungal properties (Caron, 2015). *Saxifraga oppositifolia* (Purple Saxifrage), is a common plant in the Arctic Archipelago of Canada, blooming between April and May and usually one of the first plants to flower in the spring (Aiken et al., 2011). The habitat of purple saxifrage may vary, but is generally found in harsh environments. The flowers are eaten for their sweet taste and the leaves are used to make tea by the Inuit People (Aiken et al., 2011). The full blooming of this plant has also been used as an indicator for the calving of caribou herds (Aiken et al., 2011). Its importance in Northern Arctic culture has led to it being designated as the official flower of Nunavut (Aiken et al., 2011). *Dryas integrifolia* (Mountain Avens), is a ubiquitous Arctic-Alpine plant, blooming between June and July (Aiken et al., 2011). Like the Purple Saxifrage, Mountain Avens also serves as a “time-keeper” for the change of seasons and caribou calving (Aiken et al., 2011). *Arctostaphylos uva-ursi* (Bearberry), is a widespread plant found in well-drained woodland areas, blooming between April and June (Crane, 1991). This plant is important to wildlife including deer, black bear, and hummingbirds due to its slow-spoiling fruit that lasts through the winter when other fruit are unavailable (Crane, 1991). The leaves of Bearberry have also been used to effectively treat urinary tract infections (Crane, 1991). *Rhododendron groenlandicum*, or Bog Labrador Tea, is an abundant wet-land plant found in open-canopy coniferous forests, blooming between June and July (Eflora, 2022). As the name suggests, for centuries this plant has been used to make tea and has been an important medicine to treat colds, sore throats, and headaches (Eflora, 2022) (Figure 2).

Clintonia borealis (Blue-Bead Lily)	*Saxifraga oppositifolia* (Purple Saxifrage)	*Dryas integrifolia* (Mountain Avens)	*Arctostaphylos uva-ursi* (Bearberry)	*Rhododendron groenlandicum* (Bog Labrador Tea)

(from https://www.minnesotawildflowers.info/flower/bluebead).	(from https://commons.wikimedia.org/wiki/File:Saxifraga_oppositifolia_2_RF.jpg).	(from https://davesgarden.com/guides/pf/showimage/300324/#b).	(from https://www.agefotostock.com/age/en/details-photo/bearberry-arctostaphylos-uva-ursi-catalonia-spain/Z5Z-2570519).	(from https://www.saskwildflower.ca/nat_Rhododendron-groenlandicum.html).

Figure 2. Photographs of the five species observed in this study, including *Clintonia borealis, Saxifraga oppositifolia, Dryas integrifolia, Arctostaphylos uva-ursi,* and *Rhododendron groenlandicum*.

The primary objective of our study addresses the gap in research for temperature affecting flowering date in the boreal region by taking observations from Mingan Archipelago National Park Reserve. First, we hypothesise that temperature and humidity in Mingan, Quebec are correlated. If temperature and humidity are correlated, we predict that increases in average monthly temperatures will be observed with increases in average relative humidity. Second, we hypothesise that increases in average temperatures and humidity between April to July in 2004 to 2017 have an effect on the annual first flowering dates of *Clintonia borealis*, *Saxifraga oppositifolia*, *Dryas integrifolia*, *Arctostaphylos uva-ursi*, and *Rhododendron groenlandicum* found in the islands of the Mingan Archipelago National Park Reserve in Quebec. If increases in seasonal average temperatures and humidity between April to July in 2004 to 2017 have an effect on annual first flowering dates, then we predict that earlier first flowering dates would be observed in years with higher average temperatures and humidity. This is because a plant's flowering time is expected to coincide with favourable growing temperatures to maximize fitness and prolong the survival of the species.

2. Methods

2.1 Data sources

Data were obtained through two public datasets. The first dataset contained annual first flowering dates for the five plant species *Clintonia borealis*, *Saxifraga oppositifolia*, *Dryas integrifolia*, *Arctostaphylos uva-ursi*, and *Rhododendron groenlandicum* from 2004 to 2017 on various islands at Mingan Archipelago National Park Reserve in Quebec. The data recorded the first flowering date for each species every year across 23 stations and was collected by Parks Canada “PlantWatch” program, available publicly, online at https://open.canada.ca/data/en/dataset/34347f5c-3a07-49ed-aadf-f1c65f8c6685.

The second dataset contained daily historical records of weather, including temperature and humidity, in Mingan, Quebec between the years 2004 and 2017. The data was collected from multiple Environment and Climate Change Canada data sources, available publicly, online at https://mingan.weatherstats.ca/download.html.

2.2 Data preprocessing

In the first flowering dataset, we removed the *data identification code* and *participant* columns and used the following columns in our analysis: *island_identification_code*, *island*, *station_name*, *species_name*, *survey_year*, *flowering_date*, and *day*. We renamed the column *survey_year* into *year*.

In the weather dataset, we kept the *date*, *avg_temperature*, and *avg_relative_humidity* columns and removed the others. We also only used the rows containing data from 2004 to 2017 and removed all other rows. We used the R package ‘lubridate’ to separate the information in the *date* column into separate components by creating new columns with *year*, *month*, and *day*. We then used the mean function and created a new dataframe *avg_weather* with the columns *month*, *year*, *mean_avg_relative_humidity,* and *mean_avg_temp* while filtering only for the months April to July and excluding missing observations from our analysis. Next, we used the mean function again and created another dataframe *mean_annual_temp* to find the average temperature per year.

We then merged the two dataframes from the flowering dataset and our temperature dataset and filtered out missing observations to facilitate subsequent analyses.

2.3 Data analysis

We used ggplot2 to create a scatter plot illustrating the correlation between average monthly temperatures versus average monthly relative humidity data collected between April to July in 2004 to 2017. To validate our assumption that the data for average monthly temperatures and average monthly relative humidity are normally distributed, we conducted a Shapiro-Wilk normality test and visualised the data using Q-Q plots from the R package ggpubr. Next, we conducted a Kendall’s rank-based correlation test (1) to account for the non-normal distribution of the average monthly temperature data and (2) to validate our assumption that the covariation is linear. We added the regression line from the Kendall's rank-based correlation test to our scatter plot.

To examine the effects of different variables on first flowering dates, we constructed 3 simple linear models and 9 linear mixed effect models using the R packages lmerTest and lme4. The simple linear models included (1) mean annual temperature, (2) flower species, and (3) the interaction between mean annual temperature and flower species as fixed effects on first flowering dates, respectively. To validate our assumption of normal distribution for each simple linear model, we plotted a normal Q-Q plot. To validate our assumption of homogeneity of variances for each simple linear model, we plotted a residuals versus fitted plot. For each of the simple linear models, we created additional linear mixed effect models that included (a) stations, (b) islands, and (c) stations nested in islands as random effects on first flowering date, respectively. Our best model was determined by using an Akaike Information Criterion corrected(AICc) test from the R package MuMIn.

For all frequentist analysis, a significance level of $\alpha = 0.05$ was used.

3. Results

Temperature and humidity data were collected in Mingan, Quebec between 2004 and 2017. A Shapiro-Wilk normality test revealed that the average monthly relative humidity data was normally distributed [$p = 0.2401$], but the average monthly temperature data was not normally distributed [$p = 0.0017$]. The Kendall’s rank-based correlation test revealed a significant positive correlation between average monthly temperatures and average monthly relative humidity [$R = 0.525$, $p < 0.0001$] (Table 1). Visualisation of a regression line determined by the Kendall’s rank-based correlation test validates our assumption that the covariation is linear (Figure 3).

Because the correlation between the average monthly temperature and average monthly relative humidity was significant, we chose to only focus on temperature data for the remainder of our study.

Table 1. Kendall's rank-based correlation test between average monthly temperature and average monthly relative humidity with 52 samples. The result demonstrates a significant correlation between temperature and humidity [$R = 0.525$, $p < 0.0001$].

			average relative humidity
Kendall's rank correlation tau	average monthly temperature	Correlation Coefficient	0.525*
		Sig. (2-tailed)	< 0.0001
		N	52

*. Correlation is significant at the 0.05 level (2-tailed).

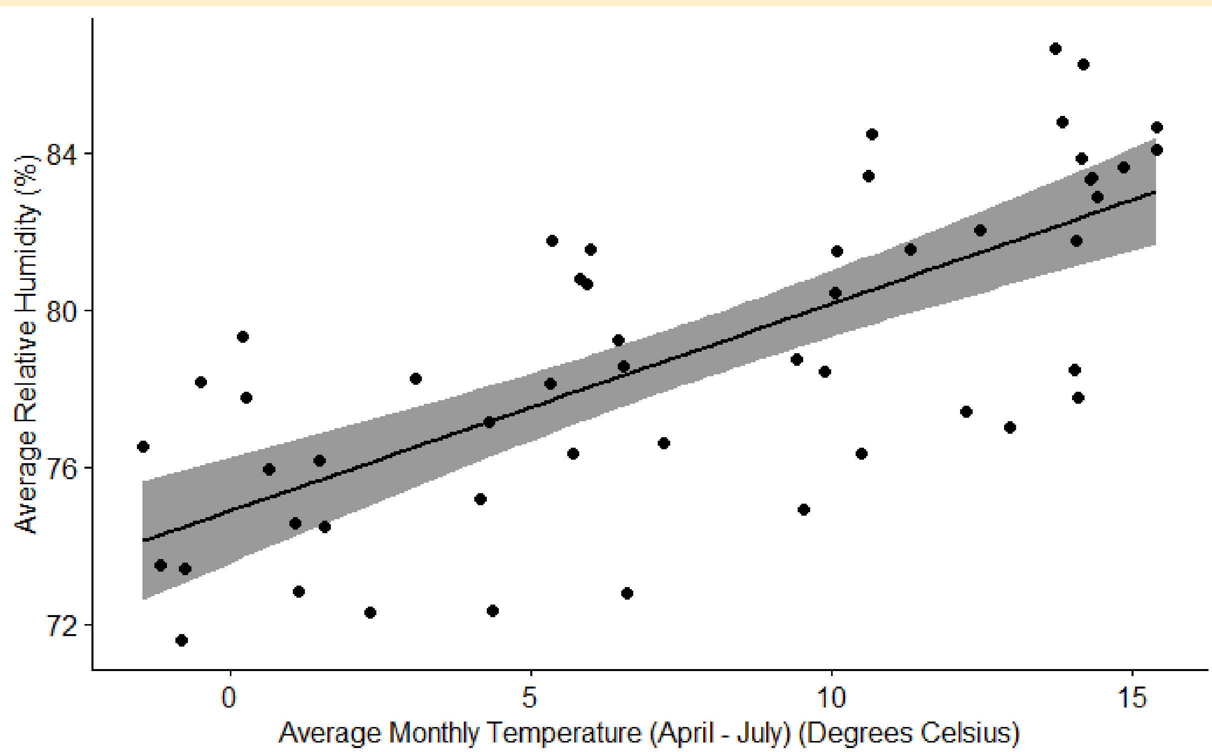


Figure 3. Scatter plot of average monthly temperature between April and July, in degrees Celsius, compared to average monthly relative humidity data collected from 2004 to 2017 in Mingan, Quebec. A regression line determined by the Kendall's rank-based correlation test is represented by the black line [$R = 0.525$, $p < 0.0001$].

The AICc test revealed that the best performing model for first flowering dates is: flowering date ~ mean annual temperature * species + (1|islands) (Model 3b). This model incorporates the interaction between mean annual temperature and species as a fixed effect and islands as a random effect [AICc = 1555.955, df = 12; Table 2].

Table 2. Comparison of models using Akaike Information Criterion corrected (AICc). All models have flowering date as the response variable. The result reveals the best fit mode, in bold, is: flowering date ~ mean annual temperature * species + (1|islands) (Model 3b).

Random effect	Fixed effect	AICc	*df*
	mean annual temperature	2003.689	3
	species	1658.439	6
	mean annual temperature + species + mean annual temperature : species	1576.592	11
a. (1|stations)	mean annual temperature	1669.499	4
	species	1658.076	7
	mean annual temperature + species + mean annual temperature : species	1573.047	12
b. (1|islands)	mean annual temperature	1994.332	4
	species	1646.235	7
	mean annual temperature + species + mean annual temperature : species	**1555.955**	**12**
c. (1|islands/ stations)	mean annual temperature	1671.584	5
	species	1660.214	8
	mean annual temperature + species + mean annual temperature : species	1574.692	13

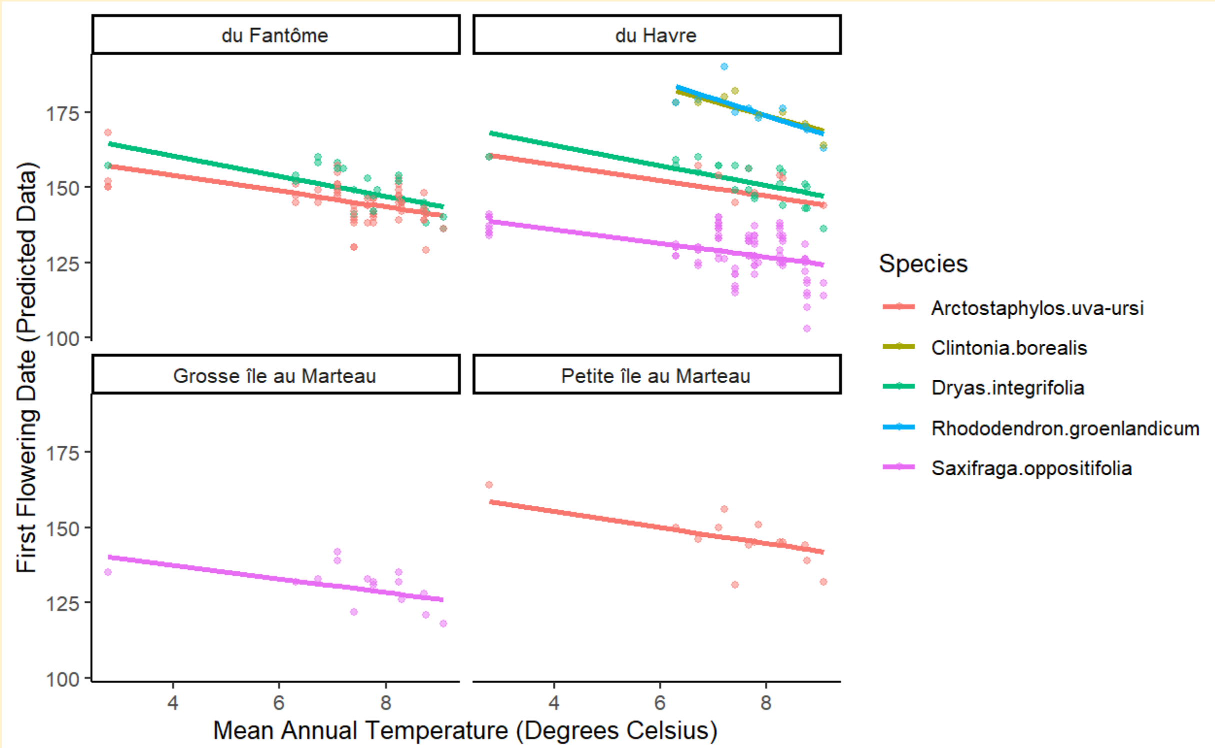
Our best performing model indicates that mean annual temperatures have a significant effect on first flowering dates [$p < 0.0001$; Table 3]. We observed a significant difference in the first flowering date of each species compared to *Arctostaphylos uva-ursi*, with the exception of *Dryas integrifolia* [$p = 0.1379$; Table 3]. *Saxifraga oppositifolia* exhibited earliest flowering dates, followed by *Arctostaphylos uva-ursi* and *Dryas integrifolia*, and *Clintonia borealis* and *Rhododendron groenlandicum* [Figure 4]. This suggests that the biology of a species plays a significant role in determining first flowering dates. The mixed effect model also revealed that mean annual temperatures had the same effect on first flowering dates across different plant species [$p > 0.05$; Table 3]. The random effect of islands accounted for approximately 16% of variation in the raw data.

Table 3. Results from the best performing model (Model 3b) for first flowering dates determined by the AICc test.

Best Model: Model 3b
(flowering date ~ mean annual temperature * species + (1|islands))

Predictors	*Estimates*	*p*
Mean annual temperature	-2.6386	**< 0.0001**
Clintonia borealis	43.7505	**0.0119**
Dryas integrifolia	9.1571	0.1379
Rhododendron groenlandicum	51.1375	**0.0032**
Saxifraga oppositifolia	-22.8738	**< 0.0001**
Mean annual temperature : *Clintonia borealis*	-2.1218	0.3348
Mean annual temperature : *Dryas integrifolia*	-0.6900	0.3914
Mean annual temperature : *Rhododendron groenlandicum*	-3.0486	0.1657
Mean annual temperature : *Saxifraga oppositifolia*	0.3409	0.5529
Initial flowering date	167.0613	**< 0.0001**

Figure 4. The graph of the best model (Model 3b): flowering date vs. mean annual temperature * species + (1|islands)



4. Discussion

In our research, we found that the correlation between temperature and humidity in Mingan, Quebec between 2004 and 2017 is significantly positive (Table 1). We chose temperature and humidity as the factors for predicting climate change since these two are the key factors that affect climate. Furthermore, previous studies have shown that temperature is the main driver for flowering time in Arctic plants (Panchen & Gorelick 2015). We assume temperature has a similar effect on flowering date in boreal biome. Hence, we chose the temperature to be the mixed effect in the models, rather than the humidity. Moreover, based on the first flowering dataset, the mean first flowering dates of all five species are concentrated between April and July. Hence, we chose the mean seasonal temperature (April–July) rather than the annual temperature for further linear model examinations.

In our best model, we found that temperature has a significant effect on the first flowering date (Table 3). The result is consistent with previous research which indicates that earlier flowering dates are observed with increasing temperature (Fitter et al., 1995; Figure 4). Also, we can predict a similar result if we tested the effect of humidity on flowering times since temperature is significantly correlated with humidity.

Our model indicates that the biological species of each plant has a significant effect on first flowering dates. Despite increases in temperature and changing islands, *Saxifraga oppositifolia* consistently exhibited earliest first flowering dates, *Arctostaphylos uva-ursi* and *Dryas integrifolia* consistently exhibited intermediate first flowering dates, and *Clintonia borealis* and *Rhododendron groenlandicum* consistently exhibited relatively late first flowering dates [Figure 4]. These results were expected because the existing literature suggests that the first flowering dates of plants are dependent on favourable environmental conditions that maximize plant fitness, which are specific to the biological requirements of each species. Earlier flowering, for example, would provide plants with a longer flowering period, less competition for pollinators, and access to higher levels of light. However, earlier flowering plants may also experience various disadvantages, including risks of reduced fitness due to frost damage from low temperatures, low availability of pollinators, or intense herbivory. Later flowering would counter these disadvantages, but may also cause plants to experience shorter flowering periods in which they are unable to complete their reproductive cycles, and greater competition with co-flowering plants for resources (Anderson et al., 2012; Kehrberger & Holzschuh, 2019). Due to biological differences between different plant species, different species evolve adaptations that may favour growing conditions that occur at earlier or later times of the year. For instance, *Saxifraga oppositifolia* have small, rigid hairs on its evergreen leaves that provide protection from arctic winds and snow, allowing the plant to flower earlier under colder conditions (Arctic Bioscan, 2020). These characteristics allow *Saxifraga oppositifolia* to flower earlier to maximize plant fitness, while accounting for risks such as frost damage under colder temperatures. As a result, our observations indicate that the genetic makeup of each plant is a major determinant of the biological requirements that should be prioritised to maximise plant fitness and, in turn, plays a significant role in determining first flowering dates.

Although we expected each species to be affected differently by temperature, we observed the opposite result—temperature has the same effect on flowering dates across the different species. For example, we expected the temperature-sensitive “time-keeper” plants such as Purple Saxifrage and Mountain Avens to be affected more strongly by temperature, but this does not align with our results since the slopes of all the plants were not significantly different. Furthermore, despite not being statistically significant, *Rhododendron groenlandicum*–which flowered the latest in the season out of the five species observed–had the greatest change in first flowering date. Previous studies have indicated that early-flowering species show greater sensitivity to climate change compared to late-flowering species . This may be observed because early-flowering in plants is triggered by spring temperatures, whereas late-flowering in plants is triggered by summer temperatures. Because the shift in temperatures between winter and spring are greater than the shift in temperatures between spring and summer, early-flowering plants may exhibit more sensitivity to climate change than late-flowering plants (Miller-Rushing & Inouye, 2009). This discrepancy between our data and the current literature may be caused by the short 13 year time-period in which our study took place. Future studies may investigate changes in first flowering dates across larger time periods to examine the sensitivity of different plant species to climate change.

Our best performing model incorporated islands as a random effect, which accounted for approximately 16% of variation in the raw data. These variations may be a result of environmental differences exhibited between the Ile du Fantome, Ile du Havre, Grosse Ile au Marteau, and Petite Ile au Marteau. However, due to limitations in our original dataset, not all plant species were observed on each of the four islands. As a result, it is unclear whether these environmental differences would impact each plant species differently.

Since, to our knowledge, no studies so far have examined the effect of humidity on flowering date, this can be tested in a future study. Furthermore, other predictors of climate change, such as precipitation, can be studied for its effect on phenology. Additionally, because the 13-year time period of our study may be too short to observe consistent trends in first flowering dates, future studies may also incorporate longer study periods.

5. Conclusion

Our study has offered new insights into the effects of climate change and warming temperatures on plant flowering dates. We predict that the results we observed–increasing temperatures show earlier flowering dates–will continue to persist as temperatures rise due to climate change. Thus, efforts to slow down climate change will be beneficial for these species and plants worldwide. Future studies can further investigate the effect of temperatures on plants that flower earlier opposed to later in the season, as well as the effect of other predictors of climate change on flower phenology, such as humidity.

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