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CLIMATE CHANGE IN NOVA SCOTIA: TEMPERATURE INCREASES FROM 1961 TO 2020

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ABSTRACT

An analysis of temperature in Nova Scotia, using climate normals for 1961-1990 and temperature records from 1961 to 2020, is presented for 16 sites across the province. These records show a slight warming trend in the first 40 years from 6.0 ± 0.5 °C (1961-1990), followed by a more significant increase in average temperature post-1990 of 1.0 °C to 6.7 ± 0.5 °C, and to 7.0 ± 0.5 in the post-1998 period. A jump in average temperature in 1998 is such that in only a few following years did the mean annual temperature fall below the average annual temperature for the previous period. A step change was coincident with La Niña events and increasing Atlantic Ocean temperatures associated with a shift of the Atlantic Multi-decadal Oscillation into a positive phase. The increase in mean monthly temperatures was more apparent in the Autumn when first frosts were later and there were fewer days with frost. This led to a significant increase in continuous frost-free days of 9.2 ± 7.9 days, with increases ranging from 0.4 to 30.6 days. Relative to other sites, Yarmouth had the smallest annual increase in mean temperature, of 0.5 °C, but this was associated with a major increase in continuous frost-free days, of 11.3. Because overall temperature change was based largely on a step change post-1998, rather than a continuous, gradual change (seen only in frost-free days), it is difficult to calculate a rate, or to predict future patterns of temperature increases. We suggest a significant influence of El Niño Southern Oscillation and Atlantic Multi-decadal Oscillation as potential contributors to the temperature increase. Increases in annual temperature and seasonality are discussed in terms of flowering phenology, including flowering in the Spring of 2021 when 31 species were blooming by the end of April.

Keywords: climate change, climate normal, flowering phenology, Nova Scotia, temperature, weather

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INTRODUCTION

Climate warming is a global phenomenon that, since the industrial revolution, has been driven by human activity, in particular the burning of fossil fuels (e.g., Bush *et al.* 2014, IPCC 2014, 2018, 2019, Walsh *et al.* 2014, Su *et al.* 2017, Cheng *et al.* 2020, Masters 2020, NOAA 2020). The warmest years on human record have been recorded in the last decade, with 2020 tied with 2016 as the warmest (Voosen 2021). In the marine realm, each year has resulted in temperature increases on an annual basis (Cheng *et al.* 2020). These changes have been reflected in increases in temperature in both air and water, with the most dramatic changes occurring in polar regions with loss of sea-ice cover, reduction in permafrost and glacial cover, and rises in sea level (e.g., Chasmer and Hopkinson 2016, Mikkelsen *et al.* 2016, Ding *et al.* 2017, and references therein).

While climate warming associated with increasing temperature is clearly occurring on a global scale, it is important to determine whether the patterns observed on such a scale are actually occurring locally, and the extent to which global changes are being either exacerbated or moderated based on local patterns of geography in both terrestrial and aquatic realms. Vincent *et al.* (2013) examined climate change in Canada from 1950 to 2010 and showed an overall temperature increase of 1.5 °C. Garbary (2018) analyzed climate change in Prince Edward Island (PEI) using historical climate data from the Government of Canada, based on three primary sites with relatively complete datasets and numerous secondary sites with incomplete data series for 1961 until 2016. The principal findings included a temperature rise of about 1 °C with an apparent step change in the late 1990s. In this paper, we focus on Nova Scotia. While some of the results that we report have been described and are publicly available (e.g., climate change.novascotia.ca), in this paper we use the underlying data in the public record (i.e., climate.weather.gc.ca), focus on a 60-year timescale from 1961 to the present, and use a simple method that facilitates replication without access to complex modelling or statistics. In addition, the evaluations of current climate and predictions used by Climate Nova Scotia are based on a model last revised in October 2006 (Lines *et al.* 2006), and it does not include empirical data from the last 14 years. Thus, our analysis provides a more comprehensive perspective on the last 60 years.

Because Nova Scotia (NS) is largely surrounded by the Bay of Fundy/Gulf of Maine and the open Atlantic Ocean, that are warmer in Winter and cooler in Summer than the Gulf of St. Lawrence, differences in temperature change might be expected between NS and PEI. Hence, we ask the following questions with respect to NS:

(1) Has there been significant temperature increase and is it comparable to that in PEI?

(2) If so, are the temperature increases distributed evenly over the entire year, or are particular months or seasons more generally impacted?

(3) Are there regional differences in climate change in NS that can be associated with particular oceanographic phenomena?

(4) To what extent is temperature change in NS consistent with global trends?

(5) Is the scale of any temperature change likely to have important ecological or agronomic consequences (e.g., length of growing season)?

Changes in temperature in Nova Scotia are discussed in the context of the oceanographic features El Niño-Southern Oscillation (ENSO) and Atlantic Multidecadal Oscillation (AMO) that affect global weather patterns on timescales from months to decades (e.g., McPhaden *et al.* 2006). As plant biologists, we use the temperature record to explain the unusual flowering phenology observed in Nova Scotia since the beginning of the century associated with late flowering into December and even January (e.g., Garbary *et al.* 2011).

MATERIAL AND METHODS

This work follows the analysis by Garbary (2018) on temperature change for Prince Edward Island (PEI) and applied here to Nova Scotia (NS). The previous study used three sites in PEI (Charlottetown, New Glasgow, Alliston) for which relatively complete datasets were available, and a suite of secondary sites for which data were more fragmentary. Our dataset used 16 (or 14, depending on data availability) sites in NS with relatively complete weather data (Table 1). All data were extracted from the official website of Environment Canada (https://climate.weather.gc.ca/index_e.html). Changes in annual mean temperature and monthly mean temperature compared climate normals (i.e., CN – the 30-year averages) for

Table 1 Locations of sites in Nova Scotia used in analysis of temperature change. Source: climate.weather.gc.ca/index_e.html. See Fig 1 for approximate locations of sites based on abbreviations in column one.

Site name (Climate ID Station number); abbreviation	Location	Elevation (m)	Comments
Bridgewater (8200600); BR	44°24'N, 64°33'W	27.4 m	Missing data: 2007, 2010-2012, 2015-2020
Cheticamp; Cheticamp CS (8200825; 8200827); CH	46°39'N, 60°57'W; 46°38'42"N, 60°56'50"W	11.0 m, 43.9 m	Combined data from 2 sites: 1961-1990, 1998-2019
Collegeville; Collegeville Auto (8201000, 8201001); CO	45°20'N; 62°01'W; 45°29'28"N; 62°00'54"W	76.2 m, 69 m	Changed location of weather station 2016
Deming (8201410) DE	45°12'59"N; 61°10'40"W	15.8 m	Data missing 2009-2020
Greenwood A (8202000); GR	44°59'N; 64°55'W	28 m	Complete dataset
Halifax Stanfield Int'l Airport (8202250, 8202251); HA	44°52'48"N; 63°30'W; 44°52'52"N; 63°30'31"W	145.4 m, 145.4 m	Data missing for 2003
Kejimkujik Park; Kejimkujik 1 (8202590, 8202592); KE	44°26'N; 65°12'W; 44°24'11"N, 65°12'11"W	126.8 m, 125.0 m	Data missing for 1961-1965; Changed weather station location 1994
Middle Musquodoboit (8203535); MM	45°04'N, 63°06'W	47.8 m	Extensive gaps 2006-2019
Nappan CDA; Nappan Auto (8203700, 8203702); NA	45°46'N, 65°15'W; 45°45'34"N, 64°14'29"W	19.8 m, 19.8 m	Changed station location 2005
Parrsboro (8204400, 8204402); PA	45°24'N, 64°20'W; 45°24'48"N, 64°20'46"W	24.3 m, 30.9 m	Data gap 2002-2004
Shearwater (8205090, 8205092)	44°38'N, 63°30'W; 44°37'47"N, 63°30'48"W	44 m, 24 m	Data gap 2006-2008

Table 1 cont'd

Site name (Climate ID Station number); abbreviation	Location	Elevation (m)	Comments
St. Margaret's Bay (8204800); ST	44°42'N, 63°54'W	17.4	Large data gaps in 2006, 2007
Sydney Airport (8205700, 8205701); SY	46°10'N, 60°02'53"W; 46°09'41"N, 60°02'53"W	61.9 m, 61.9 m	New station begins 2014
Western Head (8206240); WH	43°59'24"N, 64°39'51"W	10.1 m	Missing data 1976-1995
Yarmouth Airport (8206495, 8206496, 8206500); YA	43°49'37"N, 66°05'17"W; 43°49'51"N, 66°05'19"W	42.9 m, 43 m	Dataset complete

1961-1990, for each location, with subsequent weather data based on monthly means. Further analyses used the weather data from 1961 to 2020 to determine the following: (1) number of frost days (i.e., with minimum daily temperatures below 0.0 °C) between March and June; (2) number of frost days between September and December; (3) number of days until last frost after 01 April; (4) number of days until first frost after 01 September; and (5) number of continuous frost-free days during Summer. These metrics allowed us to evaluate the extent to which temperature has changed in the last 30 years relative to the previous 30 years and to discuss these changes in the context of the wild flora of NS.

None of the datasets for any site were complete. Gaps varied from missing days to missing months, to one or more missing years of data (e.g., Halifax Airport for 2003; see Table 1). In that case, 2003 was omitted from the analysis. When mean monthly temperatures were missing for four or more months, that year was omitted from the calculation of mean annual temperature, although the remaining data might be used for other metrics (i.e., dates of last and first frost). To fill in blanks, several strategies were implemented. For years with up to three missing monthly means, the missing values were estimated as the means of that month for the two previous years. To avoid a potential bias towards our conclusion of climate warming, we treated missing data for the period 1961-1990 (i.e., the climate normal) and our test period (i.e., 1991-2020) differently. Thus, in the period of the climate normal, missing daily data for March-April and November-December were counted as non-frost days. During the 1991-2020 period, missing data in March-April and November-December were counted as frost days. Missing daily data in May-June and September-October were counted as frost or non-frost days based on temperatures for adjacent values in the month.

Sites

Sites used in the analysis were based on the availability of data rather than on preselected criteria. These sites (Table 1, Fig 1) span almost three degrees of latitude from Cheticamp in the north (46°39'N) to Yarmouth Airport (hereafter Yarmouth) in the south (43°49'N), and six degrees of longitude from Sydney Airport (hereafter Sydney) in the east (60°02'W) to Yarmouth in the west (66°05'W). Elevations ranged from 10.1 m (Western Head) to 145 m

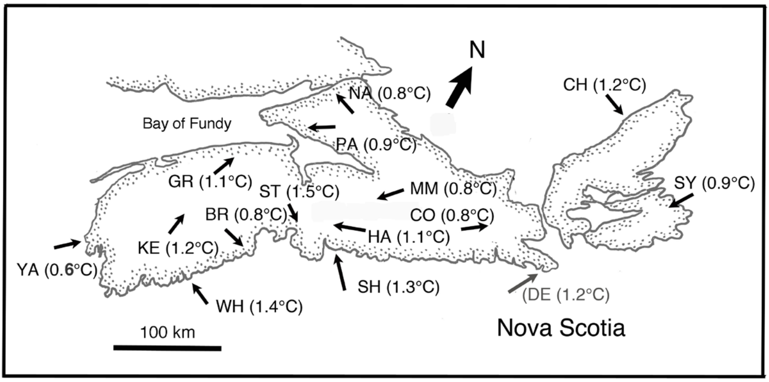

Fig 1 **Map of Nova Scotia showing sites used for evaluation of climate change. Temperatures in parentheses indicate temperature rise for 1998-2020 relative to climate normal. Sites in southwestern Nova Scotia (YA, GR, KE, WH, BR, ST, and SH, have annual mean temperature > 7.0 °C and HA is at 6.9 °C. See Table 1 for site names and corresponding abbreviations.**

(Halifax Airport; hereafter Halifax), with an overall mean elevation of approximately 40 m. Most sites were less than 10 km from the ocean, and only Kejimkujik National Park (hereafter Kejimkujik), Bridgewater, Collegeville, Middle Musquodoboit, and Halifax were 30 km or more from the ocean. While Greenwood Airport (hereafter Greenwood) is less than 20 km from the Bay of Fundy, its location in the Annapolis Valley represents more inland conditions. Coastal sites were associated with the Bay of Fundy (Nappan, Parrsboro, Yarmouth), or the Atlantic Coast (Western Head, St. Margaret's Bay, Shearwater, Deming, Sydney). Cheticamp was the only site associated with the Gulf of St. Lawrence.

Statistical Analysis

Values for each metric are presented as means and standard deviations (mean ± *s*). For each location and metric, means for climate normals for 1961-1990 or 1971-2000 were compared with subsequent values (i.e., either 1991-2020 or a subset, the years 1998-2020) using Student's *t*-tests at $P < 0.05$. One-sample Student's *t*-tests were used to compare monthly mean values for the post-climate normal period with the value for the climate normal. Since annual temperature means, pre- and post-1990, were significantly different for all sites except Yarmouth, we used one-tailed tests to compare monthly means. Statistical analyses were carried out using Excel, or online using GraphPad (https://graphpad.com/quickcalcs/contMenu). For the evaluation of monthly means for 1961-1990 and post 1991, paired Student's *t*-tests were used.

RESULTS

Change in Annual Mean Temperature

The analysis showed that a significant temperature increase occurred in Nova Scotia from 1960 to 2020. This is based on a comparison of the climate normal (CN) for the period 1961-1990 to the 1991-2020 dataset when the mean temperature went from 6.0 ± 0.5 °C to 6.7 ± 0.5 °C (significant at $P < 0.01$; Table 2). The temperature increase was significant for all sites and ranged

Table 2 **Mean annual temperature for different periods in Nova Scotia. Data for 1961-1990 and 1971-2000 are climate normals. Asterisks (*) indicate significant differences relative to climate normal for 1961-1990.**

Site	Mean annual temperature 1961-1990 (°C)	Mean annual temperature 1971-2000 (°C)	Mean annual temperature 1991-2020 (°C ± s)	Mean annual temperature 1998-2020 (°C ± s)
Bridgewater	6.7	6.9	7.2 ± 0.6	7.5 ± 0.6*
Cheticamp	6.1	6.2	-	7.3 ± 0.7*
Collegeville	5.6	5.8	6.1 ± 0.8*	6.4 ± 0.8
Deming	5.6	5.8	6.3 ± 0.7*	6.8 ± 0.5*
Greenwood	6.6	6.8	7.5 ± 0.8*	7.7 ± 0.6*
Halifax	6.1	6.3	6.9 ± 0.8*	7.2 ± 0.6*
Kejimkujik	6.4	6.3	7.3 ± 0.8*	7.6 ± 0.6*
Middle Musquodoboit	6.0	6.2	6.5 ± 0.8*	6.8 ± 0.5*
Nappan	5.6	5.8	6.2 ± 0.7*	6.4 ± 0.6*
Parrsboro	5.4	5.9	6.2 ± 0.8*	6.3 ± 0.8*
Shearwater	6.5	6.7	7.5 ± 0.8*	7.8 ± 0.7*
St. Margaret's Bay	5.9	6.1	6.9 ± 0.9*	7.4 ± 0.7*
Sydney	5.5	5.5	6.1 ± 0.8*	6.4 ± 0.7*
Western Head	5.4	-	7.0 ± 0.4*	7.1 ± 0.6*
Yarmouth	6.8	7.0	7.3 ± 0.8*	7.5 ± 0.8*
Mean	**6.0 ± 0.5**	**6.2 ± 0.5**	**6.7 ± 0.5***	**7.0± 0.5***

from a 0.6 °C increase for Yarmouth to 1.6 °C for Western Head, although the latter increase is likely an artifact of extensive missing data. The extent of the temperature increase is more apparent beginning in 1998, with a subsequent mean temperature across the province of 7.0 ± 0.5 °C. The dramatic nature of the difference between the two periods is highlighted by the fact that in the early period, only a single year had a mean temperature above 7.0 °C, i.e., 1983 at 7.1 °C, whereas in the later period, over half of the years do. Annual temperatures below 6 °C occur in over half of the years between 1961 and 1997, but in none of the subsequent years.

Fig 2A shows the change in annual temperature on a year-to-year basis, starting in 1961. Linear regression of mean annual temperatures 1961 to 2020 yields $R^2 = 0.4240$ ($P < 0.0001$), suggesting a strong relationship of time to rising annual temperature over the entire period. However, the relationship between 1961 and 1997 has an $R^2 = 0.088$, with a non-significant regression ($P = 0.074$). Similarly, the period 1998 to 2020 is also non-significant ($R^2 = 0.006$, $P = 0.73$). These linear regressions are consistent with a step change between 1997 and 1998 associated with the 1 °C difference between early and late periods, as discussed in the previous paragraph.

Changes in Monthly Mean Temperatures

Across NS, monthly mean temperatures post-1991 trended higher in each month, with increases ranging from 0.5 °C for June, to 1.6 °C for December (Fig 2, Table 3). Temperature increases were statistically significant for all months. Monthly temperature increases of 0.7 °C (or above) tended to be highly significant ($P < 0.01$). The most conspicuous seasonal patterns were the lower temperature increases from May to July (mean increase of 0.6 °C), and the highly significant increases in monthly temperature from August to December (mean increase of 1.0 °C; $P < 0.001$).

Changes in Number of Frost Days in Spring and Autumn

Changes in occurrence of days with frosts in the Spring and Autumn, and the dates of last and first frosts (Table 4), reflect the increases in mean monthly temperatures. Of the 56 comparisons of these metrics across our sites, only five comparisons were not consistent with a warming climate trend: Cheticamp and Yarmouth, number of frost days from March to June; Nappan, number of frost days from September to December; and Nappan and Sydney, days to last frost. Of the remaining 51 comparisons, 17 showed statistically changed values relative to the period of the CNs that is consistent with climate warming. However, the fact that these are population measures rather than sample estimates supports the significance of the changes.

Even though reduction in the number of frost days between March and June was significant only for St. Margaret's Bay (5.0 days), the remaining sites with declines ranged from 1.2 (Parrsboro) to 4.9 (Deming). Including the two sites where slight increases occurred, the average decline over all the sites was 2.5 ± 1.6 (significant at $P < 0.05$). This coincided with a similar decline in the number of frost days after 01 April of 4.2 ± 5.9 (significant at $P < 0.05$).

Days with frost in late Summer and Autumn (September to December) declined 4.0 ± 2.4 days, with declines ranging

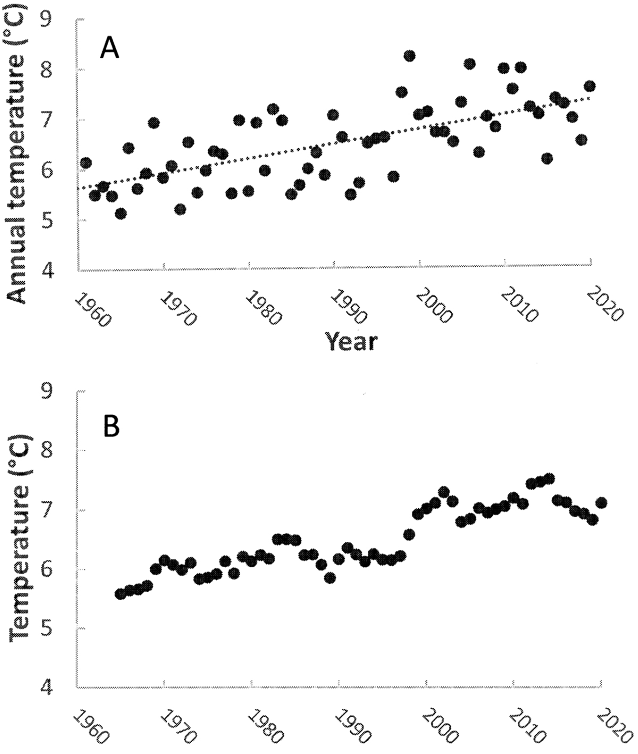

Fig 2 **Mean annual temperature in Nova Scotia. (A) From 1961 to 2020. (B) Data smoothed to show running 5-year averages; thus, 1965 is the mean of 1961-1965; 1966 is the mean of 1962-1966, etc.**

Table 3 **Mean monthly temperature (°C) in for climate normals (1961-1990) and subsequently (1991-2020). Values derived from 13 sites (see Table 1). Significance based on two-tailed, paired Student's *t*-tests: *, *P* < 0.05; **, *P* < 0.01; ***, *P* < 0.001**

Month	Climate normal 1961-1990 (°C)	1991-2020 (°C)	Temperature increase (°C)	Significance
J	-5.5 ± 1.1	-4.9 ± 1.2	0.6	*
F	-5.8 ± 1.1	-4.6 ± 1.1	1.2	**
M	-1.6 ± 0.8	-0.9 ± 0.7	0.7	*
A	3.6 ± 0.9	4.4 ± 0.6	0.8	***
M	9.1 ± 1.1	9.8 ± 0.8	0.7	***
J	14.1 ± 1.2	14.6 ± 1.0	0.5	*
J	17.6 ± 1.2	18.3 ± 1.2	0.6	*
A	17.6 ± 0.6	18.3 ± 1.0	0.8	***
S	13.6 ± 0.5	14.8 ± 0.6	1.3	***
O	8.6 ± 0.5	9.2 ± 0.6	0.8	***
N	3.7 ± 0.7	4.3 ± 0.7	0.7	***
D	-2.4 ± 1.1	-1.0 ± 1.0	1.6	***
Mean	**6.0**	**6.8**	**0.85**	***

from 2.2 to 7.1 days for Yarmouth and Kejimkujik, respectively. The reduction in Autumn frost days was reflected in a longer period after 01 September until the first frost (Table 4), with values ranging from 3.3 to 13.9 days for Sydney and Kejimkujik, respectively, and an overall frost delay of 6.9 ± 3.2 days. That this metric was significantly longer for seven of the 12 sites shows that changes in the Autumn were more pronounced than in the Spring.

Change in Continuous Frost-free Period

A conspicuous increase was noted in the number of continuous frost-free days during Summer and Autumn (Table 5, Figs 3A, B). The mean length of the frost-free period from 1991 to 2020 was 149.4 ± 21.6, and this was an increase of 9.2 ± 7.9 days for these sites. While changes for six of the 13 sites were not significant (all with less than an 8-day increase), for six sites they were significantly longer. Linear regression showed $R^2 = 0.309$ ($P = 0.0001$). Comparing only the period 1998 to 2020 to the CN, the frost-free period was extended 14.0 ± 9.0 days. Cheticamp was the frost-free period apparently reduced from 1998 to 2020, and this may reflect

Table 4 Change in number of days with frost for March-June and September-December, number of days after 01 April until last frost, and number of days until first frost for sites in Nova Scotia. Asterisk (*) indicates significant difference at $P < 0.05$. CN, climate normal.

Sites	Period	Frost days (Mar-Jun)	Days until last frost after 01 Apr	Frost days (Sep-Dec)	Days until first frost after 01 Sep
Bridgewater	CN 1991-2014	50.6 ± 7.3 47.5 ± 6.8	60.0 ± 11.9 48.4 ± 13.9*	56.6 ± 8.7 51.2 ± 7.0*	23.3 ± 8.1 33.3 ± 9.3*
Cheticamp	CN 1991-2020	49.8 ± 9.0 51.0 ± 9.1	50.7 ± 11.8 49.7 ± 9.7	39.7 ± 7.2 35.5 ± 6.1*	53.9 ± 10.3 60.3 ± 11.4*
Collegeville	CN 1991-2020	54.8 ± 8.6 51.2 ± 16.4	62.9 ±14.1 62.3 ± 15.7	54.8 ±7.9 51.0 ± 11.0	24.1 ± 9.0 29.7 ± 11.4*
Deming	CN 1991-2008	45.4 ±10.2 40.9 ± 8.8	35.0 ± 10.4 34.1 ± 10.3	32.1 ± 7.5 27.4 ± 5.0	64.7 ± 12.0 69.7 ± 10.3
Greenwood	CN 1991-2020	47.3 ± 6.9 44.4 ± 6.6	45.1 ± 10.4 41.1 ± 10.2	47.3 ± 6.9 48.0 ± 7.0	30.6 ± 12.2 36.0 ± 11.6
Halifax A	CN 1991-2020	48.8 ± 8.3 46.4 ± 7.2	37.4 ± 11.9 34.9 ± 11.8	49.3 ± 7.4 45.3 ± 6.0*	45.5 ± 10.0 51.8 ± 10.0*
Kejimkujik	CN 1991-2019	49.5 ± 7.8 47.9 ± 6.5	59.6 ± 12.8 42.1 ± 12.6*	57.8 ± 8.3 50.2 ± 7.6*	18.4 ± 10.7 32.3 ± 12.2*
Nappan	CN 1991-2020	50.1 ± 7.4 48.5 ± 11.1	51.2 ± 10.1 53.4 ± 13.2	49.9 ± 8.3 51.0 ± 7.0	26.2 ± 12.9 32.0 ± 10.9
Parrsboro	CN 1991-2020	50.9 ± 11.0 49.7 ± 8.5	57.9 ± 11.8 50.1 ± 11.7	54.3 ± 9.0 50.7 ± 8.1	26.0 ± 12.8 35.0 ± 11.0*
Shearwater	CN 1991-2020	42.9 ± 6.7 40.0 ± 7.3	34.0 ± 9.9 28.6 ± 8.4	42.0 ± 6.1 36.9 ± 5.7	53.6 ± 10.0 60.9 ± 9.3*

Table 4 cont'd

Sites	Period	Frost days (Mar-Jun)	Days until last frost after 01 Apr	Frost days (Sep-Dec)	Days until first frost after 01 Sep
St. Margaret's Bay	CN	48.3 ± 7.7	51.3 ± 10.8	54.4 ± 8.5	35.2 ± 11.6
	1991-2020	43.3 ± 9.6*	43.6 ± 12.5*	45.2 ± 13.0	38.2 ± 15.4
Sydney	CN	59.3 ± 7.3	49.9 ± 9.7	47.4 ± 8.1	47.6 ± 11.1
	1991-2020	56.2 ± 8.3	52.4 ± 12.1	43.3 ± 6.0	50.9 ± 11.5
Western Head	CN	40.8 ± 5.5	31.6 ± 6.9	39.3 ± 4.8	51.1 ± 9.4
	1991-2020	36.7 ± 7.0	31.0 ± 9.1	36.7 ± 6.4	53.7 ± 11.9
Yarmouth	CN	34.0 ± 8.0	29.4 ± 10.9	37.0 ± 9.7	50.7 ± 10.3
	1991-2020	36.1 ± 8.4	27.7 ± 9.1	35.0 ± 6.3	57.6 ± 11.4*
Mean difference		**-2.5 ± 1.6***	**-4.2 ± 5.9***	**-4.0 ± 2.4***	**6.9 ± 3.2***

Table 5 **Length of continuous frost-free period in days for 1991-2020 and differences 1961-1990 and 1998-2020. Note: *, significant at $P < 0.05$; **, significant at $P < 0.01$; NS, not significant.**

Site	Frost-free days 1991-2020	Difference from 1961-1990	Difference 1998-2020 vs 1961-1990
Bridgewater[a]	115.4 ± 15.7	3.7	23.7**
Cheticamp	162.8 ± 15.1	9.0*	8.6 (NS)
Collegeville	116.7 ± 24.9	3.6 (NS)	5.6 (NS)
Deming	188.2 ± 13.9	5.0 (NS)	7.6 (NS)
Greenwood	149.2 ± 16.7	11.2**	14.5**
Halifax A	168.9 ± 15.9	5.5 (NS)	9.4*
Kejimkujik	142.3 ± 19.8	30.6**	36.9**
Nappan	131.6 ± 19.6	3.9 (NS)	9.0*
Parrsboro	137.0 ± 19.0	17.3**	13.4*
Shearwater	172.8 ± 14.3	11.2**	15.3**
St. Margaret's Bay	140.4 ± 25.3	4.8 (NS)	13.7*
Sydney	149.8 ± 18.5	0.4 (NS)	3.0 (NS)
Western Head	173.8 ± 16.5	7.0 (NS)	-
Yarmouth	182.1 ± 15.5	11.3**	15.1**
Mean ± s	149.4 ± 21.6	9.2 ± 7.9*	14.0 ± 9.0*

[a] values missing for 1961, 2006, 2007, 2012, 2014-2020

the changed position of the new weather station with its slightly higher elevation (see Table 1). The step change post-1998 was also recognized in the linear regressions, in that the values of R^2 for the early and late periods were not significant at 0.008 and 0.011, respectively, with $P > 0.5$. Despite the difference in means between early and late periods, the five-year running average showed a steady increase between the late 1990s and 2010, with a seemingly continuous decline in the subsequent 10 years.

DISCUSSION

Relative to the 30-year period of climate normal (CN) for 1961-1990, we demonstrated for the subsequent 30-year period the following changes in Nova Scotia: (1) an increase in overall mean temperature of 0.7 °C (1.0 °C post-1998) which is reflected in

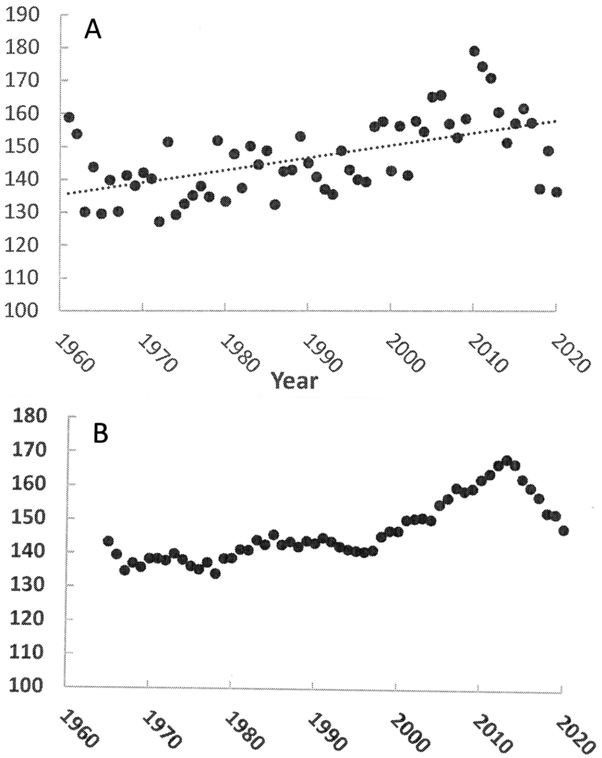

Fig 3 **Continuous frost-free periods in Nova Scotia from 1961 to 2020. (A) Year to year changes. (B) Data smoothed to show changes in running 5-year averages; thus, 1965 is the mean of 1961-1965; 1966 is the mean of 1962-1966, etc.**

statistically significant increases in all months of the year; (2) a decline in number of frost days in both Spring and Autumn; (3) earlier ending and later starting dates of frosts in the Spring and Autumn, respectively; and (4) an increase in the overall average continuous frost-free period of 9 days. While many of these points have been explicitly made by other authors with respect to generalized changes for eastern Canada (e.g., Galbraith and Larouche 2013), here we show considerable variation across the province in the extent of changes that have occurred.

Globally, 2020 was tied with 2016 as the warmest on record (Voosen 2021). Nova Scotia is out of sync with the global average in that for 2020, the mean for NS was only 7.63 °C, well below the warmest years of 1999 and 2006 with means of 8.2 °C and

8.0 °C, respectively. Regardless, temperatures at several sites along the Atlantic Coast of NS have increased more during the last 22 years than the 1.25 °C global increase over preindustrial measures, e.g., St. Margaret's Bay, 1.5 °C. This contrasts with the overall increase for the province of only 1 °C (Fig 2).

There was a slight change in method used here than for the previous analysis of temperature change in PEI (Garbary 2018). In that paper, with only with three primary sites, the monthly means for years after 1991 were normalized by each month-year value. Consequently, monthly changes at the three sites were considered separately (see Table 2 in Garbary 2018). In the current study, because there were either 14 or 16 sites, only mean values of up to 30 years were normalized, i.e., subtracted from the monthly values of the climate normal, averaged, and evaluated using one-tailed Student's *t*-tests. Overall, the patterns of monthly increases relative to CN in terms of the extent of warming, and the individual months that were significantly warmer, were basically the same for both NS and PEI. Thus, the months from August to December were all significantly warmer, consistent with PEI, with monthly increases from 0.7 °C to 1.6 °C.

It is of interest that for the period of the CN, Yarmouth, with a mean annual temperature of 6.8 °C, was the warmest of our sites (Table 2). Currently, the warmest sites based on the post 1998 dataset are two non-coastal sites, Kejimkujik and Greenwood, with means of 7.6 °C and 7.7 °C, respectively, and the coastal site of Shearwater at 7.8 °C. The coolest sites during the CN period were Western Head and Parrsboro, with annual means of 5.4 °C; the coolest sites for the most recent 30-year period are Collegeville and Sydney at 6.1 °C, with the two Bay of Fundy sites (Nappan, Parrsboro) at 6.2 °C. These shifts suggest differential patterns of warming at different sites and would seem to preclude a single regional prediction for NS as a whole.

The pattern of temperature increase in PEI was characterised by a stable annual mean from 1961 to 1997, with a step-like change beginning in 1998 and continuing until 2016. This change is less apparent for NS in that there was an increase of 0.15 °C in the climate normal from 1961-1990 to 1971-2000. However, no year from 1998 to present was below the mean for the period for the preceding 37 years. In addition, only five years (1969, 1979, 1983, 1984, 1990) in that early period were above the mean temperature for the subsequent 22 years (i.e., 6.83 °C). Furthermore, no years between 1961 and 1990 were above the mean for the 1998-2020 period. While these mean values may indicate a step increase in temperatures for NS, there has been a slight decline in annual mean temperature in the last 22 years (R^2 = -0.044 for 1998-2020). However, this trend was moderated in 2020 with a mean temperature of 7.6 °C across 12 sites when five sites (Greenwood, Shearwater, St. Margaret's Bay, and Kejimkujik) were over 8 °C. Regardless, the pattern of change since the late 1990s relative to 1961-1997 makes determination of an overall rate difficult. The slight downward trend needs to be put into the context of global temperatures where six of the hottest years since the industrial revolution have been in the past decade.

The extent of climate warming in Nova Scotia is highlighted by the fact that for 1961-1990, only one studied site, Yarmouth, had a mean temperature approaching 7 °C, whereas for 1998-2020 temperatures for only six sites had annual means below 7 °C. The changes in the other temperature metrics described here, i.e., number of frost days in Spring and Autumn, number of days until the last frost in Spring, number of days until the first frost in the Autumn, and the length of the continuous frost-free period, provide a consistent picture of increasing temperature that has accelerated over the last 30 years.

The increased length of the frost-free period may be the most dramatic impact of climate change demonstrated here. The 1998-2020 dataset's average increase of 9.2 days relative to 1961-1990 is similar to the 10-day increase described by Walsh *et al.* (2014) for northeastern USA for the period since 1901-1960. The extreme value of an increase of 37 days for Kejimkujik (1961-1990 vs 1998-2020), associated with a 1.2 °C temperature increase over the same period, is in marked contrast with Yarmouth where a 0.6 °C increase was accompanied by a 15-day increase in the frost-free period. The extreme value of an increase of 37 days for Kejimkujik may be an artifact of 5 years of missing data from the early 1960s. The second largest increase in the length of the frost-free period (i.e., 23.7 days for Bridgewater) may also be an artifact of the extensive missing data. These differences show the subtlety of climate change impacts even over short distances (here approximately 100 km and 85 m elevation change). It is of note that while the website for

Climate Nova Scotia takes note of an earlier Spring in the page 'Terrestrial Ecosystem (Land) Impacts' (https://climatechange.novascotia.ca/adapting-to-climate-change/impacts/terrestrial-ecosystem) there is no mention of the more extensive increases in the frost-free period in the Autumn.

Using modelling Brickman *et al.* (2014) predicted a temperature increase in eastern Canada reaching 2.5 °C in coming decades. They suggested that in coastal regions this increase would be faster in Summer (40-50 yr) and slower in Winter (60-70 yr). This prediction is inconsistent with the empirical results presented here, where the temperature increments for the 3-month periods ending in July, August and September ranked 12, 11, and 8, respectively; and the three months ending in January, February, and March ranked 3, 1, and 6, respectively. Hence, warming to date has been least in Nova Scotia during the warmest season. The most significant warming increases demonstrated here are for the 3-month periods ending in February and December (ranked 1, 2). The 1.25 °C increase in September is consistent with the increase in frost free days after 01 September.

Linear regressions for the paired relationships of three factors, years from 1961 to 2020, mean annual temperature, and number of continuous frost-free days per year, were mostly highly significant (Table 6). Of the 42 regressions, nine were not significant (i.e., $P \geq 0.05$) and all but one of the remaining regressions were significant at $P \leq 0.01$. The overall relationship between year and annual temperature was significant for all sites, consistent with the climate warming described here. Values for R^2 ranged from 0.162 for Collegeville to 0.628 for Western Head. The mean of these values, i.e., 0.343, suggests that within this 60-year span, the temperature trend is positive. The relationship between annual temperature and number of frost-free days was typically stronger than was the relationship for year and number of continuous frost-free days (mean r^2 of 0.187 and 0.150, respectively). This suggests that the perturbations of yearly annual temperatures and the decline of continuous frost-free days at some sites in recent years resulted in lower R^2 values. Thus, mean annual temperature provides a better approximation for continuous frost-free days than does year.

Oceanographic and Atmospheric Considerations

The overall synchrony in temperature increase in the Maritime provinces of PEI and NS suggests explanations that may be

Table 6 **Regression coefficients (R^2 values) from linear regressions of results from 1961 to 2020 for: (1) year and annual temperature, (2) year and number of continuous frost-free days, and (3) annual temperature and number of continuous frost-free days. Because of missing data, n may be less than 60, and only the smallest value for n is given for each site. Asterisk (*) indicates $P < 0.01$; NS, not significant, i.e., $P > 0.05$.**

Site (n)	Year and mean annual temperature	Year and number of continuous frost-free days	Mean annual temperature and number of frost-free days
Bridgewater (46)	0.255*	0.399*	0.300*
Cheticamp (57)	0.339*	0.056 (NS)	0.133*
Collegeville (58)	0.162*	0.009 (NS)	0.027 (NS)
Deming (48)	0.356*	0.068 (NS)	0.164*
Greenwood (60)	0.419*	0.150*	0.192*
Halifax A (58)	0.395*	0.042 (NS)	0.166*
Kejimkujik (51)	0.367*	0.448 ($P < 0.05$)	0.323*
Nappan (60)	0.274*	0.061 (NS)	0.169*
Parrsboro (56)	0.265*	0.194*	0.296*
Shearwater (57)	0.508*	0.144*	0.246*
St. Margaret's Bay (52)	0.528*	0.154*	0.185*
Sydney (59)	0.195*	0.000 (NS)	0.127*
Western Head (39)	0.628*	0.034 (NS)	0.058 (NS)
Yarmouth (60)	0.294*	0.251*	0.266*

associated with ocean temperature changes. While increases in sea surface temperature (SST) globally are caused by increases in global air temperature (e.g., Bernier *et al.* 2018), on a local scale, such as coastal areas of NS, the warmed summer water may provide a buffer in the fall and winter to maintain higher air temperatures along the coast. Accordingly, we examine oceanographic factors that can explain temperature shifts at land-based monitoring stations over the last 60 years. Here, we examine El Niño Southern Oscillation (ENSO) and Atlantic Multi-decadal Oscillation (AMO) in relation to temperature change in NS. Thus, anthropogenic increases in CO_2 and CH_4 and their consequent greenhouse effect may be the ultimate cause for increasing temperatures in NS; however, ENSO and AMO may provide for more proximal explanations and explain the differing extents of temperature increase within the province.

Galbraith *et al.* (2012) described a high correlation between air and surface seawater temperatures in the Gulf of St. Lawrence both intra-annually and over more than a century. Bernier *et al.* (2018) described the same major increase in ocean temperature in the late 1990s that we found for air temperatures in both NS and PEI. Given the peninsular shape of Nova Scotia, surrounded by three very different oceanic bodies, i.e., Bay of Fundy/Gulf of Maine, Atlantic Ocean, and Gulf of St. Lawrence, there is no question that ocean-land interactions should be a key feature of Nova Scotia's changing climate. The Atlantic coast of Nova Scotia has already been recognized as an ocean warming hotspot (Hobday and Pecl 2014, Filbee-Dexter *et al.* 2016), as is the Bay of Fundy/Gulf of Maine (GOM Symposium papers, Dec. 2019). The last few years have seen successive records in global ocean temperature with the last 5 years being the highest on human record (Cheng *et al.* 2020). These extreme values do not correlate with Nova Scotia in terms of air temperatures, and except for 2020, the last 5-10 years even suggest a temperature reduction from recent maxima.

The limited change in annual mean temperature for Yarmouth may be accounted for by the moderating effect of a tidal-driven 'topographic upwelling' of cold water in southwestern NS (Tee *et al.* 1993). This is relative to a less active, wind-driven upwelling phenomenon along the Atlantic Coast, including Western Head, described by Scrosati and Ellrich (2020). The decrease in winter ice cover in the Gulf of St. Lawrence reflects a further moderating influence for both PEI and the north coast of Nova Scotia (bordering the Gulf of St. Lawrence), as represented here by Cheticamp in northwestern Cape Breton Island. As the longshore current along the Atlantic coast of NS proceeds from Cape North to Cape Sable Island (Bundy *et al.* 2014) along the shallow depths of the land margin (i.e., the Scotian Shelf), it is warmed by increased air temperature during Summer. In turn, this warmer water moderates terrestrial temperatures in Autumn and Winter.

El Niño-Southern Oscillation (ENSO) cycles between El Niño and La Niña phases in the equatorial Pacific Ocean. These alternating phases are responsible for significant changes in sea surface temperatures (SSTs) in the tropical Pacific Ocean that in turn influence global weather patterns, e.g., McPhaden *et al.* (2006). NOAA has documented these alternating SST anomalies starting in 1950 and provides running 3-month averages of the temperature anomalies associated with ENSO (https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php). These data allow for comparison of coincident changes in air temperatures using Greenwood as our reference. The most conspicuous of these is the La Niña event that began in June-July-August of 1998 and persisted until January-February-March of 2001. This ENSO event is the strongest ENSO of the last century (WMO 2013), and corresponded to the jump in annual air temperature in 1999 in Prince Edward Island (Garbary 2018) and Nova Scotia (this paper) that has largely persisted until the present. Similarly, the extended La Niña period from May-June-July 2010 to February-March-April 2012, and the period beginning July-August-September 2020 and continuing until at least February-March-April 2021, also corresponded to elevated annual air temperatures in NS.

Further evaluation of the ENSO dataset showed that between 1961 and 1997, 57.3% of months had a moderate to very strong El Niño signal, whereas post 1998 the value was 42.8% of months. Table 7 shows the results of our evaluation of ENSO events; we compared annual temperatures for Greenwood when El Niño, La Niña, or neither condition dominated whole or parts of the year (https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php). Two weak trends were apparent. When El Niño predominated in a given year, there was a tendency for annual air temperatures in Nova Scotia to be lower by 0.33 °C (i.e., 6.8 °C vs 7.1 °C for La Niña, and 7.1 °C when neither predominated); however, with $P = 0.195$ (Student's *t*-test), this is hardly significant. The trend was stronger during La Niña events in the last 4 months of years, where overall temperature increases are higher. Accordingly, there is a weak trend of elevated temperatures in NS associated with La Niña of 0.45 °C ($P = 0.10$). While the statistical significance of these comparisons is weak, it suggests that these global phenomena are relevant to Nova Scotia.

The Atlantic Multi-decadal Oscillation (AMO) refers to changes in SSTs for the Atlantic Ocean. The AMO is similar to ENSO, except that AMO oscillates over much longer time periods (e.g., Chylek *et al.* 2001, 2016; Clement *et al.* 2015; Delworth *et al.* 2017). In addition, AMO may be the cause of longer-term oscillations of ENSO (Levine *et al.* 2017). These longer oscillations (relative to

Table 7 Comparison of mean annual temperature for Greenwood from 1951 to 2020 with occurrences of El Niño and La Niña, using the Oceanic Niño Index from NOAA (https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php). Comparisons between El Niño and La Niña used two-tailed Student's *t*-tests. In comparisons 3 and 4, all four 3-month seasons had to satisfy the criterion.

Comparison	El Niño °C (n)	La Niña °C (n)	Neither °C (n)	Comments
Predominant ENSO conditions through year	6.79 ± 0.74 (19)	7.12 ± 0.85 (23)	7.07 ± 0.76 (23)	Implies El Niño years cooler ($P = 0.195$)
Greenwood temperature 1 year later	6.99 ± 0.71 (18)	6.84 ± 0.77 (21)		No support for offset ($P = 0.530$)
Last 4 months (i.e., ASO to NDJ)	6.86 ± 0.79 (19)	7.31 ± 0.83 (18)	6.90 ± 0.82 (22)	Implies La Niña years warmer ($P = 0.100$)
First 4 months (i.e., DJF to MAM)	7.16 ± 0.77 (9)	7.03 ± 0.94 (11)	6.97 ± 0.76 (20)	No support for relationship

ENSO) have not been fully explained, and the links between global SSTs and AMO are still being clarified (e.g., Dong *et al.* 2006, Li *et al.* 2016, Yang *et al.* 2020). While the AMO seems unlikely to explain short-term variation associated with mean annual temperature change in Nova Scotia, the change in the late 1990s of AMO into a positive temperature phase is coincident with the elevation of mean air temperature in Nova Scotia and Prince Edward Island (Garbary 2018). The continued higher annual temperature since the late 1990s, relative to the previous 40 years when AMO was in a negative phase, provides a partial explanation of gross temperature change (i.e., pre- and post-1998) over the last 60 years.

It remains to be demonstrated if warming of the NS climate by global air temperatures will be moderated or reversed when AMO enters a negative AMO phase, and this coincides with a strong El Niño event. For example, 2015 was the coldest year since 1998, and this was associated with an El Niño year. Given the predictions of global temperature increases (IPCC 2018, 2019), such a reversal would seem unlikely, although these phase changes might dampen regional temperature increases in coming decades. The current La Niña phase, beginning in the Autumn of 2020 (https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php) may partially explain the elevated monthly mean temperature in NS beginning in November 2020, and presaged the extremely mild Winter and early Spring of 2021 (i.e., November to April). In these 6 months, monthly mean temperatures ranged from 1.1 °C to 3.4 °C higher across the province (Garbary, unpublished data) than averages for the post-1998 period.

Plant Phenology and Physiology

This paper focuses on the scope and scale of the temperature changes that we have documented over a 60-year period in Nova Scotia. Temperature is one variable, albeit a central one, of the many factors involved in climate change. The suite of changes includes CO_2, temperature, soil moisture, precipitation, and wind, all acting to bring about biospheric changes that may be rapid and extreme (Reichenstein *et al.* 2013). The impact of temperature on plants is both fundamental and pervasive. Temperature changes affect a plant's basic processes of respiration (Reich *et al.* 2016, Patterson *et al.* 2018) and photosynthesis (Kirshbaum 2004, Song *et al.* 2014). Potential changes in Acadian forest communities and adaptation to climate change for forestry have been modelled elsewhere (e.g., Bourque *et al.* 2007, Steenberg *et al.* 2011). In this section, we discuss how temperature changes may lead to shifts in diversity patterns. We begin with what naturalists have long noted, that is, the link between warming and flowering.

One of the most commonly described adaptations of the natural world to climate change is the timing of flowering (e.g., Vasseur *et al.* 2001, Menzel *et al.* 2005, Houle 200, Panchen *et al.* 2012). We (along with collaborators) have published several accounts of unusual flowering in Nova Scotia (Taylor and Garbary 2003, Garbary and Taylor 2007, Garbary *et al.* 2007; Hill and Garbary 2013). These late Autumn and Winter, and early Spring flowering events were interpreted as artifacts of unusual weather phenomena, i.e., harbingers of what would occur in nature should significant climate warming occur. In retrospect, the observations can be interpreted as impacts of climate change in action resulting from a warmer temperature regime. For example, the major extension of flowering well into Autumn and Winter is a reflection of the longer frost-free period and the moderation of Autumn and early Winter temperatures. Indeed, flowering of *Viola tricolor* was noted for the first time in early February in Antigonish County by one of us (DG), thus extending the season for wildflowers to all twelve months in northern Nova Scotia, albeit not in the same year or continuous 12 months. In the Annapolis Valley, several species can resume flowering in winter during warm periods; these include *Capsella bursa-pastoris* and *Cardamine pensylvanica*. We predict that winter and early spring flowering will become more prevalent, especially with cold-tolerant members of the mustard and mint families.

The early Spring flowering described by Hill and Garbary (2013) provided a key confirmation for the temperature modelling of Culbertson-Paoli *et al.* (2019) who used the flowering phenology of MacKay (1903, 1906) and a complex mathematical treatment to reflect the changing temperature climate on a time scale of more than a century. The shifts documented above for flowering phenology belie physiological changes which could have implications for plant-pollinator interactions, insect diversity and gene flow in plant populations (Scaven and Rafferty 2013). Flowering for 31 species of herbs and shrubs in March-April 2021 (Appendix 1) resembles that observed by Hill and Garbary (2013). Of the 24 species identified by Hill and Garbary (2013), only *Viola pubescens* was not observed in 2021 and eight additional species were added. We attribute this phenology to the fact that the monthly mean temperatures for February through April 2021 were 1.2 °C warmer than the post-1998 averages for these months.

Our documented temperature increase affected Autumn and Winter disproportionately, as might have been expected from the unusual flowering in both Autumn and early Spring, discussed above. The increased temperature in September and October would be expected to extend the growth period for Summer annuals in Nova Scotia. Annuals are largely absent from the high Arctic; their frequency increases as latitude decreases, although temperatures in excess of 25 °C reduce the photosynthetic performance of annuals (Zubaidi *et al.* 2020, Hatfield and Pruger 2015).

In general, annuals require a disturbed regeneration niche. Most annual plants in Nova Scotia are exotics exploiting anthropogenically disturbed habitats such as fields and roadsides (Hill and Blaney 2010). Native disturbed habitats (e.g., floodplains, coastlines, burns) are less widespread; nonetheless, there have been two new records of Atlantic Coastal Plain Summer annuals on lakeshores (*Cyperus diandrus* in 2000, *Fimbristylis autumnalis* in 2016; Hill and Smith 2017). These occurrences may relate to the substantial increase in temperature in early Autumn (1.3 and 0.8 °C for September and October, respectively) in combination with an increase in the drawdown of lakes relating to Summer droughts. These seasonally open, Atlantic Coastal Plain lakeshores in Nova Scotia are northern, heretofore unrecognized representatives of the North Atlantic Coastal Plain Ponds (NatureServe 2021a, b), where water level fluctuations provide conditions that maintain high diversity, low biomass wetland communities (Schneider 1994, Sorrie 1994).

Given the climate warming that has already occurred, and the expectation of further increases in coming decades, Nova Scotia can expect to see many additional arrivals and the wider distribution of species with southern affinities. At the same time, plants requiring cooler conditions may acquire more restricted distributions in more northern parts of the province or at higher elevations. A more comprehensive evaluation of the impacts of climate change on the terrestrial flora of Nova Scotia is beyond the scope of this paper but is needed.

Concluding Remarks

We have documented an increase in annual temperature of 1 °C and suggest that its impacts are having greatest effect in Autumn and Winter, which have warmed the most. The warming trend is not uniform across the province and varies from 0.5 °C to 1.5 °C. Lengthening of the growing season and moderation of winter temperatures have already influenced flowering phenology and may provide new opportunities for agriculture and forestry interests. However, environmental changes that are too rapid may threaten the integrity of native ecosystems and the balance in biological communities. The negative impacts of climate change in the marine sphere, i.e., increased number and severity of storms and sea level rise with its associated coastal erosion, provide further challenges in adaptation that must be similarly addressed on both a local and continental scale.

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APPENDIX 1

Herbaceous and shrubby flowering plants flowering from February to April 2021 in Nova Scotia compared to equivalent records from Hill and Garbary (2012). None of the sites from which the species listed in part (C) are known were examined. Note: amentiferous species of *Salix*, *Betula*, *Alnus* were not included in either study.

(A) Species found in both Hill and Garbary (2012) and in 2021

Amelanchier laevis, *Caltha palustris*, *Capsella bursa-pastoris*, *Cerastium vulgatum*, *Claytonia caroliniana*, *Corylus cornuta*, *Daphne mezeurium*, *Draba verna*, *Epigaea repens*, *Fragaria virginiana*, *Glechoma hederacea*, *Hedyotis caerulea*, *Lonicera canadensis*, *Myosotis scorpioides*, *Sanguinaria canadensis*, *Senecio canadensis*, *Stellaria media*, *Taraxacum officinale*, *Tussilago farfara*, *Vinca minor*, *Viola cucullata*, *Viola macloskei*, *Viola tricolor*

(B) Additional species found in 2021 absent from Hill and Garbary (2012)

Cardamine pratensis, *Chamaedaphne calyculata*, *Corema conradii*, *Erythronium americanum*, *Lamium amplexicaule, Lamium purpureum*, *Thlaspi arvense, Veronica persica*

(C) Species from Hill and Garbary (2012) not found in 2021

Viola pubescens