PAPER 4

IMPACT OF CLIMATE ON CHANGES IN THE SEASONAL TIMING OF LIFE CYCLE EVENTS OF EASTERN CANADA FROM 1901 TO 1924

ADAM FENECH[1], DON MACIVER[1], HEATHER AULD[1] AND STU BEAL[2]

[1]Environment Canada, Toronto, Ontario, Canada
[2]Qvidnon Solutions, Burlington, Ontario, Canada

ABSTRACT: From 1900 to 1923, an influential inspector of schools in Nova Scotia, Dr. A.H. MacKay, recruited a number of knowledgeable teachers around the province to use their students to observe 100 natural occurrences each year, and report them in a standardized way. This is the science of phenology - the study of the seasonal timing of life cycle events. These observations included the appearance of blooming wildflowers, cultivated plants, migratory birds, mammals, amphibians plus the freezing of lakes and rivers, appearance of frost and snow, number and severity of thunderstorms, hurricanes, etc. In addition, the timing of human agricultural practices was also recorded, including calving, seeding, potato planting, and haying. Tracking the timing of naturally occurring events helps show trends in the effects on biota and human activities as a result of climate change and weather variability. Analysis has shown that earlier Springs can be linked to El Niño events, and a trend has been observed towards earlier plant development over the last 40 years in the Edmonton, Alberta area - a trend that matches trends in warmer January to June temperatures in Western Canada. Some plant and animal life cycle events integrate the effects of various climate factors and can be used to detect subtle trends against the noisy background of normal weather variability. Many centuries of plant phenology records from Europe show us that plants and animals are sensitive weather instruments: they can be used for recording climate variables (heat, precipitation, wind) and for forecasting the best time for planting, harvesting, treating for pests, avoiding pollen or planning your holidays. Knowing valuable seasonality information such as the timing of spring flowering helps decision making for farmers and foresters, that is, to correctly time operations such as planting, fertilizing, crop protection (integrated pest management) and to predict harvest timing. It also is useful in wildlife management (the survival of deer fawns is greater in years with early spring arrival); human health (pollen warnings for allergy sufferers), and tourism (best times to photograph flowers or animals, or to go fly fishing). MacKay was an acclaimed botanist whose lichen collection and publications are part of the Nova Scotia Museum resources. The records from his environmental observation project are also part of the Nova Scotia Museum of Natural History collection, and are a valuable source of data. With over 1500 Nova Scotian schools participating, MacKay filled 20 thick volumes with meticulous records of the natural environment (6 are summary volumes). In 1998, these records were digitized, put into a database, and are now available for study. This paper examines the 20 years of MacKay data identifying trends in phenology and human activity, and its possible messages for climate change in eastern Canada.

Keywords: phenology, climate, monitoring

1. Introduction

Phenology is the study of the synchronization of developmental stages of plants and animals with the seasons. The timing of these cycles depends on factors such as temperature, moisture and day length. The phenological events of plants, which are easily observed such as buds opening or plants leafing out, can be used to characterize climate for a region (Spano *et al.*, 1999) for any given year.

Researchers have long identified how phenology can contribute to the examination of climate change and its impact (Kramer, 1996; Lechowitz and Koike, 1995; Schwartz, 1999). Schwartz (1999) calls on researchers to examine the great variety of phenological data that exists worldwide, and to carefully interpret these records in their regional and ecological context. An historical dataset of phenological observations exists in the Canadian province of Nova Scotia.

Nova Scotia is an eastern province of Canada in North America (see Figure 1). One of the Maritime Provinces, Nova Scotia comprises a mainland peninsula and the adjacent Cape Breton Island. It is bounded on the North by the Gulf of St. Lawrence and Northumberland Strait, across which lies Prince Edward Island; on the East and South by the Atlantic Ocean; and on the West by the province of New Brunswick, from which it is largely separated by the Bay of Fundy. Nova Scotia is positioned between 44° and 47° latitude and has a temperate climate with abundant rainfall.

From 1897 to 1924, Alexander Mackay (see Figure 2) was superintendent of Nova Scotia schools. Mackay enlisted the help of teachers and school children from across the province to collect phenological observations of over 100 plants, animals and features of the physical environment. From 1901 to 1923, Mackay mandated schools to teach natural history through his program of phenological observations.

FIGURE 1
Nova Scotia in North America.

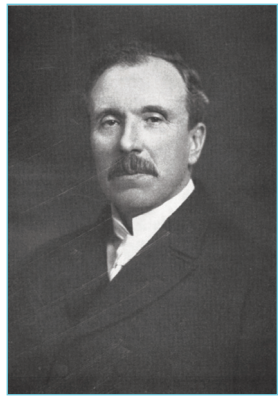


FIGURE 2
Alexander Mackay, School Superintendent of Nova Scotia, 1897 to 1924.

The Mackay observations include the appearance of blooming wildflowers, cultivated plants, migratory birds, mammals, amphibians plus the freezing of lakes and rivers, appearance of frost and snow, number and severity of thunderstorms, and hurricanes. In addition, the timing of human agricultural practices was also recorded, including calving, seeding, potato planting, and haying. Over 1,400 distinctly different schools across Nova Scotia reported these observations (see Figure 3), although observations varied each year from about 50 to over 500 schools reporting.

Mackay was very serious about his observation program. Training was provided to teachers, and meticulous records were kept. Each teacher was required to submit an annual sheet with the timing of the over 100 observations. These were tallied into ledgers (see Figure 4) of which any accountant would be proud. Mackay himself was not simply another government administrator, but he was a member of the Royal Society of Canada and published regularly on lichens and his phenological observation network across Canada.

In 1997, the Mackay ledgers were "rediscovered" at the Nova Scotia Museum of Natural History (Austen, 2000). Environment Canada provided funding to digitize the contents of the ledgers in hopes of having the data analyzed. To-date, analysis conducted on the digitized observations has been limited.

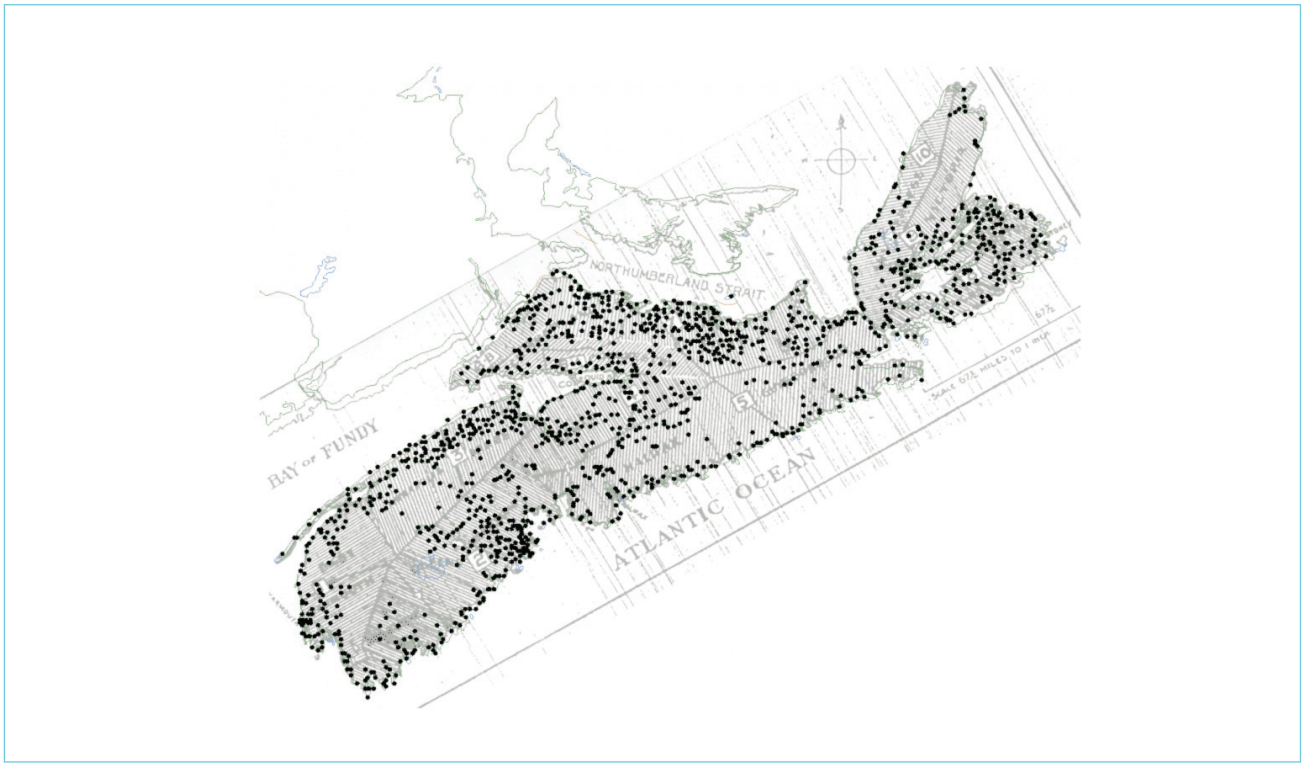


FIGURE 3
Location of Nova Scotia Schools in the Mackay Observations.

FIGURE 4
Mackay Ledger of Observations.

This paper presents an introduction to the Mackay dataset, some phenological calendars for Nova Scotia, and a preliminary investigation of the role of climate in the timing of Nova Scotian phenological events.

2. Data and Methods

2.1 Phenological data

The Mackay phenological observations of Nova Scotia span the years from 1901-1923, with some years missing including 1903, 1904, and 1909. The digitized observations are available as location of observation (an x and y co-ordinate), year of observation, and Julian day of observation (from 1 to 365). Data available in the digitized Mackay dataset were examined from the years 1901, 1902, 1905, 1906, 1907, 1908, 1910, 1911, 1912, 1913, 1914, 1915, 1916, 1917, 1918, 1919, 1920, 1921, 1922, and 1923.

The dataset is divided into three categories of observations – plant, animal and agricultural. The plant category represents 73 observations of plants flowering, shedding pollen, shedding spores, leafing of trees, florets opening, and fruit ripening. The animal category has 22 observations of bird migrations (both northward and southward), and first appearances of snakes and amphibians. The agricultural parameters are limited to seven observations including ploughing, planting, sowing, sheep-shearing, cutting and digging. This paper shows only the results from the plant observations.

2.2 Climate data

Although an official weather observatory was established in Toronto in 1839, Canadian governmental attempts to organize a national meteorological service were not begun until 1871 (Thomas, 1991). Storm warnings and general weather forecasts for Eastern Canada were instituted in 1876, and this service was extended across the West and throughout the settled portions of the country by the early years of the 20th century. Historical climatology data were published annually after 1871, but very little statistical data, delineating the climate of the country, were available prior to 1900. A beginning was made at expanding meteorological activities throughout Canada before World War I, but it was not until the 1920's that a significant number of observing stations were located nation-wide.

Climate data from 1901 to 1925 for Nova Scotia that exists today in electronic form can be found at an internal Environment Canada website archive. Interrogating the database revealed 50 climate stations in Nova Scotia (see Figure 5) with data that exists in the database during this time period. A systematic review of the data from these 50 stations revealed that few (only five) of these stations had continuous data from 1900 to 1925 - Halifax, Parrsboro, Sable Island, Sydney and Yarmouth – although these represented the four corners of the province as well as an offshore site.

2.3 Methods

The paper records of phenological observations in the Mackay ledgers were hand-processed into a digital database. Processed records were checked for accuracies, and an exercise was conducted using a random check of the digital records that were then verified with the paper originals.

The digital Mackay database was dynamically linked to a Website using a Common Gateway Interface (CGI) script (Fenech, 1999) that allows for statistical summaries of data to be produced, as well as geo-referenced maps of the observations. The link allows for queries to be made for specific observations (plants), years of data, as well as locations of data within specific ecoregions or phenochrons. Ecoregions are areas of similar ecology identified and mapped within a hierarchy of ecosystems where broad to specific levels of detail are presented on a series of maps (Neily *et al.*, 2003). The ecological data used to delineate these ecosystems include, among other things, the climatic normals for Nova Scotia. Mackay himself used an equivalent to climate zones that he called "phenochrons". A "phenochron" – the word derived from the roots of phenology

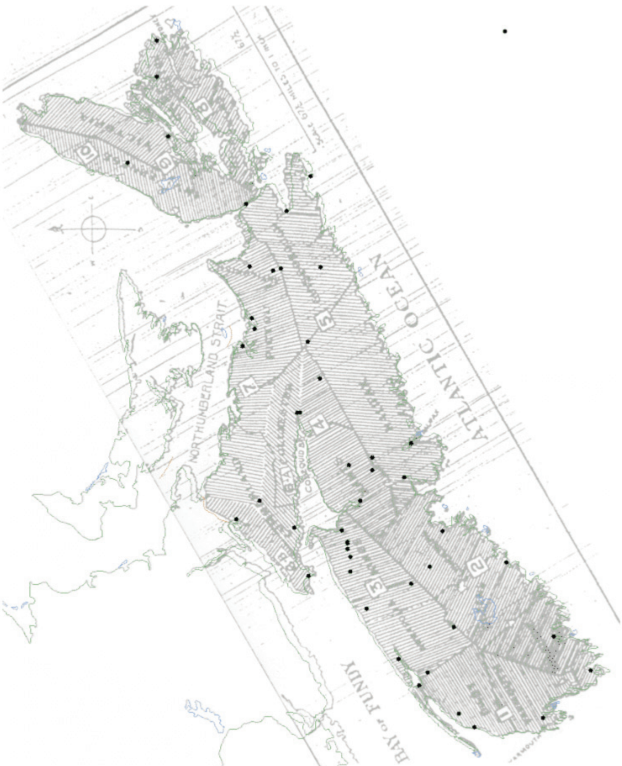


FIGURE 5
Nova Scotia Climate Stations with Data in the Archive for the years 1901-1923.

and chronology - was defined as a "climatic slope or region" each divided into a series of "belts" such as coastal, low inlands and high inlands. For Nova Scotia, Mackay defined 10 "regions or slopes"; each with 3 defined "belts", and mapped them. These can be viewed as the backdrop to Figures 3 and 5.

Summary statistics for all years of available data were computed for the plant observations to develop a phenological calendar based on mean day-of-year that the observation occurred. The maximum, minimum, standard deviation and number of observations (n.) were also recorded and graphed.

Records of climate data for Nova Scotia were compiled in a similar database to be queried. Specifically, maximum, minimum and mean temperatures, and precipitation data were added to the database. Formulae for climate indices such as accumulated growing degree days, corn heat units, water deficit, etc. were programmed into the database to produce output for given years and locations.

3. Results and Discussion

A phenological calendar for plant observations in Nova Scotia from 1901 to 1923 is shown in Figure 6. It shows the *Epigea repens,* L. as the earliest plant phenological event over the years examined. Known as the Mayflower in Nova Scotia because of its legend as the "harbinger of spring", *Epigea repens,* L. (see Figure 7) has been the official provincial flower of Nova Scotia since 1901. The *Epigea repens,* L. is known to flower before mid-June, which means it is more sensitive to daily weather than the day length (photo period).

The flowering dates of the *Epigea Repens,* L. are used as a simple examination of the role of climate in the phenological observations. Figure 8 shows the yearly mean blooming dates for the *Epigea repens,* L. for the available data. The two earliest years are 1902 (DOY 93.5) and 1910 (DOY 93.6); and the two latest years are 1914 (DOY 114) and 1923 (DOY 118). The difference between the two sets is about 3 weeks.

The daily mean temperatures for Nova Scotia for these four years are graphed in Figure 9. It is clear from the graphs that temperatures above zero degrees Celsius were more frequent in the first three months of the year for 1902 and 1910 – the years of earlier bloom times for the *Epigea repens,* L. Subsequently lower temperatures for the first three months appear in the years 1914 and 1923 – the years of latest blooming of the *Epigea repens,* L.

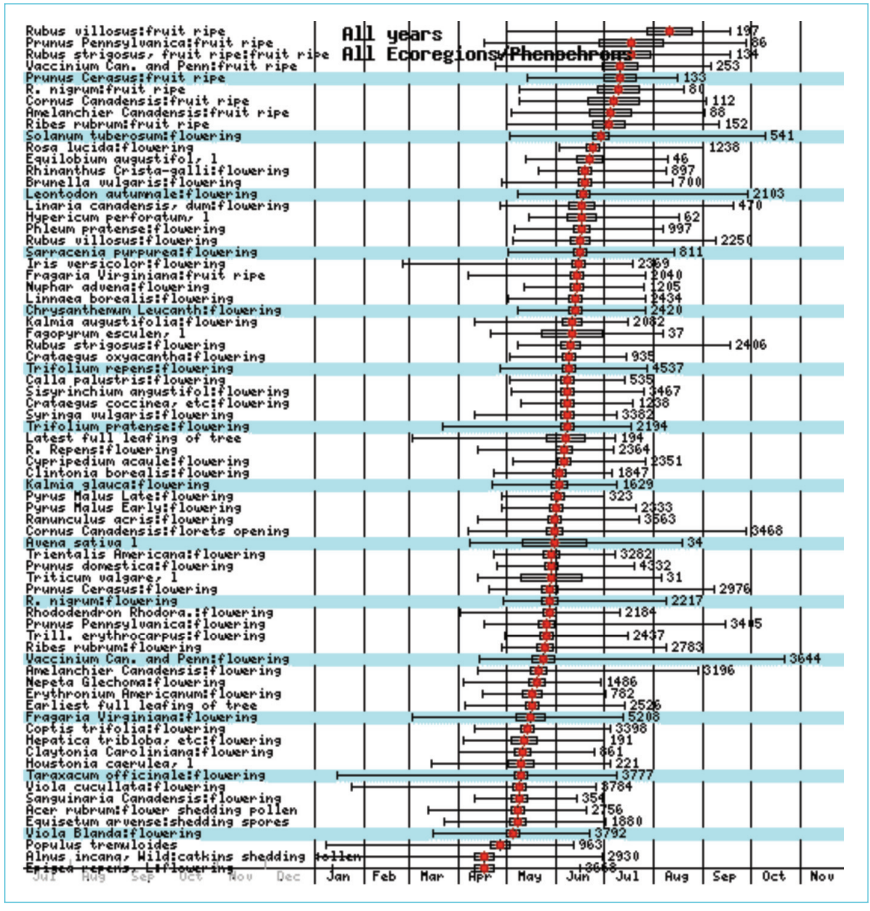


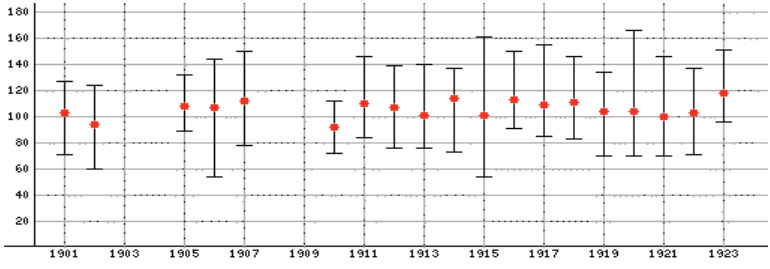
FIGURE 6

Plant Observations in Nova Scotia 1901 to 1923.

Mean shown by dot, range shown by bar (max and min at ends), standard deviation shown by rectangle, and number following bar is count (n). For common names, see appendix.

FIGURE 7

Epigea Repens, L. known as the Mayflower in Nova Scotia and its provincial flower.



Mean shown by dot, range shown by bar x axis = year, y axis = day of year blooming

FIGURE 8

Epigea Repens (Mayflower) blooming in Nova Scotia 1901 to 1923.

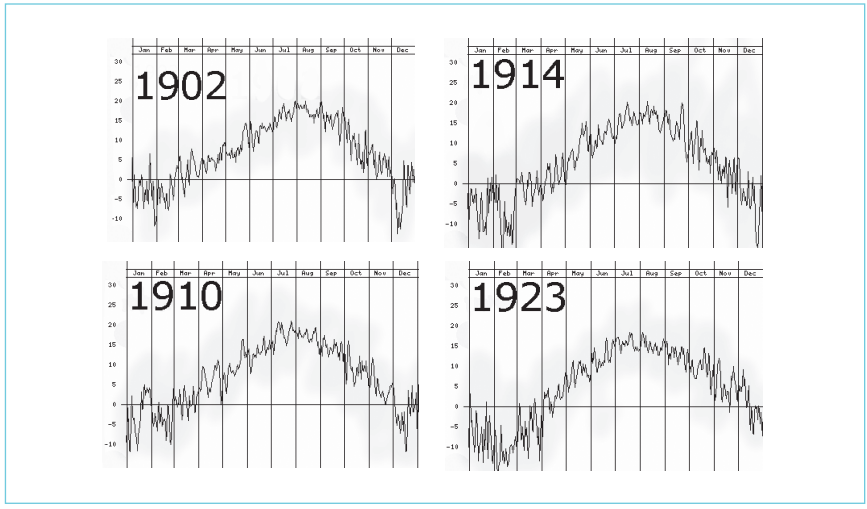


FIGURE 9
Daily Mean Temperatures for Nova Scotia in degrees Celsius.

The results of this simple examination lead to some additional areas of study. First, accumulated growing degree days should be derived from the climate database for all years and compared with each of the phenological events. Spano *et al.* (1999) have shown that using a threshold temperature of between zero and five degrees Celsius to calculate growing degree days has little effect on accuracy. A common use of zero degrees Celsius is recommended for further study. Second, from these data, a mean calculated cumulative degree-day value for each phenological event can be derived with an appropriate standard deviation. This can link the two parameters – temperature and phenological observation – together statistically, and provide results for comparing different plant species (be they native or non-native) and their sensitivities to temperature and other climate parameters. Third, the other parts of the database should begin to be studied including the animal parameters and the agricultural parameters, and their links to climate parameters should be examined.

4. Conclusions

The Mackay phenological observations provide an interesting dataset to begin examining the role of climate in the natural processes of Nova Scotia in the early 20th century. The Mackay ledgers have been successfully digitized and have provided a phenological calendar for 70 plant observations. Of these observations, the earliest, *Epigea repens,* L. has shown to be responsive to the regional temperature with warmer temperatures leading to earlier flowering times, and colder temperatures leading to later flowering times. This paper is but the beginning of a long examination of this valuable dataset.

References

Austen, I. 2000. Grassroots science. *Canadian Geographic*. May/June 2000. p. 76.

Fenech, A. 1999. Examples of innovative information management for reporting forest data and information. *USDA Forest Service Proceedings*. RMRS-P-12, 460-472.

Kramer, K. 1996. Phenology and growth of European trees in relation to climate change. *Thesis*. Universiteit Wageningen. The Netherlands. p. 210.

Lechowitz, M. and T. Koike. 1995. Phenology and seasonality of woody plants: and unappreciated element in global change research? *Can. J. Bot.*, 73, 2269-2279.

Neily, P.D., E. Quigley, L. Benjamin, B. Stewart and T. Duke. 2003. *Ecological Land Classification for Nova Scotia. Volume 1 - Mapping Nova Scotia's Terrestrial Ecosystems.* Nova Scotia Department of Natural Resources. Renewable Resources Branch. Report DNR 2003 -2.

Spano, D., C. Cesaraccio, P. Duce and R.L. Snyder. 1999. Phenological stages of natural species and their use as climate indicators. *Int. J. Biometeorol.*, 42, 124-133.

Schwartz, M. 1999. Advancing to full bloom: planning phenological research for the 21st century. *Int. J. Biometeorol.*, 42, 113-118.

Thomas, M. 1991. *The Beginnings of Canadian Meteorology.* Toronto: ECW Press.

APPENDIX 1

Phenological Observations in Mackay Dataset 1901 to 1923

Phenological Parameter	Common name	Stage
Acer rubrum	Red Maple	flower shedding pollen
Actitis macularia	Spotted Sandpiper, migrating north	migrating north
Alnus incana	Speckled Alder	catkins shedding pollen
Amelanchier canadensis	Wild Pear	flowering
Amelanchier canadensis	Wild Pear	fruit ripe
Bombycilla cedrorum	Cedar Waxwing, migrating north	migrating north
Prunella vulgaris	Heal-All	flowering
Calla palustris	Wild Calla	flowering
Ceryle alcyon	Belted Kingfisher, migrating north	migrating north
Chordeiles minor	Common Nighthawk, migrating north	migrating north
Chrysanthemum leucanthemum	Ox-eye Daisy	flowering
Claytonia caroliniana	Spring Beauty	flowering
Clintonia borealis	Corn-Lily/Clintonia-lily	flowering
Closing of lakes		
Closing of rivers		
Coptis trifolia	Golf Thread	flowering
Cornus canadensis	Bunchberry	florets opening
Cornus canadensis	Bunchberry	fruit ripe
Crataegus coccinea	Scarlet Hawthorn	flowering
Crataegus monogyna	English Hawthorn	flowering
Cypripedium acaule	Pink Lady's-slipper	flowering
Dendroica petechia	Yellow Warbler, migrating north	migrating north
Dendroica coronata	Yellow-rumped Warbler, migrating north	migrating north
Dolichonyx oryzivorus	Bobolink, migrating north	migrating north
Epigaea repens	Mayflower	flowering
Equisetum arvense	Field Horsetail	shedding spores
Erythronium americanum	Yellow Adder's Tongue Lily	flowering
First appearance, snakes		
First autumn frost, hard		
First autumn frost, hoar		
First piping of frogs		
First snow to fly in air		
First snow to whiten ground		
Fragaria virginiana	Strawberry	flowering
Fragaria virginiana	Strawberry	fruit ripe
Grain-cutting		
Hay-cutting		

APPENDIX 1 cont...

Phenological Observations in Mackay Dataset 1901 to 1923

Phenological Parameter	Common name	Stage
Hepatica americana	Hepatica	flowering
Iris versicolor	Blue Flag	flowering
Junco hyemalis	Dark-eyed Junco, migrating north	migrating north
Kalmia angustifolia	Lambkill	flowering
Kalmia polifolia	Pale Laurel	flowering
Last snow to fly in air		
Last snow to whiten ground		
Last spring frost - hard		
Last spring frost - hoar		
Leontodon autumnalis	Fall Dandelion	flowering
Linaria vulgaris	Butter-and-Eggs	flowering
Linnaea borealis	Twinflower	flowering
Melospiza melodia	Song Sparrow, migrating north	migrating north
Glechoma	Ground Ivy	flowering
Nuphar variegatum	Yellow Pond-lily	flowering
Opening of lakes		
Opening of rivers		
Phleum pratense	Timothy	flowering
Ploughing first of season		
Populus tremuloides	Trembling Aspen	
Potato-digging		
Potato-planting		
Prunus cerasus	Sour Red Cherry	flowering
Prunus cerasus	Sour Red Cherry	fruit ripe
Prunus pensylvanica	Wild Red Cherry	flowering
Prunus pensylvanica	Wild Red Cherry	fruit ripe
Prunus domestica	Plum	flowering
Pyrus malus	Apple	flowering
Ranunculus repens	Creeping Buttercup	flowering
Ribes nigrum	Black Currant	flowering
Ribes nigrum	Black Currant	fruit ripe
Ranunculus acris	Tall Buttercup	flowering
Rhinanthus crista-galli	Yellow Rattle	flowering
Rhododendron canadense	Rhodora	flowering
Ribes rubrum	Red Currant	flowering
Ribes rubrum	Red Currant	fruit ripe
Rosa virginiana	Common Wild Rose	flowering
Rubus strigosus	Raspberry	flowering
Rubus strigosus	Raspberry	fruit riope
Rubus pensilvanicus	High Blackberry	flowering
Rubus pensilvanicus	High Blackberry	fruit ripe
Sanguinaria canadensis	Bloodroot	flowering
Sarracenia purpurea	Pitcher Plant	flowering

APPENDIX 1 cont...

Phenological Observations in Mackay Dataset 1901 to 1923

Phenological Parameter	Common name	Stage
Setophaga ruticilla	American Redstart, migrating north	migrating north
Sheep-shearing		
Sisyrinchium montanum	Blue-eyed-grass	flowering
Solanum tuberosum	Potato	flowering
Sowing		
Carduelis tristis	American Goldfinch, migrating north	migrating north
Sturnella magna	Eastern Meadowlark, migrating north	migrating north
Syringa vulgaris	Lilac	flowering
Taraxacum officinale	Dandelion	flowering
Trees appear green		
Trientalis borealis	Star Flower	flowering
Trifolium pratense	Red Clover	flowering
Trifolium repens	Creeping White Clover	flowering
Trillium undulatum	Painted Trillium	flowering
Archilochus colubris	Ruby-throated Humming Bird, migrating north	migrating north
Turdus migratorius	American Robin, migrating north	migrating north
Tyrannus tyrannus	Eastern Kingbird, migrating north	migrating north
Vaccinium myrtilloides, Vaccinium angustifolium	Dwarf and Canadian Blueberry	flowering
Vaccinium myrtilloides, Vaccinium angustifolium	Dwarf and Canadian Blueberry	fruit ripe
Viola blanda	Sweet White Violet	flowering
Viola cucullata	Blue Violet	flowering
Water in streams - high		
Water in streams - low		
Wild ducks		migrating north
Wild ducks		migrating south
Wild geese		migrating north
Wild geese		migrating south
Zonotrichia albicollis	White-throated Sparrow, migrating north	migrating north