VASCULAR SYNPHENOLOGY OF PLANT COMMUNITIES AROUND CAMBRIDGE BAY, VICTORIA ISLAND, NUNAVUT, DURING THE GROWING SEASON OF 2015

Johann Wagner[1 *], Donald S. McLennan[1], and A.K. Pedersen[1]

[1] *Polar Knowledge Canada, Cambridge Bay, Nunavut, Canada*

* *johann.wagner@polar.gc.ca*

Abstract

Phenology is the study of the timing of life cycle events, and the phenological development of plant species is strongly dependent on seasonal variations in environmental factors, especially temperature. Phenological records of entire plant communities—synphenology—over periods of many years can serve as invaluable proxies for interannual changes in temperature that are due to climate change and global warming. While the synphenology of temperate ecosystems has been fairly well researched, there are comparatively fewer phenological observations in the Arctic, and synphenological work has never been performed in the high-latitude regions around Cambridge Bay, Victoria Island, Nunavut. The phenology of the most representative vascular plant species in the region was recorded during the growing season of 2015, from mid-June to the beginning of September. Vegetative (leaf) as well as generative (flower/seed) development in shrubby, herbaceous, and graminoid plant species was assessed at weekly intervals using a phenological key with 11 phenological stages, from the development of the first leaf / first floral bud to leaf death/seed dispersal. In addition, the different phenological stages of plants were documented by digital photographs that were taken at the time of phenological assessment. This phenological data has been assembled into synphenological diagrams, which facilitate the overview of the phenological development of entire plant communities as well as the comparison of different years.

Résumé

La phénologie est l'étude de la chronologie des événements du cycle de vie, et le développement phénologique des espèces végétales dépend fortement des variations saisonnières des facteurs environnementaux, en particulier la température. Les enregistrements phénologiques de communautés végétales entières – la « synphénologie » [synphenology] – sur des périodes de nombreuses années peuvent servir de repères précieux pour les changements de température interannuels attribuables au changement climatique et au réchauffement de la planète. Bien que la synphénologie des écosystèmes tempérés ait fait l'objet de recherches assez poussées, il y a relativement moins d'observations phénologiques dans l'Arctique, et des travaux synphénologiques n'ont jamais été effectués dans les régions de haute latitude à Cambridge Bay, sur l'île Victoria, au Nunavut. La phénologie des espèces de plantes vasculaires les plus représentatives de la région a été enregistrée pendant la saison de croissance de 2015, de la mi-juin au début de septembre. Le développement végétatif (feuilles) ainsi que génératif

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(fleurs/graines) chez les espèces de plantes arbustives, herbacées et graminoïdes a été évalué à intervalles hebdomadaires à l'aide d'une clé phénologique à 11 stades phénologiques, depuis le développement de la première feuille et du premier bourgeon floral jusqu'à la mort des feuilles et à la dispersion des graines. De plus, les différents stades phénologiques des plantes ont été documentés par des photographies numériques qui ont été prises au moment de l'évaluation phénologique. Ces données phénologiques ont été rassemblées en diagrammes synphénologiques, qui facilitent l'aperçu du développement phénologique de communautés végétales entières ainsi que la comparaison des différentes années.

Introduction

Phenology can be defined as the study of life cycle phases (phenophases) of plants and animals in their temporal occurrence throughout the year, whereas phytophenology is the branch of phenology studying the seasonal rhythms of plants (Puppi 2007; Forrest and Miller-Rushing 2010). The phenology of plants is strongly dependent on environmental factors in harsh and highly seasonal environments such as tundra ecosystems (Thórhallsdóttir 1998), with temperatures having the most important influence (Mooney and Billings 1961; Thórhallsdóttir 1998; Bjorkman et al. 2015), as well as photoperiod (Mooney and Billings 1961; Heide 1992; Keller and Körner 2003) and snow cover (Borner et al. 2008; Bjorkman et al. 2015) having significant roles. Plant species in all environments are shifting their phenology in response to global climate change (Cleland et al. 2007). Arctic regions are already experiencing the fastest changing climate, with increasing temperatures and changes in precipitation (IPCC 2007), which are expected to strongly influence the life cycle events of plants that are growing under significant environmental constraints. Phytophenological observation over long periods of time can serve as invaluable proxies for climate variation and change (Fang and Chen 2015).

Given the importance of monitoring the phenology of plants in polar and alpine regions, a number of studies investigate the timing of life cycle phases of plants in natural or simulated tundra environments (Borner et al. 2008; Molau 1993; Mooney and Billings 1961; Thórhallsdóttir 1998; Wagner and Simons 2008; Wookey et al. 1993; Bjorkman et al. 2015; Wheeler et al. 2015). However, most methods focus on an individual species or a limited number of species (Bean and Henry 2003; Molau et al. 1996; Mark et al. 2016; Panchen and Gorelick 2015; Reynolds 1984), either using historical phenological sources (Panchen and Gorelick 2017) or studying species taken out of their plant community context (Panchen and Gorelick 2016). Synphenological approaches, which investigate the phenological rhythms of entire plant communities (Dierschke 1989b; Puppi 2007), have been employed predominantly in temperate, mostly forest ecosystems (Coldea and Wagner 1993–1994; Dierschke 1972, 1982, 1989a, 1991; Pilková 2015; Wagner 1994). Few phenological studies investigating entire plant communities have been performed in high-latitude, tundra environments.

This paper presents the results of a preliminary synphenological study in several of the Arctic ecosystems described around Cambridge Bay, Victoria Island, Nunavut (McLennan et al. 2018) during the growing season of 2015, from mid-June, shortly after snowmelt, to the beginning of September, after the senescence of most plant species.

Materials and methods

Synphenological observations were performed during the growing season of 2015, from mid-June to the beginning of September, at approximately weekly intervals at the sites presented in Table 1, in some of the more important ecosystems (ecosites) around Cambridge Bay (McLennan et al. 2018). For assessing the phenology, the method first introduced by Dierschke in 1972 and perfected in subsequent years (Dierschke 1982, 1989b, a, 1991) was used. The original phenological keys for vascular plants from Dierschke (1989b) were adapted to the characteristics of the flora of the Arctic, and are presented in Table 2. The phenological keys assess both the vegetative (leaf) and generative (flower/seed) development of the plants, and these keys were separated for shrubs, herbaceous plants, and graminoids. They characterize the phenological development of the plants through 11 stages, from early shoot / floral bud development to leaf senescence and death, as well as seed dispersal.

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Table 1: Sites on which synphenological observations were performed during the growing season of 2015.

Site Name	Mount Pelly Road	Wetland	Seashore	Long Point	Dew Line Road	West Road
Latitude	69.15672	69.15849	69.10578	69.09373	69.15757	69.11432
Longitude	-104.91185	-104.91240	-105.38382	-105.44079	-105.19082	-105.37647
Ecosite	01 – *Dryas integrifolia – Saxifraga oppositifolia* (lithic)	09 – *Carex aquatilis*	16 – *Leymus mollis* (marine littoral)	16 – *Leymus mollis* (marine littoral)	01 – *Dryas integrifolia – Saxifraga oppositifolia*	01 – *Dryas integrifolia – Saxifraga oppositifolia* with *Vaccinium uliginosum*
Description	Mesic tundra, zonal ecosite most reflective of regional bioclimate	Sedge fen, the most common wetland type	Seashore ecosite on sandy substrate	Seashore ecosite on sandy substrate	Mesic tundra, zonal ecosite most reflective of regional bioclimate	Mesic tundra, zonal ecosite most reflective of regional bioclimate

Table 2: The phenological stages recorded for vascular plants at the site.

Shrubs

Vegetative phenological stage	Generative phenological stage
0 — buds completely closed	0 — no floral buds
1 — buds with green tips	1 — 1st buds/inflorescence visible
2 — 1–30% leaf development	2 — buds just before opening
3 — 31–60% leaf development	3 — 1–30% of flowers open
4 — 61–99% leaf development	4 — 31–60% of flowers open
5 — maximum leaf development	5 — full flowering
6 — first leaf senescence	6 — most or all flowers wilted
7 — 1–30% of leaves turned colour	7 — fruits visible
8 — 31–60% of leaves turned colour	8 — fruits almost at full size and green
9 — 61–99% of leaves turned colour	9 — fruits almost ripe, brown or dry
10 — shrub leafless or with dead leaves	10 — seeds dispersing

Herbaceous

Vegetative phenological stage	Generative phenological stage
0 — fully snow-free; only dead leaves	0 — no buds/inflorescence
1 — first growth of the season/first leaf	1 — 1st buds/inflorescence visible
2 — 1–30% leaf development	2 — buds just before opening
3 — 31–60% leaf development	3 — 1–30% of flowers open
4 — 61–99% leaf development	4 — 31–60% of flowers open
5 — maximum leaf development	5 — full flowering
6 — first leaf senescence	6 — most or all flowers wilted
7 — 1–30% of leaves dry	7 — petals fully shed, and fruits visible
8 — 31–60% of leaves dry	8 — fruits almost at full size and green
9 — 61–99% of leaves dry	9 — fruits almost ripe, brown or dry
10 — stem and leaves completely brown and dead	10 — fruits fully ripe and seeds dispersing (bulbils dispersing)

Graminoids

Vegetative phenological stage	Generative phenological stage
0 — fully snow-free; only dead leaves	0 — no inflorescence
1 — first shoot of the season/first leaf	1 — 1st inflorescence visible
2 — 1–30% of shoots developed	2 — inflorescences just before opening
3 — 31–60% shoots developed	3 — first anthers visible
4 — 61–99% shoots developed	4 — 31–60% of anthers open
5 — maximum shoot development	5 — full flowering
6 — first leaf senescence	6 — anthers beginning to senesce
7 — 1–30% of leaves dry	7 — anthers fully senescent, achenes visible
8 — 31–60% of leaves dry	8 — fruits almost at full size and green
9 — 61–99% of leaves dry	9 — fruits almost ripe, brown or dry
10 — stem and leaves completely brown and dead	10 — fruits fully ripe and dispersing

p — overwintered, persistent leaves from previous year
m — marcescent

During the observations, an attempt was made to record the phenology of all vascular plants visible and identifiable on the sites. Additionally, the different phenological stages of plants were recorded by digital photographs that were taken at the time of phenological assessment, both for documenting the phenological stages and for a later confirmation of the phenological stages. The observations on the various phenological stages were assembled in a phenological table, with species ordered by their flowering phenology from earliest to latest. Table 3 presents an example of such a phenological table. Some of the plant species present in these ecosystems are small and inconspicuous, and were therefore identified for the first time only later in the season, or were not found again after an initial observation. Such species, for which insufficient phenological data was collected, were eliminated from the phenological tables. While such phenological tables already offer a useful insight into the phenological phases of most of the plant species of the ecosites, in the case of a larger number of species, a graphical representation of the data from these phenological tables in the form of synphenological diagrams makes the overview and analysis of the phenological data easier. Similar to phenological tables, in which dates are in columns, in synphenological diagrams, the date is on the horizontal

axis, while species are presented on the vertical axis in order of their flowering phenology, from earliest to latest. Their vegetative development is depicted by horizontal bars with vertical lines, higher line densities corresponding to vegetative phenology stages closer to full leaf development. Their generative development is represented by vertical bars, the height of which suggest the magnitude of flowering, with colours corresponding to the flower colour. Figures 1 and 2 preliminarily present the synphenological diagrams of two of the investigated sites from Table 1.

Table 3: Phenological table of a marine littoral ecosystem at Long Point, Cambridge Bay.

Date		20-6-15	27-6-15	5-7-15	10-7-15	21-7-15	31-7-15	8-8-15	19-8-15	27-8-15	3-9-15
Saxifraga oppositifolia	V	3	4	5	5	5	5	5	6	7	7
	G	4	5	6	6	7	8	8	9	10	10
Salix arctica	V	1	3	4	5	5	5	5	6	10	9
	G	3	5	5	6	7	8	8	10	10	10
Draba corymbosa	V	2	4	4	5	5	5	5	7	7	7
	G	2	5	5	6	6	8	8	10	10	10
Draba glabella	V	2	3	3	3	5	5	5	7	7	7
	G	2	4	5	5	7	8	8	10	10	10
Pedicularis lanata	V	1	3	5	5	5	5	5	6	6	10
	G	0	1	5	5	7	8	8	9	9	10
Saxifraga tricuspidata	V	2	3	4	5	5	5	5	6	6	8
	G	2	2	3	5	5	6	8	9	10	10
Oxyria digyna	V	2	3	4	5	5	5	5	7	8	9
	G	2	3	5	6	7	8	10	10	10	10
Oxytropis arctica	V	2	3	4	5	5	5	5	6	7	8
	G	1	3	5	5	5	8	9	9	9	10
Papaver radicatum	V	2	3	4	4	5	5	5	6	6	7
	G	1	1	4	5	6	8	8	10	10	10
Silene acaulis	V	2	4	4	5	5	5	5	5	6	7
	G	0	1	4	5	6	7	7	9	10	10
Taraxacum phymatocarpum	V	2	3	4	4	5	5	5	6	6	9
	G	1	1	4	5	5	10	10	10	10	10
Oxytropis arctobia	V	1	2	3	5	5	5	5	7	7	7
	G	0	3	1	5	6	8	9	9	10	10
Armeria scabra	V	2	3	4	5	5	5	5	6	6	7
	G	1	2	2	5	6	6	7	8	10	10
Silene uralensis	V	1	2	4	4	5	5	5	7	7	10
	G	0	1	3	5	5	8	10	10	10	10
Potentilla pulchella	V	1	4	4	5	5	5	5	5	6	7
	G	0	3	3	5	5	6	7	9	10	10

Date		20-6-15	27-6-15	5-7-15	10-7-15	21-7-15	31-7-15	8-8-15	19-8-15	27-8-15	3-9-15
Minuartia rossii	V	1	3	3	5	5	5	5	5	6	8
	G	0	3	3	5	5	5	7	7	7	9
Astragalus alpinus	V	1	3	4	4	5	5	5	6	6	8
	G	0	1	3	4	5	6	7	9	9	10
Chamerion latifolium	V	1	2	3	4	5	5	5	5	6	9
	G	0	1	2	2	5	5	7	9	9	9
Poa arctica	V	1	2	2	2	5	5	5	5	6	7
	G	0	0	1	2	5	6	7	7	9	10
Festuca brachyphylla	V	0	1	2	4	5	5	5	6	6	7
	G	0	0	1	2	4	6	7	9	9	10
Leymus mollis ssp. villosissimus	V	1	2	2	3	4	4	5	5	6	7
	G	0	0	2	1	3	6	6	6	8	8

Results and discussion

In contrast to temperate ecosystems, in which the phenological development of plant communities stretches over five to six months of growing season, with up to 10 clearly marked phenophases (Coldea and Wagner 1993–1994; Dierschke 1982, 1989a, 1991; Wagner 1994), the phenological development of plants in our study sites is strongly compressed, with little discernible separation into phenophases (Fig. 1, 2).

Figure 1: Synphenological diagram for a 16 – Leymus mollis *marine littoral ecosystem at Long Point, Cambridge Bay.*

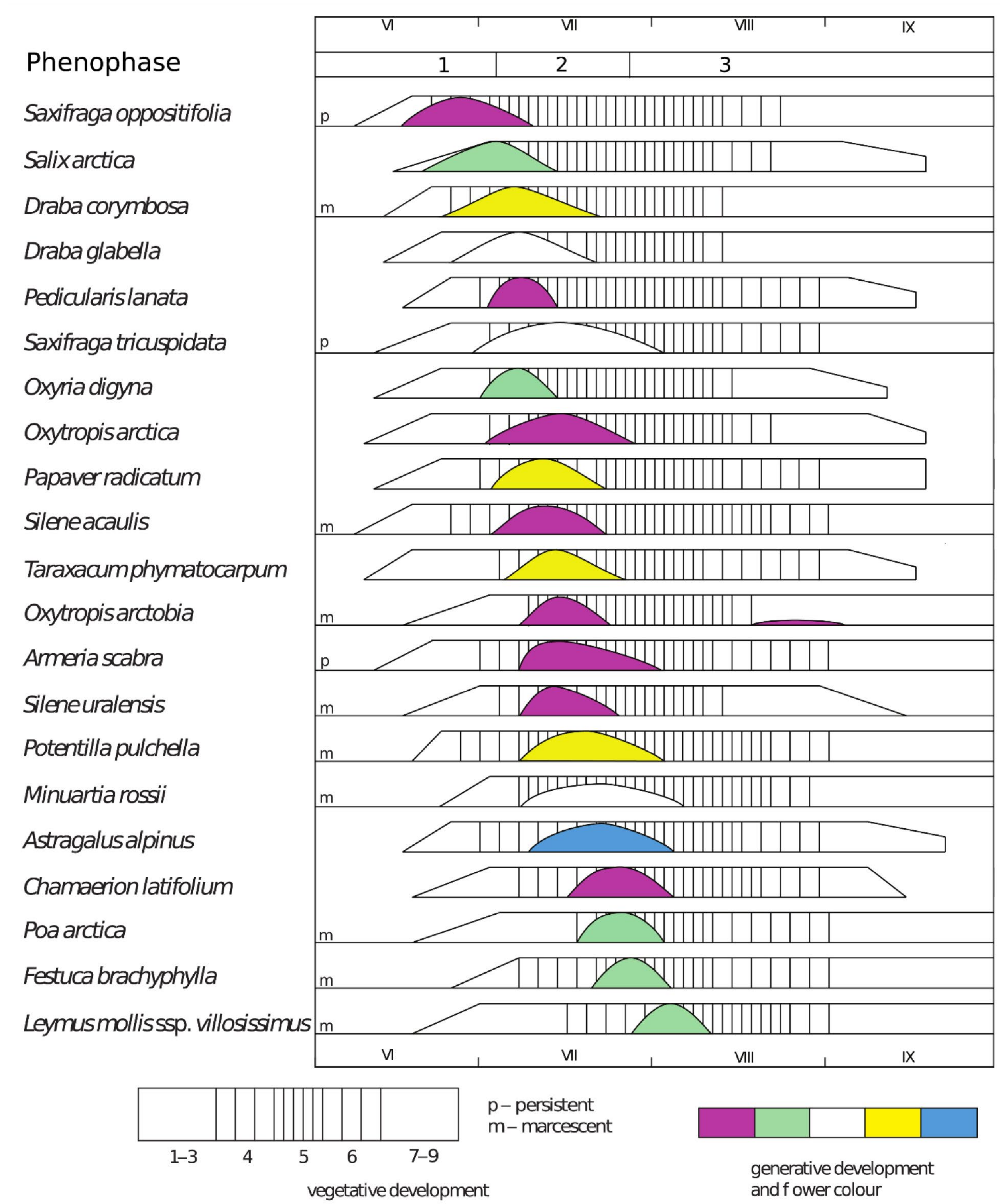
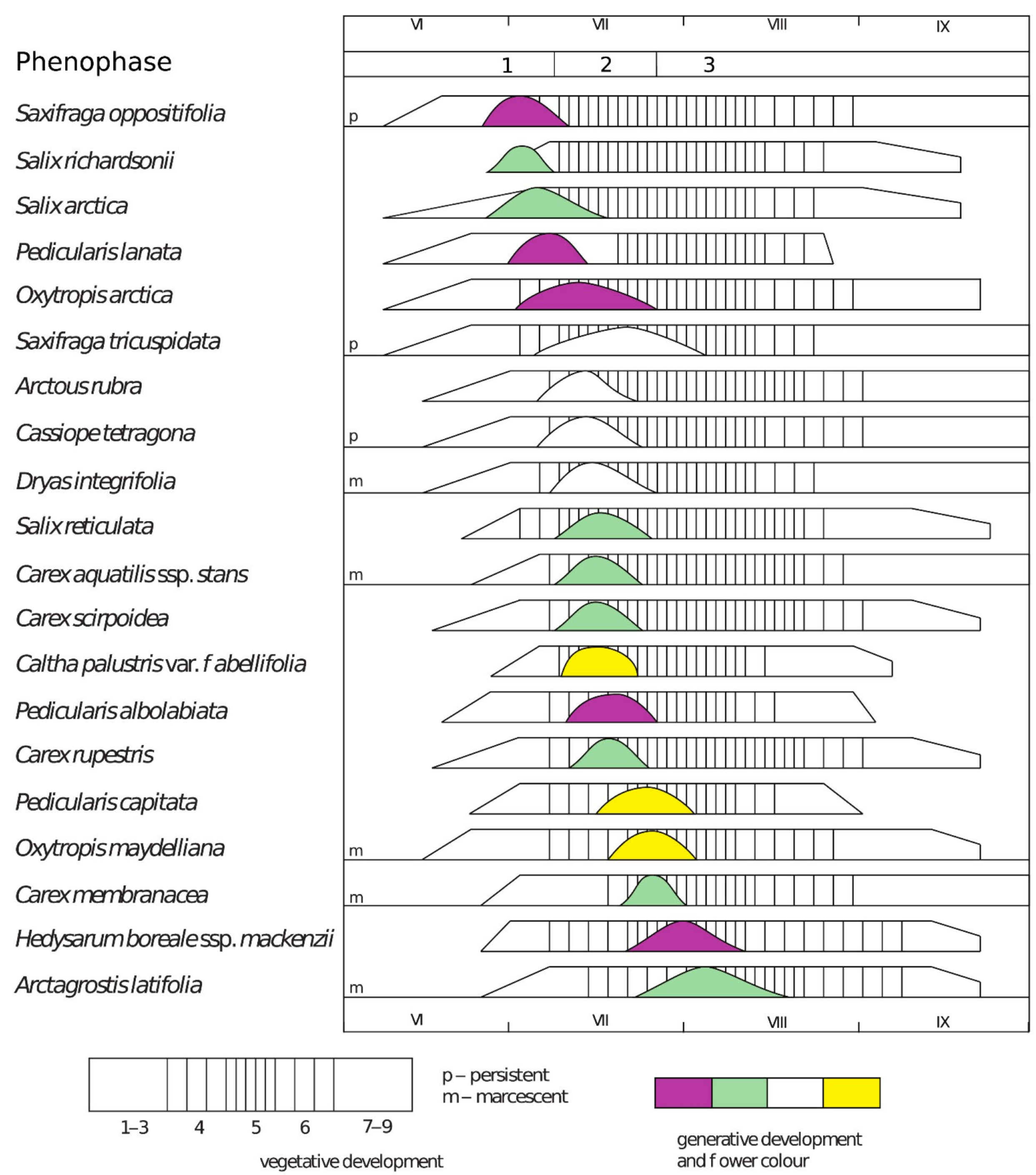


Figure 2: Synphenological diagram for a 01 – Dryas integrifolia – Saxifraga oppositifolia *mesic tundra ecosystem along the Dew Line Road, Cambridge Bay.*



The strong compression of phenophases can be attributed to having only six to eight weeks available for plant growth in the Arctic climate of Cambridge Bay, where the cool and short growing season puts severe constraints on plant development. Depending on the particular year, complete snowmelt does not usually occur before mid-June (Environment Canada, 1953 onwards), with most plants already senescing in the second half of August (Fig. 1, 2). Therefore, there are only three somewhat discernible phenophases. The earliest phenophase, in which only species that overwinter with almost mature floral buds bloom, occurs immediately after snowmelt, while there is still only minimal leaf development in these species; for example, the purple saxifrage (*Saxifraga oppositifolia*), the willows *Saxifraga richardsonii* and *S. arctica*, and a few *Draba*. The second phenophase starts with the flowering of *Pedicularis lanata*, followed by the blooming of most other plants in the ecosystem. The last phenophase starts at the end of July or beginning of August with the flowering of a few late bloomers such as *Hedysarum boreale* ssp. *mackenzii*, *Leymus mollis* ssp. *villosissimus* and *Arctagrostis latifolia* (Fig. 1, 2). When considering the flowering of the various species, there does not seem to be any tendency for flowers of a certain colour to bloom together in a certain phenophase, which is the case in some temperate ecosystems, where species with yellow flowers tend to bloom towards the end of the growing season (Coldea and Wagner 1993–1994; Wagner 1994).

The senescence of most plants appears to be starting mid-August, when daily mean temperatures go below +7°C for the first time (Environment Canada, 1953 onwards). After this date, the daily mean temperatures decrease rapidly, and by the end of August most plants are completely senescent (Fig. 1, 2).

An interesting flowering phenology is exhibited by the legume *Oxytropis arctobia*, which flowers profusely in the first half of July, together with the species *Dryas integrifolia* and *Oxytropis arctica*. This species presents, however, a secondary flowering peak of a smaller magnitude very late in the season, towards the end of August, after its leaves start senescing (Figure 1). It is unknown whether this secondary blooming phase is due to a small number of individuals that delayed their flowering by several weeks, or individuals that are flowering twice, once during the main flowering phase and a second time late in the season. Because of the flowering energy investment constraints that plants in the Arctic are subjected to, it is almost certain that the secondary flowering event is due to delayed flowering of a subset of individuals. The evolutionary and adaptive significance of this second blooming event is presently unknown, but would represent an interesting topic for a future project.

Conclusions and community consideration

Because of the sensitivity of plant phenology to environmental factors (i.e., weather and climate variations), long-term phenological and synphenological observations are an important tool, not only for ecosystem monitoring, but also for climate change monitoring. Moreover, phenological observations require few resources, and are therefore particularly well suited for community-based monitoring, by which local communities, very observant to the slightest environmental changes, can bring an invaluable contribution. Our synphenological observations performed over the duration of a single growing season are but a glimpse into the complex interactions between ecosystems and a harsh, unpredictable environment, both within the growing season and between growing seasons. A phenological monitoring program continued over many years, or even decades, would bring a much more accurate picture of the interplay between plants, ecosystems, and the changing environment. Synphenological diagrams offer a comprehensive overview of the phenology of entire plant communities. When relative cover of plants in various phenological stages is recorded during observations, synphenological diagrams can offer both qualitative information about the phenophases and quantitative data on the magnitude of these phenological phases. As next steps, we will continue our synphenological observations in the most important ecosystems of southeastern Victoria Island, using an improved phenological key system with 12 phenological stages and also recording the relative cover of species in the various phenological stages.

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