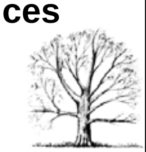
Life cycles, Phenology, and environmental influences

1. What is Phenology?



2. Effects of temperature on phenology
3. Effects of photoperiod on phenology
4. Effects of CO2 on phenology??

What is Phenology?

Greek "phainesthai" = to appear.

Greek "logos" = word (or, to study)

∴Phenology = "The study of appearances"

Related words: "phenomenon", "phenotype"

What is Phenology?

A modern definition:

"The study of periodic biological events and their relationship to seasonal climate changes"

David Gates, 1993

What is Phenology?

Phenotype vs. genotype

- **Phenotype is the macroscopic appearance of an organism**
- **Genotype is the the genetic makeup.**
- **Two individuals of identical genotype may have different phenotype, due to environment**

What is Phenology?

Covers a broad scope of biological events:

Animals: mating/reproduction, fur/shedding, metabolism, migration.

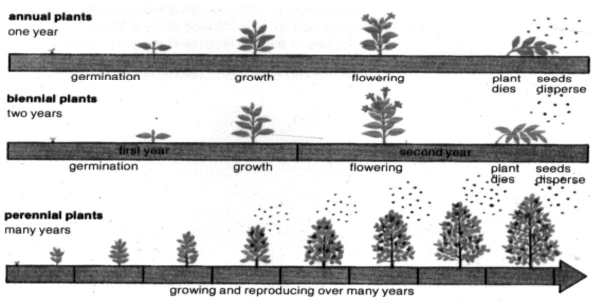
Plants: growth, bud initiation/burst, leaf development/senescence, flowering, fruit ripening, seed development

What is Phenology?

Phenology records:

Monks
Farmers (e.g. wine harvests)
Amateur Naturalists (birders, botanists)
Herbarium samples (e.g. Arnold Arboretum)
USDA Regional Phenology Network

Phenological events occur on vastly different time scales depending on lifespan



Both heat accumulation and chilling accumulation play roles in determining spring budburst/flowering.

Heating accumulation makes intuitive sense in terms of the biochemistry of tissue development and adaptive protection against risky early budburst/flowering.

What is the adaptive significance of a chilling requirement?

History:

Heat accumulation requirement first suggested by Reaumur (1735)

René Antoine Ferchault de Réaumur.

Effects of temperature on phenology

Growing Degree Days (GDD; Woodward 1992) = (No. days where T_{ave} >0 ^{0}C) x (T_{ave} over that period)

TABLE 2 **Growing degree-day totals for expected dominant physiognomies.**

Physiognomy	Growing degree-days (GDD) Reproductive	Vegetative
Broadleaved deciduous	2800–2100	2100–1700
Evergreen coniferous	2300–1500	1500–900
Deciduous coniferous	1900–1100	1100–700
Tundra	1600–700	700–200

(From Woodward, 1992.)

Effects of temperature on phenology

Keep in mind:

There are several different definitions of GDD.

Many researchers use 5°C instead of 0°C, others use 10°C

Effects of temperature on phenology

How to incorporate both chilling requirement and heating requirement?

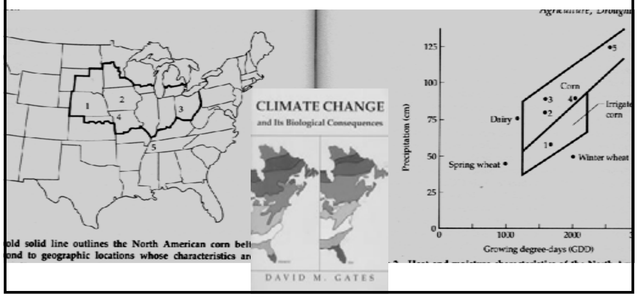
Several modeling approaches:

1. **Sequential model – chilling requirement satisfied first, then heating model. (I.e. heating not effective until chilling requirement met)**
2. **Parallel model – assumes heating model operates simultaneously with chilling model.**
3. **Alternating Model, Four Phases Model, “deepening rest” model.**

Effects of temperature on phenology

Crop emergence can be reliably predicted based on GDD.

(Water requirement increases with GDD requirement)



Effects of temperature on phenology

GDD: Indicates that it is the integral of thermal energy, rather than simply threshold or peak temperature, or length of suitable temperatures, that most controls plant phenology.

Energy/time = Power

Energy x time = momentum x distance ????

(no idea if there is a physical term for this, but maybe there should be)

Effects of temperature on phenology

Hopkins Law: Andrew Delmar Hopkins (1857-1948)

"… the time of occurrence of a given periodical event in life activity in temperate North America is at the general average rate of 4 days to each 1 degree of latitude, 5 degrees of longitude, 400 feet of altitude, later northward, eastward and upward in the spring and early summer, and the reverse in late summer and autumn"

Hopkins AD (1918) Periodical events and natural laws as guides to agricultural research and practice. US Dept Agric. Monthly Weather Review, Supplement 9

Effects of temperature on phenology

Hopkin's Law:

Adiabatic lapse rate ~ 0.6^{o}C per 100m altitude (ball park average - varies with humidity)

So Hopkin's law roughly translates into 4 days per ¾ ^{o}C change.

An big lack of understanding, and an opportunity for a significant advance in the science of phenology:

"The critical problem with mechanistic phenology models is that the basic biochemistry and biophysics during dormancy is currently unknown"

-**Chuine, Kramer, Hanninen 2003**
Phenology: An Integrative Environmental Science

Lambers et al.:

"Vernalization is believed to require perception of low temperature in the vegetative apex. Cold treatment supposedly induces the breakdown of a compound that accumulated during exposure to short days in autumn and which inhibits flower induction; this might be ABA. At the same time, a chemical compound is produced that promotes flower induction, most likely gibberlic acid."

vernalization n. Subjection of seeds or seedlings to low temperature in order to hasten plant development and flowering.

Effects of light on phenology

- **Plants show daily and seasonal rhythms independent of temperature**
- **Daylength plays a large role in controlling flowering time**
- **Plants 'determine' daylength by tracking length of night**
- **Phytochrome (protein pigment) is a substance involved in photoperiodism**
- **Phytochrome likely induces growth or growth inhibiting hormones (e.g. gibberilins or Absisic acid).**

Effects of light on phenology

High nighttime sensitivity of phytochrome

FIG. 8.5. Growth of Douglas fir (*Pseudotsuga menziesii*) after 12 months on photoperiods of 12 hours, 12 hours plus a 1-hour interruption near the middle of the dark period, and 20 hrs (*left to right*). [From Downs (1962). Copyright ©, The Ronald Press Co., New York.]

Phenology and light: Climate Change Significance.

For a given latitude photoperiod does not change, so annual/interannual variability in phenology can't be caused by photoperiod.

However, plants that migrate across latitudes will experience changing photoperiod.

Tree Physiology 19, 289–300

Effects of elevated atmospheric CO_2 on phenology, growth and crown structure of Scots pine (*Pinus sylvestris*) seedlings after two years of exposure in the field

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Summary Three-year-old Scots pine (*Pinus sylvestris* L.) seedlings were grown for two years in the ground in open-top chambers supplied with either an ambient or elevated (ambient + 400 µmol mol^{-1}) CO_2 concentration. Phenological observations and measurements of height and stem diameter growth, absolute and relative growth rates, starch and soluble carbohydrate concentrations of the needles, and crown structure and needle properties were made at frequent intervals throughout the two growing seasons. Elevated CO_2 significantly advanced the date of bud burst in both years. The increase in total needle area in response to elevated CO_2 was accounted for by longer shoots and an increase in individual needle area in the first year, and by an increase in the number and length of shoots in the second year. Stem diameter and tree height were enhanced more by the elevated CO_2 treatment in the first year than in the second, indicating a decreased effect of CO_2 on growth over time. This was confirmed by a study of absolute and relative growth rates of leader shoots. During the first growing season of CO_2 enrichment, mean weekly relative growth rates over the growing season (RGR_m) were significantly enhanced. During the second year, RGR_m in ambient CO_2 closely matched that in elevated CO_2.

Keywords: canopy structure, carbohydrates, elevated carbon dioxide, growth, open-top chambers, phenology, relative growth rate.

ogy, morphology, carbon allocation and photosynthe (Ceulemans and Mousseau 1994, Lee and Jarvis 1995). It h been suggested that species with indeterminate growth a therefore large sink capacity are less likely to exhibit acclim tion than species with determinate growth (Kaushal et 1989).

In trees, elevated CO_2 can increase total leaf area (Koch al. 1986), leaf weight (Brown and Higginbotham 1986, Nor and O'Neill 1989), leaf weight to area ratio (Conroy et 1986, Berryman et al. 1993, Pettersson et al. 1993), a branching frequency (Sionit et al. 1985, Samuelson and Sei 1993). Root biomass, root length, root branching and late root production are also reported to increase in response elevated CO_2 (Rogers et al. 1994, Day et al. 1996, Janssens al. 1998).

Several studies have shown that elevated CO_2 affects t growth rhythm of forest trees by altering the timing of b burst and growth cessation (Cannell and Smith 1986, Murr et al. 1994, Ceulemans et al. 1995). In the boreal region, ea bud burst results in the early onset of growth thereby prolo ing the short growing season and potentially increasing wo production (Beuker 1994). Earlier bud burst, however, m increase the risk of frost damage from late spring frosts (M ray et al. 1989). Increased atmospheric CO_2 concentratio

Phenology and elevated CO2

800 ppm CO2 increased bud burst by 6 days!

Some research ideas…