# Do longer growing seasons lead to more growth in woody species?

## Consolidated thoughts from LucidChart (work we did on Jan 16th?):

### Questions to answer for readers of review paper

- Why do ecologists think (net) growth (uptake of carbon?) is related to growing season length?
- Why might it not be? What evidence do we have for yes / no?
- What data / experiments needs to be collected to determine this either way?
- Why is it important to get this right / know this?

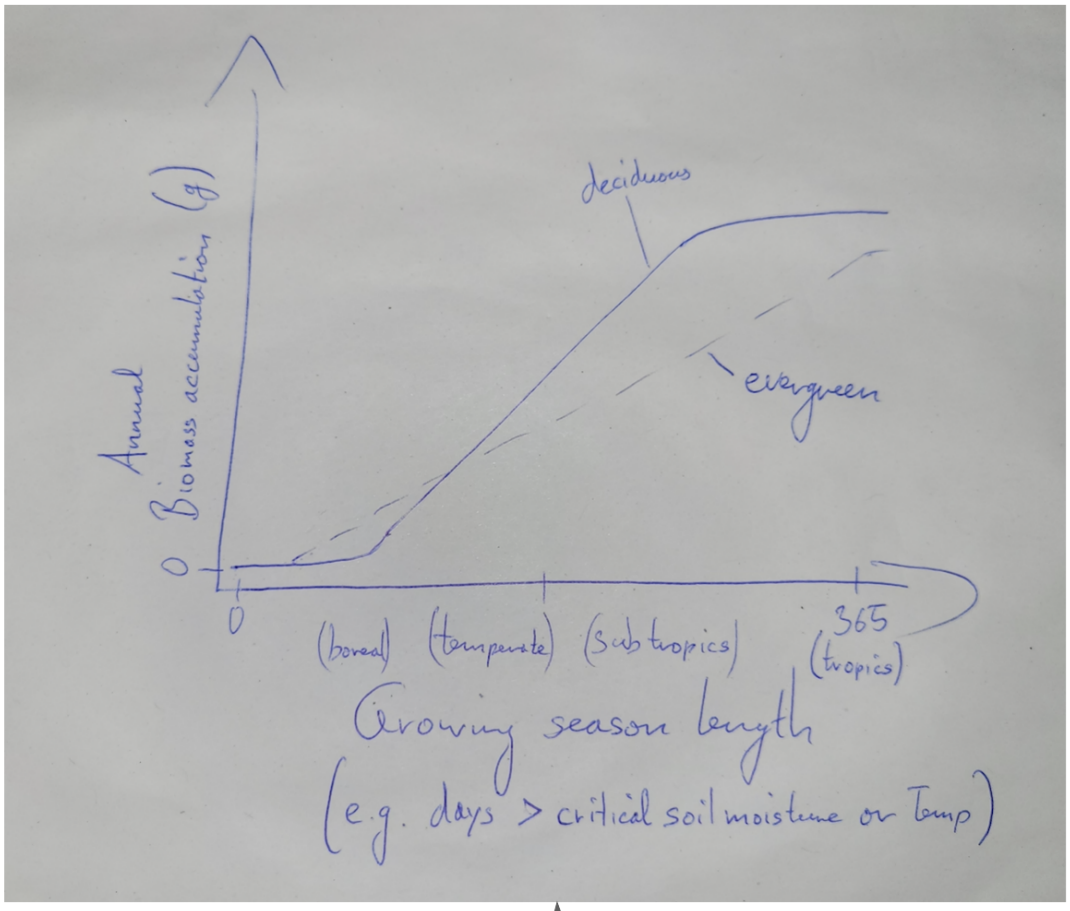
### Figures:

- Conceptual figures starting with increasing temperature and each expected factor with the strength of supporting science we have for it [**Ruben's figure might fit into this conceptual figure, or be the new version of it**]
- Map of changes in annual Growth. Does this exist? Where does it increase/decrease?
    - in places where conditions are optimal: does increased growth match the potential GS window?
    - if not: Is there no additional C uptake or does it goes somewhere other than radial growth?
    - flux towers?
- Map of PEP725 + ITRB overlay (w/ Rubén)
- Schematic of data / experimental design that would allow us to address this question
- Possibly: Figure showing flow of information / literature on this topic (e.g. papers over time on this topic, gaps in types of data)

### Temperature and length of growing season and growth:

- To evaluate the relationship between growth and growing season length: there might be a species-specific linear zone that gets non-linear at both ends because of
    - too short GS to complete cycle affecting fitness and survival
    - dormancy restrictions that prevent from benefitting from extended GS

- What is the interplay of longer growing seasons, growth rate, and increased incidence of drought under CC
- What is the regional variation like in the growth phenology relationship?
    - Are there places where growth is clearly increasing?
    - If so, what is the climate like?
    - Where would we expect growth to increase with a longer GS? Where would we not?
    - How much local adaptation is there in G x P?

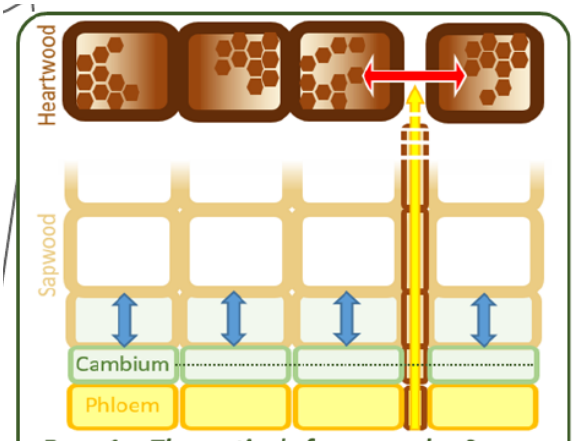



- Highlight example studies quantifying effect of longer growing season on growth (i.e. those finding a relationship and those not finding a relationship)

Process synchronization of phenology and growth timing going out of sink?

- How does the timing of photosynthate availability relate to the timing of growth?

- Related: When does the growth actually happen, most importantly early season vs later season growth?
- What about the timing of optimal nighttime VPD for growth? Are they in-sync?




**Box 1.** ***Theoretical framework:*** Sugars produced by leaves fuel the vascular cambium, the vigorous layer that divides to produce sapwood and phloem cells as trees grow radially. Newly created cells require positive internal water pressure (turgor – blue arrows) to expand. When water availability is low, turgor pressure is insufficient to breach the yield-threshold for cell wall division and expansion[16,17] and growth ceases throughout the tree[18]. Trees mainly grow at night when high vapor pressure allows for sufficient turgor[19], but rising temperatures and drier air are now constraining the carbon sink potential of forests[2]. However, sugar is still produced by trees during the day when cell formation is limited at night. A mass balance perspective suggests that sugars must be retained in the tree, but their storage space is limited. I propose that: *if sapwood production is turgor-limited, then sugars are allocated to production of carbon-rich polyphenolics deposited in the heartwood*. These decay-resistant compounds are produced by files of living cells called rays that carry sugar radially (yellow arrow) from phloem to the zone of heartwood formation deep in the trunk. The deposition of polyphenolics (red arrows) marks the conversion of sapwood to heartwood, and thus the extension of carbon-store longevity.

## Possible constraints to growth response

- What is the constraint hypothesis? (And what does it predict?)
- Do phenological shifts push the growing season into periods of low VPD? This should enhance growth if turgor is the limit, but might lead to more regional variation in response. Can we test this with treeNet data?
- To what extent can the internal phenological program constrain C uptake/additional growth and influence the fate of C

## Variation: intra and inter species

- Species are different
  - Key of species differences, though I think that could be part of point 1 discussion
  - Species are different! How well has this been studied?
- Within species differences
  - How much local adaptation is there in G x P?
  - Photoperiod effects and how it interacts with climate change impacts
  - To evaluate the relationship between growth and growing season length: there might be a species-specific linear zone that gets non-linear at both ends because of:
    - too short GS to complete cycle affecting fitness and survival
    - dormancy restrictions that prevent from benefiting from extended GS

Data to use

- Datasets:
    - PEP725
    - ITRB
    - Arnold arboretum common garden
    - treeNet data
- Things we could do:
    - Show **PEP725 + ITRB** overlay (w/ Rubén) and highlight potential of this data in understanding growth-phenology
        - Related idea: Do traditional phenology and dendro (long-term) are based on the same data? (degree of spatial / taxonomical overlap?)
    - Common garden:
        - Potential data set: tree cores from **Arnold Arboretum** plus phenology from arboretum (single year measured on the ground across diverse species- could address this question either in a single year across species and/OR use remote sensed phenology data to relate to on the ground data for one year and expand dataset to multiple years)
        - Potential data source is from the Arb common garden using the height, SLA and phenology data
        - Related: Are there other common gardens out there that weren't planted for phenology but are maybe useable? What about orchards?
    - Do phenological shifts push the growing season into periods of low VPD? This should enhance growth if turgor is the limit, but might lead to more regional variation in response. Can we test this with **treeNet data**?
    - Compare numbers: ring growth across elevations/across time/in dendro studies/dendrometers ← potentially get at the base relationship between phenology and growth as it relates to climate (temperature)
- What does the flux tower data tell us about the availability of photosynthate for growth? Can we use this to make assumptions about the sugars going elsewhere, like to heartwood?

Implications

- Implications and applications: forestry/timber yields?, NCS, GCM models, others?
- Species are different ... which ones would show strongest G x P?
- carbon storage and sequestration potential
- Difference between Growth and carbon storage