Do growing season length and growth relate?
And if not, why not?
And if we're not sure, why is that?

Team Grephon

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Contents

1   The table is done in late June!

Remember what our main new aims for the paper: We're interested in constraints, resource limitations, species and interdisciplinarity; we should stay focused on this. Species too...
What we have found overall (3 July 2023 meeting):

1. Lizzie reported out on the question of which studies do or don't find relationships. Seems like of the common growth metrics, annual cores do not find our definition and they don't always find their definition either. No relationships with country or biome jump out (pretty biased towards certain places though). We need to do some more work to look at species as that looks complicated, but nothing jumped out in which species do or do not show relationships.

2. Team external: lots of tree ring studies look at external and they all find a relationship. Not many experiments do and whether they find a relationship or not is more mixed than for tree rings. Next steps for this could be that the experimental and forest-scale results need to connect better: maybe this means looking at better metrics than temp and precip (such as PET) or looking at interactions or TBD.

3. Team endogenous found three major types of effects: provenance, species (and functional types) and 'growing early' (Zohner paper bolus; though Frederik only mentioned Zani paper: 'Greater GPP, higher Photosynthesis, earlier growing season leads to earlier senescence (Zani 2020)'). Very few studies mechanistically try to understand what causes provenance, species effects. (Of the 56 rows in our table 23 indicate that authors have looked and found evidence for endogenous factors.)

(a) Maybe we (or physiologists) need to review what the mechanisms could be? Ideas are...

    i. Leaf life span

    ii. Tade-offs between reproduction and growth

    iii. budset programming

    iv. Proportion of determinate vs. indeterminate buds. Can we get info on that?

    v. Maybe group species by CSR or shade tolerance?

    vi. Check out Silvics manual (`https://www.srs.fs.usda.gov/pubs/misc/ag_654/table_of_contents.htm`)

    vii. It could be nice to discuss the tradeoffs involved of a tree's growing season ending. Potential gains in growth, fruit production and reserve allocation vs. Tissue damages and fitness loss (unripened fruits, dieback), loss of nutrients in foliage due to delayed senescence.

(b) Whatever it is, we need to somehow see it scale up to latitudinal variation (provenance effects); this reality seems to be missing from Zohner and other work

4. Next steps from Frederik: It seems there is not much to get out of the table regarding endogenous factors. If we would like to include a section in the paper about this I suggest we gather and discuss the current hypothesis around this topic. What comes into my mind is: amortization time, reach a certain reserve level, distinguish between determinate and indeterminate growth, photoperiodic constraints and induction of bud set, senescence and dormancy. I would be interested to do that!

Also, Lizzie checked out Rossi *et al.* 2013 (cited in Korner paper from 2023) and it does not appear relevant to our table. See `https://link.springer.com/article/10.1007/s00442-006-0625-7` if you want to check for yourself.

2 Outline

1. Introduction (what's happened in the past and where this paper goes)

(a) Unexpected controversy over GSL[1] and tree growth _____ `needs organizing`

    i. Basics: GDD model of growth suggests GSL x growth (with some base temperature for GDD)

    ii. But ... Tree ring old studies do show GSL x growth (ring width) ... this might `Do they? Need refs` be inferred through tree line or such.

    iii. Back when: Ecosystem scale growth (NPP?) increases with warming

    iv. New studies: Tree rings don't show GSL x growth (ring width)

(b) What's going on?! (Briefly)

    i. Measurement issues

    ii. Biophysical constraints (endogenous)

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[1]GSL: growing season length; RL: resource limitation

        iii. Resource limitations (exogenous)

    (c) Here, we. ...

        i. Hypotheses for why GSL x growth is not found are not equally tested across fields: Constraint issues in provenance but not tree ring etc.

        ii. Our premise is that some hypotheses for what's going may be tractably already answered by combining data across fields/methods

        iii. And, you could go far by cross-field tweaking of what each field is doing

    (d) This is important!

        i. Carbon storage and climate change

        ii. Fundamental to physiology, species assembly

2. Section: Review three reasons for not growing

    (a) Overview paragraph of three reasons

        i. Measurement – see box/figure (include measurement only here or briefly so we move through it fast)

        ii. Resource limitation

        iii. Constraints

    (b) Resource limitation, evidence for an against   `[Table will help us with this]`

        i. Nutrients

        ii. Water

        iii. Is this more species-specific?

    (c) Constraints, evidence for an against   `[Table will help us with this]`

        i. Leaf life span

        ii. Budset stuff ... (Zohner, Sool.)

        iii. Evidence across species? Or which is species-specific

3. What do do next (The future! Is there a framework to our future directions? It would be nice if we found one)   `[This needs a total overhaul after the table; figure out the section headers]`

Where are we submitting?
Nature Climate Change (3-4K, 4-6 figures), *Global Change Biology*, *New Phytologist* ... thinking of places where we will get an interdisciplinary audience.

Methods: Found 33 refs through ISI search on 12 April 2023: "growing season length" AND "tree ring*" (ALL FIELDS). We then looked through citations within and cited since, as well as incidental during the review process.

Stuff that might work for the future directions

Plan is to do the table, then work with fresh heads on the future directions .. THEN come back and look at these notes

1. If you want to resolve this debate, you need comparable estimates – you have to report similar models

2. Some of the fields (tree rings, where we found so far studies do not look consistently at growing season length x growth, they are more interested in spring temperatures x growth) do not care as much about the mechanism... but it really matters

3. Very difficult to compare studies as terms are defined differently (e.g., growing season length) ... could compare what the terms mean across fields

    (a) Semantic issues make it difficult to know what is or has been tested

    (b) Everyone is measuring stuff in a slightly different way makes it really hard to compare (especially when everyone is doing only part of the diagram (see figure idea below))

    (c) Briefly about growing season length: Which to measure? Actual growth end/start as growth (but which growth) or phenological start/end ...

4. Two major ways to measure growing season length: phenological and growth data (xylogenesis)

1. Tree ring people should ... get better phenology data and a better sampling design ... and figure out the transfer f(x)

    (a) core trials with phenology data

    (b) PEP725 x ITRB plot – sampling overlap; sample more places/species withe phenology data

    (c) Take more fine-scale measurements

2. Permanent plot data (provenance/forestry plots) need some temporal resolution and need more allometry data

    (a) Do they have GSL?

    (b) They calculate growth every 5 years, they need annual data!

    (c) Allometry here is big opportunity: measuring at different heights (more fine-scale data)

3. Greenhouse/chamber experiments

    (a) Our experiment (which needs a name)!

    (b) VPD x temperature curves – figure those out, include more xylogenesis here

4. Big experiments

    (a) You could do one for this topic

(b) Measure GSL and tree rings in other ones: FACE, Phynwald, Rainout things, SPRUCE

5. Constraint experiments (yes, messy topic ... not sure where all this goes ...)

(a) Give plants everything they want and show they still shut down growth at the same time (this goes with some full factorial experiments with drought etc. so we could estimate when the constrain matters ... we could say 'of course there is a constraint but we need to better understand when it would matter with climate change)

(b) How do people show constraints?
    i. You sort of need the mechanism ... molecular, experiment on proximate cues etc.
    ii. Show variation across latitude often for this

6. Species! Species differences – keep thinking about where to fit this in; can we look at representativity across tree ring / phenology / experiments (mention competition in future directions; we have to get a handle on this conceptual diagram first)

Wait, WTF is a constraint? Or is there a gradient of constraint to RL ...

1. Lifespan determination growth mush

(a) Seasonal growth stops: Budset, Zohner equinox paper
(b) Does high temperature fit here? (Definitely on a different timescale)

2. High temperature limitation – enzymatically it's over

3. Low temperature limitation – sort of like energy limitation

4. Things we feel sure are resource limitation

(a) Nutrients
(b) Water

5. Terms we could use. ...

(a) Phenomenological without a real mechanism (plants stop growing at the same time every year)
(b) External versus internal
(c) Abiotic versus biotic

6. Kavya adds: I was thinking a little more about the whole constraints vs. limitation thing and this is a thought I had: Is the distinction between resource limit and constraint that resource limitation occurs across a spectrum while constraints have more rigid boundaries (even for the same organism)? In this case (and following Alana's cool figure), temp could be both — at the two ends of the spectrum it's a constraint (cannot photosynthesize below or above a threshold (enzymatic limits)) but in the middle, it's a resource limitation? Or maybe up till Topt it a resource limit and beyond that it becomes a constraint? Also I think it would be good for us to distinguish between net C uptake and allocation to

growth? As in trees might still be photosynthesizing but not growing, or not growing in the ways we think they would. Or maybe this just goes into the measurement box with the idea that we aren't measuring the correct/all of the facets of growth.

7. Janneke then added: problem is that temperature influences the rate of everything to do with growth and resource uptake (e.g., water and nitrogen) and is also damaging agent (e.g., frost, denaturing)

Things that need a home

1. Patterns of GSL x growth across elevation/latitude

2. What is growing season length? (Actually when growth starts? Or something else?)

3. Measurement issues

   (a) Maybe they are growing and you measured the wrong thing

   (b) What scale of effect can we detect (and do we expect)?

   (c) Maybe we are measuring the wrong species ...

4. Conifers (tree ring data) versus deciduous (phenology data)

5. Conifers: Does leafout matter in conifers or would it be much more related to when they start photosynthesizing with old leaves?

6. Species diversity in tree ring studies ... maybe make table on whether the studies with tree rings and growth have looked at dominant canopy species

7. Maybe ... which species have budset constraints been shown in?

add to Janneke's table?

3 Figure ideas

1. Ruben's figure

2. Alana's rate x temperature (x limitations) figure: maybe add in agriculture

3. Conceptual of connections (sort of path diagram figure)

   (a) Start simple: temp $\rightarrow$ GSL $\rightarrow$ growth (this was NEP x growth studies from a while ago; and the tree ring people go backwards along this diagram)

   (b) Next: Just the conceptual: temp $\rightarrow$ GSL $\rightarrow$ growth PLUS resource bubble

   (c) Supp figure on measurements? Figure with methods layered on, maybe do just for start and end of GSL or such

   (d) Layer onto this figure: What each fields offer – size of arrow is the number of studies that do it

   (e) Layer onto this figure: What each field could offer if they did x, y, z – FUTURE directions also

(f) We need relative magnitude of these arrows

(g) Message here: Full path diagram of what is happening is more complicated than perhaps is being let on, and no one has tested it fully

    i. The provenance people have a lot to offer but they don't measure annual growth ... they have the constraint information, but asking it for a different reason.

    ii. Could they manipulate temp and resource?

    iii. Or we need the tree ring people to work on this: tree rings across distribution $\rightarrow$ response + variability of response

    iv. Greenhouse/growth chamber folks can do the full figure

4. ISI cross-pollination currently across fields or see `https://www.connectedpapers.com/`

    (a) tree rings in climatology

    (b) tree rings in ecology

    (c) constraint folks

    (d) forestry plots (provenance trials)

    (e) experiments ...

5. PEP725 x ITRB plot

6. Figure for future part?

7. Table/figure on advantages/limitations for each approach? Key places where interdisciplinary opportunities (leverage)